EVALUATING THE EFFECTS OF COAL SEAM GAS DEVELOPMENT ON FARMS IN THE SURAT BASIN, QUEENSLAND

A Thesis submitted by

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For the award of

Doctor of Philosophy

2017

Abstract

Previous studies have explored the contentious coexistence of agriculture and coal seam gas (CSG) development, but little research has focused on the implications of the production and profitability of individual farm enterprises and the strategies that could be implemented alongside the financial opportunities arising from coexistence. This thesis aims to address these knowledge gaps by providing insights and indicative scenarios of the potential synergy between farming and CSG operations in the Surat Basin. It is composed of three interdependent studies, which highlight the key features of the overlapping relationship of both sectors in Queensland, Australia.

Study One characterises the biophysical characteristics of the agricultural areas with tenements (leased by gas companies) in the Surat Basin. These areas are classified, through fuzzy logic, according to their current land use (generally as cropping or grazing) and their inherent potential for production intensification. The study identifies these areas based on their productive value. The spatial map (using ArcGIS) is an important tool for landholders to devise management strategies to improve their farm, given the prospect of an additional cash stream from compensation.

Study Two undertakes a case study analysis of some of the typical farming systems currently undergoing CSG development. Data on the spatial extent of CSG infrastructure is combined with long-term simulations of production and cash flow to estimate the possible financial losses incurred from CSG footprint. The results of the study show that both an increase in cost and a reduction in income are less than 10 percent on a farm paddock basis. Increased costs due to decreased machinery efficiency (also affected by the design of well spacing) may constitute a significant impact, which is not considered by gas companies when compensating landholders. These findings highlight important factors for farmers to consider when negotiating agreements with CSG companies.

Lastly, Study Three focuses on the financial opportunity that coexistence between agriculture and CSG presents. This study demonstrates the benefits of the compensation arrangement, for which there is a gap in literature. The results of the study show that the overall financial performance of the farm enterprise improves with the advent of compensation as cash flow becomes steadily positive. The study concludes that the indicative amount of compensation is enough to restore the profitability of a hypothetical farm paddock to its baseline production prior to CSG development, and that farm investment is the most profitable option for both dryland and irrigated farming systems.

This is a novel research, which provides information and documentation of the coexistence of agriculture and CSG development. The thesis serves as an important input for negotiations and contract agreements. It highlights key areas and strategies that can minimisecosts and maximise benefits of coexistence. Further research is recommended on areas of coexistence related to: (a) modelling of other important farming systems within CSG development areas, such as grazing, and (b) valuing intangible impacts.

Keywords: Agriculture, coal seam gas, tenement, coexistence, simulation, compensation

Thesis certification page

This Thesis is entirely the work of ETHEL BANZUELA-SAMALCA, except where otherwise acknowledged. The work is original and has not previously been submitted for any other award, except where acknowledged.

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Student and supervisors signatures of endorsement are held at the University.

Acknowledgements

This thesis was made possible through the unprecedented support and guidance of different people and organisations, in which I have the highest salutation. I would like to extend my sincerest gratitude to the following:

- The CSIRO Postgraduate Studentship and the Australian Commonwealth Government through the Research Training Program for sponsoring my higher degree study here in Australia;
- The GISERA for providing the academic and logistic information that I need for undertaking my PhD thesis. This work would not have been possible without the assistance and network of support provided by the group.
- To my supervisors, Dr. Geoff Slaughter and Dr. Neil Huth, for not only providing valuable insights for the completion of this PhD thesis, but also giving moral encouragement and professional inspiration to keep me on track with my endeavour.
    - I would like to thank Dr. Neil Huth for simulating the farming systems in APSIM.
- The panel members during my proposal confirmation, Dr. Peter Carberry, Dr. Kate Reardon-Smith and Dr. Shahbaz Mushtaq, who gave constructive criticism for the improvement and refinement of my work.
- To the CSIRO Agriculture Flagship in Toowoomba, Brett Cocks, Oswald Marinoni, Javier Navarro, and Perry Poulton, for sharing your expertise in the field that is an important foundation of my thesis. I also appreciate your camaraderie, making me feel ‘at home’.
- Andrew Zull and James Hagan of DAF for providing data and contributing knowledge about the productivity of the Darling Downs region.
- Ian Heiner and Timothy Green of DNRM for sharing information on the legislation and policies relevant to the coexistence of agriculture and the CSG industry.
- The landholders, gas companies, agronomists, researchers, and local groups who offered to impart their thoughts, data, and information on the topic of coexistence.
- The BELA Faculty staff for their academic support and guidance.
- Janelle Cruickshank for her trustworthy proofreading.
- To my husband, Irvin, for providing assistance in my spatial and statistical analysis. Also, for sharing the journey and hurdles of PhD life. I would like to express gratitude for his unwavering personal support.
- To my loving and ever-supportive family for your constant prayers and endless encouragement. You are truly my inspiration.

Lastly, this endeavour would not have been possible without the mercy and grace of Almighty God. His countless blessings and faithful love has steered the path of this journey. To Him be the glory and praise!

Contributors to the Research Studies Conducted

The author would like to acknowledge the valuable contribution and data provision of other authors to the three (3) interdependent research studies of this thesis.

Study One: *Agricultural Productivity Assessment of Tenement Areas*

> Oswald Marinoni (CSIRO Land and Water) and Irvin Samalca (USQ, PhD candidate)

Study Two: *Farm Systems Modelling of the Impacts of CSG Footprint on Farm Enterprise*

> Neil Huth (CSIRO Agriculture and Food), Perry Poulton (CSIRO Agriculture and Food), and Andrew Zull (DAF)

Study Three: *Strategic Coexistence Management*

> Neil Huth (CSIRO Agriculture and Food), Anonymous source from CSG company

List of Refereed Conference Papers

Samalca, E., Huth, N., & Slaughter, G. (2015). Identifying areas where coal seam gas development may assist agricultural intensification. *"Building Productive, Diverse and Sustainable Landscapes"*. Edited by T. Acuña, C. Moeller, D. Parsons and M. Harrison. *Proceedings of the 17th Australian Agronomy Conference 2015,* 21-24 September 2015, Hobart, Tasmania.

Samalca, E., Huth, N., & Slaughter, G. (2015). Agricultural productivity assessment and farming systems modelling to identify costs and opportunities from coal seam gas in the Surat Basin. *"Partnering with industry and the community for innovation and impact through modelling"*. Edited by T. Weber, M. J. McPhee, and R.S.Anderssen. *Proceedings of the 21st International Congress on Modelling and Simulation (MODSIM),* 29 November - 4 December 2015, Gold Coast, Queensland.

Huth, N., Poulton, P., Cocks, B., & Samalca,E. (2015). Methods for designing farms that include a coal seam gas extraction enterprise. *5th International Symposium for Farming Systems Design,* 7-10 September 2015, Montpellier, France.

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List of Abbreviations

ABARES	-Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	-Australian Bureau of Statistics
AGL	-Australian Gas and Light Company
ANOVA	-Analysis of Variance
APLNG	-Australia Pacific LNG
APPEA	-Australian Petroleum Production and Exploration Association
APSIM	-Agricultural Production Systems sIMulator
ASRIS	-Australian Soils Resource Information System
CBM	-Coal Bed Methane
CCA	-Conduct and Compensation Agreement
CSG	-Coal Seam Gas
CSIRO	-Commonwealth Scientific and Industrial Research Organisation
DAF	-Department of Agriculture and Fisheries
DEM	-Digital Elevation Model
ENSO	-El Niño-Southern Oscillation
ESP	-Exchangeable Sodium Percentage
GDA	-Geocentric Datum of Australia
GDP	-Gross Domestic Product
GIS	-Geographical Information System
GISERA	-Gas Industry Social and Environmental Research Alliance

GPS	-Global Positioning System
IEA	- International Energy Agency
IEO	-Index of Education and Occupation
IER	-Index of Economic Resources
IRSAD	-Index of Relative Socioeconomic Advantage and Disadvantage
IRSD	-Index of Relative Socioeconomic Disadvantage
LNG	-Liquefied Natural Gas
ME	-Machinery Efficiency
NSW	-New South Wales
OECD	-Organisation for Economic Co-operation and Development
PAWC	-Plant Available Water Capacity
QALA	-Queensland Agricultural Land Audit
QCG	-Queensland Gas Company
RIDA	-Regional Interests Development Approval
RPI	-Regional Planning Interest
SCL	-Strategic Cropping Land
SEIFA	-Social Economic Indexes for Areas
SILO	-Scientific Information for Land Owners
SRTM	-Shuttle Radar Topography Mission
UNEP	-United Nations Environment Programme
USA	-United States of America
WTC	-Willingness to be compensated
WTP	-Willingness to pay

Definition of Terms

Cash flow	-movement of money into and out of the enterprise
Coal seam gas	-unconventional natural gas consisting of methane trapped in underground coal seams
Coexistence	-the state of having CSG and agricultural operations on the same territory at the same time. It could also mean a condition of pursuing the diverse interests of both parties in harmony
Cropping frequency	-the long-term average of the number of crops planted per year
Depreciation	-a decrease in the economic value of an asset
Diversification	-an investment strategy of putting capital into a spectrum of non-agricultural business enterprises
Externalities	-a positive (benefit) or negative (cost) outcome incurred by a party not directly related to an economic or productive activity.
Footprint	-spatial coverage of CSG infrastructure, logistics, and operation within the agriculture (farm) territory
Gross margin	-difference between variable production costs and farm income
Intensification	-increasing production without expanding farm land through additional farm inputs and improved management strategies
Land use	-*“the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.”* (Di Gregorio & Jansen 1998)
Machinery efficiency	-a measure of the capacity of agricultural equipment to operate
Opportunity cost	-value of choosing one decision over a mutually exclusive/alternative decision
Productivity	-rate of agricultural output to farm inputs

Profitability	-the financial gain of the enterprise
Salvage value	-estimated resale value after the productive life of an asset
Shale gas	-naturally-occurring gas extracted from shale
Simulation	-imitation of the real world through modelling a characteristic, behaviour, and/or function of a process or system
Tenement	-a claim, lease, or licence given to the holder to explore and produce resources

Part 1: Overview of the Thesis

1 Introduction

This thesis explores the management of two important industries in Australia – agriculture and mining. These industries each plays a crucial role in the economy yet they can be in conflict, as they compete for the space within the same landscapes. This research provides insights into the coexistence relationship and the potential advantages and disadvantages for farming enterprises in the Surat Basin, Queensland.

Agricultural enterprises operate in complex environments, where productivity is dependent on biophysical, social, and economic interrelationships (Squires & Tow 1991). Some external aspects, such as the advent of coal seam gas (CSG) development, are largely beyond control of farm management. The growth of the gas resource on farming land is challenging, despite the financial opportunity it provides to farmers in the form of compensation payments (Collins et al. 2013).

This thesis commences with the background of the research on evaluating the impacts of CSG on farming, followed by interdependent research studies related to coexistence of both industries. The conclusions and implications of the findings in the last part of the research provide insights for future research directions.

1.1 Background of the Research

Agriculture is a critical part of human history that has evolved and adapted throughout the years according to different technological, ecological, and economic settings across the world (Greer, Talbert & Lockie 2011; Mazoyer & Roudart 2006). However, environmental changes, such as climate variability, shifting temperatures and precipitation, and other weather phenomena, hinder the capacity of agriculture to feed the world (Fuhrer 2003; Jones & Thornton 2003; Lin 2011).

The dilemma of an ever-growing global population confronts every nation with the challenge of how to optimise the productivity of its land resources. This is an ever-increasing challenge, with agricultural landscapes across the world showing signs of degradation and declining productivity (FAO 2016). This is compounded by the fact that only 36 percent of the land globally is suitable for agriculture (FAO 2002). This is evident in Australia, where a large part of the country has low and variable rainfall and poor soils, making cropping or pasture improvement unviable (Malcolm, Sale & Egan 2009).

Agriculture also experiences land use conflict with other industries, such as mining, resulting to structural changes in agriculture. This phenomenon is evident from the increasing rate of farmers and farm workers moving out of farming over time, due to higher returns and wages in non-agricultural industries (Malcolm, Sale & Egan 2009).

Competition from land development, such as urbanisation and mining can also constrain agricultural expansion and intensification (Fischer, Byerlee & Edmeades 2011). Mining activities, in particular, can create land use conflicts in farming, resulting in the reduction or elimination of agricultural activities (Mazoyer & Roudart 2006). This 'mining-farming' land management conflict is evident in several Australian regions, such as the Hunter Valley, Illawarra, the Bowen Basin, the La Trobe Valley, and the Surat Basin. These regions house rich coal and gas resources under fertile soils and highly productive farming enterprises. The overlapping geographic footprint results in issues related to land access, productivity, economic costs, operational logistics, technical requirements, and social disruptions (Greer, Talbert & Lockie 2011).

Given the issues outlined above, positive mutual relations that foster improved coexistence of agriculture with other land users need to be achieved to maximise regional development in resource-rich areas (Williams, Stubbs & Milligan 2012). Economic policy should be towards unbiased development for both food and energy, securing a balanced and sustainable land use management system. More importantly, farmers must have a strategic management system so they can adapt and viably coexist with the other land stakeholders.

1.2 Research Objectives, Hypotheses and Questions

Agriculture must inevitably deal with the overlapping footprint of CSG development, and critically improve coexistence with the gas-mining sector. The general objective of the thesis is to evaluate the effects of CSG development on farms in the Surat Basin, with an underlying hypothesis that:

CSG will provide a means to improve individual farm financial performance in the Surat Basin.

The following are the research questions (RQ) and objectives to address the hypothesis.

RQ1. What are the physical characteristics and productive value of the farming areas within CSG tenements within the Surat Basin?

Objective 1: To characterise the biophysical conditions of those farms.

Objective 2: To classify those farms using the characterisations in Objective 1 to facilitate further analysis.

RQ2. What are the effects of CSG operations on agricultural production and enterprise in different farming systems in the Surat Basin?

Objective 3: To identify the extent of the different infrastructure footprints of CSG operations on a farm.

Objective 4: To ascertain aspects of farm operations (i.e. farm machinery) affected by CSG development.

Objective 5: To model estimates of the gross margin changes incurred from CSG infrastructure footprints.

RQ3. What are the local farm investment strategies that would enable improved coexistence between agriculture and CSG development?

Objective 6: To assess the existing compensation structure system as a financial input for agricultural investment.

Objective 7: To recommend enterprise investment options for different farming systems under varying coexistence scenarios.

This thesis makes inferences by simulating a typical farm set up under lease by a gas company to improve the understanding of the coexistence phenomena of agriculture and CSG development. Other literature has focused mostly on the community and regional impacts of CSG development while, this research contributes to the following aspects:

(a) Identification of farming areas with tenement that have production potentialfor intensification. This is not currently considered in evaluating the land value in negotiation of compensation agreements,

(b) Translation of the impact of the CSG footprint in dollar terms through modelling the financial performance of the farm enterprise, and

(c) Provide investment options using compensation payments to develop agriculture and create synergies, fostering an adaptive and successful coexistence relationship.

1.3 Justification of the Research

This thesis contributes to the planning and negotiation arrangements of landholders and gas companies by providing information on the positive and negative consequences of CSG development on farm enterprises. The diversity of the biophysical and economic characteristics of farms at the Surat Basin requires tailored outcomes from the CSG negotiations. Therefore, this study weighs the effects of CSG development at the micro scale (i.e. farm paddock level) and explores strategic farming decisions that can be adapted to different simulated farm scenarios.

The basis for undertaking this research is justified by the following: (a) a need to refocus on how farmers' perceive coexistence, by balancing the losses and benefits alongside it; (b) there is limited research about the outcomes of farming and CSG development coexistence at a farm paddock level; and (c) exploring an alternative approach in evaluating the sensitivities of farming and CSG development coexistence.

Most of the studies conducted relating to CSG development in agriculture revolve around the potential decreases in productivity on arable land. In the Surat Basin, farming lands require intensive management to maintain productivity (Clements & Cumming 2017; Langkamp 1985) and thus, the CSG infrastructures and associated activities directly impact farming operations. The Interim Report of Senate Standing Committees on Rural Affairs & Transport (2011) stated that "*exploration for, or production of, gas has the potential to severely disrupt virtually every aspect of agricultural production on cropping lands and, in extreme circumstances, remove the land from production*". Without adequate regulation, the CSG industry would be relatively short-lived and would potentially incur large-scale irreversible damage to agricultural productivity on some of the best farmland in Australia (de Rijke 2013). The development of CSG mining has been scrutinised for its particular impact on soil and ground-water quality (Swayne 2012), introduction of harmful chemicals into water sources (de Rijke 2013; Hamawand, Yusaf & Hamawand 2013), and adverse effects from the use of CSG extracted water on crops (Dalgliesh 2006; Sessoms et al. 2002).

Nevertheless, research has not fully explored the intricacies behind farming and CSG development coexistence. There is an underlying knowledge gap in this specific field of interest. An online random survey conducted by The Australian Institute (2013) reveals that more than a third (36 %) of the general public respondents had not heard about CSG. Furthermore, most of the assessments on the outcome of CSG projects are not rigorous, and based on speculative projections. Most environmental assessments of CSG projects remain questionable, because of an absence of thorough scientific analyses and lack of definitive evaluation on its impact on groundwater tables, land stability, and density, or volume of carbon emission (Batley & Kookana 2012; Hamawand, Yusaf & Hamawand 2013; Hepburn 2013; Lloyd-Smith & Senjen 2011).

Previous research has focused on the disadvantages of farming and CSG development coexistence. Most of the literature to date has examined the potential negative outcome from changes in the agricultural system brought about by CSG development. However, compensation overlooked some impacts of CSG development on farming activities. Agricultural landholders receive compensation to cover the potential costs of coexistence with mining and energy industries. Compensation serves as supplementary income that offers financial protection from factors, including weather and market-related disruptions. Individuals perceive it as a sort of 'drought-proofing' in areas vulnerable to climate variability. There are also instances where landholders are employed to maintain the CSG infrastructure on their own properties, which also gives them an opportunity for another income stream while ensuring minimal impact of CSG development on their own farms (Collins et al. 2013).

Landholders under current legislations cannot stop CSG development. Therefore, coexistence is inevitable and reducing conflict is critical. As such, this thesis provides an understanding of the nuances of the gas-farm interactions that can facilitate synergy and adaptation. Given that there is limited research on farm management strategies addressing the need for a resilient agriculture under a coexistence set-up, this research provides insights that can assist in mitigating stakeholders' conflict and confusion, which can hinder an effective and successful coexistence agreements between the two industries. This information further supports policy makers' and rural stakeholders' use of plans in developing sustainable land amidst CSG development.

Further justification for this research relates to the lack of literature that discusses the extent of the effects of CSG operations on farmers' profit and financial performance per farm paddock, where most systems management decisions take place. Previous research on CSG and farming tend to focus on community to regional perspectives, not on individual farm enterprise. There is a paucity of comprehensive investigation on the impact the CSG footprint imposes on farm management operations, and to what extent it affects farm gross margins.

A number of studies have examined the qualitative/intangible effects (subjective and uncertain) of the impacts of CSG development on the farmlands and landholders. Some of these include the negative consequences on numerous social (Williams & Walton 2013b), economic (Chen & Randall 2013; Consulting 2001), and environmental issues (de Rijke 2013; Hamawand, Yusaf & Hamawand 2013) (Averina, Rasul & Begum 2008; Davis & Robinson 2012; Entrekin et al. 2011; Johnston, Vance & Ganjegunte 2008; Williams, Stubbs & Milligan 2012). There are also initial studies on the environmental impacts (i.e. ground water and soil quality) of CSG development. However, limited literature exists regarding the outcome of coexistence on farm productivity and gross margins using direct measures at the surface of the farmland.

This thesis uses an alternative method of investigating farm and CSG mining coexistence. Simulation provides an objective mechanism to examine the spatial overlap between agriculture and CSG mining. There are a limited number of research that measure the exact scope of CSG footprint due to the difficulties in access and gaining permission from stakeholders to undertake ground assessments. Simulation also allows farm-scale modelling of the biophysical characteristics of areas within CSG tenements, taking into account the land's potential for agricultural intensification. CSG companies do not fully consider this agricultural prospect in the compensation structure. This research demonstrates an objective account of the financial performance of the agricultural enterprise amidst CSG mining and the possibility of maximising the benefits of coexistence through compensation, without incriminating legal, ethical, and social implications.

1.4 Scope and Delimitation

The thesis initially covers areas within CSG tenements in the Surat Basin as its study area. The case studies on cropping areas model the CSG footprint and its impact on the profitability of the farm enterprise.

The farm paddock configuration was utilised for modelling different farming systems enterprises. Inputs to the model are based on past research information and current data sets. The study opted to focus on an objective valuation using a simulation approach, due to the resource and logistical limitations in which the research study is undertaken. Data collection, analysis, and validation, as well as funding, are within the timeframe and governance of the research project of the Gas Industry Social and Environmental Research Alliance (GISERA), in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The overall effect on the financial performance of the agricultural enterprise results from the estimated change in productive area from the installation to the operational stage of CSG development (excluding the exploration and rehabilitation phase). The information on the hypothetical compensation value and investment opportunities for selected dryland and irrigated areas within CSG tenements supports the evaluation of the financial impact of coexistence to agriculture. Effects of CSG operation on livestock production, land (erosion) and soil (compaction) quality, and water quality and availability is indirectly mentioned in the study but does not form part of the analysis, and may be explored in future research. The perceived and intangible consequences of CSG development on individuals and farming communities are also beyond the scope of this thesis.

1.5 Literature Review

This section highlights the issues and related concepts with regard to agriculture and energy resource coexistence. It frames the context underlying the research problem discussed in Section 1.2. The review of available information demonstrates that both agriculture and CSG development substantially contribute to the development of individual, community, and regional wealth. However, coexistence triggers concerns related to legislative claims and the uncertainty of CSG development impacts. To provide some background and context to these issues, the following sections examine the importance of agriculture and energy in Australia.

1.5.1 Agriculture in Australia

Australia is a major producer of agricultural goods. Around 52 percent of the country's land mass is devoted to agriculture, according to the 2012-13 Rural Environment and Agricultural Commodities Survey (ABS 2014). It is estimated that the country has 665 million hectares of farmland (ABS 2016a). The agriculture industry contributes around 2.4 percent to Australia's annual Gross Domestic Product (GDP) in 2011-12 (ABS 2016a). The value of the country's farm production exhibits an increasing trend, valued at $53.6 billion in 2014-15 (ABS 2016a). Australia's main agricultural export commodities include wheat, beef, dairy and wool products with net food export earnings of $20 billion in 2014-15 (ABARES 2015).

Agriculture is also integral to the Queensland state economy. Almost one-quarter of Australia's total land area under agriculture is in Queensland (Figure 1-1). The state's agricultural industry contributed an estimated $11.9 billion to its economy, roughly 22 percent of the total gross agricultural production in Australia (ABARES 2016). The Darling Downs region (Figure 1-2) is a major centre for agricultural production in Queensland, as it has highly fertile soils and a suitable climate for both winter and summer cropping. It is also known for its horticulture, cereal grains, irrigation, and grazing industries. Major crops cultivated include sorghum, linseed, sunflower, barley, maize, oats, wheat, canary seed, panicum, and millet (ABS 2011). The Darling Downs encompasses the Surat Basin, where the development of large-scale CSG mining also takes place. This phenomenon is not unique to the Surat Basin, as other areas such as in New South Wales (NSW), South Australia, and Western Australia, experience the impact of CSG and coal mining activities on farm operations.

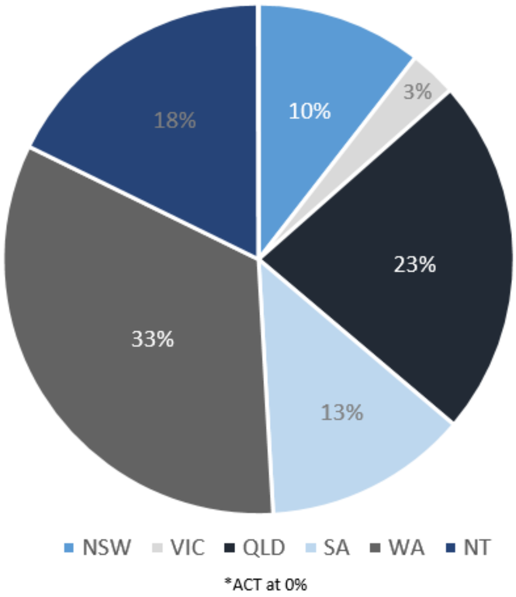


Figure 1-1 Total percentage land area devoted to agriculture by States, 2015
Source: ABS (2016b)

Changes in land use show a decreasing total area devoted to agriculture in Australia, even in areas with a promising outlook for agriculture. Areas of farm enterprises decreased by 10 percent between 1992 to 2012, based on the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) national scale land use assessment (DAFF 2013). This decline in the relative importance of agriculture is caused by changes in consumer expenditure and market pressures, declines in prices of agricultural commodities, and emerging environmental concerns (ABARES 2012; Productivity Commission 2005). Other contributing factors in the decline in agricultural land area include government policies on subsidies, taxes, property rights, infrastructure, and governance arrangements (Lambin, Geist & Lepers 2003).

The decline in the performance of the agriculture sector is also consistent with Australia's volatile productivity associated with fluctuations in climatic conditions and incidence of extreme events, such as the El Niño Southern Oscillation (ENSO). Production activities are dependent on natural resource characteristics such as soil type, topography, vegetation, and rainfall. There is also an ongoing challenge for Australian agriculture related to labour migration from rural areas to cities and from agriculture to higher paying jobs, such as in the services and mining. The services industry contributed 3.9 percent per annum and the mining industry has 4.6 percent per annum contribution to the GDP in 2003-04. In spite of these challenges to Australia's agricultural production, the country's agriculture remains the highest contributor to its national economic output compared to other Organisation for Economic Co-operation and Development (OECD) members (Productivity Commission 2005).

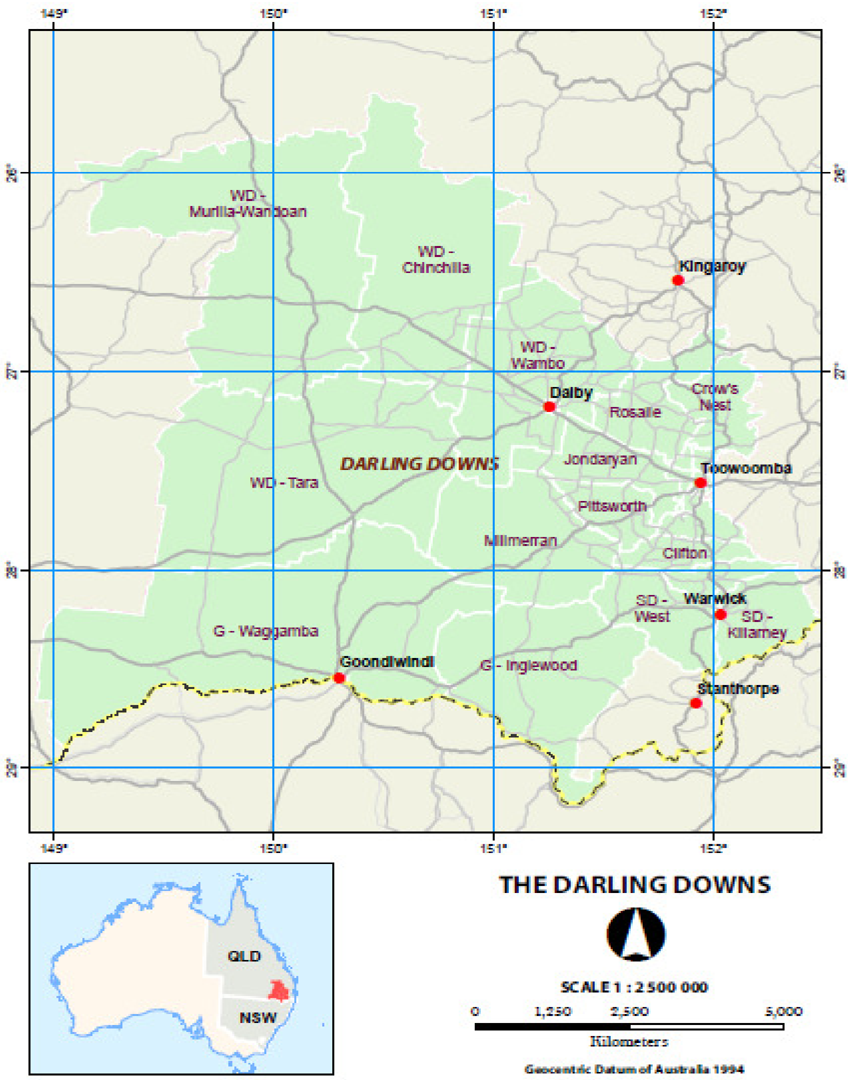


Figure 1-2. Map of Darling Downs

While agricultural land is declining, food demand is increasing in line with global population growth. The total household food consumption expenditure in Australia is increasing throughout the decades. It was recorded as $92 billion in 2015-16 as compared to $49 billion in 1989-90 (Hogan 2017). Therefore, it is essential to maintain the ability to sustain food production in arable areas, such as the Surat Basin. The global demand for energy resource is of paramount importance as well. Seventy-two percent (72%) of the total energy production exported in 2013-14 makes Australia the eight largest energy producer in the world. Thus, coexistence between both agriculture and gas industries is critical (Kerr 2012).

1.5.2 Energy Sector in Australia: Gas

The entire energy sector is a significant contributor to the Australian economy, which is worth $1,320 billion in gross value in 2012 (BREE 2013). It contributed six percent of the economy in 2014-15 (DIIS 2016). This sector continuously provides employment opportunities (Skills Australia 2011). In 2009-10, the energy related industries employed 106,000 people (BREE 2012), which increased to 155,000 individuals in 2014-15. Out of the total employment in the energy industry, 24,000 people are in the oil and gas extraction sector (DIIS 2016). However, this figure is less than the employment contribution provided by the agriculture, forestry and fishing industry, which has 314,000 employed or 2.6 percent of the total employment in Australia in 2015 (Vandenbroek 2016).

The energy produced in Australia serves both domestic (37%) and export (63%) markets. Energy exports were valued at $67 billion (39% of total of Australian commodity exports) in 2014-15. The country's largest energy export commodity is coal, with earnings of $37.9 billion for the same year. This is followed by Liquefied Natural Gas (LNG), with earnings of $16.9 billion, while crude oil and other petroleum products earned $11.5 billion in 2014-15 (DIIS 2016) (Figure 1-3). The total gas industry is considered to be the third largest energy sector in Australia (DI & BREE 2013), accounting for 2 percent of the world's supply (DRET, GA & ABARE 2010). Figure 1-3 further demonstrates the comparison of the industry balance between energy and agriculture. The graphs illustrate that while energy exports, consumption, and production are continuously increasing through the years, agriculture has a fluctuating performance in terms of real value of production and exports. This shows that the agriculture sector is more volatile than energy as a trade resource.

The production and use of energy presents a major environmental challenge. Energy projects include the associated risks of air and water pollution, potential loss of biodiversity, increased noise levels and loss of heritage values (EnergyMatters 2012; Hamawand, Yusaf & Hamawand 2013; Huth et al. 2014). These concerns are evident by the growing trend towards extraction of natural gas or methane from geological formations, referred to as either conventional or unconventional gas resources, depending on the geology of the reservoir (Ross 2013).

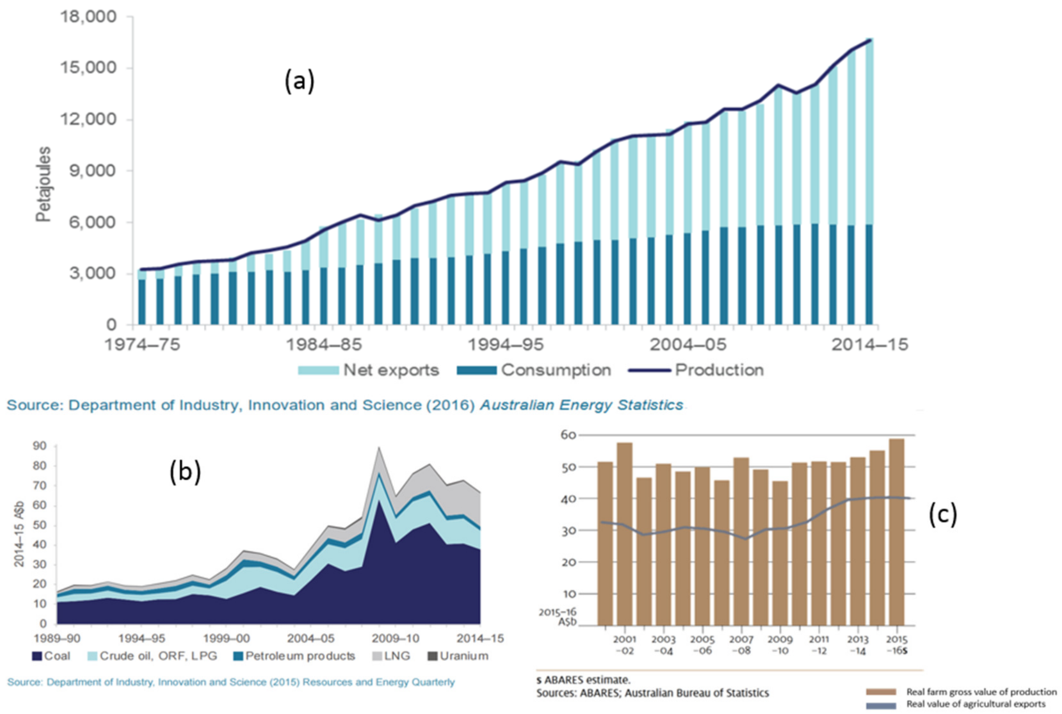


Figure 1-3. Australia's energy and agriculture balance
Note: (a) Total energy sector balance, (b) Energy exports by product, (c) Agriculture industry value of production and exports. ORF is other refinery feedstock

The common unconventional gases in Australia include shale, tight gas and coal seam. Shale gas occurs in shales and fine-grained carbonates with low porosity and permeability restricting gas migration within the reservoir rocks (DRET, GA & ABARE 2010; Hunter 2012). Tight gas refers to gas trapped in limestone, sand stone and sand-like layers of impermeable hard rock (Grafton 2012; Hunter 2012). Coal seam methane is naturally found in the cracks and pores of underground coal deposits to which 'dewatering' is performed to extract the dry gas (Grafton 2012; Ross 2013). CSG production in 2007-08 was recorded to be at 1,833 petajoules (PJ) (DRET, GA & ABARE 2010). This increased to 2,587 PJ in 2014-2015. Western Australia accounted for 60 percent of total CSG production, predominantly in the Carnarvon, Basin. CSG deposits form 18 percent of national gas production and are found in Queensland and NSW, particularly in the Surat Basin (DIIS 2016). At present, there is no production of tight gas or shale gas in Australia. However, potential sources for tight gas are located in onshore Western Australia and South Australia, while shale gas is found in the Northern Territory (DRET, GA & ABARE 2010).

1.5.3 Overview of the Coal Seam Gas Industry

CSG is a natural gas composed of methane, also referred as coal bed methane (CBM). The adsorbed gas extracted from underground coal beds at depths of 300 to 1,000 metres is in a near-liquid state (Figure 1-4). The reduction of coal seam pressure produces CSG, releasing the methane gas for extraction at the surface. Ground-water accompanies the methane gas during the extraction process (Shen et al. 2011). CSG separates from the water produced and then liquefied for easy transport. LNG is re-gasified for use by industry, domestic consumers and for electricity generation (Grafton 2012).

The uncertainties in the supply of conventional sources of energy in the world triggered the growth of CSG development. The social and political instabilities in Arab nations, the catastrophe at Fukushima nuclear power station in Japan, and the nuclear phase-out in Germany are some of the events that contributed to the demand for LNG (Lyster 2012). Thus, CSG production has become a burgeoning industry helping to meet the rising energy demand worldwide. The International Energy Agency (IEA) referred to it as ‘a golden age of gas’, which indicates a 50 percent increase in the utilisation of gas from 2010 levels and an increase in global energy demand of more than a quarter by 2035 (Lyster 2012). CSG production is predominant in countries such as the United States, China, India, Canada, Australia, and Europe (DRET, GA & ABARE 2010; Hamawand, Yusaf & Hamawand 2013; Ross 2013). The expansion ofunconventional gas supplies has motivated many of these countries to shift from being net importers to producers and net exporters.

Australia has already identified more than 150 trillion cubic feet of CSG reserves (Grafton 2012), resulting in a total value of exports of $16.9 billion in 2014-15, with 12 percent market share. The largest importer of the country in 2014 was Japan (DIIS 2016). In 2015, Australia is considered to be the world’s second largest LNG exporter, behind Qatar (IGU 2016) (Figure 1-5).

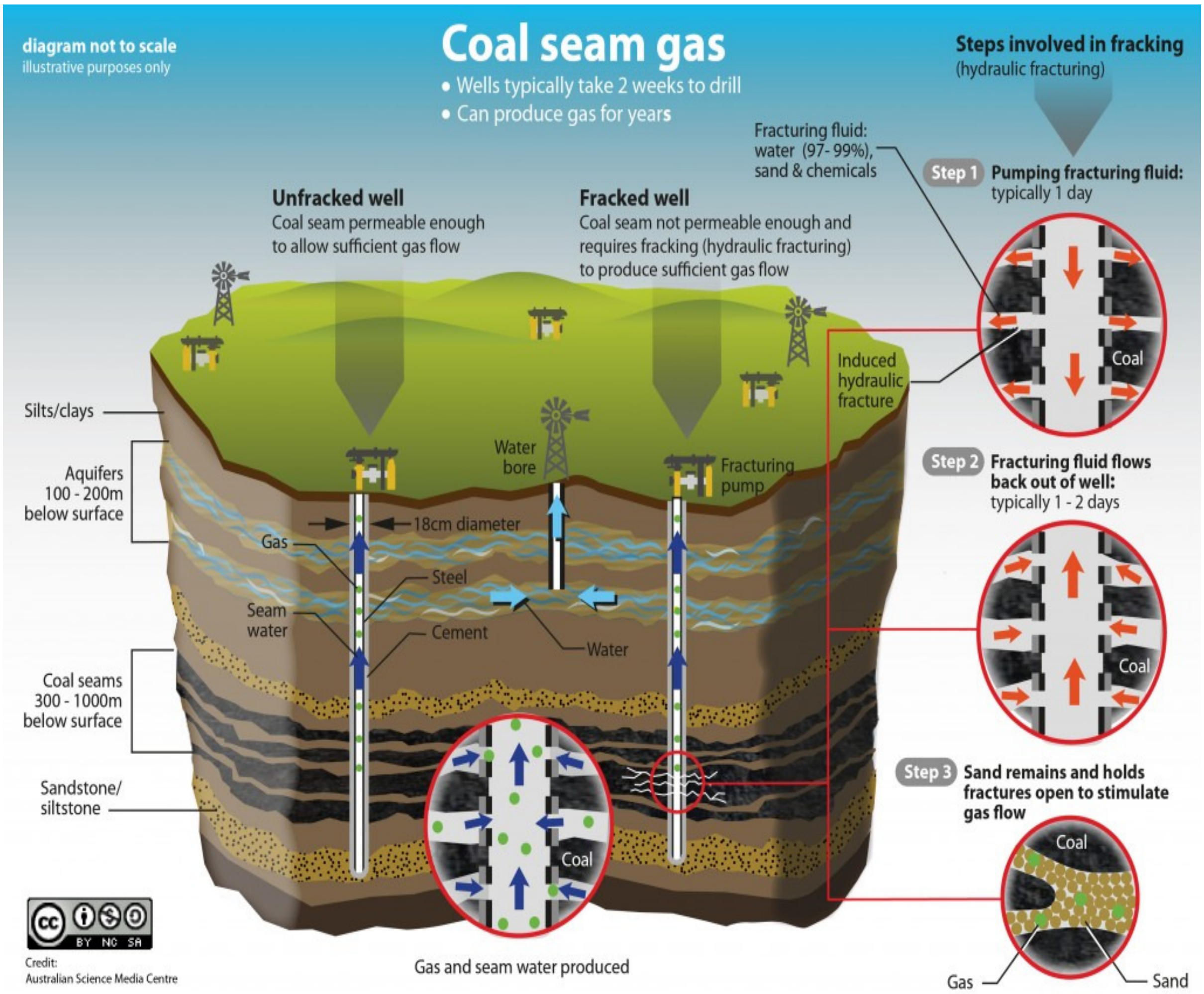


Figure 1-4. Coal seam gas extraction and operation
Source: Australian Science Media Centre

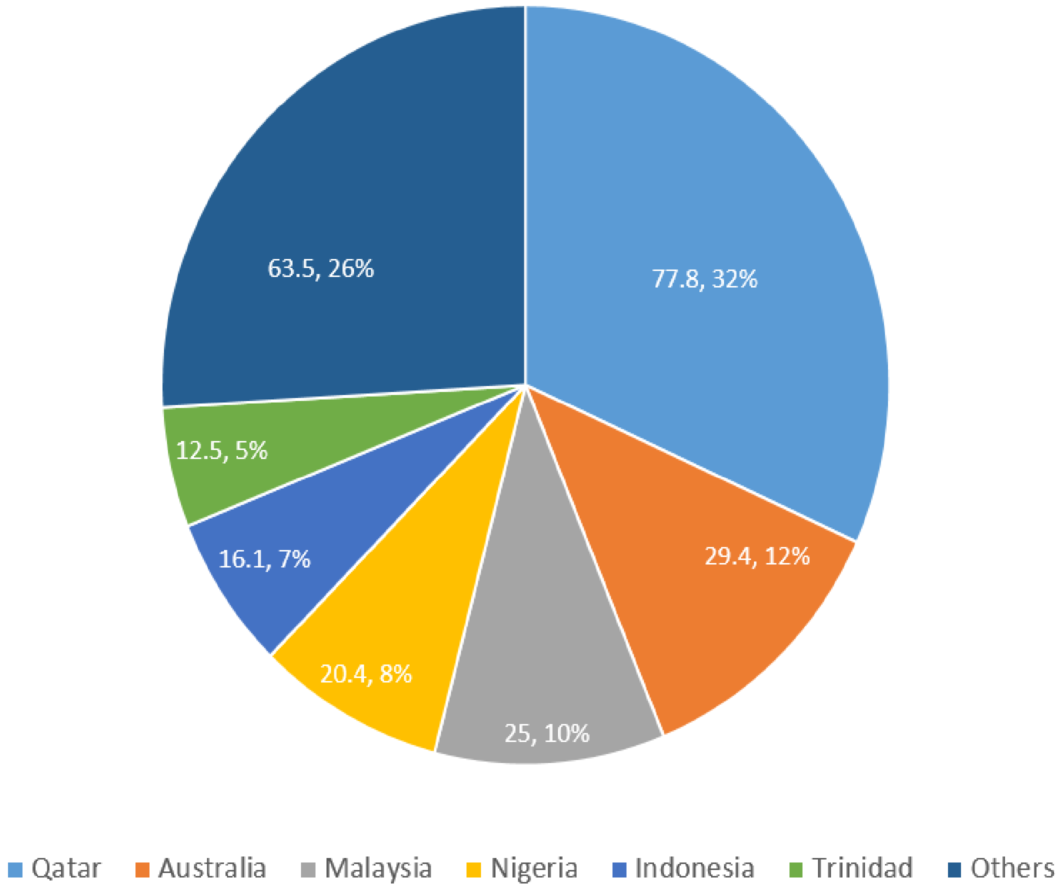


Figure 1-5. Major LNG exporters in metric tons and percent market share
Source: IGU (2016)

Large reserves of CSG exist in geological basins in eastern Australia. The major CSG production areas are in Queensland (BREE 2013; Day 2009; Hamawand, Yusaf & Hamawand 2013; Roarty 2008). This industry has grown rapidly from 200 wells in 2005-06 to 1,600 wells drilled in 2013-14 (Thomas 2015). The Bowen (Permian coal measures) and the Surat (Jurassic Walloon coal measure) basins provide more than 79 percent of the total gas in Queensland. The Surat Basin in south east Queensland has become the primary supplier of CSG since 2005. The commercial production of CSG in the basin originated from the Kogan North CSG area west of Dalby followed by the areas around Chinchilla (DNRM 2013b).

CSG industry also promotes regional economic development in other countries. In Colorado in the United States of America (USA), the gas industry contributed more than USD 6.6 million in royalties and USD 300,000 in local sales tax in 2011. Research has also shown that in this area of Las Animas County, CSG (or CBM) activity supports agriculture, recreation, tourism, and employment. In 2010, CBM provided 80 jobs, which translates to $630,000 total income for the region. Water extracted from

CBM creates opportunities for fishing, hunting and boating. (Harvey Economics 2012). In Australia, research shows that CSG investment increased employment by 2,900 full-time positions and increased GDP by 0.20 percent in 2011; and would contribute $15.2 billion to the national income by 2035 (Williams, Stubbs & Milligan 2012). Particularly, it is projected that in 2030 the energy sector share (including mineral resources) of to Australian GDP would be 2 percent, while agriculture and food products would be 0.8 percent (Anderson & Strutt 2014). However, while these findings point out substantial financial and economic benefits, there are significant issues and conflicts associated with CSG production. Literature suggests that CSG presents a significant threat to the environment and agriculture, which may outweighs its minor benefits.

1.5.3.1 Issues and Conflicts within CSG

Land access and use has become an issue with respect to CSG development because its operations taking place on farms and grazing properties (Thomas 2015). The unprecedented attention to gas development has raised a number of environmental concerns, linked to its drilling and fracking extraction technologies. There have been 43 recorded incidents of groundwater contamination from more than 20,000 wells drilled with hydro fracking in the USA. This environmental issue is tantamount to the community concerns in Australia because of multiple CSG field development. Landholders and conservation groups point out that CSG wells often pass through a number of overlying aquifers and the chemicals used in fracking can contaminate and decrease the level of groundwater used for farming and domestic water supplies, as a result of CSG extraction (Letts 2012). France, the Netherlands, Germany, Romania, and Bulgaria declared a moratorium on drilling unconventional gas resources due to fears of contaminating drinking water. However, some European countries perceive the moratorium as based on myths, misinformation, vested interests, and lack of available information. This is despite acknowledging at the same time that there are scientific experiments and study to support these claims. The opposition from grassroots environmental lobbyist is based on perceived and estimated impacts of gas extraction on ground water safety, adequate waste water management, seismic events and greenhouse gas emissions (Umbach 2013).

Controversies have also been ongoing in the communities of Montana and Wyoming in the USA, due to the emergence of national energy policies favouring CSG development. Natural gas provides 29 percent of energy needs in the USA (DIIS 2016). However, the country will need 50 percent more natural gas to meet demand in 2020. It is a net importer of natural gas, majority of its imports (95% in 2016) coming from Trinidad and Tobago. Thus, it is important for the country to look for unconventional resources such as CSG to support its need. Natural gas would play a significant role in energy policy since even if the USA improves its energy efficiency, there will still be a need for more energy supplies. Elevated natural gas prices, resulting from the increasing demand and limited supply, could have an impact on domestic electricity prices, home heating bills, and the cost of industrial production (Arthur, Langhus & Seekins 2005). Various stakeholders have formed alliances highlighting the negative impacts of the gas industry. These alliances build cases around the effects of living in oil and gas country (Duffy 2005). Some of the social influence of CSG development in communities includes psychological stress levels, alteration of rural lifestyles, landscape, noise, and population change (Arthur, Langhus & Seekins 2005). There is a sudden influx of population in these areas due to the promising increase in revenue for the community, causing social unrest and increased traffic. CSG production is also dominant in areas of New Mexico, Colorado, Alabama, Oklahoma, Virginia, and Pennsylvania (Fisher 2003).

Production of unconventional gas also poses a threat to biodiversity. CSG activity results in the clearing of bushlands, fragmentation of patches of native vegetation, spread of invasive species and increased fire risk. Studies in Pilliga Forest in NSW specifically point out that this fragmentation may lead to less food for fauna, more predators and restricted adaptive behaviour for the fauna (Williams, Stubbs & Milligan 2012).

Gas mining and agriculture are major contributors to the Australian economy. Oil and gas extraction industries had the highest portion of gross value added of the total energy sector, amounting to $31 billion in 2014-15 (DIIS 2016). However, Australia is caught between the two industries' spatial and economic competition and conflict (Schandl & Darbas 2008). Rural communities are apprehensive about the increasing demand on exports of natural gas. Gas prices in Australia are cheaper compared to international standards (Roarty 2008), leading to more gas projects. Long-term effects of CSG production can be uncertain since its impacts are cumulative and region-specific (CSIRO 2012). Some of the impacts of CSG extraction are related to infrastructure footprint, water treatment and disposal, access to land and water resources, social capital and infrastructure, and community identities (CSIRO 2012). A study on rural community feedback on CSG mining found that people's primary concern is inadequate consultation with stakeholders on the direct, potential, and cumulative impacts, as well as the economic, social and environmental benefits of the CSG (Lloyd, Luke & Boyd 2013). This has become a source of criticism against CSG companies by media and social groups (e.g. Lock the Gate Alliance) referring to it as a lack of social licence to operate.

There is a direct link between CSG development and farming. However, conflicts arise when either CSG or agricultural operation displaces the other from the land and competes with related natural resources (i.e. land and water). Those lands that offer significant potential for CSG exploration are mostly productive for agriculture (John 2013). Stakeholders expressed that Australia's limited areas of highly productive land is under threat from CSG mining (Duddy 2011). Farmers argue that mining on good quality cropping soil will make it unproductive, degrading and devaluing farming properties and reducing food production and export (CEDA 2012). Large quantities of water by-products, soil quality degradation, noise, dust, increased traffic, and impacts on wildlife and ecosystems are among the other numerous issues between farming communities and gas industries (Bryner 2003).

Managing the interference of CSG development on farm operations entails farm business decisions, such as timing of planting and chemical application, movement of stock, and changing farming systems. Other issues relate to time spent on non-farm activities (i.e. negotiations), construction over runs, transportation, water, lighting, and landscapes and fire are also considered risks by farmers, which are unwarranted as part of gas companies' claims to land access rights (Kerr 2012).

There is a need for a structure, which promotes synergy between mining and farming interests. The government and the energy companies invoked legislation and action to compensate landholders, with the aim of promoting mutual interest and sustainability in the development of CSG. Gas companies need to negotiate with individual landholders regarding access to their properties, even if landholders have no legal right to refuse entry. Compensation paid to landholders recoups the losses, damage, and contamination caused by CSG development. Devaluation of properties is also considered an effect of coexistence covered in the compensation agreements (Ross 2013).

The Conduct and Compensation Agreement (CCA) is a negotiated manifestation of a concerted effort to coexist and create partnerships. Part of this is a guideline of payments at the exploration, appraisal, and production stages of CSG development. However, the reparation received by agricultural landholders is widely variable and subjective (Shannon 2012). A thorough structure for negotiation that would enable compromised coexistence agreements islimited (Clarke 2013). There is also limited documentation of the actual derivation of estimates for compensation. Tools considered in determining the value of compensation include costs, benefits, and disturbances and inconveniences, considered on a case-by-case basis.

Moreover, negotiation and settlements are innovations that could prove difficult for farmers who may not have the political skills and expert knowledge to deal with them (Kerr 2012). Most farmers resort to solicitors and law consultants for advice, incurring additional financial and time costs, even though there are guidelines for undertaking the agreement process (Clarke 2013; DEEDI 2010; Queensland Resources Council 2012). Those who have the ability to negotiate favourably will benefit from the process. However, those that remain in conflict or call for a veto to land access will have to constantly struggle and lobby.

1.5.3.2 Property rights

The importance of Australian farming is realised through its role in food supply. An average farmer in Australia has the capacity to feed 600 people; farmers produce 93 percent of the country's daily domestic food supply (Kerr 2012). On the other hand, the gas industry demonstrates a promising and significant role in the economy. The gas industry supports present and future energy demands of agriculture. Hence, while programs and policies are towards preservation of the productive capacity of the land, there is current development of minerals and petroleum as well.

Property rights, including land and minerals, depend on specific legislations within a country. In Europe (e.g. England, Sweden, Ireland, Portugal, Finland, and Germany) and Australia, the State or Crown often owns and controls the higher-valued minerals However, in the USA, where the traditional Anglo-American common law is exercised, the owner of the surface land also owns the assets of the subsurface. Mineral rights and land ownership in South Africa could be private until 2002 but are now being provided as a common heritage (Liedholm Johnson 2010).

This 'split' rights to surface and mineral resources is an issue in Australia, as landholders have surface rights, while the mineral rights belong to the Federal and State governments. These mineral rights can be leased or sold to private resource industries including mining, energy generation and transmission, and environmental control industries such as greenhouse gas storage (Alliance 2011; Clarke 2013). In the colonial era, land titles gave landholders control of all the natural resources in their land. It was from the 19th century that Australia adopted a government policy of reserving minerals, thereby removing private acquisition of petroleum resources with land purchase (Crommelin 2009). The Crown/Government bestows permission to have access to underground resources. This refers to the 'tenement' classified as either exploration licences, retention leases or production licences (Productivity Commission 2015).

Exploration and operation activities by oil and gas companies are conducted at the expense of other stakeholders and the environment, as mineral rights take precedence over surface rights (Duffy 2005). Miners claim their legal right to access property, despite farmers insisting on their right of exclusion being titleholders of their piece of land. This overlap in perceived rights and ownership causes tension, often resulting in legal and political battles. Much of the discussion regarding disputed property rights of miners and landholders is directed toward individual ownership, rather than representing community and ecological interests (Galloway 2013), overlooking the impacts of licences and permits on the social and environmental aspects of mining.

The concept of private property has legal and/or economic perspectives. Its fundamental premise is based on the concept of improvement of land and labour by Locke (1965). His work suggests that land becomes private when man begins to toil on the resource and intrinsically has the highest productive use to satisfy individual utility. Philosophically, if a person has property rights, others have the duty not to interfere with his possession and use. A lesser entitlement could only be claimed by others such as privilege, liberty or mere use (Cole & Grossman 2002).

Property rights are the basis for efficient resource usage and exchange, assuming there is a well-defined functioning market. The Coase theorem (Coase 1960) implies that entitlement is rewarded to a party that incurs a lower transaction cost or costs of abatement to maintain efficient allocation and trading of resources since externalities are solved. There is a presumption that farming communities operating at minimum risk exhibit the higher regard for preservation and commitment to the region, while CSG and other energy sectors are the exploiters, imposing (economic) opportunity costs at others' expense. This is manifested by the environmental and social risks and uncertainty issues against the energy resource (Kerr 2012). The analysis of Chen and Randall (2013) also demonstrates that venturing into agricultural enterprise is favourable or would acquire net social benefits in the midst of the external costs of CSG development and decreasing gas prices. The study acknowledges that CSG extraction could creates negative impacts on agriculture and the environment and could compromise future economic benefits. CSG royalties are also not enough to cover costs or damages incurred, despite the jobs and taxes collected by the government. In the long term, net economic benefits are higher for agriculture-only enterprises than for engaging in CSG or a coexistence scenario.

In reality though, legislative and political conditions determine who stands where and what can be taken out of the land, giving the extractive industries such as CSG the grounds to pursue their interests above farmers' claims. Though CSG development does not take away the property rights of landholders (Collins et al. 2013), farmers deem CSG as diminution of their ownership rights and freedom of land use.

The claim to property rights is commonly resolved through negotiations and compensation as part of the tenement privilege. A key mechanism in the operationalisation of the tenement is economic rent (energy resources are quantified according to their value of production minus the cost) and a risk premium (to cover uncertainties) (Productivity Commission 2015). Undertaking tenement agreements previously was straightforward when gas companies were operating in vast and remote rangelands, where productivity is sparse. This changed when arable lands and settlements became susceptible to gas development. There were instances where companies were drawn to purchase the land and even neighbouring farms, offering a premium of 15 to 40 percent more than the land value as recompense in order to avoid community tensions that relate to additional costs for the companies (Kerr 2012).

1.5.3.3 Legislation

The rights and agreements governing the coexistence of agriculture and the gas industry come under the umbrella of the Petroleum Act of 1923 (Queensland Government 2014a) and the Petroleum and Gas (Production and Safety) Act 2004 (Queensland Government 2004) in Australia. CSG production is administered by the Mineral Resources Act 1989 (DNRM 2013c), while the Land Access Code of 2010 (DEEDI 2010) underpins the compensation arrangements undertaken in Queensland. Further, there had been improvements to harmonise the operation of agriculture and CSG development with the legislation of Minerals and Energy Resource Act 2014 (Queensland Government 2014c) and guidelines in the Gas Action Plan (DNRM 2016) enacted.

There are several parallel legislative Acts within State legislation that manage the Australian gas industry, particularly the CSG industry. These legislations maximise efficient development of gas resources without compromising sustainability, safeguarding farm production, environment, biodiversity, natural resources, and water. Figure 1-6 and Table 1-1 present and describe some of these legislations. The red arrows show points of interest relating to surface ground operations and demonstrating the significance of managing coexistence (with other resources) within leased areas, relevant to this research. The following sections set out the legislative Acts and the operational management aspects of the overlap between CSG development and agriculture.

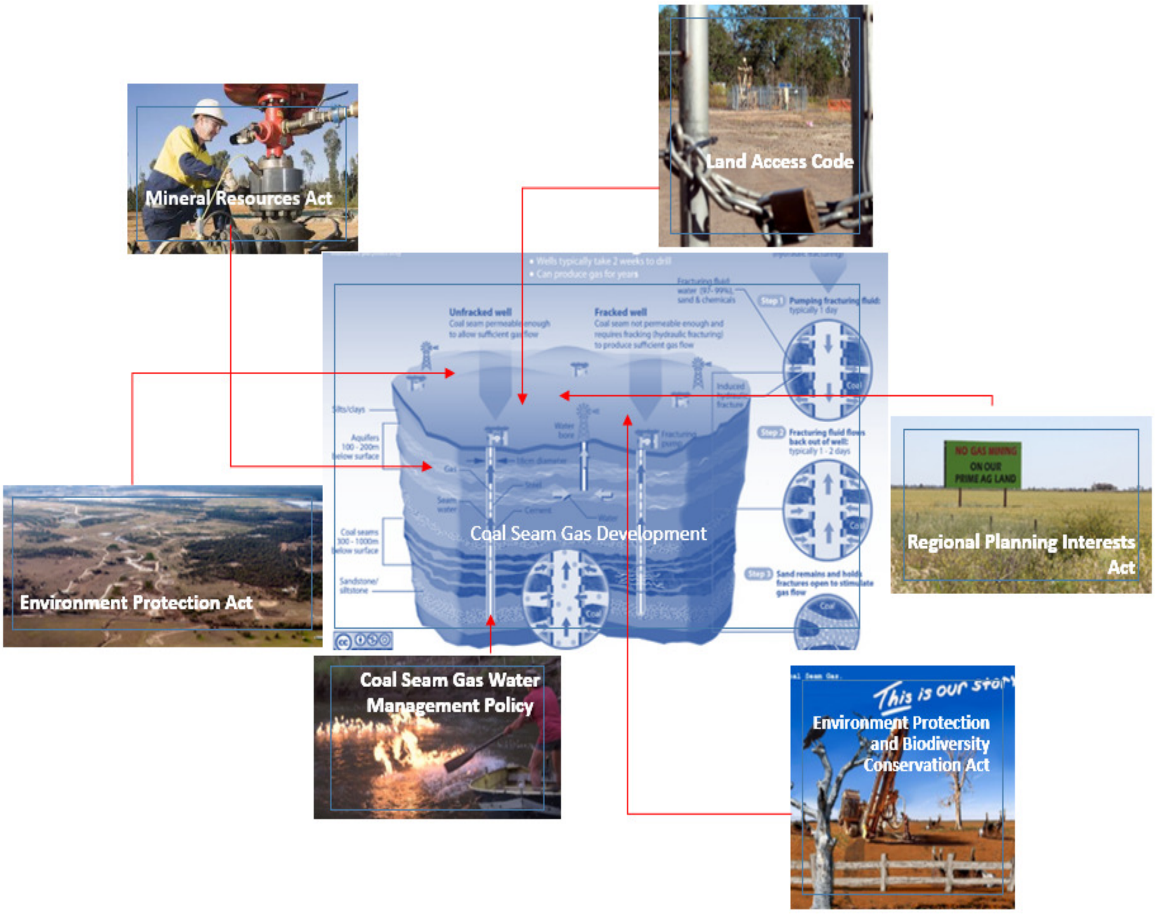


Figure 1-6. Some of the legislation concerning CSG development in Queensland
Photo credits: various issues of 'The Conversation'; and related articles

Table 1-1. List of several articles of legislation concerning CSG development in Queensland

Legislation	Year	Goal
Land Access Code	2010	Balancing the interests of the agricultural and resource sectors to address issues related to land access for resource exploration and development • *Best practice guidelines for communication between the gas companies and owners of private lands*

Legislation	Year	Goal
Petroleum and Gas (Production and Safety) Act Petroleum Act	2004 1923	Facilitate and regulate the carrying out of responsible petroleum activities and the development of a safe, efficient and viable petroleum and fuel gas industry • *The regulation prescribes reporting requirements, which ensure there is an adequate level of information being supplied in relation to the application for tenement*
Regional Planning Interests Act Strategic Cropping Land Act *(Repealed)*	2014 2011	An Act to manage the impact of resource activities and other regulated activities on areas of the State that contribute, or are likely to contribute, to Queensland's economic, social and environmental prosperity. • *Manage the coexistence, in areas of regional interest, of resource activities and other regulated activities with other activities, including, for example, highly productive agricultural activities.* *Area of regional interest: priority agricultural area, priority living area, strategic cropping area, strategic environmental area* An Act to protect land that is highly suitable for cropping, manage the impacts of land development, and preserve the productive capacity of the land for future generations
Environmental Protection Act	1994	Protect Queensland's environment while allowing for development that improves the total quality of life in a way that maintains ecologically sustainable development • *When applying for environmental assessment, operators of petroleum activities must include assessment of the likely impact of each relevant activity on the environment.*

Legislation	Year	Goal
Mineral and Energy Resource Act	2014	Create a simplified common framework for managing resources to optimise development and use of Queensland's mineral and energy resources and to manage overlapping coal and petroleum resources
Minerals Resources Act	1989	Encourage and facilitate exploring the mining of minerals; enhance knowledge of the mineral resources of the State; minimise land use conflict; encourage environmental responsibility; ensure an appropriate financial return to the State
Coal Seam Gas Water Management Policy	2012	Encourage the beneficial use of CSG water in a way that protects the environment and maximises its productive use as a valuable resource
Environment Protection and Biodiversity Conservation Act	1999	Enables the states and territories to provide a national scheme for environment and heritage protection and biodiversity conservation

Source: Various legislative documents

1.5.3.4 Regional Planning Act and Queensland land audit: spatial overlap of CSG development and agriculture

Policies to protect prime agricultural areas and mitigate impacts of CSG footprint were formulated and executed (Owens 2012; Swayne 2012), to mitigate the possible risks associated with CSG development and operation. One significant piece of legislation is the Regional Planning Interest (RPI) Act 2014 (Queensland Government 2014d). This replaces the Strategic Cropping Land (SCL) 2011 (Queensland Government 2011), established to provide protection for highly suitable areas for cropping (DNRM 2013a). It identifies areas of interest such as priority agricultural areas, priority living areas, strategic environmental areas and strategic cropping areas; these areas require a Regional Interests Development Approval (RIDA) before gas-mining activities occur. The size of the strategic cropping area is approximately 10.17 million hectares, identified through the SCL trigger map (DILGP 2014) (Figure 1-7). Eighteen (18) percent of SCL areas in the Surat Basin are with tenements.

The RPI Act limits resource activities on protected and potential areas for cropping. These areas are characterised based on the combination of their soil, climate and landscape features (Queensland Government 2014d). This implies that gas companies should not consider locating their wells in strategic cropping areas. CSG companies are not permitted to inflict permanent impact including, but not limited to: surface area disturbance, mixing of soil layers, soil compaction, erosion, subsidence, changing of physical, biological and chemical soil structure, and impediment to cropping (DNRM 2012). However, this is not the case as demonstrated in Figure 1-7, where location of the areas within CSG tenements coincides with the SCL areas. These are concentrated in parts of Chinchilla, Dalby, Wandoan, and Surat, which possess Vertosol soils suitable for intensive agriculture (i.e. cropping).

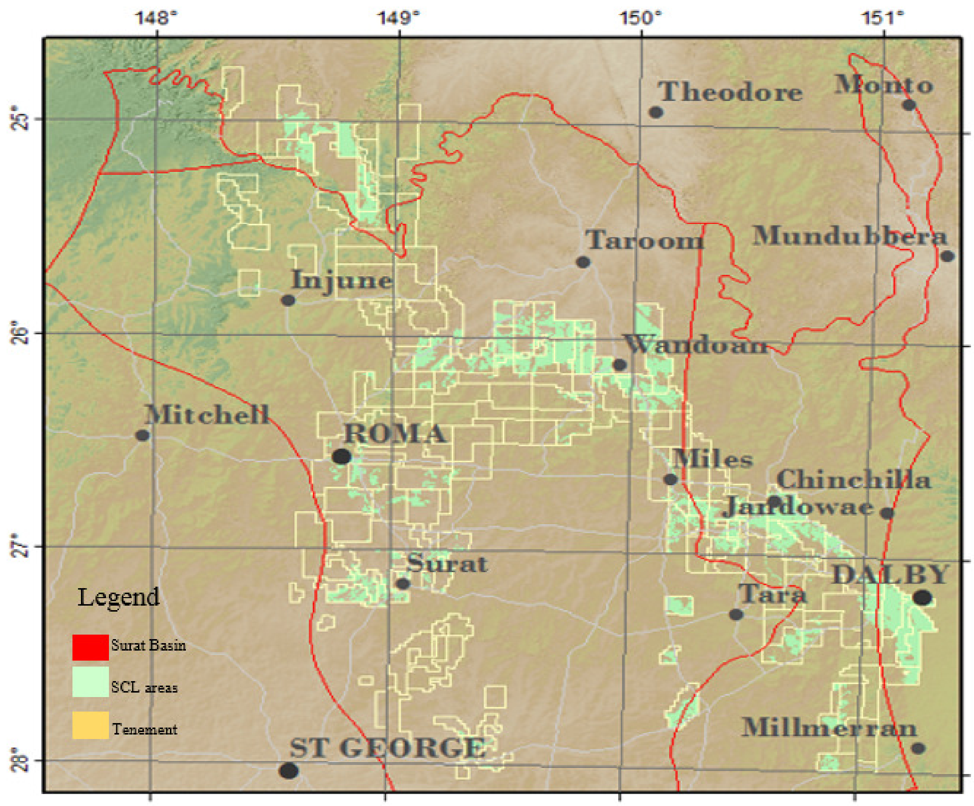


Figure 1-7. Distribution of the areas with tenement under SCL areas

An alternative effort devised by the Queensland Government to preserve the agricultural sector is through a spatial information tool, the Queensland Agricultural Land Audit (QALA). This spatial web database system pinpoints present and future agricultural production development areas. The Audit takes into account an updated inventory of all natural resources to map out the current and potential land uses of the regional boundaries in Queensland (Department of Agriculture 2014). Figure 1-8 presents the distribution of the land use in QALA for areas with tenement.

The spatial findings corroborate the SCL, pointing to significant areas of cropping for development, which are vulnerable to disruptions from resource activities. Images in Figure 1-7 and Figure 1-8 suggest that gas companies can still establish their operations on potentially highly productive and strategic agricultural areas. Thus, there should be an efficient regulatory mechanism, underpinned by scientific research to set boundaries for leased areas -ensuring that more intensive cropping operations could be a future option.

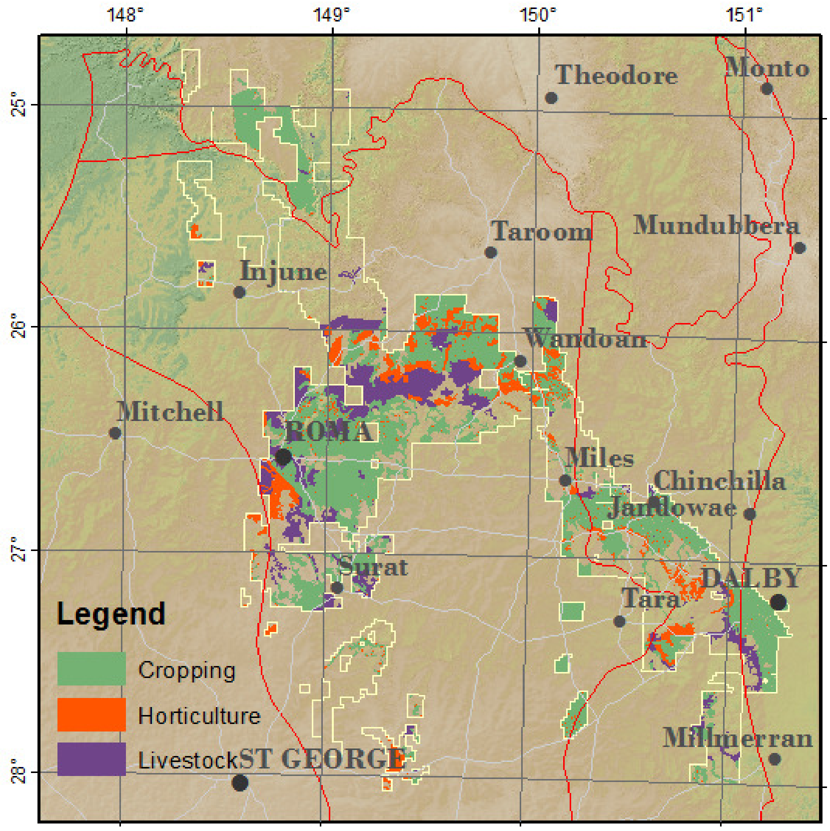


Figure 1-8. Distribution of QALA in areas with tenement

1.5.4 Theoretical concepts

1.5.4.1 Theory of cooperation and competition

The coexistence of the gas industry and farm enterprise struggles between cooperation and competition, motivated by an interest in either livelihood or landscape. The premise of cooperation and competition was developed by Morton Deutsch (Deutsch, Coleman & Marcus 2011), and relates to the positive and negative interdependence of goals and the actions taken by the stakeholders. Cooperation is a rational strategy when dealing with common pool of resources such as extractive goods. In the decision game for managing public goods, information is an important consideration on whether individuals would cooperate (Cárdenas & Ostrom 2004). However, information asymmetry leads to resource collapse, leading to theoretical predictions of destruction of natural resources as predicted in the case of CSG coexistence with agriculture (Ostrom 2009).

Cooperation leads to improved productivity, interpersonal relations, psychological health and self-esteem, as opposed to the results of competition (Johnson & Johnson 1989). This theory implies that people must aspire to achieve a constructive resolution when faced with conflict. This leads to a ‘win-win’ state. A ‘win-lose’ orientation (one party only benefits) promotes either a protracted dispute or a manufactured ‘win-win’, where the winning party is compelled to find a fair process of assisting the loser. This is through compensation (Deutsch, Coleman & Marcus 2011). The thesis postulates that coexistence should be cooperative, rather than conflicting, to be sustainable and economically viable.

1.5.4.2 Compensation

Compensation institutionalises the mitigation and recouping of losses from the CSG footprint. It is an efficient legislative and economic means for two parties to meet ‘common ground’. The right to compensation through legislation offers landholders a customised commensuration based on a set of negotiations undertaken by the parties involved (Productivity Commission 2015). Compensation can be in monetary form or service as a compensatory restoration (Flores & Thacher 2000). A comprehensive compensation arrangement discourages adversarial relationships and lowers transaction costs (Productivity Commission 2015).

The usual principle for compensation is to pay full costs for all damage. Full compensation corresponds to that amount from which the victim could recoup all losses and restore their level of welfare before the injury (Cernea 2003; Friedman 1982). Some CSG companies also provide payments in the form of royalties, sharing their income with landholders in order to maintain a sense of partnership (Productivity Commission 2015). Fairness is also an important principle of compensation in maintaining an efficient market. People are cooperative in negotiation agreements since they have the tendency to resist inequitable outcomes, despite social and economic assumptions that stakeholders tend to exclusively pursue self-interest and material payoffs. Therefore, fairness is tied up with equality that promotes cooperation (Fehr & Schmidt 1999).

Compensation not only shows concern for the individual's welfare but also relates to resource loss. It is considered an entitlement or rights of people affected, as a form of replacement cost for lost asset (Cernea 2003). The 'conservation of resources' theory by Hobfoll (1988) stipulates that loss in a resource leads to stress. Individuals encounter stress when threatened with actual loss of a resource or failure to receive gain from resource investment. This is comparable to the coexistence scenario, such that material resource loss due to CSG displacement has an impact on farmers and stakeholders. The extent of resource loss is variable depending on the subjective and culturally-driven individual's perspective or through an observable and detached process (Hobfoll 2001). This hypothetically implies that a landholder may find the CSG footprint to cause a reduction in production yield due to the area displaced for farming, while others are adamant to open up their gates because of the perceived effect on their landscape and rural legacy. Thus, each individual measures the adequacy of compensation differently.

Compensation is not a new investment or a benefit. Its value is not more than or above something they had before and was taken away from affected or displaced people. More often, compensation can result in impoverishing people, if it is undervalued. Some possible reasons for under-compensation could be undercounting of assets, arbitrariness or subjectivity of asset value, unrecognition and difficulty of measuring non-physical losses, loss in consumer surplus, and price changes in asset value (Cernea 2003).

The efficient use of a natural resource such as land also requires its use and non-use values in order to reflect its total social benefit (Prato 1998). Thus, the total economic value of farming in compensation structures and cost-benefit analysis of the overall large-scale impact of coexistence are imperative. This requires 'commodification' of the services (both private and public benefit) provided by agriculture (Perman 2003). Empirical estimates reveal that the willingness to be compensated (WTC) is generally higher than willingness to pay (WTP) when households perceive that their welfare loss is more serious than welfare gain from a change in environmental or resource quality (Prato 1998). The cautious behaviour of landholders of not giving up their property rights (ownership) over the leased land reinforces this notion. Though this thesis focuses on the financial aspect of coexistence, it is a substantial preliminary input in generating a fair and sustainable compensation structure.

Given that gas companies are obliged to offset (through compensation) the losses brought about by their operations, there is the probability of synergy between landholders and gas companies. The number of CSG wells installed on a farm provides supplementary income that landholders could utilise for farm improvement and/or non-farm investment ventures. In some cases, landholders become employees of the CSG companies to maintain CSG well sites. Such set-ups recruit landholders as partners rather than opponents to the coexistence process, providing them with information about how the resource companies operate (Collins et al. 2013). It also offers a steady stream of income additional to the farm business operation. Compensation acts as a 'buffer', an income independent of the seasonality and variability of the farming system.

1.6 Conceptual Framework

Food demand of the growing global population, coupled with reduction of available arable land, is putting increasing pressure on farm production (Alexandratos 1995; Lefroy, Bechstedt & Rais 2000; Pinstrup-Andersen & Pandya-Lorch 1994). Farmers are subject to risk and uncertainty brought about by their limited ability to predict elements such as weather, prices and biological responses to different farming practices (Pannell, Malcolm & Kingwell 2000). They also face the challenge of land use competition from non-agricultural development.

A multidisciplinary approach addresses these fragmented problems and conflicting interests in agriculture. Such a concept involves systems thinking (Bosch, Maani & Smith 2007). The systems thinking model recognises interactions, synergies, and relationships between stakeholders and their situation/environment (Maczkowiack 2008). This is a holistic approach of relating the natural and social systems of agriculture (Monat & Gannon 2015; Packham, Petheram & Murray-Prior 2007).

There are two kinds of systems thinking: 'hard' and 'soft'. Hard systems thinking focuses on the objective means of solving problems. It is a systematic way of modelling the real world through a scientific testing, implementation and evaluation process (Jackson 2003). On the other hand, the soft systems approach is an organised and action-oriented method of handling perceived problematic (social) situations. It involves multi-interaction of 'people' in interpreting subjective world problems (Reynolds & Holwell 2010). This thesis is associated with the hard systems thinking, through the use of computer modelling, to provide an analogue of the biological and financial aspects of farming. This type of approach is based on an operational domain of simulation in predicting performance for the entire system, and selecting the best solution and alternatives in addressing an issue (Jackson 2003).

The conceptual model developed for this thesis demonstrates the systems thinking approach. The research problem is primarily categorised based on the level of complexity and diversity of the environment (system) and participants involved. A simple system of the unitary (one-person approach) process of investigation defines participants as having similar values, beliefs, and interests resulting in easy decision-making. As the systems become more complicated, more participants and variables are involved, requiring a pluralistic approach to knowledge (Jackson 2003). Such circumstances enable the systems thinking approach to transcend from hard systems thinking to soft systems thinking.

Figure 1-9 demonstrates where the thesis perspective is under the umbrella of systems thinking. This research realises the inextricable linkage of the agricultural system to other developments in society. This thesis concentrates on the systematic approach of systems thinking, which focuses on the quantifiable process of observation (i.e. simulation). A systematic approach ensures that the observer is not affecting the results but could identify parts of the system and interpret the changes that transpired (Schiere et al. 2004).

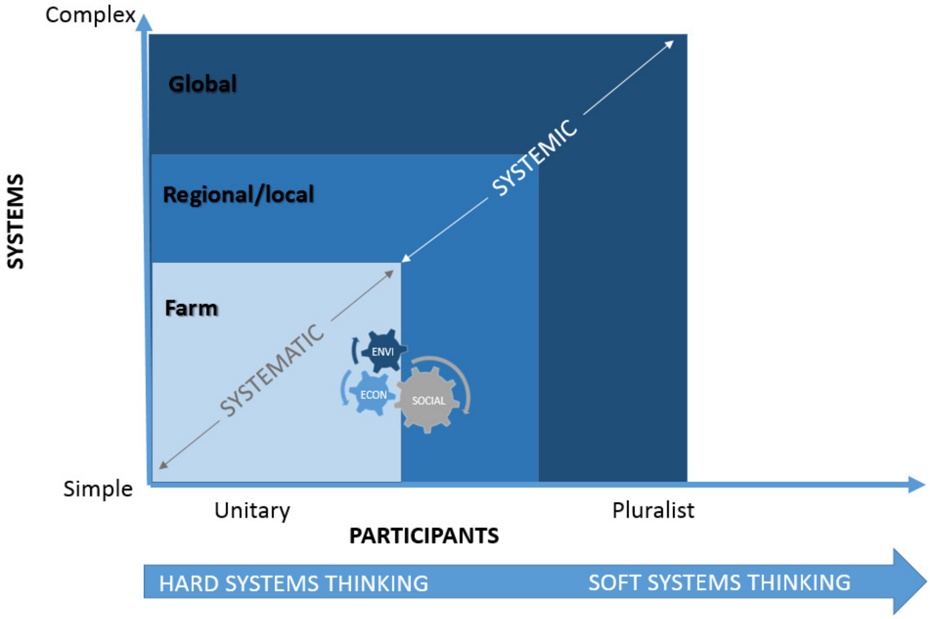


Figure 1-9. Conceptual model of the thesis under Systems Thinking

The farm scale analysis of coexistence in the thesis involves the biophysical characterisation and financial consequences of the interaction of farming and CSG development, and its influence on a landholder's management behaviour and investment decisions. Hence, the research serves as an information tool to further comprehend the complex interface of coexistence from a regional to a global perspective, without qualitative judgement.

Within the systems thinking framework is the triangulation of the financial, environmental and social aspects of the analysis (Figure 1-10). The interactions of these components underpin the systematic flow of analysis of the thesis. It provides a link between biophysical and financial components for understanding the social implications of production and resource management to people (stakeholders).

Figure 1-10 shows the collaboration as a 'gear' process, in that the movement of one aspect would have an effect on the others. The illustration presents the financial and environmental analysis as the same size, but smaller when compared with the social. This represents the level of intricacy of each component. Human interaction is complex, multi-faceted, and better understood under the premise of a wider sphere of research. This is the reason why the social component is outside the scope of the research (Figure 1-9).

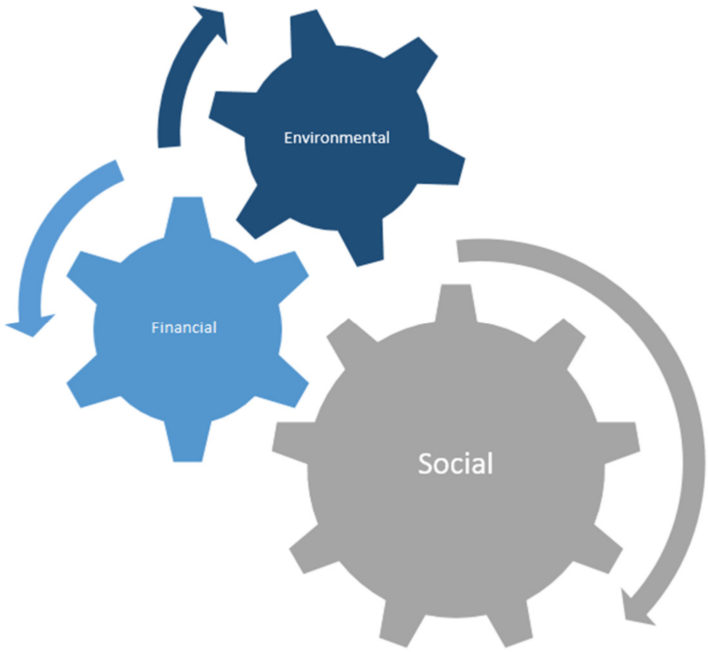


Figure 1-10. Aspects of analysis of Systems Thinking

The environmental aspect of coexistence would drive the 'gear' clockwise. This denotes that the inherent biophysical characteristics and the existing natural resources would determine the degree of interaction and decision-making of the stakeholders. Intuitively, arable lands devoted to agriculture would prioritise farming over other non-agricultural activities, especially for those areas that have a favourable environment. A highly intensive and efficient farming management yields a higher financial output. There would be an interruption in the systems flow if there is an external force that would counter the process, such as CSG development. The hypothesis is that CSG operations have a deleterious effect on agricultural productivity, creating social conflict and confusion. These outcomes lead to inefficiencies and higher costs in farm management.

On the other hand, the financial aspect of systems thinking drives the process flow of analysis counter-clockwise. This situation transpires when profit from a certain venture acts as the main factor in decision-making and interrelationships. Landholders are flexible as to what enterprise they would engage in, regardless of whether or not its environment is suitable for farming. However, the consequences of any decision would influence the sustainability of the environment and resources. It is dependent on whether the inherent environmental suitability of the land use is coherent.

Though an environment-driven flow is the more efficient, stable and sustainable approach in managing farming systems, the systems flow is dependent on the capacity of the landholders' decision. Those who benefit more from land resources hold different interests to those who do not. 'Well-endowed' landholders are concerned about preservation while those who are 'less-endowed' want to further explore financial opportunities and find their own investment niche. This is reflected in the social engagement of landholders, in which they are either willing to take on risk in negotiation, resource investment, and cooperative management, or not.

1.7 Methodology

1.7.1 Research Philosophy

The fundamentals for modelling coexistence lie within its knowledge claim. Knowledge claims could be referred to as paradigms (Creswell 2009; Lincoln, Lynham & Guba 2011), philosophical assumptions (Saunders, Lewis & Thornhill 2009), epistemologies and ontologies (Creswell 2009; Saunders, Lewis & Thornhill 2009), or research methodologies (Neuman 2006) in literature. The research embraces the positivism and/or realism philosophy as the scientific way of doing research (Creswell 2009; Crotty 1998). This relates to scientific inquiry, under which objectivism is used to derive assumptions. It leads to quantitative research involving strict observation and the numerical control of variables in explaining and predicting a phenomenon (Saunders, Lewis & Thornhill 2009).

A positivist paradigm attempts to simulate situations through replicated scientific methods in which variables are controlled and manipulated. The researcher's view or emotions are irrelevant in reviewing the problem of the study. This kind of philosophical approach is usual in the natural sciences, which prefers the observable social reality in creating generalisations and laws in interpreting the physical environment. A deductive research design is adapted by developing a research strategy to test the hypothesis (Saunders, Lewis & Thornhill 2009).

Business research, such as this thesis topic, possesses a multi-level organisationalstructure and is not held as an independent entity at a realist context (Bhaskar 2010). It is why this thesis is insufficient when regarded of its own value. The micro-perspective of a detailed farm scale of analysis contributes to the increase in the validity of a complex interrelation in the coexistence phenomena. This research is an explanatory type of study that establishes the relationships among variables. The conduct of case studies used secondary information from the coexistence scenario at a particular farming system. It includes multi-method data collection involving quantitative techniques. Figure 1-11 demonstrates the overall flow of the thesis' research design.

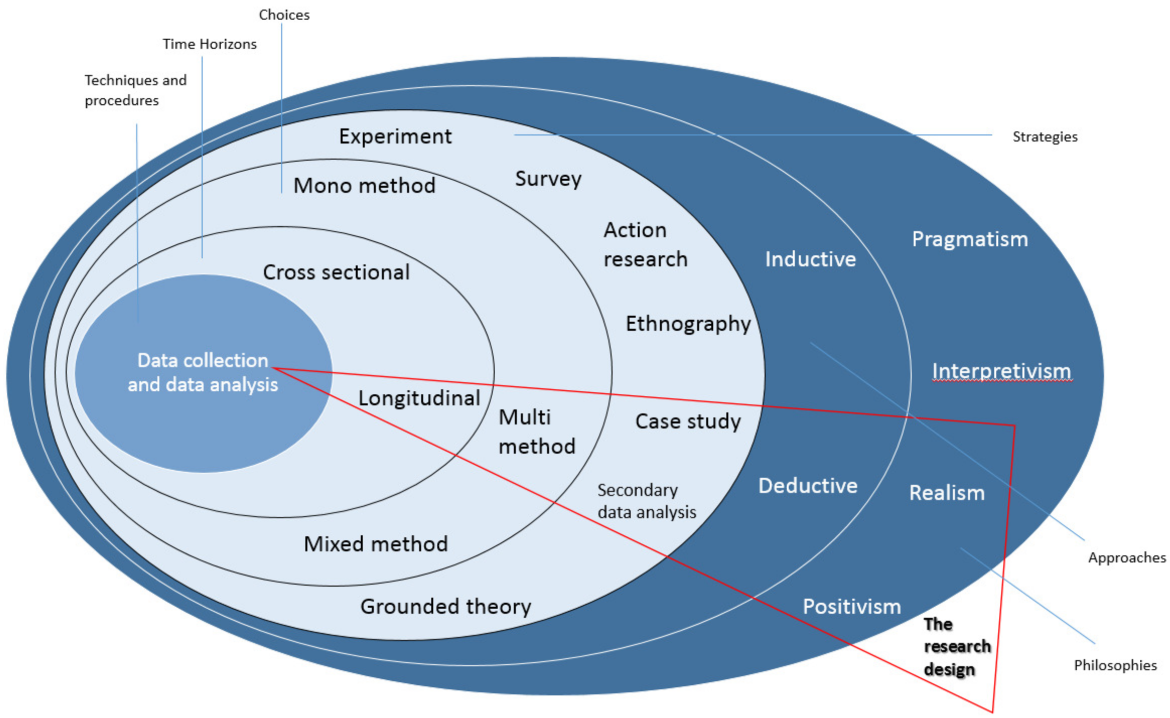


Figure 1-11. The thesis research design

1.7.2 The Study Area

This research is towards the Surat Basin of the Great Artesian Basin, one-third of which is within northern NSW and Queensland. The Surat Basin is playing an increasingly important role in energy development in Queensland due to its large resources of open cut thermal coal, with higher permeability and lower drilling, and completion costs as compared to the Bowen Basin (Halliburton 2014).

The research area of the thesis is the CSG development (tenement) areas within the Surat Basin region in Queensland, located in the regional areas of Maranoa, Western Downs and Goondiwindi, covering 178,834 km^2 (Figure 1-12). Roma, Miles, Chinchilla, Dalby, and Toowoomba are the centres of the population.

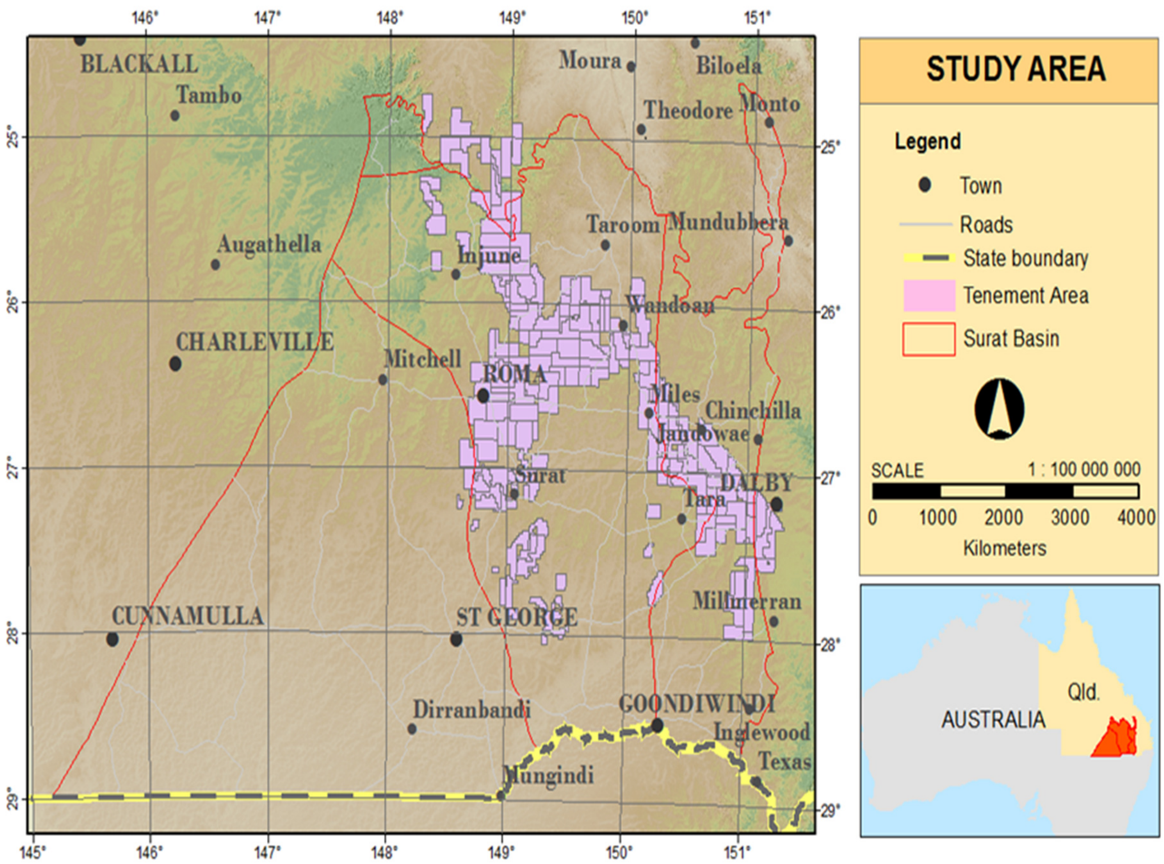


Figure 1-12. Location map of study area

Property sizes in the Surat Basin are the largest in the southwest to west towards the northern portion (Figure 1-13). The parcel of land in some major localities and towns such as Cuttaburra, Hebel, and Bollon reaches more than 30,000 hectares. On the other hand, property sizes are smaller in areas of Mitchell, Roma, Miles, Chinchilla, Brigalow, Warra, and mainly in the eastern parts of the Surat Basin ranging from less than 250 hectares to 1,500 hectares.

Agriculture is the main enterprise in the Surat Basin area (Figure 1-14). The southwestern part of the basin holds predominantly grazing farms (Figure 1-15) since the landscape becomes drier towards the west (Schandl & Darbas 2008). The southeast to eastern part contains cropping areas –particularly in the surrounding areas of Chinchilla (Figure 1-16). These fertile lands are the Australian 'food bowl' (Schandl & Darbas 2008) having mostly dryland and irrigated broad-acre cropping with commodities including cereals, pulses and cotton, irrigated vegetables, and fruit and vineyards (Clarke 2013).

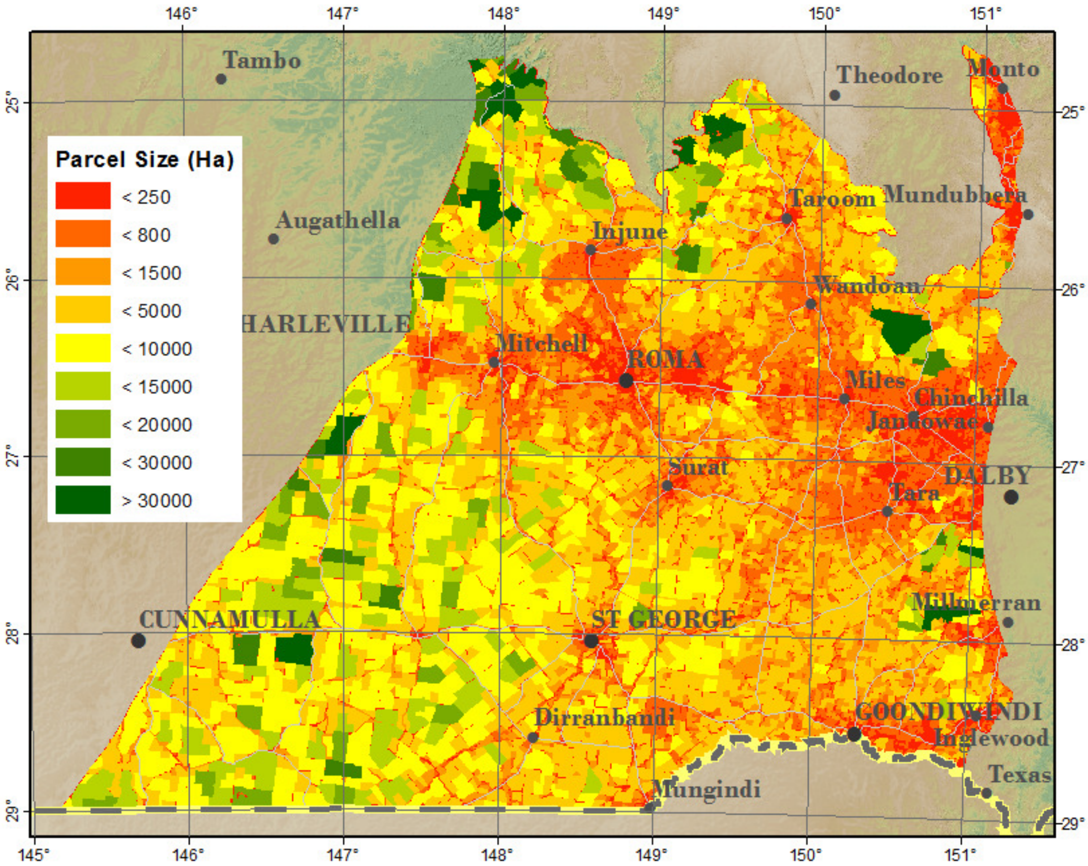


Figure 1-13. Parcel size in Surat Basin

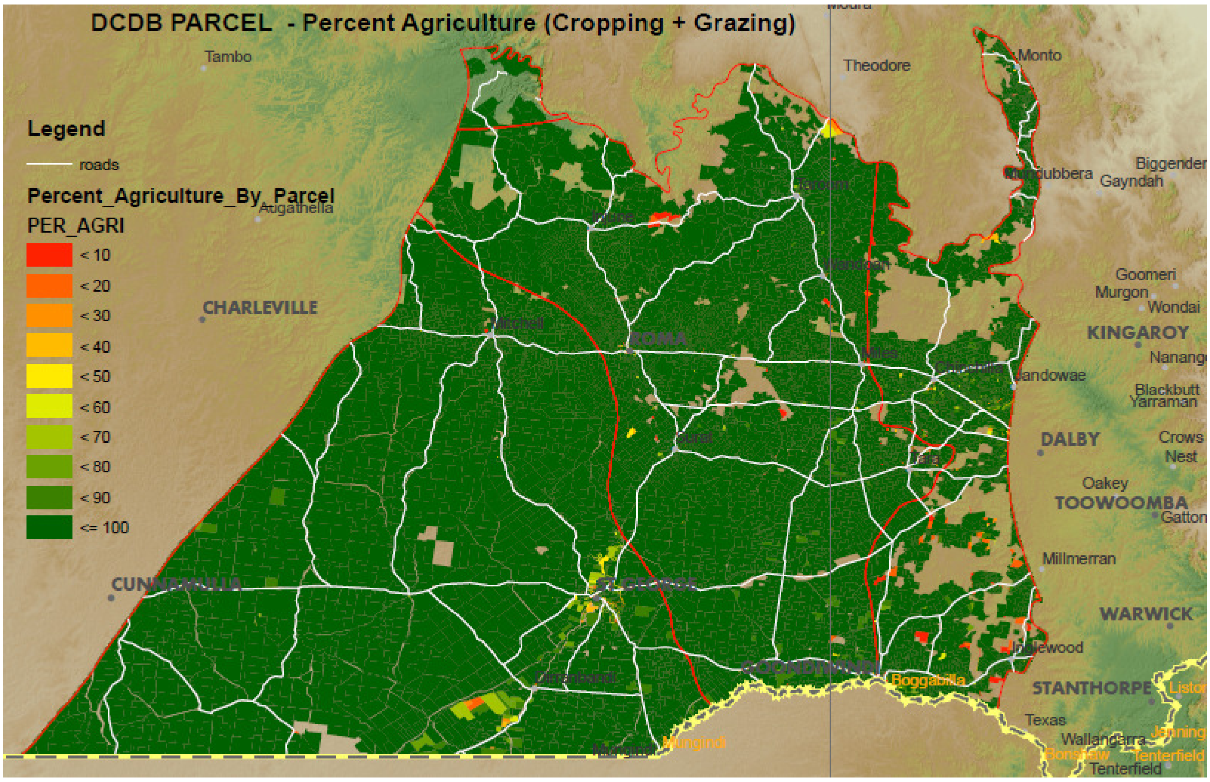


Figure 1-14. Percentage of agriculture in Surat Basin

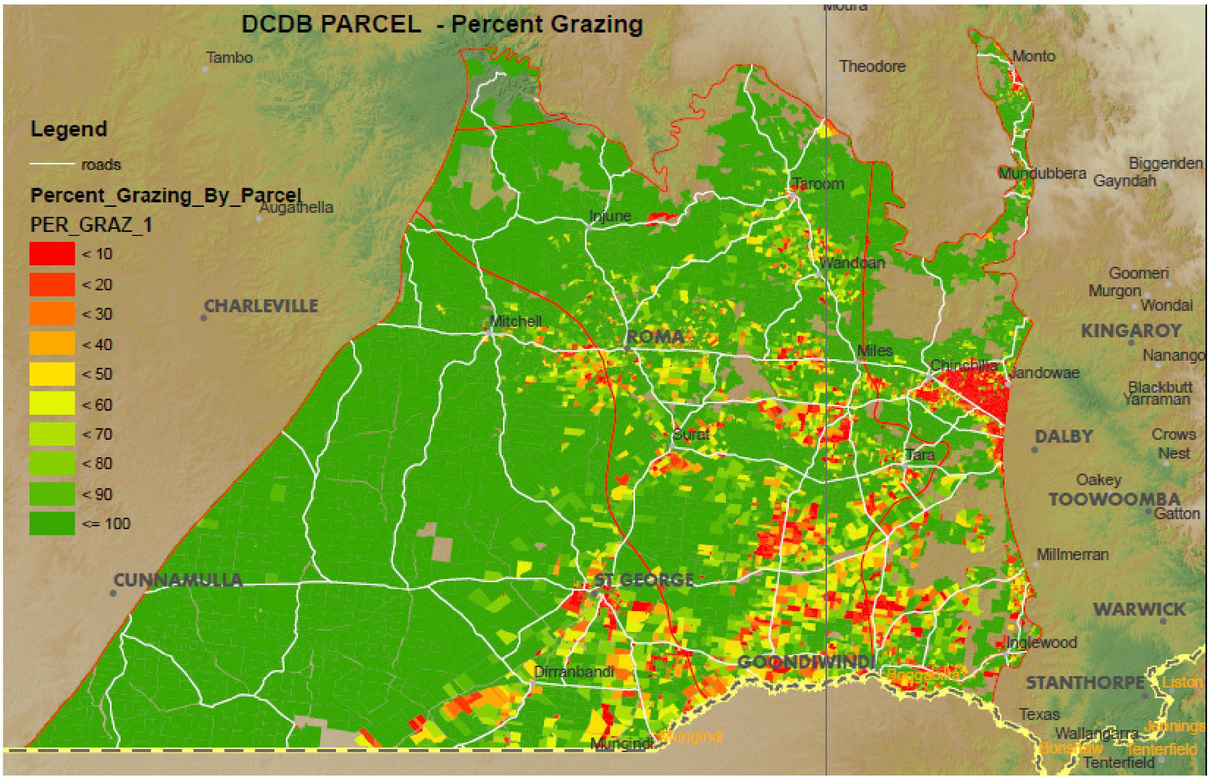


Figure 1-15. Percentage of grazing in Surat Basin

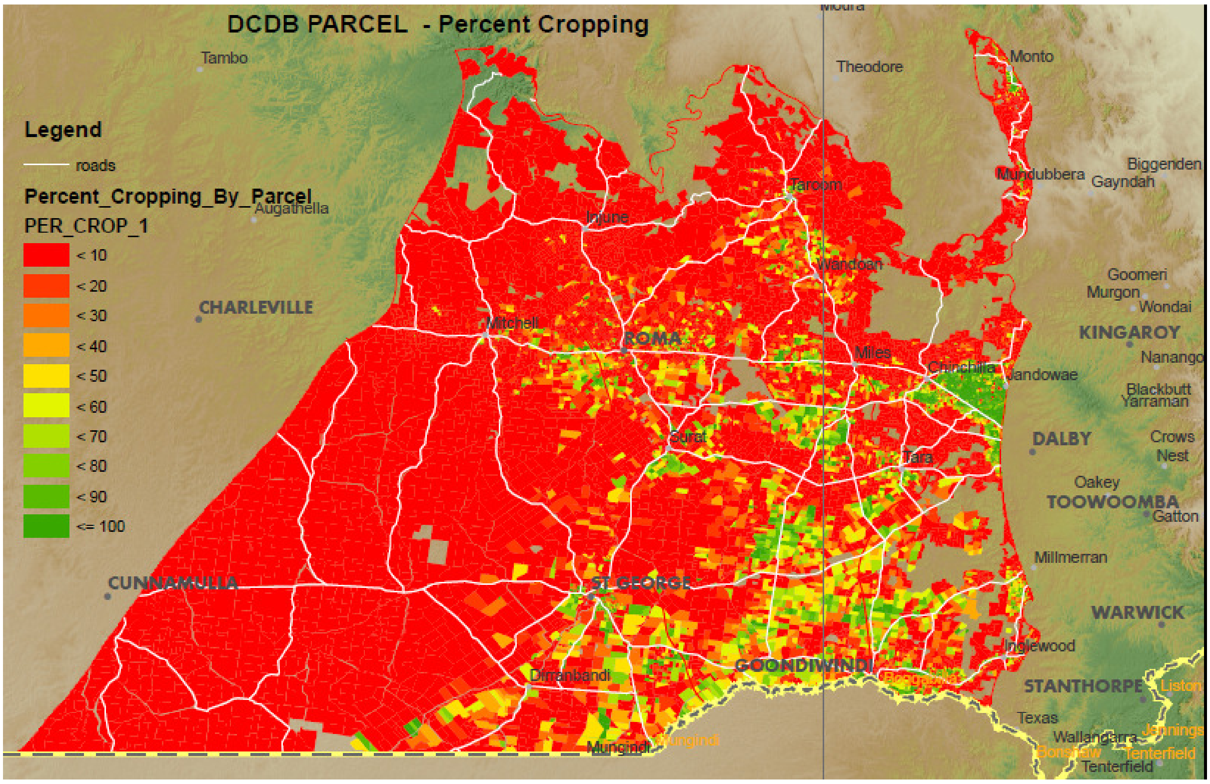


Figure 1-16. Percentage of cropping in Surat Basin

1.7.2.1 Areas with tenement

The areas with tenement lie on the north-eastern part of the Surat Basin. It covers 15percent (2,653,479 hectares) of the total land area (17,883,402 hectares) of the Basin. These areas are mostly large field parcels with an estimated size of less than 5,000 to less than 25,000 hectares (Figure 1-17).

There are gas wells currently operating within the Surat Basin, predominantly in areas of Tara, Miles, Roma, and Injune (Figure 1-18). Different gas companies operate in the Surat Basin for the exploration and extraction of CSG. The Santos gas company (Santos QNT) operates mainly in Roma and Beilba, while the Arrow Energy Group works in parts of Dalby and Chinchilla (through the Australian CBM). In Millmerran, Wallumbilla, Durham Downs, Waikola, and Mt Howe, APLNG possesses the tenure on gas development. QCG (BG International) are in areas such as Columboola, Grosmont, Bundi, Kumbarilla, Montrose, Wieambilla, and Nangram. LINC are in Yuleba and the AGL gas company operates in Parknook and Noorindoo (Figure 1-19).

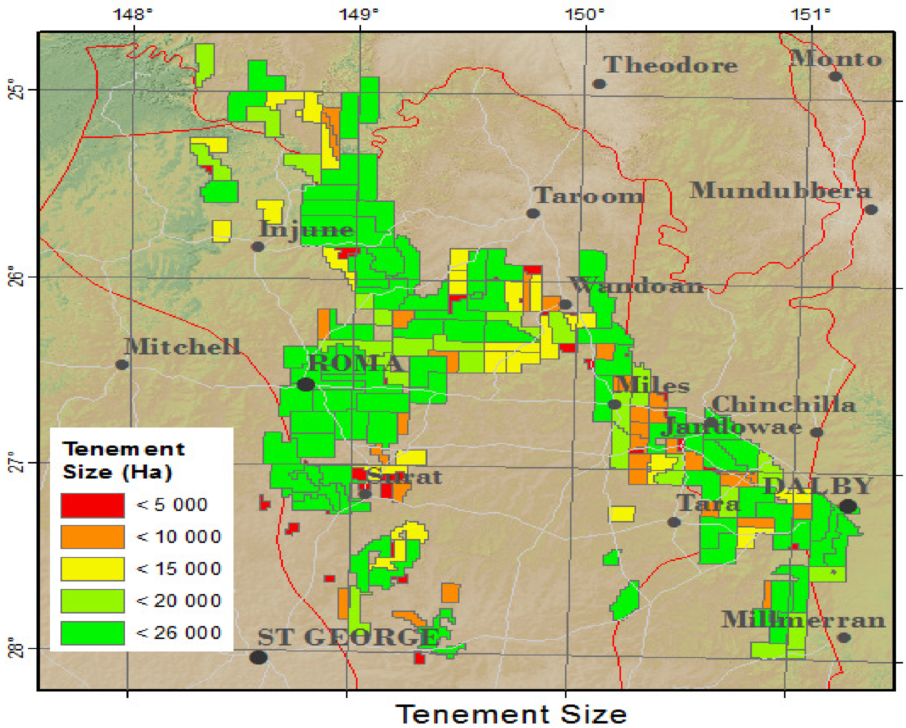


Figure 1-17. Size of areas with tenement in Surat Basin

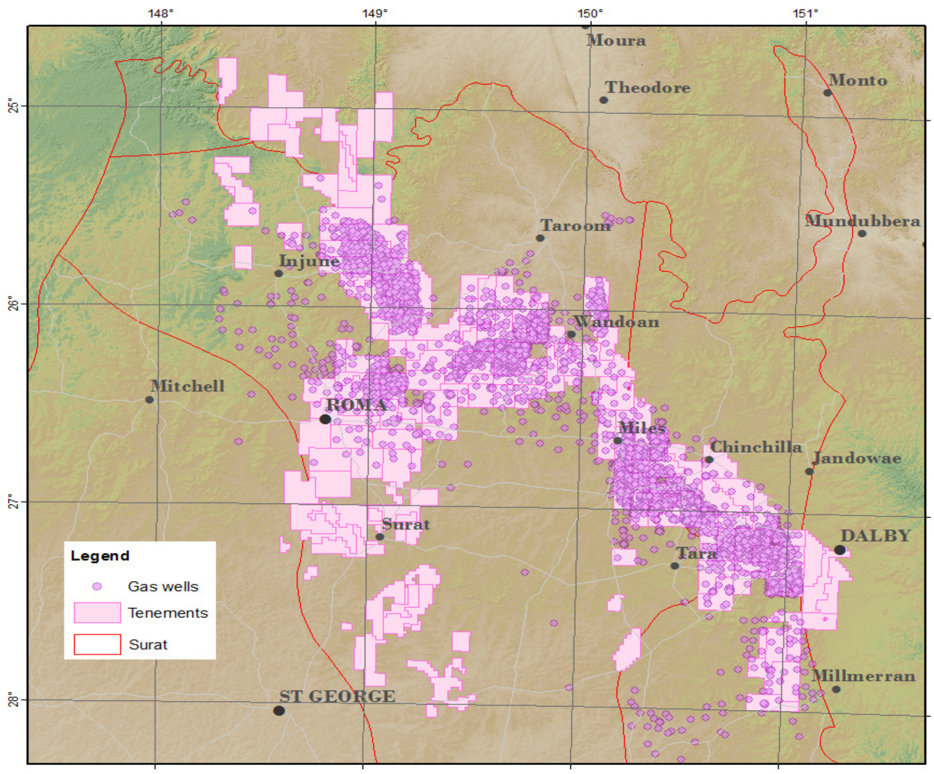


Figure 1-18. Distribution of gas wells operating in the Surat Basin

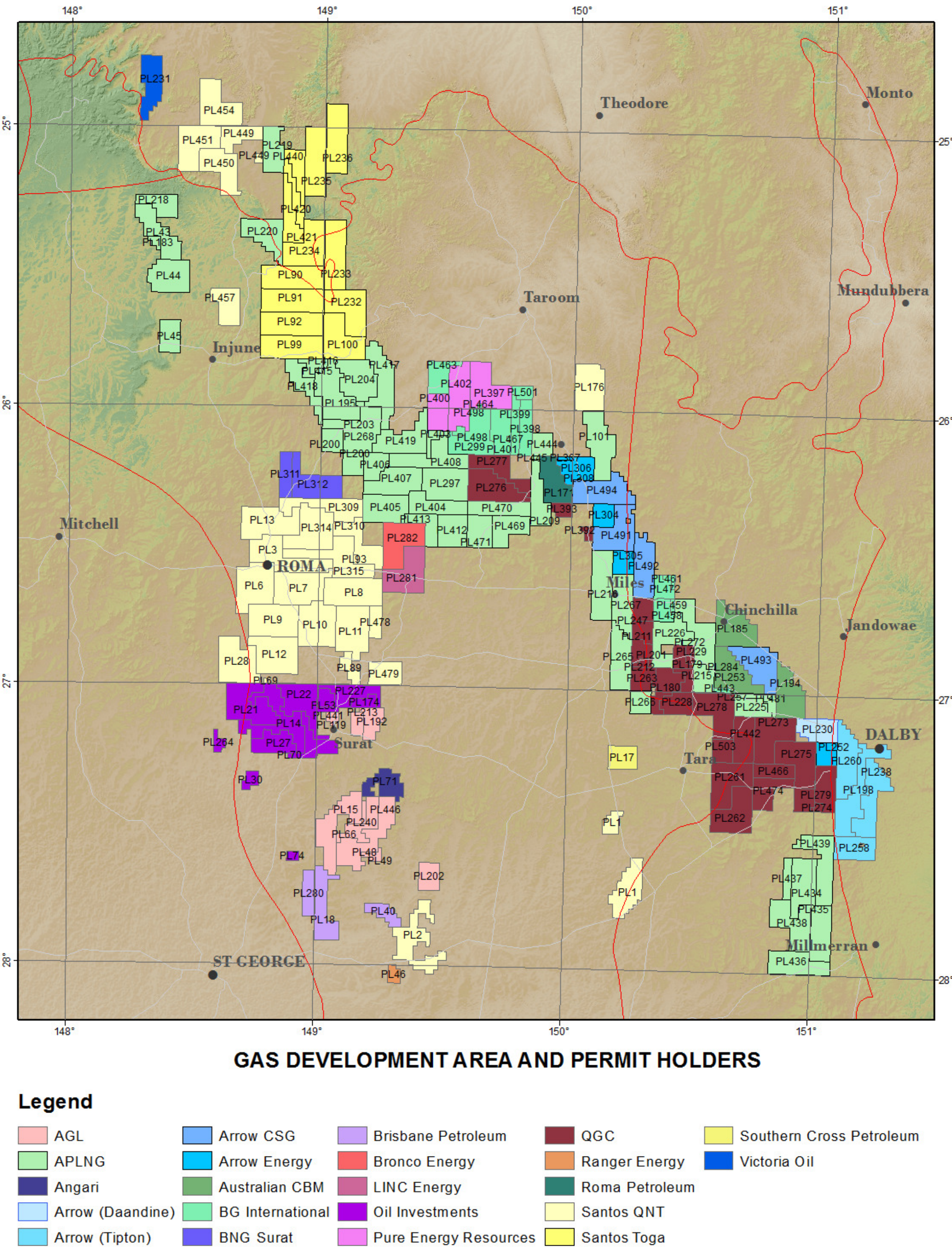


Figure 1-19. Gas companies operating in areas with tenement in the Surat Basin

1.7.2.2 Agricultural areas with tenement

The extent of agricultural lands in areas with tenement identifies the range of productive area where CSG development could potentially have impact. Figure 1-20 shows the distribution of agriculture areas with tenement. Cropping areas lie mainly in parts of Dalby to Cecil Plains, while grazing areas are in the central part of the study area. These predominantly lie in Roma, Wandoan, Miles Tara, Surat, and other parts.

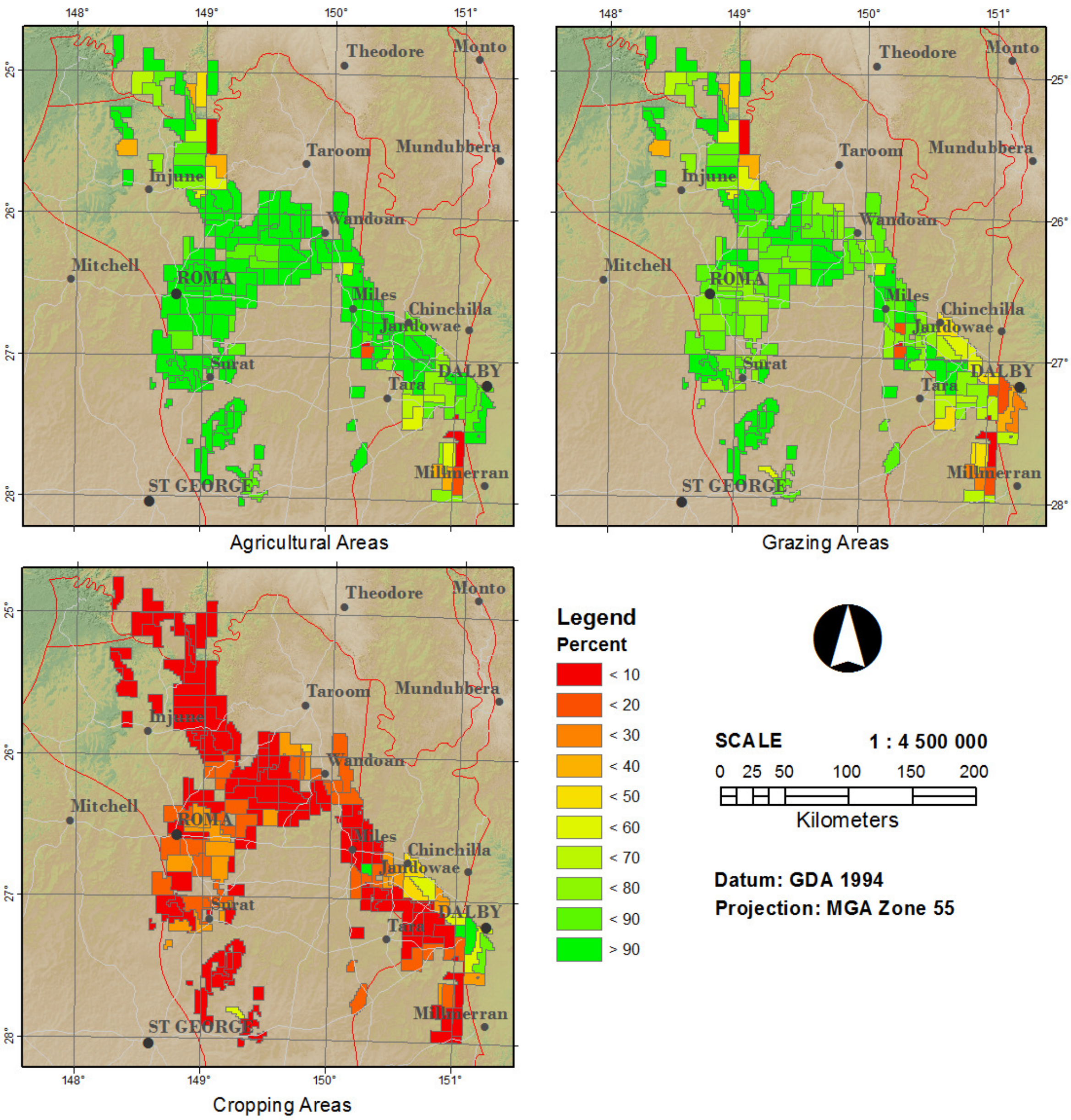


Figure 1-20. Percentage distribution of agriculture –cropping and grazing areas with tenement

Gas tenements occupy approximately 2.6 million hectares of total land area. Table 1-2 shows the land use categories of areas with tenement. The table demonstrates that the majority are agricultural (88%) with an area of 2.32 million hectares. The remaining non-agricultural areas are comprised of feedlots (intensive animal husbandry), residential and farm infrastructures/buildings, production forestry and conserved areas, wetland areas, mining, and other infrastructure. The majority of these agricultural areas are grazing lands. Specifically, 87 percent (2.04 million hectares) of these lands are devoted to native pasture or vegetation grown for livestock consumption.

Table 1-2. Land use of agricultural areas with tenement

Land Use	Area (Ha) in Tenements	% of Land Use to Total Agricultural Area	% of Land Use to Total Tenement Area
Dryland Cropping	252,160	10.84	9.50
Dryland Horticulture	130	0.01	0.00
Irrigated Cropping	30,190	1.30	1.14
Irrigated Perennial Horticulture	95	0.00	0.00
Irrigated Seasonal Horticulture	750	0.03	0.03
Grazing Modified Pasture	1,148	0.05	0.04
Grazing Natural Vegetation	2,041,775	87.77	76.95
AGRICULTURAL AREAS	2,326,248		87.67
NON AGRICULTURAL AREAS	327,231		12.33
AREAS WITHIN CSG TENEMENTS	2,653,479		100.00

1.7.3 Research Plan and Data Analysis

This research simulates the characteristics of a representative farm with tenement within the study area. The underlying assumptions for modelling were derived from primary and secondary data from scientific institutions, national agencies, research organisations; and were validated by a group of agronomists, resource economists, and spatial science experts.

The thesis comprises three parts, inclusive of three interdependent studies addressing the research questions provided by the research. The initial section of the thesis (Part 1) provides an overview of the thesis. It presents the subject matter of the thesis and its underlying knowledge. Part 1 also specifies the gaps in the literature and how the scope of the research addresses them. It embodies the overall perspective of what to expect in the succeeding parts of the thesis.

Part 2 of the research starts with Study One relating to Research Question 1: *'What are the physical characteristics and productive value of the farming areas within CSG tenements within the Surat Basin?'* This aspect of the thesis is about knowing the 'space' of the research. It works towards characterising the physical and production environment of the areas with tenement in the Surat Basin. This focuses on spatial classification of the farms using information on the biophysical and agro climatic conditions, particularly the raster data such as soil pH, plant available water capacity, aridity and slope. Fuzzy membership classified these data. This becomes an input for locating areas where opportunities could be explored and effects are aggravated due to the coexistence of CSG mining and agriculture, by showcasing the productive capacity and intensification potential of the areas within CSG tenements.

The analysis of the effects of CSG development on farm enterprise is reported in Study Two. This points out the 'process' of setting the framework for evaluating the effects of coexistence. It relates to Research Question 2: '*What are the effects of CSG operations on agricultural production and enterprise in different farming systems in the Surat Basin?'*, which deals with identifying the extent of the CSG infrastructure footprint, ascertaining aspects of farm operations affected, and estimating gross margin changes in farm enterprise at the farm paddock level under varying scenarios of coexistence. A hypothetical farming system in three case studies is simulated. The secondary data on the average gross margin of crops of a specific cropping rotation supplements the simulation process. The modelling of the climate variability, agronomic parameters, and machinery (farm implement) efficiency depict the impact of CSG footprint on the farm enterprises' income and costs.

The last study is about taking 'action' in adapting the coexistence set-up. This explores the decisions made within the premise of coexistence. It deals with the potential agricultural investment strategies that landholders could pursue to maximise benefits from compensation during different phases of CSG development. These potential farm investment options include intensification, expansion, and diversification. It also provides estimate of the amount of returns from each of these investment options, required to arrive at the most rational decision. The study indicates that strategic management of the financial opportunities from compensation would lead towards a more synergistic relationship between agriculture and the CSG industry, reducing the compounding issues of conflict and uncertainties from coexistence.

Figure 1-21 shows the operational flow of the thesis.

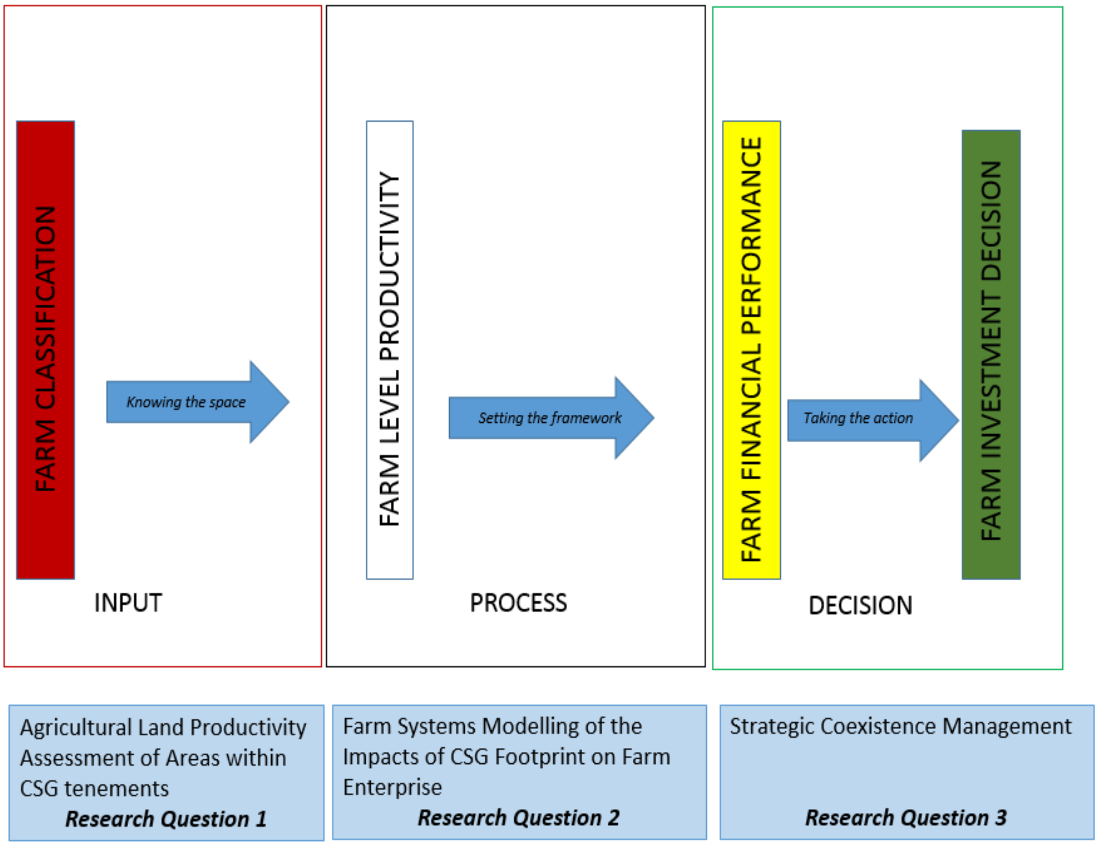


Figure 1-21. Operational flow of the thesis

1.8 Conclusion

Part 1 of the thesis provides an overall perspective of the research. It discusses the overarching concept of coexistence between two important sectors in Queensland, agriculture and gas mining. Existing literature stipulates that there is an escalating conflict between these industries due to the economic, environmental, and social impacts of CSG development at an individual to community scale. This issue is also embedded in the arguments regarding ownership of the land, in which title holders feel ‘powerless’ in exercising their rights.

However, there is inadequate understanding of the general outcomes of coexistence, in terms of its spatial impacts and the financial prospects. In particular, the thesis intends to explore the consequence of CSG development on the financial performance of the farm enterprise by indicating possible management strategies to minimise costs and maximise benefits. Due to variability in information and a high level of confidentiality, the research employed quantitative modelling of case study farms in deriving generalisations.

The next part of the thesis presents the first of the three interdependent studies that demonstrate an indicative farm level scenario of the coexistence set-up in areas within CSG tenements or leased by gas companies. These studies are simulated and provided a broad description of the extensive construct of the outcomes landholders could expect with CSG development.

Part 2: Research studies related to coexistence

This segment of the thesis highlights the key arguments behind the relationship of agriculture and CSG mining by providing three interdependent studies, each discussing different features of the coexistence scenario. The first study deals with characterisation of areas within CSG tenements in the Surat Basin. Tenement gives the CSG companies the right to access some productive areas. The initial chapter focuses on the biophysical and spatial attributes of the areas leased by gas companies and categorises these sites in order to identify localised and indicative management strategies.

Study Two discusses the impacts of the CSG footprint on both agricultural production and the financial performance of the farm enterprise at a farm paddock level. The case studies selected are areas of dryland and irrigated farming systems, which lie within CSG tenements in the Surat Basin. The study demonstrates the consequences of coexistence on overall farm enterprise profitability, exhibited by changes in gross margins. The findings of the study serve as an information tool in negotiating compensation agreements by identifying aspects where landholders could minimise impacts and maximise benefits from the coexistence set-up.

The last study focuses on possible financial opportunities from the compensation provided by gas companies. The study addresses the gap in literature regarding the management strategies that would make agriculture resilient to CSG development. The study intends to construct synergy in the relationship between landholders and gas companies, by postulating different investment options using the additional cash inflow.

2 Study One – Agricultural Land Productivity Assessment of Areas within CSG Tenements

2.1 Introduction

An estimated 82 percent of Australia's farmland is devoted to grazing or native pastures in the arid and semi-arid zones (ABS 2016b). However, the northern, eastern, south-eastern, and south-western parts of the country have climates ranging from tropical to temperate, making cropping possible (Jayasuriya 2003). Other areas employ irrigation technology to maintain farm viability, despite low rainfall distribution.

Aside from climate, the biophysical characteristics of an area are determinants of the capacity of the land for agricultural production (Ceballos-Silva & Lopez-Blanco 2002). Physical and chemical soil properties, temperature, precipitation, solar radiation, topography and human management, define the natural capacity (Lobell et al. 2002) and predisposing conditions for land use and land cover, managed in terms of zones or land units across space and time (Bajocco et al. 2016; Geist et al. 2006; Reddy & Maji 2004). Geographers and agricultural ecologists also included the importance of natural flora and fauna as major factors in the location of a farming system (Duckham & Masefield 1970; Hole et al. 2005; Marshall & Moonen 2002). Improved productivity can be achieved through collecting baseline information on soil and environmentally-related features and limitations (Muya et al. 2011), matched with suitable and adaptable agricultural commodities.

Australian land cover has evolved through time, giving way not only for cropping and pastures but for other forms of land use, including forestry, mining and residential development (Barson, Randall & Bordas 2000). This opens up a range of enterprises that may not efficiently utilise the biophysical characteristics of a given site. In some instances, economic motivations are more likely to influence which industries are put in place – a case of '*nature proposes, man disposes*' (Duckham & Masefield 1970). This affects the sustainability of natural resources and leads to land use competition (or conflict), which is apparent within agriculture, extractive industries, and urbanisation (Greer, Talbert & Lockie 2011). This phenomenon is apparent in some areas in Queensland. The sharing of productive land of agriculture with CSG development has become an issue.

Only 1.5 percent of the total area of Queensland consists of good quality, irrigated cropping soils. Though, some CSG projects in the Surat Basin coexist on these arable lands. This raises serious questions as to which of these areas must be critically and exclusively preserved for agricultural production (DEEDI 2010; Lockie 2015). CSG production affects agricultural productivity, farm costs, landscape, and land and water quality degradation (Lockie 2015). However, there is limited information on the geographical extent of the overlap between agriculture and CSG infrastructure and its impact on farm production and financial performance of the farm enterprise.

This study aims to analyse the inherent agricultural potential of areas within CSG tenement in the Surat Basin. Tenement is defined in mining and energy as being the right of the holder to access, explore, and develop resource energy in a specific area. It exists in the form of licences and leases. Areas within CSG tenements are also areas leased by the gas companies. Study One classifies areas within CSG tenements by their intrinsic biophysical characteristics to explore their suitable and potential productivity. This study also demonstrates the overlap of agriculture and CSG operations in areas of prime arable lands, investigating claims that food production and natural resource preservation might be compromised in the future.

2.2 Methodology

This part of the study categorises the areas leased by gas companies according to their current land use and suitability for agricultural intensification. The study highlights the basis for productive value of areas with tenement, information that would eventually be useful for financial negotiation and farm management. The classification process uses a set of selected biophysical factors, representing climate, topography, and soil characteristics of the area. These factors are fundamental determinants of land use patterns and agricultural productivity in Australia (Jayasuriya 2003).

2.2.1 Biophysical parameters

Detailed information on the interaction of biophysical factors such as climate, topography, and soils is proven to be costly and tedious to obtain (Arayaa et al. 2013). Hence, the study employs the use of surrogate parameters or indicators in characterising the areas with tenement. These include aridity, plant available water capacity (PAWC), soil pH, and slope. A fuzzy membership technique classifies the areas within CSG tenement according to set of criteria. This spatial decision-making tool addresses the vagueness of the boundaries of classifying areas that have multi-membership based on sets of characteristics (Qiu et al. 2014). The succeeding sections of the study elaborate this process.

The surrogates for climate, topography, and soil data as biophysical factors are in Table 2-1. Aridity index represents the climate factor. Slope provides the topographical description of the area, while PAWC and soil pH demonstrate soil type.

Table 2-1. Indicators of the biophysical factors for fuzzy logic analysis

Biophysical factors	Indicators
Climate	Aridity index
Topography	Slope (%)
Soils	PAWC (mm water/cm soil)
	pH

The climatic indicators (rainfall, temperature and aridity), in raster format, having a spatial resolution of 0.05 degrees (approximately 5 kilometres), are obtained from the Bureau of Meteorology (BOM 2014b, 2014a). This dataset is calculated as a 30-year average, covering the years from 1976 to 2005. Aridity is the quotient of rainfall and pan evaporation, which denotes that available precipitation is measured over atmospheric water demand (UNEP 1997). Aridity is also derived as a 30-year average dataset from 1976-2005.

Topographic data, represented by elevation, comes from the hole-filled Shuttle Radar Topography Mission (SRTM) (Farr et al. 2007) Digital Elevation Model (DEM) data with spatial resolution of three arc-seconds (approximately 90 metres) (Jarvis et al. 2008). Percentage slope was derived from the DEM data using the Slope Tool available from ArcGIS (ESRI 2014).

The PAWC dataset used in this study is obtained from the Australian Soils Resource Information System (ASRIS) (CSIRO 2013). This data measures the potential amount of water available to plants to a soil depth of 100 centimetres. PAWC is a proxy for soil data as it directly indicates the capability of the soil to provide sufficient moisture for plant growth (Araya et al. 2013; Burk & Dalgleish 2008; Dalgliesh & Cawthray 1998; Mullins 1981).

Soil pH spatial data refers to a 1:5 soil: $CaCl_2$ solution extract at a map scale of 1:250,000 from ASRIS (CSIRO 2013). This soil solution is optimal in supplying the necessary nutrients, affecting both the activity of the soil microorganism and the level of exchangeable aluminium to plants.

2.2.2 Fuzzy logic classification

One way to model the biophysical characteristics of an area is through representation and the grouping of similar parameters or properties into a classification that would concisely summarise the data (Berkhin 2006). This would depict the agricultural typology, which allows for site-specific management practices (Hutchinson et al. 2005) However, such an amalgamation of these factors may be subject to uncertainty and fuzziness.

Prior research dealing with classification had been confronted with the difficulty of crisp setting of boundaries in data (Dombi 1990). The notion proposed by Zadeh (1965) regarding fuzzy logic has now given way to viewing objects as a continuum. This theory quantifies imprecision and uncertainty in the grouping of individuals into classes. It implies that an entity is not confined to belong to a particular group. Fuzzification is about taking into account the varying degree of membership of an element (McBratney & Odeh 1997; Robinson 2003; Sasikala, Petrou & Kittler 1996). The fuzzy set theory violates the fundamental laws of Boolean algebra. Boolean theory stipulates that a proposition is either true or false; a value of either 0 or 1 is assigned in the universal set, excluding any third or middle (Robinson 2003).

The fuzzy logic process is initiated by the transformation or reclassification of the indicators of biophysical factors into a continuum of values from 0 to 1, based on predefined fuzzy membership functions. A membership value of 0 means that the data has no membership to the given set, while a value of 1 translates to definite inclusion in the membership (Kainz 2008). Such a technique sets a critical value or a crossover point at a value of 0.5 (ESRI 2014). The fuzzy overlay tool defines the likelihood for a cell or pixel area to be included in a particular set by combining multiple criteria of classification.

2.2.3 Spatial data preparation

The collected spatial data comes with varying spatial resolution and geographic coordinate system. Hence, all spatial data are resampled to match the highest spatial resolution – that of DEM. The data are projected to the Map Grid of Australia (1994) Zone 55 using Geocentric Datum of Australia (GDA) 1994. Utilising common datum and projection ensures the seamless integration of data, minimising distortion and error in measuring area and distances (Lowry 2004).

The extent of gas tenement is buffered at five kilometres distance to capture areas immediately outside its input features. The ArcGIS clip raster tool extracts the extent of the indicator for a specific biophysical factor as defined by the tenement boundary. The clipped data is subjected to fuzzification using ArcGIS in order to categorise the environments of the tenement areas sharing related biophysical characteristics. The 2010 catchment scale land use data from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) provides information on the extent of agricultural areas within CSG tenements, particularly the cropping and grazing zones.

This study is a simplified process of providing a reliable characterisation and sustainable valuation of the areas leased by gas companies. It highlights the areas within CSG tenement where agricultural intensification and development may be limited by the irregularity in environmental factors (i.e. climate) and have limitations in their inherent attributes (i.e. soil, topography), and where a supplementary financial support from gas companies may be deemed beneficial.

The succeeding discussions provide the operationalisation of the fuzzy logic approach undertaken by the study as the operative method for spatial representation of the agricultural areas with tenement. This information is useful for future research by determining the possibility of positive coexistence between CSG development and agriculture.

2.2.4 Fuzzification technique

The raster data of indicators (PAWC, slope, soil pH, aridity) of the biophysical factors have undergone fuzzification as shown in Figure 2-1. The data are assigned to particular membership function and are spatially overlayed, depending on the transformation of the modelled data.

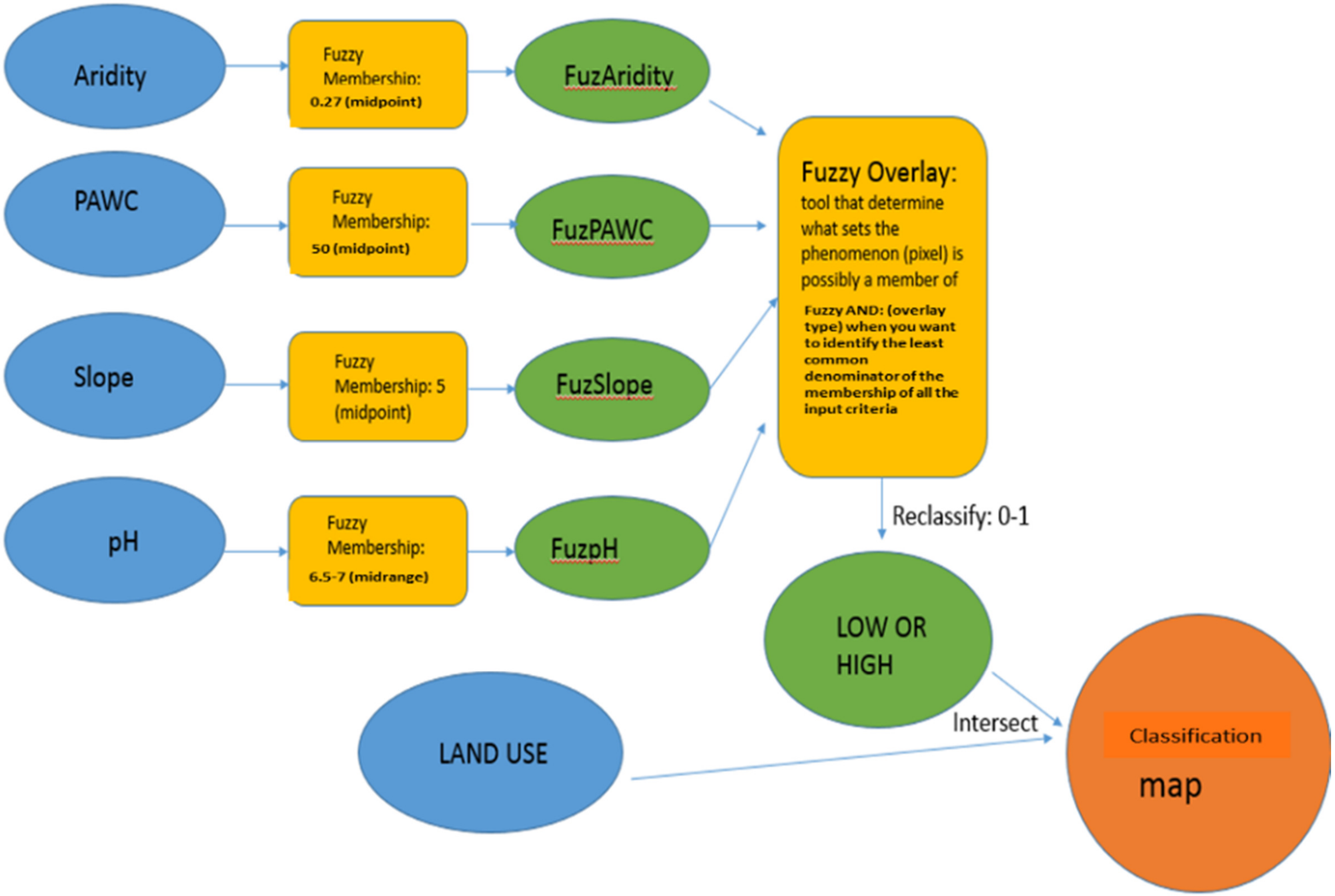


Figure 2-1. Fuzzification process used in the study

2.2.5 Fuzzy Class criteria

The indicators of biophysical factors were subjected to fuzzy membership based on the following premises.

2.2.5.1 PAWC

For the PAWC, the membership type chosen is fuzzy 'large' (Equation 1). This form of class transformation is used if the input data of large values is more likely to be a member of the set (ESRI 2014). Large values of PAWC would indicate strong belongingness to the set or having a value approaching 1. According to the Atlas of PAWC from ASRIS, areas having 20-40 millimetres of PAWC in their soil have low water-retention capacity. Thus, the midpoint is set to 100 millimetres, demonstrating that values higher than this has a larger possibility of membership. The spread of the function is 10.

Equation 1

$$\boldsymbol{\mu(x)} = \frac{\mathbf{1}}{\mathbf{1} + \left(\frac{\boldsymbol{x}}{\boldsymbol{f2}}\right)^{-\boldsymbol{f1}}}$$

Where: μ(χ) is the membership value of the parameter. f1 is the spread of the function and f2 is the midpoint.

2.2.5.2 Slope

The western cropping zone is suitable for cropping if the slope is less than or equal to three percent. A slope of up to five percent is acceptable for other zones (Shaw 2011). The midpoint is therefore set at five percent slope in determining the membership of a particular point in the study. This type of fuzzy class uses the fuzzy 'small' transformation (Equation 2), in which smaller input values have higher membership (ESRI 2014). A slope with a value higher than five percent would mean that its membership is approaching a value of 0. The membership function is set at a midpoint of 5 and the spread of the function is 10.

Equation 2

$$\mu(x) = \frac{\mathbf{1}}{\mathbf{1} + \left(\frac{x}{f2}\right)^{f1}}$$

Where: μ(χ)is the membership value of the parameter. f1 is the spread of the function and f2 is the midpoint.

2.2.5.3 Soil pH

Soil pH between 6 and 7 is ideal for growing most crops, while some crops grow best under a slightly acidic soil. As soil becomes more acidic (lower end) or more basic (upper end), crops development tends to respond negatively. This type of membership behaviour is best described by the fuzzy 'Gaussian' membership function (ESRI 2014). This type of membership function shows a bell-shaped membership, wherein the highest possibility for membership (value of 1) lies between pH of 6-7. This type of membership function transforms the input values into a normal distribution, with the crossover point having the value of 1 (approximately set at pH 6.7). As soil pH values move away from this midpoint, membership value decreases until it reaches a point where it becomes far from the 'ideal', or approaching 0. For this membership, midpoint is set at 6.75 and the spread of the function is 0.23.

Equation 3

$$\mu(x) = e^{-f1*(x-f2)^2}$$

Where: μ(χ) is the membership value of the parameter. f1 is the spread of the function and f2 is the midpoint.

2.2.5.4 Aridity

Finally, the aridity index used in the study is a function of precipitation (rainfall) and pan evaporation, adopted from the UNEP classification. This is an indication of the degree of dryness of the climate in a particular area. Those areas considered arid have an index of 0.03 to 0.20, while semi-arid regions have a 0.2 to 0.5 index. The index of humid areas is higher than 0.65 (UNEP 1997). The study uses 'fuzzy-large' (Equation 1) as the fuzzy membership class for aridity data, with a midpoint set at 0.27 and spread of 10.

Figure 2-2 summarises the membership distribution function of each of the variables used and subjected to fuzzy overlay.

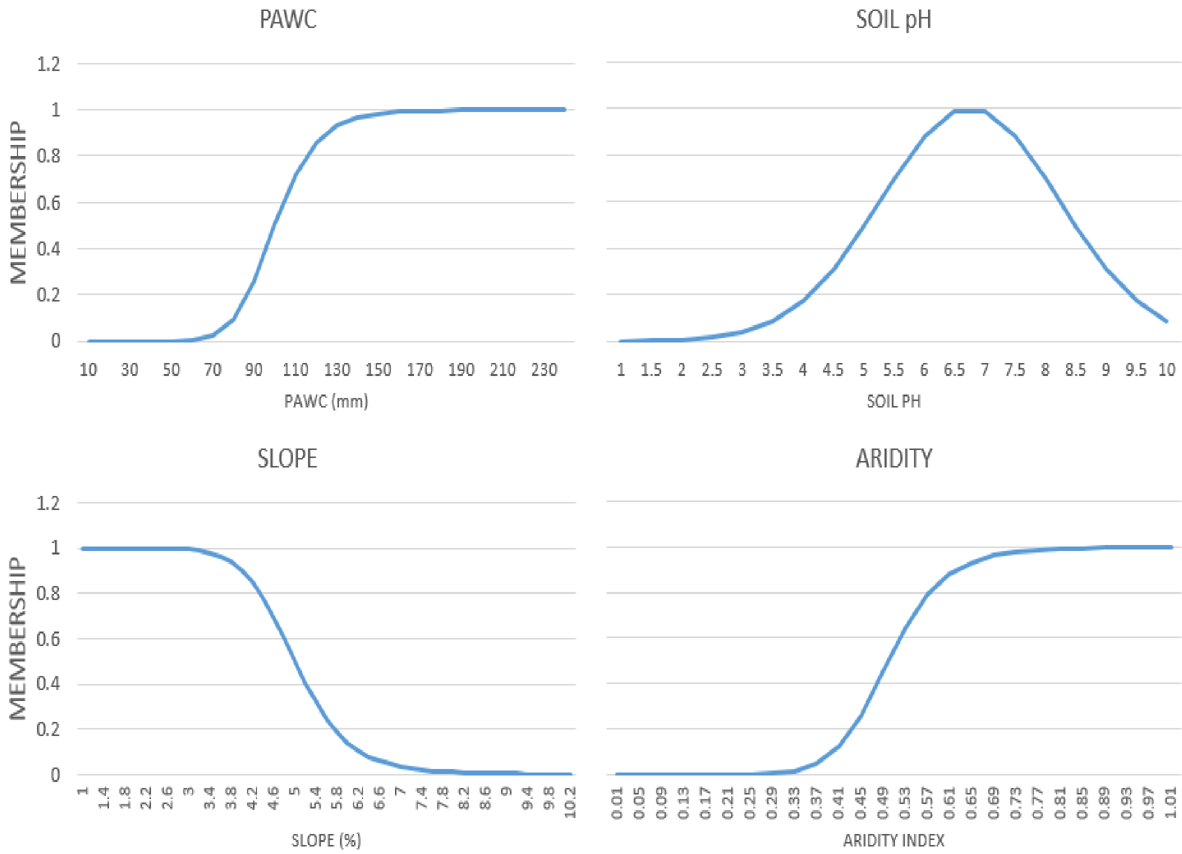


Figure 2-2. Fuzzy membership of indicators of biophysical factors

2.2.5.5 Fuzzy Overlay

The objective of overlaying all four indicators of biophysical factors was to categorise the tenement areas according to its suitability for agricultural intensification. The input rasters having a membership value between 0 and 1 can be regarded as either with high or low suitability for intensification. The spatial overlay type used is 'FuzzyAnd', which combines the fuzzy membership of all the input criteria by determining the least common denominator. 'FuzzyAnd' enables the classification of a cell based on its minimum value, thus reflecting the 'weak' membership of a spatial entity as the deciding factor for its suitability for intensification. 'FuzzyAnd" is defined by the function below:

Equation 4

$$FuzzyAnd\ value = \min(\mu(\chi_1), \dots \mu(\chi_n)$$

Where $\mu(\chi_i)$ represents the membership value for parameter i (where, $i=1 \dots n$).

The fuzzy overlay rule classified the membership value as:

- 0 to 0.39 = low suitability for intensification
- 0.40 to 1 = high suitability for intensification

The fuzzification of the raster inputs was compared to the land use data derived from the catchment scale land use mapping of Australia (ABARES 2010).

2.2.5.6 Spatial output: Productive value

The productive capacity of the land is based on its biophysical characteristics (i.e. PAWC, slope, pH and aridity index), which is not easily changed over time; and land use, which is dependent on farmer's decisions and practical knowledge and production resources (labour, capital and technology) liable to change over time. Information on both the inherent attributes and the actual land use serves as an assessment tool of the impacts of CSG development, necessary in the negotiation process.

Areas within CSG tenements are classified according to their productive value (PV) through a fuzzy overlay. PV is the function of the (current) land use and the actual level of suitability for 'intensification' (Equation 5). In this instance, intensification does not necessarily pertain to the process or system of increasing productive efficiency, but rather to the gross value of commodity output per unit area. More output per unit of area is defined as more intensive land use. Generally, land devoted to cropping is assumed to be of higher land use value compared to grazing (*ceteris paribus*) because of its higher suitability for intensification, given it has a higher output (in terms of volume and value) per unit area. The spatial output of this method is a classification map related to the productive value quadrant (Figure 2-3).

Equation 5

$$PV_x = f(fuz\,(a_{nx}), lu_x)$$

Where *PV* is the productive value and *lu* corresponds to spatially determined land use: cropping areas =H and grazing areas =L.
fuz represents the fuzzy membership of the suitability for intensification of the area.
fuz $(a_n)= H$, if membership values is at 0,…,0.39 and *fuz* $(a_n)= L$, if membership values is at 0.4,…,1.
a is the biophysical attribute subjected to fuzzy membership (PAWC, slope, aridity index and/or pH); and *n* is the value of the biophysical attribute of a specific area χ.

Such that Figure 2-3 presents the following derivations,
PV(x)= HH is for lu_x and fuz(a_n) of H (Equation 5a)
PV(x)= LH is for lu_x of L and fuz(a_n) of H (Equation 5b)
PV(x)= LL is for lu_x and fuz(a_n) of L (Equation 5c)
PV(x)= HL is for lu_x of H and fuz(a_n) of L (Equation 5d)

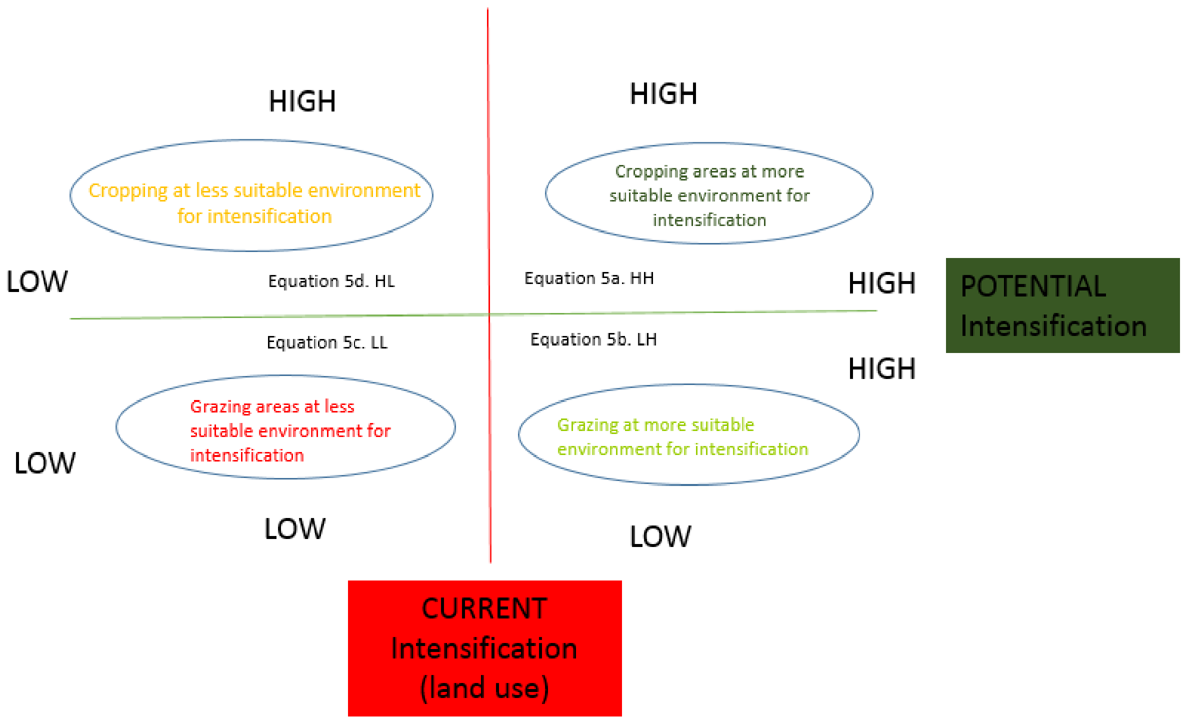


Figure 2-3. Productive value quadrant

Note: The horizontal axis relates to the potential of the area to intensify production, having a continuum value of low to high starting from left to right. The vertical axis is the continuum of current land use or the present level of intensification of the area, starting from bottom to top. Each circle is located based on the level of intensification listed, which will determine their productive value.

The spatial output of the study provided an indication of the capacity for agricultural intensification of the areas within CSG tenements. The premise is that areas with high suitability for intensification would be mostly affected by counterproductive activity of coexistence.

2.2.6 Socioeconomic (spatial) index

The productive value classification and the socio-economic indexes for areas (SEIFA) are cross-referenced. This helped to explore the ability of landholders of a particular area with tenement to adapt to changes brought about by the advent of CSG development, based on their wealth and social status. The information provided by the productive value map and SEIFA map would determine how landholders would value the compensation payments given by the gas companies. Those classified as highly productive and well-endowed farmers would find CSG development as a 'curse' while low productive and poor farmers see the compensation payments as financial opportunity.

SEIFA is developed by the Australian Bureau of Statistics (ABS) in order to rank the areas in the country according to their level of advantage or disadvantage based on relative socio-economic parameters. This serves as an ordinal reference for the relative socio-economic analysis of the status of an area at a given point in time, but not at an individual level. The ranking of the areas depends on indicators of its neighbourhood such as income, education, employment, public resource, transport, infrastructure, and environment. Broadly speaking, it is a measure of the extent an area is able to provide the ability for people to access resources and participate in society. These indexes consist of: (1) IRSD –The index of relative socio-economic disadvantage; (2) IRSAD –the index of relative socio-economic advantage and disadvantage; (3) IEO –the index of education and occupation and (4) IER –the index of economic resources (ABS 2006). The study spatially compared the productive value of an area with the IER. IER considers the financial aspect (including wealth and income) in identifying the relative socio-economic advantage or disadvantage of an area. This excludes parameters relating to how individuals could attain wealth such as education and occupation. 'Savings and equities' as an asset is also not part of the classification. The higher the index score, or decile, the more financially advantaged the household (ABS 2013a).

2.3 Results and Discussion

2.3.1 Biophysical characteristics of areas within CSG tenements

Table 2-2 and Figure 2-4 identify the average values of the attributes of the areas with tenement in the study. Generally, the study area indicates the potential for farming, having a relatively flat area (2% slope) situated in a semi-arid zone. Its soil has a relatively high PAWC of 66 and a pH of 6 (CSIRO 2013). These attributes make the area feasible for cropping.

However, an estimated average annual rainfall of 600 millimetres for the area suggests that it has a relatively arid to semi-arid (dry) climate. This is similar to the overall average annual rainfall data for the whole of Australia, making the country the second driest continent (after Antarctica) (ABS 2012).

Table 2-2. Average values of biophysical factors and its indicators in areas with tenement

Biophysical factors	Indicators	Average values
Climate	Rainfall (mm)	600
	Temperature mean (Maximum) (degrees Celsius)	27
	Temperature mean (Minimum) (degrees Celsius)	13
	Aridity Index	0.3
Topography	Elevation (m)	333
	Slope (%)	2
Soils	PAWC (mm water/100 cm soil)	66
	Soil pH	6

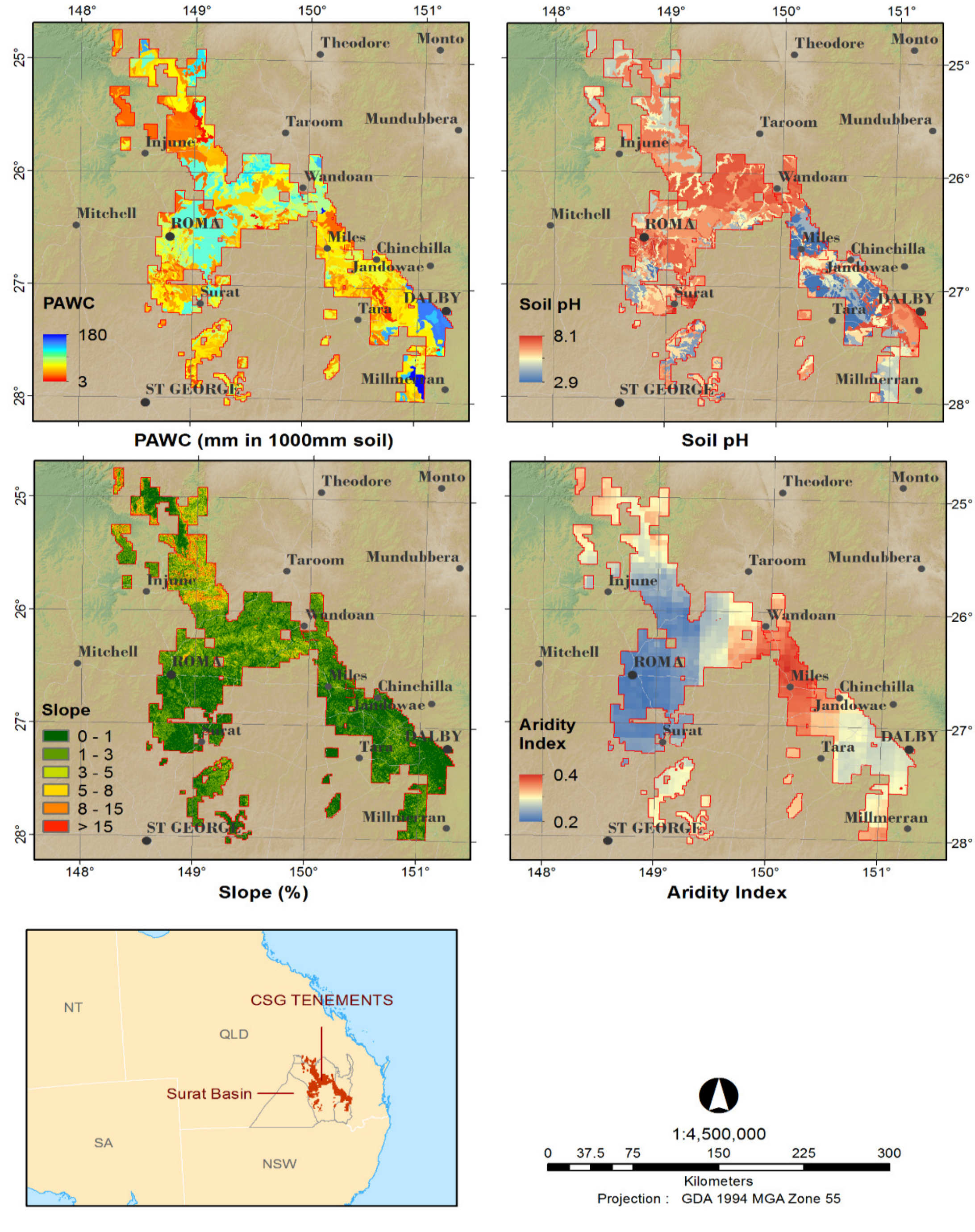


Figure 2-4. Biophysical indicators in areas with tenement

The northern part of the areas within CSG tenement has high rainfall and elevation, and warmer temperature (approximately 12 to 26 degrees Celsius (Appendix A)). Acidic soils, such as Tenosol, Sodosol, and Rudosol, are found in this area (Figure 2-5). Acidic soils are low in both fertility and water-holding capacity. Sodosols are vulnerable to soil erosion and dryland salinity (Isbell 2002; Queensland Government 2013). Thus, the northern area of the study site is mostly grazing or pastures.

The southeast end of the areas within CSG tenements is flat, with a considerably high PAWC and soil pH, but with colder temperature. Dalby, Chinchilla, and Cecil Plains are some of the localities, which belong to this part. Figure 2-5 shows that this area contains the type of soil suitable for crop production, especially Vertosols. Vertosols have high fertility due to their ability to hold water and absorb nutrients. They are dark clayey soils with shrink-swell properties (Isbell 2002). This soil characteristic describes the soil as cracking (or have fractures) when it dries during summer or when moisture evaporates faster. During winter snow melt and spring runoff, this property enables soil to expand up to 10 percent, making it called 'expansive' soils (Mokhtari & Dehghani 2012).These soils have natural fertility if well-managed due to their high water-holding capacity, essential for crop development. This makes them suited, where rainfall is erratic, to dryland cropping (Virmani, Sahrawat & Burford 1982). However, Vertosols also have low hydraulic conductivity and infiltration rates (Eswaran & Cook 1988). These characteristics are imperative when taking into account the management of soil moisture retention. Australia has the world's largest area of Vertosols (70.5 million hectares), found mostly in NSW and Queensland (Chan, Hodgson & Bowman 1995).

The western part of the tenement areas possesses a feature that is suitable for dryland cropping or grazing due to low rainfall (arid) and warm temperature, with patches of both high and low PAWC. The localities in this area include Roma, Surat, Wandoan, and Miles.

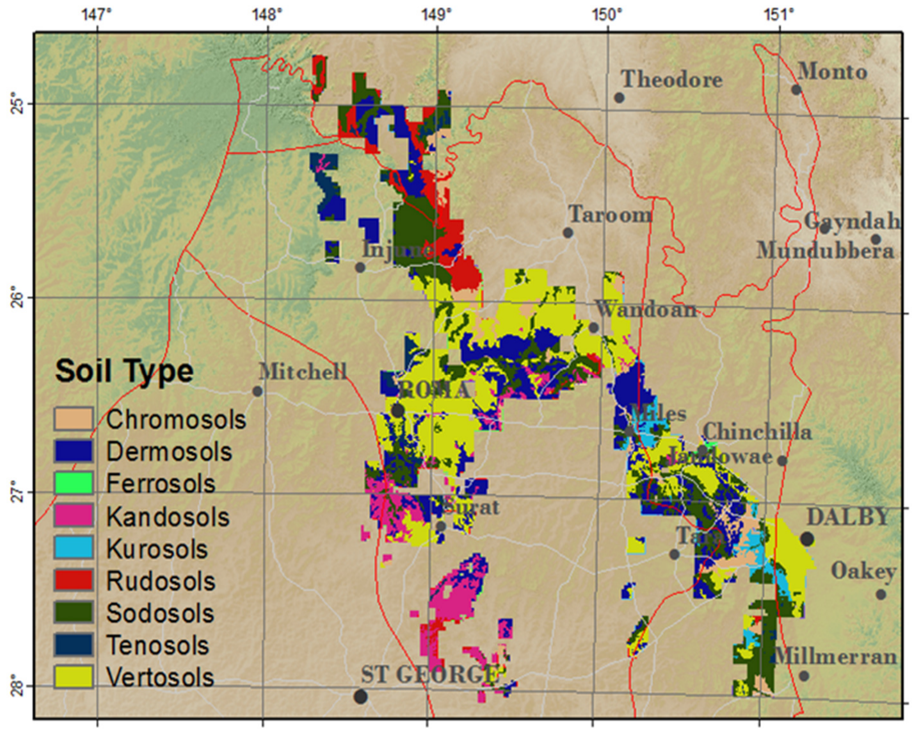


Figure 2-5. Soil types in areas with tenement

2.3.2 Productive value classes of areas within CSG tenements

Figure 2-6 is the productive value map that shows the spatial output of the fuzzy logic classification of the areas with tenement. The area distribution table (Table 2-3) shows that almost half of the CSG tenements (49 %) are grazing areas, with an environment less suited to intensification. This means that the majority of the areas with tenement in Surat Basin has a low productive value (LL productive value class), as well as having environmental limitations to shift an intensive land use (e.g. cropping). This category is predominant in western areas of the Darling Downs, such as Roma and towards Miles, where initial CSG explorations took place.

However, there are also a significant number of areas that have the capacity to alter land use based on farmers' decisions and other external factors (e.g. LH productive value class). This is apparent in grazing areas in Goombi to some part of Chinchilla, exhibiting a potential for intensification, given their suitable biophysical factors. This class consists of 902,051 hectares (39%) of the areas within CSG tenements (Table 2-3).

Cropping areas are mostly located in the eastern portion of the Surat Basin region. Portions of Dalby heading to Cecil Plains have fewer CSG operations and are yet in the early stages of gas exploration and development. These are contested areas for coexistence due to their favourable environment and high potential for intensification (HH productive value class). Nine percent of the tenement areas belong to this class.

Table 2-3. Area distribution and description of the productive value of areas with tenement

Productive value class	Description	Area (ha)	Percentage to the total areas (%)	Localities
HH	Cropping at more suitable environment for intensification	209,848	9	Cecil Plains, Grassdale, Ducklo, Springvale, Nandi, Crossroads, Hopeland, Brigalow, Chinchilla (parts), Dalby (parts)
HL	Cropping at less suitable environment for intensification	73,477	3	(In patches) Blythdale, Roma, Orange Hill, Bungil, Tingun
LH	Grazing at more suitable environment for intensification	902,051	39	Kumbarilla, Chinchilla (parts), Dalby (parts) Goombi, Wieambilla, Clifford, Bundi, Guluguba, Woleebee
LL	Grazing at less suitable environment for intensification	1,140,872	49	Kogan, Columboola, Miles, Kowguran, Dalwogon, Gurulmundi, Blythdale, Roma, Mooga, Tingun, Bungil, Waikola, Durham Downs, Euthula, Orange Hill
Total		2,326,248	100	

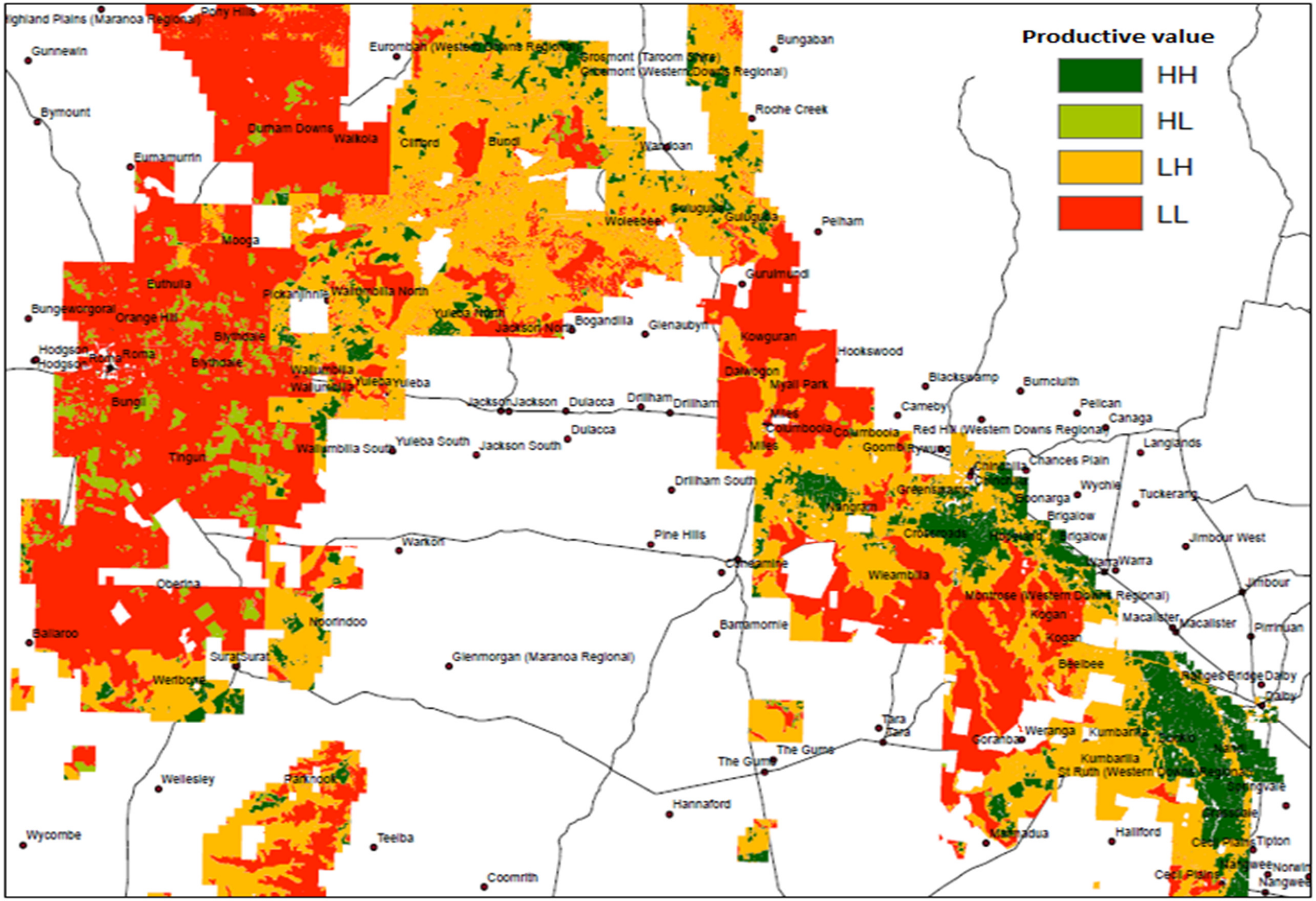


Figure 2-6. Productive value map

The rest of the areas within CSG tenements (73,477 hectares) may encounter issues in sustaining their productive capacity. These areas, scattered in patches throughout the western side of the study area, are the lands that have less suitable biophysical components to sustain intensive farming (HL productive class).

2.3.2.1 Productive value and Biophysical characteristics

CSG development becomes more apparent in cropping areas as it moves from west to east. Resource extraction technology (e.g. CSG installations) commenced on large farms in the west, where livestock grazing areas have a drier and warmer climate (Figure 2-7). Within Chinchilla region, where patches of lands with high potential for intensification (LH and HH productive value classes) are present, CSG operations are rapidly progressing. On the other hand, agricultural productivity is high in Dalby and Cecil Plains, where some HH productive value class are located. It has relatively smaller farm size, but has high value commodities managed through irrigation (Huth et al. 2014). These highly intensive farms are more affected by CSG development than those of the western areas. Agricultural economic studies on the spatial patterns of profits and revenues in the area corroborate this observation (Marinoni et al. 2012). Access to these fields is a contentious issue, yet approvals for petroleum leases are under way. There are 170 petroleum leases under way within the tenement area (110 of these are granted leases and 60 are for approval).

Table 2-4 presents the overall biophysical characteristics of the productive value classes in areas within CSG tenements. All classes have an average soil pH of 6 to 7, which is within the optimum level of pH for crops and pastures (NSW Agriculture 2000).

Areas with a high productive value (HH class) are flat and have a high water-holding capacity, which correlates to having predominantly Vertosol soils in the area (Table 2-5). Vertosols are productive soils found in low elevation landscapes, referred to as alluvial soils or black cracking clays. However, because of their shrink-swell property, Vertosols poses constraints to low-input agriculture. Proper management and timing of cultivation is critical in dealing with Vertosols (Eswaran & Cook 1988).

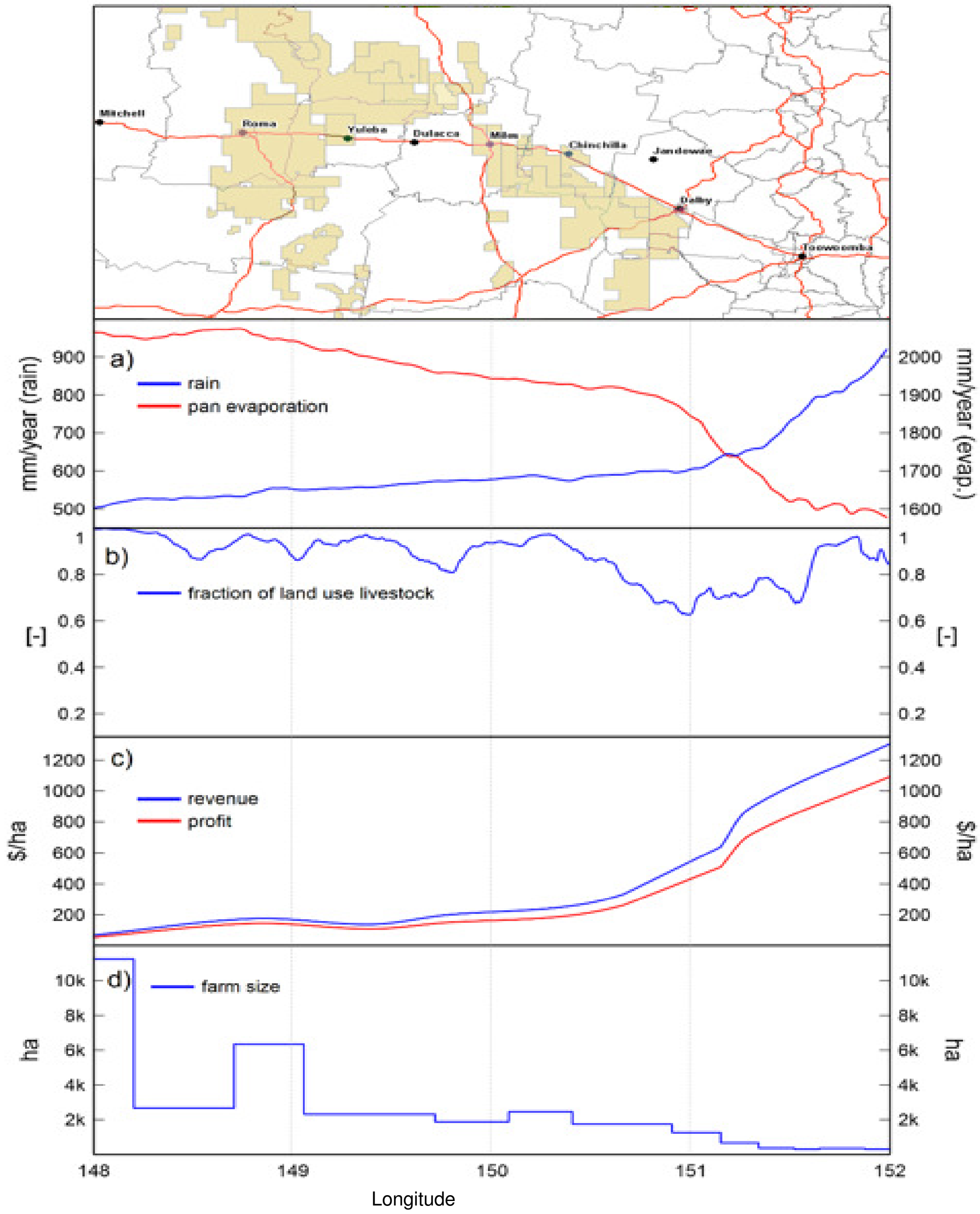


Figure 2-7. Overall spatial characterisation of areas with tenement
Source: Huth et al. (2014)

Table 2-4. Average values of indicators of biophysical factors by productive value of areas with tenement

Biophysical Factors	Indicators	HH	HL	LH	LL
Climate	Aridity Index	0.29	0.25	0.30	0.28
Topography	Slope (%)	1.37	1.72	2.07	5.41
Soils	PAWC (mm water/cm soil)	87.62	43.46	75.98	45.23
	pH	6.74	6.76	6.70	5.95

Table 2-5. Soil type distribution of areas with tenement by productive value

Soil type	HH		HL		LH		LL		Total Area (ha)
	Area (ha)	Percentage of the Total Area (%)	Area (ha)	Percentage of the Total Area	Area (ha)	Percentage of the Total Area (%)	Area (ha)	Percentage of the Total Area (%)	
Chromosols	2,360	1.12	1,256	1.71	71,801	7.96	40,514	3.55	115,931
Dermosols	22,088	10.53	10,406	14.61	169,903	18.84	255,965	22.44	458,362
Ferrosols	551	0.26	1	0	3,733	0.41	20	0	4,305
Kandosols	6,196	2.95	2,844	3.87	80,633	8.94	114,908	10.07	204,581
Kurasols	1,583	0.75	81	0.11	39,378	4.37	22,393	1.96	63,435
Rudosols	134	0.06	334	0.45	17,233	1.91	78,828	6.91	96,529
Sodosols	19,985	9.52	10,058	13.69	173,062	19.19	292,750	25.66	495,855
Tenosols	44	0.02	3,171	4.32	3,744	0.42	63,916	5.60	70,875
Vertosols	156,907	74.77	45,326	61.69	342,564	37.98	271,578	23.80	816,375
Total Area (ha)	209,848		73,477		902,051		1,140,872		2,326,248

Vertosols are also present in areas of HL productive value class (61.69%). Yet, their PAWC is 43 millimetres, relatively lower than grazing areas of high potential for intensification (LH productive value class). This affects the rooting depth and increases crop lower limit, resulting in less water and nutrients available for plants (Dang et al. 2006). However, such areas are generally flat (1.72% slope) and have the lowest aridity index (Table 2-4). Dermosols are the second largest groups of soils in this class. Dermosols are clayey soils found mostly in arid areas. It is relatively high in salt and tends to have a blocky structure. It also exhibits a cracking during dry season (Isbell 2002). This soil is suitable for sugarcane and wheat (McKenzie et al. 2004).

Grazing areas with environment suitable for intensification (LH productive value class) almost resemble the characteristics of those areas of high productive value (HH class). They are semi-arid (0.30 aridity index) and have moderately high PAWC (75.98mm). However, these areas are situated in slightly sloping field (2.07% slope) (Table 2-4) and regarded as grassland pasture. Parts of Chinchilla and Dalby, together with Kumbarilla, Goombi, Clifford, Bundi, and Wandoan are some of the localities in this class. Varying soil types are also found in this class, mainly Vertosols (37.98%) to Kandosols (9%) and Chromosols (8%) (Table 2-5). Kandosols are commonly described as red-brown soils. They, too, have clay content and are found in woodlands and open forests. This soil is used for cereal, oilseed, sugarcane, and native pastures (Peverill, Sparrow & Reuter 1999).

The areas with low productive value (LL class) have high slope (5%), with predominantly Sodosol (25.66%), Vertosol (23%), and Dermosol (22.4%) soils (Table 2-5). Sodosols are found within 13 percent of Australia (Isbell, McDonald & Ashton 1997), where areas receive less than 1,200 millimetres of mean annual rainfall. These soils occur commonly on plains or gently undulating to rolling landscapes and may possess strong salinity and a high exchangeable sodium percentage (ESP) (McKenzie et al. 2004). It concludes that areas with Sodosols have a limited capability to support crop growth. Water and air are restricted in these soils due to swelling. Sodosols may not be suitable for vegetable cropping that requires irrigation because of their low storage capacity (DPI 2000). Therefore, Sodosols are used for grazing, dryland agriculture, and native and plantation forestry (McKenzie et al. 2004). Cereal crops are widely planted in these soils in winter dominant rainfall zones (Isbell, McDonald & Ashton 1997).

Other soils found in areas within CSG tenements include Chromosols, Rudosols, Kurasols, Ferrosols, and Tenosols. These soils are used for sheep and cattle grazing in native pasture.

2.3.2.2 Productive value and Land use classifications

The classifications of the productive value validate the actual agricultural practices in the particular tenement area. Table 2-6 shows that grazing at natural vegetation is commonly found in those areas of low productive value (LL class). Production and farm maintenance are less intensive in these areas and the CSG footprint may not have a great impact. However, these grazing areas also contain lands with inherent attributes suitable for intensification (LH productive value class), having 900,971 hectares of native grazing pastures. Modified grazing pastures are also present in this class. Given the biophysical attributes of this class, landholders (graziers) may also have the option to continue grazing and further improve the management of its pasture vegetation, given sufficient capital and knowledge.

On the other hand, the area distribution of productive value classification and land use generally warrants that there are considerable areas of dryland cropping in areas within CSG tenements in the Surat Basin, although irrigation is also present in some parts. Irrigated areas with high productive value (HH class) are consisted of 28,456 hectares and 1,734 hectares are cropping areas with less potential for intensification (HL class). Seasonal cropping is also substantial in the areas classified as having high productive value (HH class), which denotes the ability of landholders to venture into enterprises of higher and faster turnover rate, such as vegetable production. Water availability is a crucial endowment for these cropping areas. This is why groundwater and other hydrological concerns are some of the main sources of contention for landholders in negotiation arrangements with gas companies.

Table 2-6. Land use distribution by productive value classification of areas with tenement

Land use	HH (ha)	Percentage of total HH area (%)	HL (ha)	Percentage of total HL area (%)	LH (ha)	Percentage of total LH area (%)	LL (ha)	Percentage of total LL area (%)	Total Area (ha)
Grazing, Natural vegetation	0	0	0	0	900,971	100	1,140,804	100	2,041,775
Grazing, Modified pasture	0	0	0	0	1,080	0	68	0	1,148
Dryland Cropping	180,447	86	71,713	98	0	0	0	0	252,160
Dryland Horticulture	121	0	9	0	0	0	0	0	130
Irrigated Cropping	28,456	14	1,734	2	0	0	0	0	30,190

Land use	HH (ha)	Percentage of total HH area (%)	HL (ha)	Percentage of total HL area (%)	LH (ha)	Percentage of total LH area (%)	LL (ha)	Percentage of total LL area (%)	Total Area (ha)
Irrigated Perennial Horticulture	74	0	21	0	0	0	0	0	95
Irrigated Seasonal Horticulture	750	0	0	0	0	0	0	0	750
Total Area (ha)	209,848		73,477		902,051		1,140,872	0	2,326,248
Percentage of the (overall) total area (%)	9		3		39		49		

Note: The percentage values are rounded off.

2.3.2.3 Productive value and socio-economic indexes for areas (SEIFA)

Investigating the biophysical characteristics of areas with tenement would be more meaningful when associated with their socio-economic conditions. Spatial distribution of population across landscapes demonstrate differing levels of comparative advantage in economic, political and social adaptability (Adger 2000). Areas where individuals have high SEIFA values would have more flexibility and capability to adapt to shocks and changes in their environment. Transition of farms that exhibit suitability for agricultural system intensification and substantial productive value (HH and LH productive value classes) could only be achieved with sufficient resource investments. Those farmers who have the capital and inputs would be able to survive and adapt to the coexistence scenario by either improving or changing their current farming system, notwithstanding a strategic farm management recommendation based on resource characterisation of the area.

There is no generalised spatial relationship between the productive value classification and the level of wealth (Figure 2-8 and Figure 2-9). There are areas with low productive value (LL class) in the eastern part of the Darling Downs exhibiting low IER, particularly in Kogan. This area needs an additional or alternative source of income since it is not suitable for an intensive farming system. One landholder in an Origin Energy tenement had recognised this opportunity. Peter Thompson declared that financial benefit from CSG compensation would allow him to take on additional labour, pay his own debt and develop his property (ABC News 2015a). However, the western part of the Darling Downs has the similar biophysical characteristics, yet households have high IER. Graziers in this region practice large-scale farming enterprise. Any supplementary financial benefits that these landholders derive from gas companies could only be devoted to the improvement their existing grazing management practices.

Those with a high productive value (HH class) and high IER in areas of Chinchilla and Dalby, Hopeland, Brigalow, Warra and Cecil Plains are mostly in the eastern part. Landholders from this area are identified as those who are vehemently opposing the CSG operation on their farm due to the perceived disruptions it may cause to their agricultural enterprise (Greer, Talbert & Lockie 2011). The most extreme incident of protest was the reported suicide of a known anti-CSG campaigner, George Bender (ABC News 2015b). Thus, exploration and development of CSG are cautiously undertaken, with few infrastructures yet installed in these areas. The financial opportunity from CSG development can only be a means to safeguard the existing farming system against the impacts of coexistence. It acts as a supplementary fund for transaction and legal expenses. It can also be an additional cash inflow used as investment capital to expand assets of landholders, thereby spreading risk of farm enterprise loss.

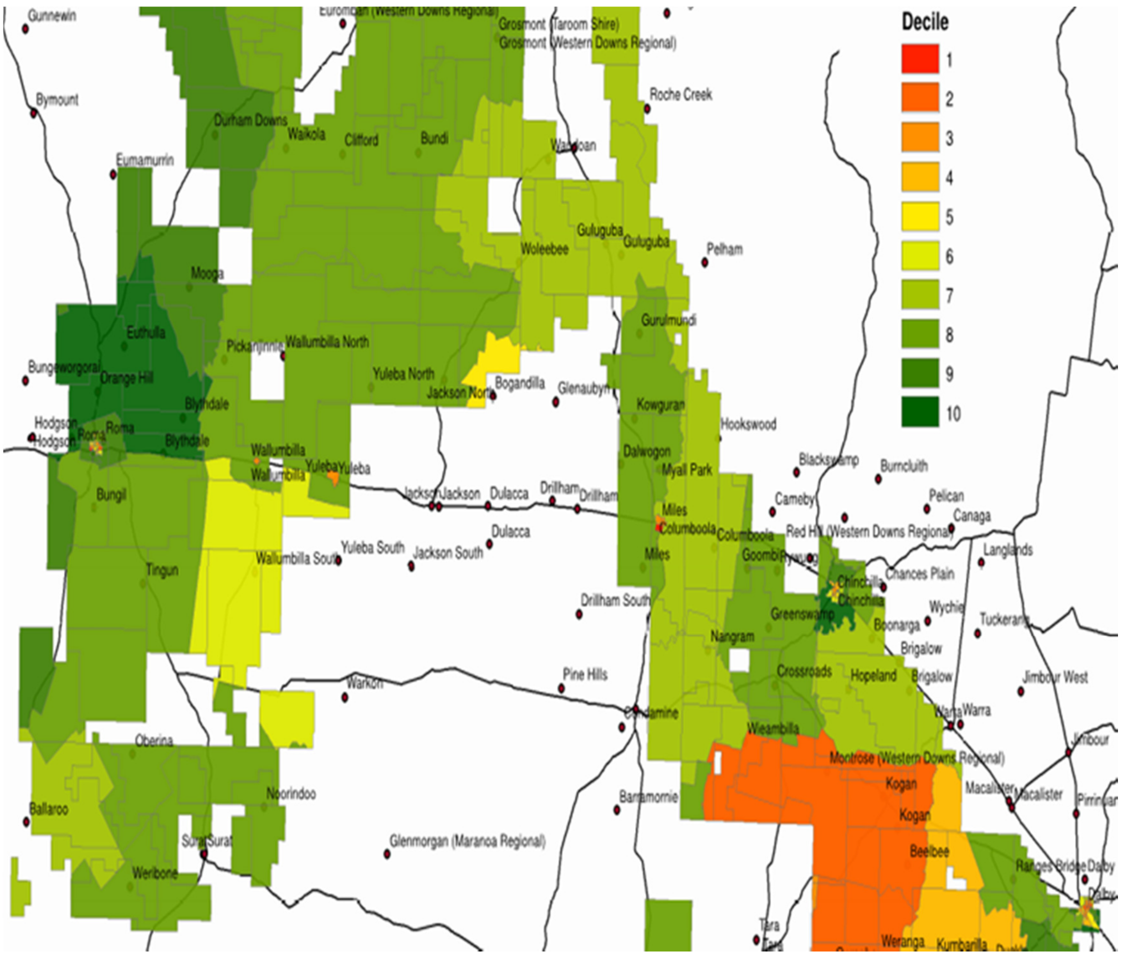


Figure 2-8. SEIFA distribution (IER) by income decile in area with tenement

Areas within CSG tenements categorised with LH and HL productive value have an income decile ranging from 7 to 10. Landholders in cropping areas in the western region (e.g. Blythdale, Roma, and Tingun), with an unfavourable environment for intensification (HL productive value class) are assumed to have sufficient capital for investing in agricultural development. However, based on the land's inherent biophysical limitations, they may opt either to continue their suboptimal farming system or venture into more appropriate management enterprises.

Farmers' decisions to adapt to coexistence on grazing areas that have potential for more intensive farming (LH productive value class) depends on whether an individual is a risk taker or risk averse. A risk-taking landholder could use the additional financial resource from compensation to intensify farming by shifting to cropping. Conversely, being risk averse would imply modernising and expanding the current grazing enterprise.

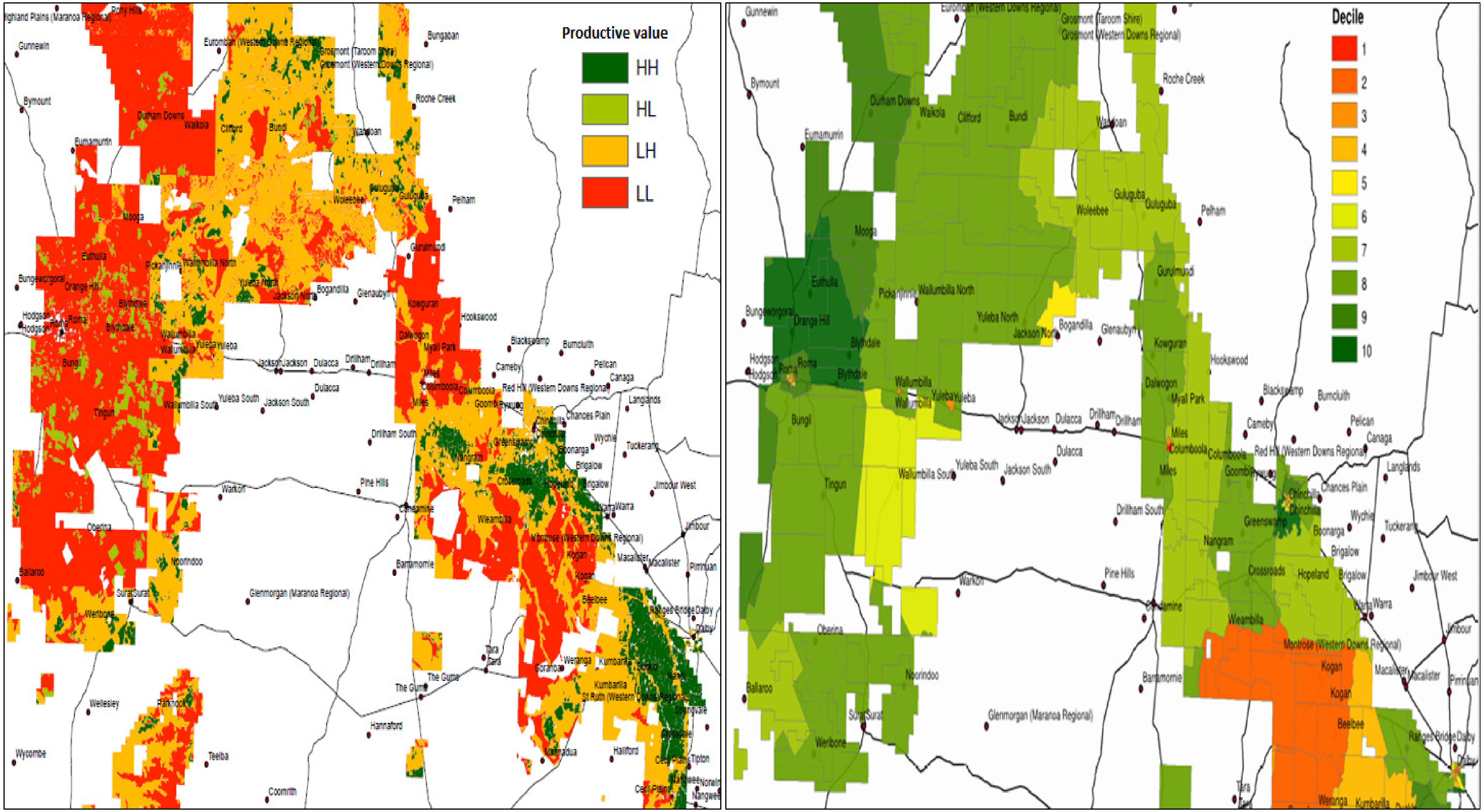


Figure 2-9. Comparison of the productive value classification and SEIFA (IER) in areas with tenement

2.4 Summary and Conclusion

There is limited investigation on the agricultural extent and productive capacity of areas within CSG tenements in the Surat Basin, despite initial research efforts in describing the physical and economic conflict and overlap of agriculture and CSG development. This study presents a novel typology of the productive value of the leased areas by gas companies, as indicated by its inherent biophysical characteristics, using the spatial fuzzy logic membership of the current and potential land use. The impact of CSG development is variable due to the diverse biophysical attributes and land uses, generating different reactions from landholders.

The spatial characterisation of the areas within CSG tenements reveals that the western part of the Surat Basin mostly accommodates CSG development, since landholders have larger farm properties compared to those in the east. This facilitates gas companies' exploration and operation. It is also assumed that productivity is not as severely affected in the west, because the level of inherent potential for intensive and dense production in these areas is less. Most of these areas have grazing as its land use.

However, the study reveals that some of the grazing areas within CSG tenements have suitable biophysical characteristics for intensification and are able to transition to a farming system with more productive output per land unit (i.e. cropping). These areas have LH productive value, where their full production capability is yet to be tapped. Hence, its current land use is undervalued. Maximising their potential is possible if given an additional cash inflow (e.g. compensation) and farming knowledge to convert into a more productive agricultural system (e.g. cropping). These areas gain the greatest advantage from coexistence arrangements by utilising the financial opportunities for appropriate management intervention and investment options.

The study also pointed out areas within CSG tenements with high productive (HH) value and potential for intensification. This zone has a favourable environment with climatic and soil resources suitable for intensive farming. These areas are currently taking advantage of their full agricultural potential and could incur the highest disruptions from CSG development among all productive value classifications. Some landholders in these areas may regard CSG operations as unnecessary to their current system (i.e. landholders that are socio-economically advantaged and cropping). Others have a negative impression of, and are in opposition to, the gas companies (Huth et al. 2014). Landholders in these areas may utilise the additional income from engaging with gas companies in enhancing their current farming system, financing the legal costs of the negotiation process, and employing a management techniques (including an optimised gas-farm design layout) that would mitigate their losses from coexistence.

The results of the study shows that there are areas where present and potential farming systems may be inconsistent as well, such as cropping areas lying in less favourable environments for sustainable production. Areas that are located in less suitable environments and have HL productive value are least-found in the study site and are sporadically situated. Payments given by gas companies could improve the production efficiency of the cropping system, given its biophysical limitations, through machinery, genetics, and technological implements. Otherwise, these payments may also serve as an alternative source of financial wealth, if landholders decide not to engage further in agriculture in order to minimise risks and losses.

This is also the same recommendation for grazing areas having low productive value (LL). These areas within CSG tenements have less favourable environment and biophysical characteristics for intensive production. Thus, payments from gas companies are either an alternative source of income or a ‘catalyst’ to develop the current farming systems. For instance, graziers could use the additional cash inflow provided by gas companies to install fences to mitigate herd migration as a result of CSG operations.

The findings of the study are coherent with the spatial map of SCL and Queensland Agricultural Land Audit (QALA), except for the surrounds of Roma, Blythdale, Tingun and Bungil, considered to be cropping areas less favourable for intensification, but were included in the SCL trigger map as protected prime lands for production. QALA also signifies some areas as suitable for cropping, yet the productive value map classifies them as having low potential for intensification (LL). The selection of variables as criteria for classification and the spatial variation are plausible explanations for such differences. The SCL criteria employs more extensive selection for its classification threshold including rockiness, gilgai, soil depth, soil wetness and salinity (Queensland Government 2011). On the other hand, this study employs a more simplified framework of grouping using selected biophysical characteristics.

The results of the study provide a substantial input for effective management of the negotiation and compensation process during coexistence. Gas companies consider the diminution of value of the affected land in their compensation structure as a result of the operation and development and productive value of the lease area. However, the current basis for land valuation is the existing farming system, which is generalised. It is important for gas companies to also consider examining the future productive capacity and possibility of transitioning to other farming systems of its tenement sites. The landholders would receive the proper compensation if calculations were based on agronomic results, reflecting long-term land value, rather than on existing market value. The information provided by the study enhances the landholder's ability to negotiate compensation for his property. For instance, graziers on areas with high potential for intensification may bargain for higher compensation since they know the future productivity and the corresponding losses they could incur from the impacts of CSG development. Compensation should commensurate the level of their agricultural potential for intensification, even though the decision to transition is only indicative.

Overall, the study claims that there is no generalisation of the consequences of coexistence. Subsequent studies further investigate the degree of impact of CSG development on farm enterprise wealth based on the increases in farm costs and losses in income.

3 Study Two – Farm Systems Modelling of the Impacts of CSG Footprint on Farm Enterprise

3.1 Introduction

Non-agricultural activities, such as mining and energy development, often compete with agriculture in areas of fertile soils and high value production. This is particularly evident in the Surat Basin in Queensland, which encompasses the highly productive Darling Downs food-producing region. Soils are mostly fertile in the eastern part of the Surat Basin, while the landscape becomes drier to the west, with more emphasis on dryland cropping and grazing. This broad range of dryland and irrigated broad-acre agriculture produces commodities such as cereals, pulses and cotton, irrigated vegetables, fruit and grapes, as well as broad-acre and intensive livestock industries (ABS 2013b; Huth et al. 2014; Schandl & Darbas 2008). In contrast, the northern part of the Surat Basin is experiencing intensive development because of the extensive CSG and thermal coal reserves (Collins et al. 2013).

CSG wells are inserted into agricultural landscapes at a density of one to two wells per square kilometre (Antille et al. 2014; Huth et al. 2014; Thomas 2015). Each well is situated within a one hectare lease area at construction and decreases in size to an 80 metre by 60 metre footprint near the decommissioning stage (Grigg 2014). Servicing these wells is an extensive network of pipelines, road networks, dams, stockpile areas, worker accommodation camps, and water and gas processing facilities (Marinoni & Garcia 2015). Estimates of CSG footprint (Figure 3-1) show that infrastructure such as access tracks or dams can have greater spatial impact than the wells and lease areas themselves. Yet, there is no common knowledge or well-documented literature or negotiation agreement related to this information.

CSG operations can disrupt ongoing agricultural activities (Olson & Doherty 2012; Shi et al. 2014), despite being extracted from underground coal seams. Studies of farmers' perceptions regarding coexistence with CSG development have raised issues such as dust, noise and light pollution, loss or degradation of farmland, increased weed or erosion threat, and impacts on livestock behaviour (Huth et al. 2014). The CSG footprint also affects soil quality due to infrastructure and traffic caused by its heavy equipment vehicles through compaction, surface disturbance, and layer inversion (Arrow Energy 2012; Vacher et al. 2014). It can likewise limit machinery and input efficiencies (Arrow Energy 2012; Collins et al. 2013).

Antille et al. (2014) simulated the outcome of farming and CSG mining coexistence on grain yield in Chinchilla for wheat crop using a 115-year period of climate data. The cumulative distribution probability on production for a grey Vertosol area showed that there was a yield reduction of 53 percent within the tenement area. This reduction is a result of decreased water supply due to compaction damage to the soil, impairing its capacity to absorb water. Another source of yield reduction is reduced rooting depth. Soil disturbance also tends to cause runoff and erosion leading to unstable crop growth. This damage to soil resource is evident at the farm level even during the process of rehabilitation or the decommissioning phase of land reclamation and restoration. However, this is not extensively documented due to the difficulty of investigating private tenements.

The level of farm impact of a CSG footprint varies with the development phase of CSG activities (Marinoni & Garcia 2015). Impacts of CSG infrastructure could either inflict permanent or temporary loss in field area. Most of the impacts are visible and evident at the initial stage of exploration. Activities such as installation of pipelines, clearing the roads, and establishment of the well pad create disturbances in soil quality and fertility. Each of these activities highlights different patterns of impact in the specific shared land area. For instance, pipelines would impose a massive impact during the installation process by having its entire area footprint devoted to the digging of the canal. The area recovers from lost in production once the pipes are in place and the soil is piled again. On the other hand, a more permanent damage occurs for roadways or access roads. An area is lost due to clearing and construction of roads throughout the development and operation of CSG. It is only during the decommissioning phase or rehabilitation of the site (the end of the CSG project where the infrastructure is removed) that the impact decrease and leave the land productive again. Simulation studies revealed that rehabilitated soils, cultivated to a depth of 300 millimetres to 350 millimetres, allows for sufficient root growth and soil water storage and reduce crop failure (Antille et al. 2014). Gradual soil recovery could be linear or non-linear and increases land productivity in time. After CSG production is finished and the soil is rehabilitated, impacts drop to zero and the land becomes available for agriculture again (Marinoni & Garcia 2016). Other operations that recur during CSG operations in leased areas are well rig workover and fencing, which could have impact typology that is nonlinear or variable in nature.

The consequences of coexistence on the financial performance of the farm enterprise have not been adequately investigated due to the limited information on the impacts of CSG activities on farm production and farming operations. There is a need to determine the extent of the impacts of the coexistence at the farm-scale level, since most systems management and investment decisions are at this stage. This research explores the overall effect of CSG development on the farm financial performance during the installation and operational phases. The study does not include the exploration and rehabilitation phases. This analysis focuses on quantifying the impact of CSG operations on the production and profitability of cropping systems. Case studies provided this information regarding the indicative dryland and irrigated farming systems within the Surat Basin.

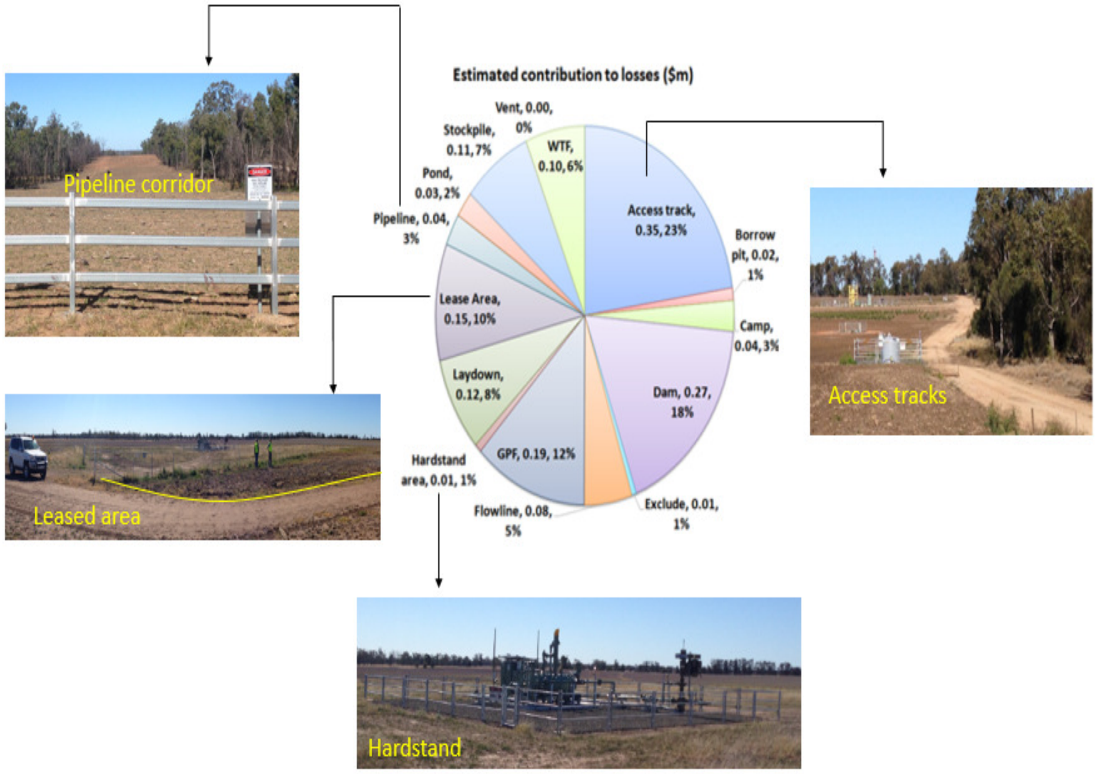


Figure 3-1. Distribution of the CSG footprint and estimates of losses at whole tenement scale Source: Marinoni and Garcia (2015)

3.2 Methodology

The direct outcomes of the coexistence scenario are tangible and measurable manifestations in the surface ground, particularly affecting the farming operations. The CSG footprint is comprised of the extent of productive space taken out of farming and variation in time (machinery and labour) of agricultural operations caused by the number of CSG infrastructures in place, as enclosed in the red box in Figure 3-2. Other impacts of CSG in agriculture are those that are more subjective and indirectly measured such as stress, amenity loss, uncertainty, etc., excluded in the analysis of the study.

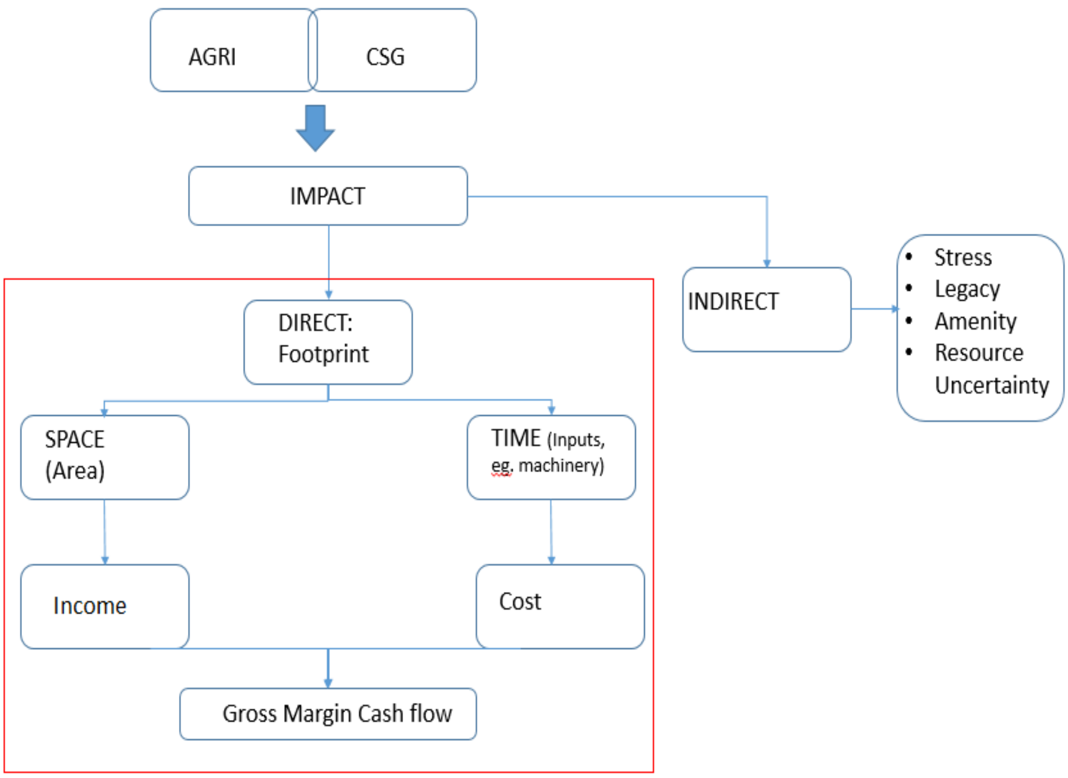


Figure 3-2. Framework of analysis of the overlap of agriculture and CSG footprint

Figure 3-2 shows the impacts of coexistence in terms of space and time, as indicated by the change in area and machinery efficiency, respectively. The difference in the spatial impact assumes the decrease in production yield and farm income, while the additional time component affects cost of production due to disruptions in farm operations by the number of additional tracks made to avoid the gas wells and other infrastructure installed.

Simulation (modelling) estimates of the impacts of CSG infrastructure on farm productive area and machinery operations. This technique addresses the issue of data facilitation and enumeration in an uncertain and dynamic agricultural environment. While (social) surveying would comprehensively cover all the necessary details of real and actual farming conditions, it proves to take longer and is more difficult to manage, especially when people are involved. It also cannot make conclusions for others due to its specificity considerations. Thus, simulation offers an alternative method in solving a counterintuitive phenomenon.

However, information generated from simulation is limited, based on the assumptions and computational capacity that the researchers impose upon the model. Unrealistic expectations and inaccurate data produce useless tools (Centeno & Carrillo 2001). Simulation models are highly dependent on the user's logic and purpose and cannot solve and explain problems and scenarios by itself (Chung 2003). Moreover, the difference between the simulated and observed data comes from the fact that models are in a controlled environment. Models are limited in scope when compared to a complex world. Human and statistical errors also contribute to the margin of resulting values (Shannon 1998). Despite these constraints, simulation is the most suitable method in undertaking the study, given the scope and resources of the research.

The research scope is within the CSG development areas between the townships of Chinchilla, Miles, and Condamine in the Western Darling Downs region of the Surat Basin. The appraisal of CSG footprints is an input to farming systems simulation, which provides long-term estimates of agricultural production under climate variability. Subsequently, an economic model explores the impact of the CSG infrastructure on overall financial performance of the representative field. The following sections describe in more details the components of this work.

3.2.1 Farming systems model

This study estimates the long-term farm productivity for different regions within the CSG development area, which account for local climate variability, soil conditions and agronomic methods using the Agricultural Production Systems sIMulator (APSIM) (Holzworth et al. 2014). APSIM is chosen for this purpose because it has been developed and tested widely for the Darling Downs region (Peake et al. 2013; Poulton, Huth & Carberry 2005; Whish et al. 2005). It provides a framework for integrating models of individual soil, crop, and climate processes with models of farm management to simulate complex farming systems such as those on the Darling Downs. It also simulates changes in the soil water and nitrogen availability (Probert et al. 1998), subject to weather and farm activities. These factors are critical in determining farm production. The model has previously been used to explore issues such as decision support for farmers and farm consultants, whole-farm modelling, crop and livestock interactions, informing crop breeding, biotic constraints, climate adaptation and environmental impacts (Holzworth et al. 2014).

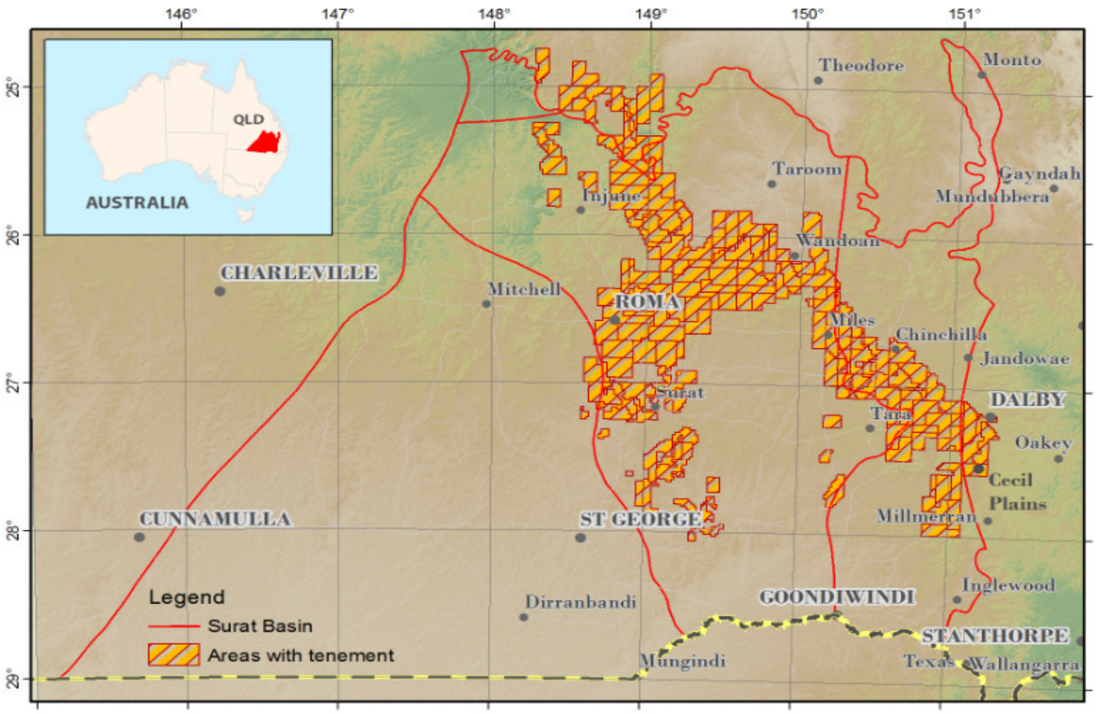


Figure 3-3. Tenement areas within the Surat Basin

Simulations of indicative farming systems on a 200-hectare area are conducted using soil, climate and agronomic data characteristics of the areas around Chinchilla, Dalby and Cecil Plains, which lie within the tenements of CSG development within the Surat Basin (Figure 3-3). Daily temperature, rainfall and solar radiation data for a 114-year period (1900 to 2013) are obtained from the SILO climate database (Jeffrey et al. 2001) to capture the variable climate of the region. Representative soil properties for each area are chosen from the APSoil, a database of soil water characteristics (Dalgleish & Foale 1998). Clay soils are common for cropping lands in all three regions. A grey Vertosol soil (APSoil Record number 46) is present in the Dalby and Chinchilla regions and a black Vertosol soil (APSoil Record number 104) is chosen for Cecil Plains. Representative agronomic parameters are chosen in consultation with a local agricultural consultant to reflect the soil management conditions (Table 3-1). These parameters include the selection of appropriate crop cultivars and plant populations, dates for sowing windows for each crop, appropriate levels of sowing soil moisture and rainfall for crop establishment and fertiliser management.

The simulation is based on dryland farming system at Dalby and Chinchilla and an irrigated farming system at Cecil Plains. The dryland systems consist of a wheat and sorghum opportunity cropping system in which the winter crop (wheat) or summer crop (sorghum) are sown in any season of any year, if sowing conditions are appropriate. The irrigated system is a three-year rotation consisting of two summer cotton crops followed by a wheat crop. Each simulation provides annual values of production of each commodity (including failed planting opportunities) and irrigation and fertiliser use for the chosen 114-year period.

Table 3-1. Parameters for simulating an indicative farming system in Surat Basin

	Dryland		Irrigated	
	Wheat	**Sorghum**	**Wheat**	**Cotton**
Agronomic Parameters				
Date of the start of sowing window	1-May	15-Sep	15-May	10-Oct
Date of the end of sowing window	30-Jun	14-Nov	10-Jul	20-Oct
Plant available soil water required for sowing (mm)	100	150	50	100
Rainfall (previous 3 days) required for sowing (mm)	25	25	25	10
Amount of N at sowing (soil + fertiliser) (kg/ha)	130	130	150	300
Cultivar	Hartog	Buster	Hartog	S71BR
Plant population (/m^2)	100	6	100	6.8
Economic Parameters				
Price ($/t grain or $/bale cotton)	235	175	281	480
Fertiliser N Price ($/kg N)	1.17	1.17	1.17	1.17
Volume Costs ($/t grain or $/bale cotton)	11	9	11	60
Operational Costs ($/ha)	200	236	281	1005
Irrigation cost ($/mL)	0	0	60	60
Management costs ($/ha)	28	36	54	200

3.2.2 Spatial impact of CSG

The level of CSG infrastructure within an agricultural field can vary widely depending on its location (Marinoni & Garcia 2016). A 200-hectare area is identified as a representative case study for the simulation of CSG infrastructure within cropping farmlands. The field includes four wells and related pipeline networks. It also includes a section of water pipeline used to transport water produced from the CSG processing plant to irrigated farmlands nearby. The chosen field is far enough from processing facilities to be representative of a farm level coexistence setup rather than industrial conditions close to processing facilities, which usually include higher levels of CSG infrastructure (Marinoni & Garcia 2016).

All CSG infrastructure within the farm paddock (or 200-hectare area) are mapped using methods appropriate to the type of infrastructure element. Locations of wells are obtained from publicly-available spatial datasets (http://qldspatial.information.qld.gov.au/). Small elements such as gas vents, water vents, and signs were mapped manually using hand-held Global Positioning System (GPS) units. Aerial photography identified areas removed from production, such as gravelled roadways or vehicular access areas. The footprint of water and gas pipelines is calculated from their locations and the standard width of their access areas ('right-of-ways').

In some cases, the positioning of CSG infrastructure can obstruct movement of agricultural machinery resulting in a loss of productive area outside of the registered CSG lease areas. A standard 'cut-and-fill' well pad on the field, in which sloping land is levelled to provide a flat surface for CSG operations, resulted in an additional area of lost production due to machinery impacts. Manual mapping using hand-held GPS units estimates this additional area of lost production, with later corroboration from on-board GPS units on farm machinery operating within the field.

The spatial differences in the CSG footprint are a function of the progression of project development phases. For instance, the installation of pipelines caused a high degree of disruption in farm operations at the construction phase of CSG project. Its impacts are minimised (if not eliminated) when CSG well undertakes production stage, where pipelines become an underground infrastructure.

The area lost in production is calculated as follows for the purpose of this study:

Equation 6

$$Area\ loss\ from\ pipeline = Area\ of\ pipeline\ installed\ \times \%\ of\ pipeline\ area\ lost$$

Equation 7

$$Leased\ area\ affected = Leased\ area\ \times \%\ leased\ area\ lost$$

Equation 8

$$Remaining\ effective\ area = Total\ field\ area - Total\ area\ lost\ from\ CSG\ infrastructures$$

3.2.3 Machinery Impacts

The placement of CSG infrastructure within cropping systems can impact on the efficiency of various farm operations (Arrow Energy 2012). Wells, roadways, gas and water vents, signs, and water tanks can all provide obstacles that obstruct machinery. These will affect the time required to undertake operations, the amount of fuel used, fertiliser, herbicide and pesticide use, labour, and other associated costs. Many of these will be difficult to quantify. This study assumes that impacts on machinery operating time are a suitable indicator on overall impacts of CSG development on machinery efficiency and operating costs in general.

Spatial data are gathered for machinery operating on two farms within the CSG development area near Miles and Chinchilla. The on-board GPS monitoring systems obtained the information on the time, speed, and location of different farm machinery. This includes machinery involved in applying fertiliser prior to sowing, and boom sprays operated during a summer sorghum crop. For each dataset, the amount of extra machinery operating time caused by each well is determined by comparing the operating time around the well with a nearby area of the same size. This comparison ensures similar tractor speed and similar numbers of vehicle turns in the case of well pads on the edges of fields. The difference in the total operating time within each area is used as an estimate of the extra operating time caused by the presence of the well within the field. The calculation of the impact on relative machinery operating efficiency (ME) for four wells within the given farm paddock is therefore:

Equation 9

$$ME = \frac{T_{50}}{T_{50}+T_{extra}}$$

Where T_{extra} is the extra operating time calculated as described above (minutes) and T_{50} is the time required for the given machinery to work 50 hectares of a field at normal operating speed. T_{50} was determined directly from the GPS data.

3.2.4 Economic model

The study seeks to determine the degree of loss that coexistence could inflict upon agricultural production. This is by modelling the economic (financial) impact of CSG development to the gross margins. Cash flow and gross margin terms are used interchangeably in the study. Gross margin is used in partial budgeting, which compares enterprises in terms of its operation (Moran 2009). This excludes the overhead or fixed costs (e.g. depreciation, rents) on which the farm still spends regardless of the enterprise mix. Variation in the gross margin indicates the changes in the incomes and costs of farming operations.

The information of the gross margin for each of the representative field crops (i.e. wheat, sorghum, cotton) is from AgMargins, published by the Queensland Department of Agriculture and Fisheries (DAF). The annual simulated yield from the APSIM is matched with parameters such as price, input costs on planting, fertilisation, crop protection, consultancy, levy, insurance, harvesting, and post-harvest to demonstrate the cash flow stream. The results are simulated under an indicative setting and are assumed to be at the same time periods for the purposes of discussion. The effects of inflation, economic and market forces, and other factors affecting price variation are excluded.

The study has undertaken a simulation of the potential yield and income of three sites: Chinchilla, Dalby, and Cecil Plains. It is comprised of a time series data of 114 years of climatic data (1900-2013) divided into ten 'Startof' periods, each comprised of 15-year climatic cycle (inclusive of start and ending planting times) for dryland (rain fed) wheat-sorghum and irrigated cotton-wheat rotations. The 'Startof' periods represent the commencement of the planting year of the simulation. Different climatic scenarios are modelled to depict the variations in production in areas around the Surat Basin caused by a high level of rainfall variability, leading to income vulnerability.

The CSG footprint, which displaces the agricultural productive space based on the number of CSG infrastructures installed, affects income as well. Agricultural income is expressed in Equation 10 as:

Equation 10

$$AI_{xi} = |P_{xi}| \times Y_{xi} \times A_{xj}$$

Where AI is the agricultural income; P is price of the commodity (constant); Y is commodity yield; and A is the difference in spatial impact. The commodity is represented by *x* and the time period by *i* in all equations henceforth.

Alternatively, the changes in cost are affected by CSG activities disrupting farm operations due to the number of additional tracks needed to avoid the gas wells and other infrastructure. Also, additional inputs are required, such as labour and fuel (machinery), in order to maintain the productive capacity of the land and avoid the probability of machinery damage. All these contribute to the machinery efficiency, which increases variable costs of production. The farm enterprise experiences diseconomies of scale by having increasing costs over a limited area of production. Equation 11 and Equation 12 represent the formulas for computing costs without CSG wells (baseline) and with CSG wells, respectively.

Equation 11

$$\boldsymbol{OC_{xi} = AE_{xi} - (MC + TC)_{xi}}$$

Where OC is the operating cost consisting of the expenses for planting, crop protection, fertiliser, harvesting and labour; AE is the annual expenditures per unit; MC is the management cost comprised of consultancy fees, crop insurances, levies, crop license fees and other non-volumetric expenses; and TC is the transport cost including post-harvest and cartage.

Equation 12

$$\boldsymbol{OME_{xi}} = \frac{\boldsymbol{OC_{xi}}}{\boldsymbol{ME}}$$

Where OME is the operating cost of farms with CSG wells; OC is the operating cost; and ME is the machinery efficiency which varies as more CSG wells are installed.

The gross margin formula, adapted from Rodriguez et al. (2013), takes into account the income and cost effect is obtained as follows:

Equation 13

$$\boldsymbol{GM_{xi}} = [\boldsymbol{YPA}]_{xi} - [(\boldsymbol{C} + \boldsymbol{L} + \boldsymbol{H} + \boldsymbol{I} + \boldsymbol{S} + \boldsymbol{F} + \boldsymbol{N})]_{xi}$$

Where GM is the gross margin as a function of the simulated yield (Y) multiplied by the commodity price (P) and the production area (A). The cost component consists of: cartage (C); levies (L); harvesting (H); irrigation (I); sowing (S); fallow management (F); nitrogen fertilisation (N).

In simple terms,

Equation 14

$$\boldsymbol{GM} = \boldsymbol{YPA} - (\boldsymbol{MC} + \boldsymbol{OC} + \boldsymbol{TC})$$

3.3 Results and Discussion

3.3.1 Farming systems model

The summary results from the farming systems modelling are shown in Table 3-2 for some key agronomic statistics. The model is parameterised to mimic local agronomic management practices, including decision-making regarding the sowing of summer and winter crops within the dryland farming systems. Model predictions for cropping frequency at Chinchilla and Dalby are consistent with a study conducted by Hochman, Prestwidge and Carberry (2014), which surveyed 94 fields over seven cropping seasons, finding that cropping frequency ranged from 0.29 to 1.33 crops per year with a mean of 0.94. The same authors also observed that winter crops accounted for 76 percent for all crops sown. These results indicate that the yields for Dalby and

Chinchilla gathered from this research are consistent and in line with expectations provided by the local agronomist consulted during simulation development.

On the other hand, the simulated cropping frequencies for Cecil Plains are a simple reflection of the chosen fixed cropping rotation. Irrigated crop yields for Cecil Plains are consistent with published values for the region for wheat (Peake et al. 2014) and cotton (Rural 2013). Peake et al. (2014) simulated the potential yield for wheat to be at eight to nine tonnes per hectare, while Rural (2013) specified that the average yield of cotton in 2012-13 is at 10.2 bales per hectare.

The findings also indicate the variability in cash flow introduced by a variety of factors. Variability in dryland cropping systems in Chinchilla and Dalby is strongly driven by climate. Crop yields are dependent upon rainfall in such water-limited environments. Rainfall patterns influence cropping frequency under opportunistic cropping practices. Farmers may sow one or two crops a year when conditions are favourable or sow nothing under drought conditions.

This variability in climate is indicated by the relationship of cropping frequency and crop yield of the simulated dryland areas, as indicated in Table 3-2. It shows that while Chinchilla has a higher cropping frequency of 0.88 per year, the yield of individual grain crops (wheat and sorghum) is higher in Dalby. Both are considered to be semi-arid areas. Though Chinchilla registered a higher annual rainfall, its average temperature makes it drier as compared to Dalby (as indicated in Study One, Figure 2-4). This results to a higher gross margin for Dalby ($350.75 per year) than for Chinchilla ($312.56 per year) under the same cropping rotation.

The climate variability causes the annual gross margins in dryland areas to be negative during droughts or no-harvest periods, as costs for field maintenance are not met with income from production. There are also high episodes of climate variability under irrigated conditions due to rotations employed to protect soil health. A long fallow period after the wheat break crop in the rotation results in a year without income but with associated costs for field maintenance. Despite this, the simulation results for an irrigated farm in Cecil Plains have the highest amount of production among the three sites, with a gross margin of $2,516 per year for its rotation. This could be attributed to both its favourable biophysical characteristics (e.g. soil properties) and stable supply of water.

The climatic conditions of the simulated areas lead to variation in annual gross margin, which is higher than the long-term average. Such variability is reflected and accounted for in the economic analysis of the research.

Table 3-2. Summary statistics of output from farming systems modelling undertaken using APSIM

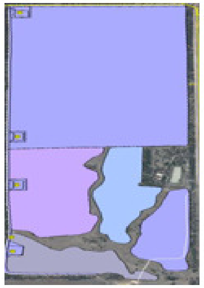
		Location		
		Chinchilla	**Dalby**	**Cecil Plains**
Cropping Frequency (per year)	Wheat	0.58	0.45	0.33
	Sorghum	0.30	0.36	
	Cotton			0.67
	Total	0.88	0.81	1.0
Crop Yield (kg/ha, bale/ha)	Wheat	2869	2948	7065
	Sorghum	4542	4742	
	Cotton			9.5
Gross Margin ($/year)	Mean	$312.56	$350.75	$2516.00
	Std Dev.	$351.98	$388.65	$2175.76

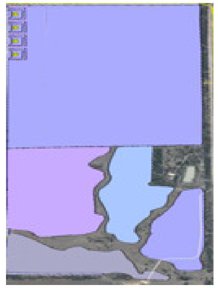
Note: Results include cropping frequency (i.e., the proportion of years sown to a particular crop), mean yield for each crop, and mean and standard deviation (S.D.) of annual gross margin.

3.3.2 Spatial Impacts

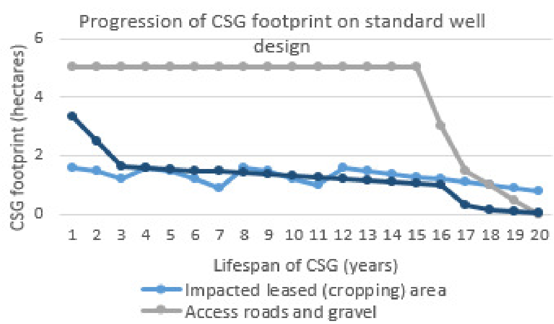
Based on the ocular inspection, GPS survey, and analysis of satellite imagery conducted, a typical 200-hectare farm paddock would have a 5 percent CSG footprint (9.9 hectares) given four existing CSG wells installed (Figure 3-4). Figure 3-4 illustrates how the impacts of CSG wells on indicative dryland farm paddock are derived. The wells are assumed to be kept on the side corners of the farm paddock to minimise obstruction in farming operations. Meanwhile, it is presumed that irrigated farm in Cecil Plains would use a multiple well-pad design to maximise the machinery operation.

The total footprint is predominantly comprised of access roads and gravel, pipelines, and the actual leased area. There is a total of 9.9 hectares of footprint for a standard well design (Figure 3-4), while this is proportionately estimated to be 5.1 hectares for a multiple well-pad design. The multiple well-pad design allows strategic location of multiple wells in a single pad, resulting in a larger surface area. However, the cumulative surface disturbance is lower. Thus, the leased area makes a smaller footprint. This CSG footprint fluctuates in size because of other recurring CSG activities affecting it, such as workover rigs and well maintenance, which further decreases the effective area by half hectares for cropping. Well rig workover operation is done every three years on average (based from Arrow Energy) throughout the life of the well to reconfigure it in order to continuously extract water, apart from gas. Access roads and gravel are permanently lost throughout the CSG construction and operations phases. This is considered the biggest CSG footprint, consistent with the findings of the study conducted by Marinoni and Garcia (2015). Pipeline footprints are impacts that generally decrease over the lifespan of CSG development. Pipelines are buried underground after installation, enabling the surface area to be potentially productive for farming.





CSG footprint	Area covered on standard well design (description)	Area covered on multiple well pad design (description)
Access roads and gravel	5 ha. (Area lost from production until decommissioning)	3.1 ha. (Area lost from production until decommissioning)
Impacted leased (cropping) area	1.6 ha. (Loss changes over time with CSG operations)	
Pipelines	3.3 ha. (Loss decreases with ongoing rehabilitation)	2 ha. (Loss decreases with ongoing rehabilitation)
Total footprint	9.9 ha.	5.1 ha



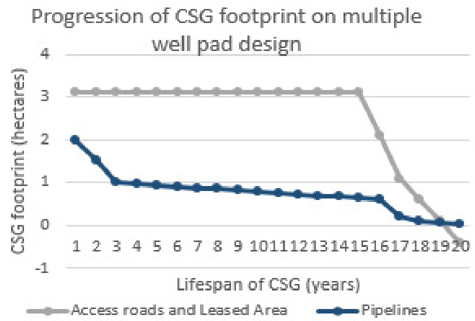
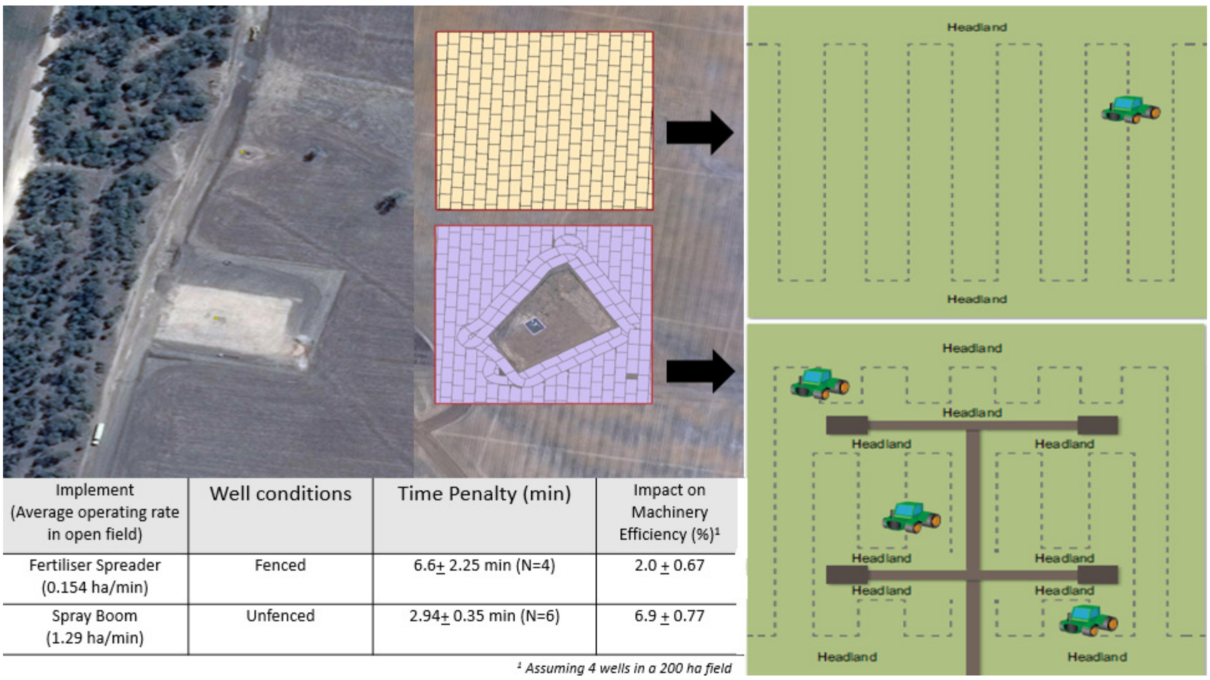


Figure 3-4. CSG footprint in a farm paddock and description of impact

3.3.3 Machinery Impacts

The field survey also reveals that CSG footprints affect farm logistics in terms of machinery operating time. Figure 3-5 depicts how CSG infrastructures influenced the movement of farm implements, found from the survey of different wells in Monreagh (Tallinga tenement) and Heatherly (Condabri tenement) sites. It shows that machinery operations are initially unobstructed, bringing machinery efficiency to its full capacity (100%). However, with the installation of CSG wells, a tractor may need to make extra turns throughout the farm paddock. A fertiliser spreader takes an average of eight minutes to move around a fenced well resulting in a two percent decrease in machinery efficiency. Results from the GPS survey likewise show that machinery performance could be affected by up to eight percent if a spray boom is used in unfenced wells.

These time-based estimates of CSG impact exclude the added risk of accidents that could occur by avoiding obstruction from other infrastructure such as signs and vents, among other things. The study assumes 92 and 96 percent machinery efficiencies for dryland areas, and 98 and 96 percent machinery efficiencies for irrigated areas in its scenario analysis of the financial impacts of CSG on farm enterprise.



Implement (Average operating rate in open field)	Well conditions	Time Penalty (min)	Impact on Machinery Efficiency (%)[1]
Fertiliser Spreader (0.154 ha/min)	Fenced	6.6$\pm$ 2.25 min (N=4)	2.0 $\pm$ 0.67
Spray Boom (1.29 ha/min)	Unfenced	2.94$\pm$ 0.35 min (N=6)	6.9 $\pm$ 0.77

[1] Assuming 4 wells in a 200 ha field

Figure 3-5. Impact of CSG footprint on machinery efficiency

3.3.4 Economic Impact

Changes in income, costs, and gross margin for scenarios are enumerated in Table 3-3. In general, there is a four percent decrease in income with the advent of CSG wells in all leased cropping areas in all sites. This is predicted to have a substantial effect given with an actual farm could have more than four farm paddocks.

Cost increases as CSG footprints cause obstructions in farming operations. There is a three percent increase in costs in dryland farms due to installation of CSG wells causing four percent inefficiency in machinery performance (96% ME) on a standard well spacing. Meanwhile, a six percent increase in costs from the baseline production (having no wells) occurs if machinery efficiency is further decreased to 92 percent. These changes in income and costs would decrease gross margin ranging from 13 to 17 percent in Chinchilla and 11 to 15 percent in Dalby at different scenarios.

Table 3-3. Impact of CSG wells in the financial performance by income, cost, and gross margin in indicative farms at Chinchilla, Dalby and Cecil Plains

Sites	**Machinery Efficiency (% relative to no wells)**	**Income per farm paddock (% difference from Baseline)**	**Cost per farm paddock (% difference from Baseline)**	**Gross margin per farm paddock (% difference from Baseline)**
Chinchilla	100%	$ 138,821.63	$ 79,510.91	$ 59,310.72
	96%	$ 133,489.92 (-4%)	$ 81,825.53 (+3%)	$ 51,664.39 (-13%)
	92%	$ 133,489.92 (-4%)	$ 84,341.42 (+6%)	$ 49,148.50 (-17%)
Dalby	100%	$ 145,657.57	$ 76,934.03	$ 68,723.54
	96%	$ 140,017.55 (-4%)	$ 78,887.24 (+3%)	$ 61,130.31 (-11%)
	92%	$ 140,017.55 (-4%)	$ 81,284.29 (+6%)	$ 58,733.26 (-15%)
Cecil Plains	100%	$ 852,084.70	$ 342,179.09	$ 509,905.60
	98%	$ 834,881.20 (-2%)	$ 346,748.45 (+1%)	$ 488,132.75 (-4%)
	96%	819,270.71 (-4%)	358,088.75 (+5%)	461,181.96 (-10%)

Note: These values are average of ten simulation of 'Startof' periods (each with 15-years production) to capture the effects of climate variability.

Table 3-3 further reveals that the cash flow of the farm enterprise is more affected by increased costs than decreased income. This indicates that CSG development primarily influences the gross margin of the farm enterprise by affecting the cost of farm inputs. However, compensation structure and negotiation agreement are concerned by the spatial changes brought about by the CSG footprint, but have not addressed its impact on farm operations and logistics.

On the other hand, the impact of CSG development on machinery efficiency is a different scenario for Cecil Plains because of its multiple well-pad design, which causes less interference to farm operations (Arrow Energy 2012). The study used 98 percent machinery efficiency for this type of well design. There is only a one percent ($346,748.45 per farm paddock) increase in costs if landholders have multiple well-pads. This smaller percentage change in costs is based on the assumption that the CSG footprint does not affect major components to the cost structure, such as irrigation.

If there is no possibility of a change in well design, a standard well spacing is assumed to generate four percent inefficiency in machinery performance. This results in an increase in cost by five percent or $358,088.75 per farm paddock. The cost and income effect on the gross margin of Cecil Plains results in a decrease of four to 10 percent. These percentage changes are lower than the dryland cropping due to the stability in production yield of an irrigated cropping system. This result implies that well spacing and design influences the gross margin of an enterprise. Therefore, landholders and gas companies should be able to strategise the positioning of CSG infrastructure and plan the timing of CSG logistics that would minimise disruption farm operations (Arrow Energy 2012).

The effect of the 'cost squeeze' or the impact of cost to the gross margin is illustrated in Figure 3-6. It shows that as cost increases, gross margins are 'pushed' upwards and decreased in value. This is evident in dryland cropping sites (i.e. Chinchilla and Dalby), where the remaining profit or gross margin is less than half the income. For Cecil Plains, however, the composition of the income and gross margin does not differ much throughout different scenarios.

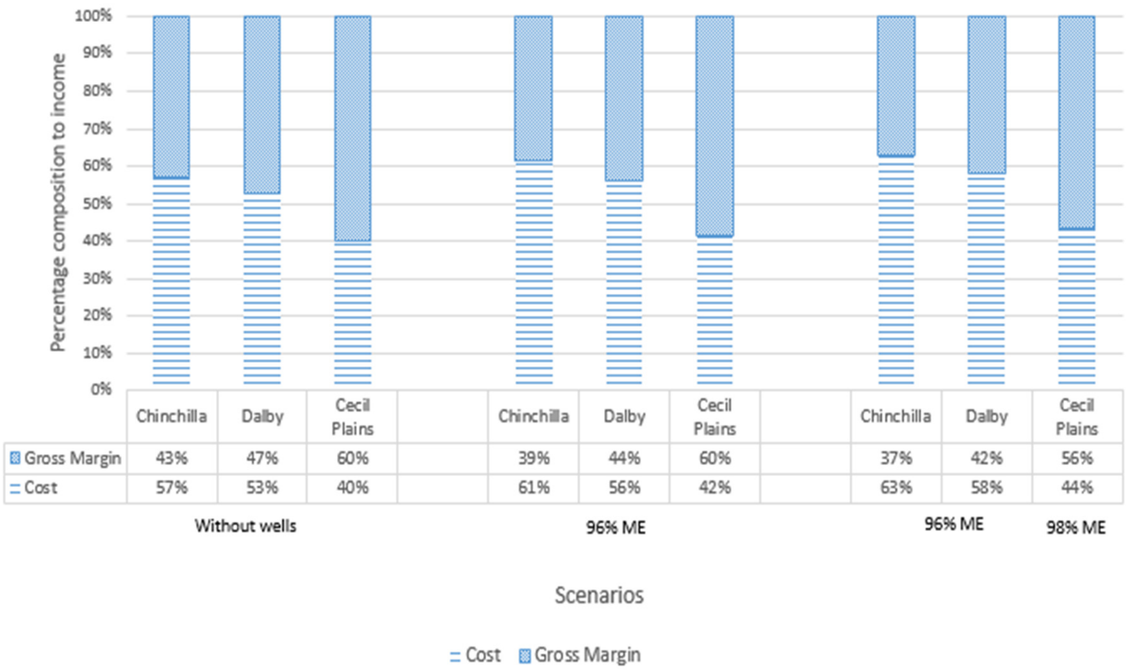
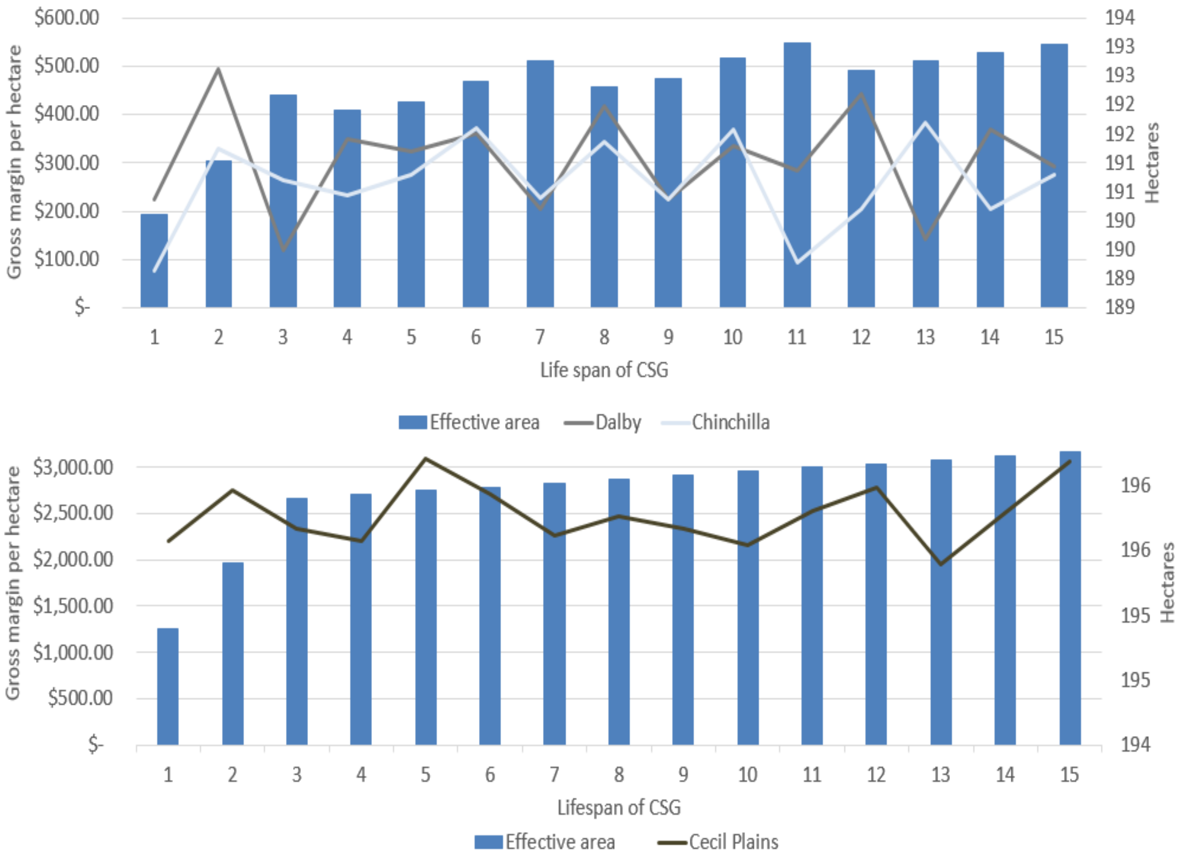


Figure 3-6. Percentage composition of the cost and gross margin to total income of Chinchilla, Dalby and Cecil Plains

Another implication of the cost component is the relationship of cash flow through gross margin and the CSG footprint. Figure 3-7 shows the average gross margin per hectare of the sites with tenement throughout the 10 simulated cycles of 15-year periods. The effective area is the remaining productive space for cropping at a given CSG footprint. Year 1 is the onset of construction and installation of CSG infrastructure resulting in the lowest effective area and gross margin for the site. However, there are incidences where effective area does not dictate the expected level of gross margin in various periods throughout the lifespan of CSG development. Year 11 for Chinchilla marks a gross margin of less than \$100 per hectare, despite cropping the maximum effective area possible at 193 hectares. Similar observations were found at Year 13 for Dalby. These results pertain to 'Startof' simulated periods of low yield, fallow, and drought that coincide to a particular year of CSG development. These periods still incur a 'fixed' management expense per unit, such as weed and pest control, in order to maintain the area of production.

These findings point out the substantial effect of the CSG footprint on production cost, affecting the cash flow performance of the enterprise but not accounted for in compensation. While most studies are concerned with the consequences of coexistence on farmer enterprise income, it is actually the 'cost side' that steers the resulting profit. The Petroleum and Gas Act of 2004 (Queensland Government 2004) incorporates the factor of land productivity in reparation efforts but does not give emphasis to consequences of CSG footprint on farm inputs, labour and machinery.



Note: Gross margins shown are average values for all simulated periods at 96 percent machinery efficiency for dryland farms (Chinchilla and Dalby) and 98 percent machinery efficiency irrigated farm (Cecil Plains).

Figure 3-7. Comparison of the effective area (bars) and gross margin per hectare (lines) in Chinchilla, Dalby, and Cecil Plains

3.4 Summary and Conclusion

The study investigates the potential effects of the spatial overlap of the CSG infrastructures and activities and farming operations. The cash flow of the farm enterprise is affected by the decreases in production area and machinery efficiency brought about by CSG development. These outcomes are demonstrated in representative farm paddocks in dryland (Chinchilla and Dalby) and irrigated (Cecil Plains) farming systems.

The study considers that the visible distortions on the surface of the rural landscape are results of CSG development in agriculture. It reveals that these distortions caused by CSG footprints vary over time depending on the phase of CSG project development. The three types of CSG footprint are the leased area, pipelines, and access roads, which are either temporarily or permanently lost (until the rehabilitation or decommissioning phase). The well spacing design or placement also influences the CSG footprint. A standard well design with four CSG wells installed at a 200-hectare farm paddock causes a larger impact as compared to a multiple well pad design. The standard well design is employed in the simulation of the spatial impact of dryland areas while, a multiple well pad design is introduced for irrigated farm.

Thus, negotiations should incorporate the factor of well placement. The case at Cecil Plains of having a multiple well-pad presents the advantage of a sound scheme that curtails the CSG footprint from barricading the manoeuvring of machinery and cropping practices. It decreases expenses in farming operations and losses in profit. Negotiation and compensation contracts should include an efficient and detailed plan of where to put CSG wells at the best location, where there is least damage and both landholders and gas companies agrees. The characterisation of CSG footprints also incorporates the periodical CSG activities such as workover rigs, which lessens the effective area for cropping. Such information is important in enabling landholders to effectively manage their farming operations and negotiate on a synchronised arrangement on the timing of CSG maintenance activities, coinciding with periods where there are fewer farm practices in the field (i.e. fallow or drought periods) to minimise further losses (Arrow Energy 2012).

The study further shows that changes in variable expenditures can significantly affect gross margins of the farm enterprise on a farm paddock basis ('cost-squeeze'). It is affected by additional machinery operations and inputs such as fuel, labour, repair, and maintenance in avoiding leased area and tracks, which are aggregately reflected as the change in machinery efficiency. Its influence on gross margin is larger than the decrease in income brought about by the displacement of the productive or effective area for cropping yet is often less observed. Climate variability also contributes to the extent of the impact of CSG development on the financial performance of the farm enterprise. The more variable the climate of an area, the larger would be the effect of CSG development on farm gross margin. This is manifested by comparing the cost-squeeze effect on all the case studies if given the same standard well spacing at 96 percent ME (Figure 3-6). Such results also include the costs incurred, even during periods of crop failure and/or no production for crop maintenance.

These results are significant in framing the compensation agreement, where loss in profit or reduction of gross margin is the usual basis for remuneration. Compensation should be considered based on the lost income incurred by farmers, rather than reduction in gross margin, because farmers still have to pay costs of maintaining the land (e.g. tillage, weed management, pests, disease).

This study is a fundamental approach in valuing the impacts of CSG footprint on the financial performance of typical farm paddocks in the Surat Basin. It indicates that there is a need for a negotiated gas-farm design, focusing on the design principles and management of synchronisation and optimisation of the farm operations and CSG logistics. The results derived are estimated figures and may not reflect an actual farm. However, the method employed by the study is the most appropriate way of reflecting the coexistence set-up of CSG and agriculture given the complexity, variability, and confidentiality of this research space.

4 Study Three – Strategic Coexistence Management

4.1 Introduction

The impact of CSG extraction on agriculture is a highly charged subject. CSG development spans a spatially distributed landscape, affecting varied and complex stakeholders. Landholders either perceive this resource activity as a challenge or opportunity. The lack of consistent framework to promote synergy between agriculture and energy has created contention among media, community, and research groups (Turton 2014). However, there is little research showing the promising economic opportunities that the resource industry may provide to agriculture. This is despite the contribution of Australian mining industry to the economy through royalties estimated to an amount of $1 billion per annum (Taylor 2015).

CSG activities are being contested, due to the notion that they mainly operate in prime agricultural areas, compromising profitability for landholders, and threatening the food security of future generations. This affects succession planning for the business enterprise or family legacy, since long-term investment is now replaced with risk and uncertainty (Hossain et al. 2013). Study Two demonstrates that CSG development affects farm production by increasing farm costs, driving enterprise profitability to decline at the farm scale under simplified scenario models.

However, the benefits of CSG should be considered alongside the needs of farm enterprises. Compensation, employment opportunities, agricultural redevelopment, and partnership are some of the potential advantages identified by landholders (Collins et al. 2013; Fleming & Measham 2013). Hence, the continuum of net results between losses and benefits would steer the decision of whether a landholder would cooperate or compete with gas companies.

The number of CSG wells installed within the areas leased by gas companies reflects the opportunity for supplementary income that landholders could utilise as capital for their farm and/or non-farm investment ventures. This steady stream of income is in conjunction with agricultural operations and acts as a ‘buffer’ wealth for landholders. However, negotiations for compensation arrangements are confidential. Research to date does not provide clear insights into all aspects of the process and many issues are not transparent, creating uncertainty. The development of an appropriate valuation process for compensation is challenging.

The Petroleum and Gas Act of 2004 (Queensland Government 2004) specifies that the compensatable factors, which landholders have the right to negotiate include: displacement and limitations on land use; reduction in land value; severance from the surrounding land; and damage to infrastructure (Fibbens, Mak & Williams 2014; Fibbens, Mak & Williams 2013; Productivity Commission 2015; Queensland Government 2014b). There is no regulation of the amount of compensation offered to landholders, nor is there a well-defined and uniform structure for compensation. Compensation agreements are variable and could be subjective. Most of the legislation governing the CSG industry is under an umbrella of generalised rules and obligations.

Fibbens, Mak and Williams (2014) illustrate how legal courts approach the process of valuing compensation through a summation process, in which gas companies pay landholders on a per well basis. This is the most common practice undertaken by gas companies. For instance, a gas company provides a payment ranging from approximately $1,500 to $3,000 per well annually (Fibbens, Mak & Williams 2013). However this payment excludes the indirect damage inflicted on other properties surrounding the CSG development site.

Clarke (2013) suggested an alternative approach to compensation. He presented case studies of the compensation schemes adopted by CSG companies and the characteristics of landholders' engagement. One type of compensation is based initially on a payment determined by CSG footprint during construction and then an annual lease fee in the succeeding years. The scheme allows for flexibility in arranging the footprint payment, but the lease payment is fixed throughout the span of CSG development. Fibbens, Mak and Williams (2014) refer to this as a piecemeal approach.

Another case study on compensation presented by Clarke (2013) demonstrated a flexible system in which the market value of a property is based on adjusted consumer price indices. This gives the landholders the ability to improve their productivity, gaining an edge in negotiations. The negotiation agreement is considered and compensations may be adjusted after five years to include improvements provided by CSG companies, such as roads, gates, and grids.

There are also well-informed landholders who can maximise the outcomes of the negotiations with CSG companies. It was postulated that a landholder could negotiate compensation above the usual 'per-well' payment by deliberately itemising the areas where their farm operations could be impacted. This includes the well infrastructure footprint and drilling activities, and even the opportunity cost of time associated with the changed management and operational activities necessary to accommodate the wells. It was established that the landholder was able to get a compensation of up to $145 per hour of his lost time (Clarke 2013). This is an additional payment other than obligated under the Mineral Resource Act of 1989 (Queensland Government 1989), which does not cover the property owner's valuation and legal costs (Swayne 2012). The compensation scheme suggests that negotiation between parties would be successful if transparency is maintained and if landholders are able to assert that their rights to be compensated are commensurate with the losses incurred.

Each gas company devises its own process and composition of compensation payments. A landholder may receive compensation that is calculated differently to a payment offered to their neighbour. Compensation paid will depend on several factors, including the type of land considered, its current use, and its location. Currently, landholders receive compensation based on the property market value of their land (Fibbens, Mak & Williams 2013). This existing compensatory system only considers the present land use and productivity or the market value of the property, but does not fully reflect land sustainability. It creates an opportunity cost for landholders by not taking into account potential income from a better farming system. Study One revealed areas with tenement in the Surat Basin that have potential for intensification, but this productive value is not included in the compensation process. This undervalues the real compensatable effect of coexistence of an area.

This study considers compensation as a foundation for creating a productive coexistence by securing financial opportunities for the farm enterprise. The compensation structure adopted by the study is based on existing literature on landholder surveys and informal interviews with gas companies. It is assumed that landholders protect themselves from future losses, mitigate (recover previous) their losses, and enable themselves to increase their assets by investing this financial resource. The financial opportunity gained from compensation would also perpetuate the family enterprise legacy and assets. This study provides potential investment strategies for the development of the farm enterprise during and after CSG operations.

Compensation should be dealt under the premise of fairness and cooperation. However, the principle of fairness in valuing compensation package of CSG companies is excluded in the study. Also, the amount of compensation that may be able to cover indirect or intangible impacts of coexistence (e.g. time) is beyond the scope of the study.

4.2 Methodology

The study recognises that the coexistence of CSG mining and farming has financial implications on agricultural production. Gas companies address these issues through a negotiated structure of compensation. This process of commensuration intends to mitigate the impacts of CSG that could influence agricultural productivity even after operations had ceased (Chen & Randall 2013).

This study investigates the effect of additional cash inflow through compensation, on farm enterprise. The study explores the extent to which compensation could improve the financial performance of the landholders' farm enterprise. A simplified depiction of investment strategies (intensification, expansion, and diversification) within three typical cropping areas in the Surat Basin is provided. The term 'farm' also refers to agricultural areas where CSG operations exist.

4.2.1 Assumptions of the compensation structure

The compensation structure employed in this study is based on the legislative guidelines (i.e. Petroleum and Gas (Production and Safety) Act 2004), literature, and gas companies' appraisals. This study reveals three kinds of periodic compensation payments that coincide with phases of CSG development: the CCA, construction, and operation. The rehabilitation (or decommissioning) phase is excluded. The overall consideration of what constitutes the payments and value of compensation is derived from the information gathered from various interaction and meetings conducted with gas companies under the GISERA collaborative project. The results are mainly for the purpose of comparison of a hypothetical farm typical of dryland and irrigated areas in Surat Basin, and are indicative values. There is little or no existing public documentation regarding the amount of compensation received by landholders due to its highly confidential nature as a contentious issue.

An upfront payment is given to landholders at the initial stage of negotiations and CCA. This payment is comprised of the land value of the leased area by the gas company and an indicative amount to cover other costs. The land value is the worth of the property as estimated by its market value based on per hectare value. This value varies depending on the location and type of farming system. More intensive and irrigated broad-acre crops and horticulture areas in the East of the Darling Downs (i.e. Cecil Plains) have a higher value per hectare, compared to those further west where less intensive options such as dryland cropping and grazing are undertaken (i.e. Chinchilla). The market value used by the study is from estimates by a local real estate agent in the Darling Downs.

The level of land productivity is measured through its gross margin, which is another parameter in the compensation structure. Payment based on gross margin is a function of the CSG footprint and the average gross margin of the simulated farm paddock. The gross margin is the difference of the mean per hectare of the simulated yield (from APSIM) and commodity price (from AgMargins) of different climatic periods, and the production costs. The costs are variable expenditures of the farm operation, including farm inputs and labour. It does not take into consideration depreciation and salvage costs of farm machinery. These costs include machinery efficiency decreased to 96 percent once four wells are installed in dryland farm paddock and 98 percent for irrigated farmland. The gross margin derived from the simulation relies on the climatic conditions parameterised in APSIM to highlight the effect of CSG development and compensation on the cash flow of the agricultural enterprise. Thus, commodity prices are at constant values to isolate other market force externalities.

Another parameter in the compensation structure includes 'other costs', which are adjusted depending on the stage of CSG development –construction or operation. This consists of indirect impacts and time devoted in managing coexistence. This is highest during the construction phase, when the production impact and CSG footprint are also at their maximum. However, the compensatory value is based on gas companies' discretion or by agreement between the negotiating parties.

Compensation payments received by landholders are based on a footprint of having four wells on a 200-hectare farm paddock representing an average well density. Compensation is examined from two perspectives. Firstly, it serves as an additional cash flow that could significantly affect the financial stability of the farming enterprise. The gross margins of each simulated 15-years 'Startof' period of the indicative farms in dryland (Chinchilla and Dalby) and irrigated (Cecil Plains) farms are compared. 'Startof' represents the beginning year of the climatic cycle of the simulation; for example, 'Startof1909' translates as 'from 1909 to 1923'. Each comparison uses different scenarios, namely: (a) without CSG (baseline agricultural production), (b) with CSG wells (without compensation), and (c) with CSG compensation.

Secondly, the estimated amount of compensation derived for the three cropping sites is the basis for exploring its individual agricultural investment decisions. The study proposes options such as intensification, expansion, and diversification that can improve the financial performance of an enterprise. Although there are diverse investment choices available for landholders, these options best showcase the conventional strategic management undertaken by landholders in the Surat Basin at a given capital investment. Recommendations are not exhaustive, as it is not possible to explore all options. This approach focuses on the implication of CSG development on agricultural production and financial performance without overshadowing the value of compensation by the complexity of other issues, such as market and production risks and economic uncertainties. The choice of investment of landholders is based on the assumption that they have full equity on profit and that there is no variation in market prices of commodities and land in all simulated years and various phases of CSG development, to highlight the compensation effect on cash flows of the farm enterprise. These are also based on the assumption of a simplified perfect environment (i.e. farms are tax free, debt free), to isolate the returns from each option and avoid complicating the process with other financial variables.

4.2.2 Comparison of cash flow

The study analyses the changes in farming enterprise cash flows , with or without CSG compensation for the hypothetical farms in Chinchilla, Dalby, and Cecil Plains. Quantitative measures, such as the paired comparison of the Analysis of Variance (ANOVA) and Tukey's HSD post-hoc test, are performed for a relatively small sample size of the simulated data. The null hypothesis is that there is no difference (throughout the simulated climatic periods) between the means of the gross margin of different paired scenarios: (a) without CSG wells (baseline) versus with CSG wells but without compensation, (b) without CSG wells (baseline) versus with CSG wells and compensation, and (c) with CSG wells but without compensation versus with CSG wells and compensation.

Sparklines and boxplots represent the changes to gross margins. Sparklines are used to signify the points where the gross margin increases and decreases from baseline to with-compensation scenarios. Boxplots provide a non-parametric presentation of data according to their quartiles. It also provides information on the degree of dispersion and skewness (median) of the data through the spacing of the parts of the box.

Cash flows are set to reference 2015 prices. The variability in the values of income and costs, which account for the gross margin, is mainly caused by climatic or seasonal implications. Hence, the study does not use a discounted cash flow.

4.2.3 Business strategies

There is limited literature examining the risk attitudes and management strategies of Australian farmers in handling scarce resources under exogenous conditions (Nguyen et al. 2007). This study investigates the conventional investment decisions available to landholders in mobilising financial resources, focusing particularly on an additional cash inflow stream of a hypothetical farm enterprise. It is presumed that the landholder has existing wealth or working capital (before an offer of CSG compensation), which is sufficient to cover the cost of production for a particular farming system. This assumption is made to highlight the effect of compensation on investment decisions to be made by farming landholders.

Chen and Randall (2013) conclude that if agriculture in an area is highly favourable, compensation must be sufficient to offset production losses in order for coexistence to be possible. Thus, the proposition is that agricultural development would be the priority of a rational and risk-neutral individual, since coexistence primarily affects farming operations. A risk-neutral mindset is indifferent to preference, instead focusing on the level of profit or payoff from an investment.

Compensation is expected to recoup the losses incurred due to the effects of the CSG footprint on farming operations. Any surplus after recovering these expenses is available for other investment opportunities. The study utilises CSG payments during both construction and operations for the analysis. It is undertaken using an expected 15-year CSG project span.

Agricultural investment strategies include options for expansion or intensification (e.g. dryland areas in Chinchilla and Dalby). Intensification can address the issue of a reduction in available farming area, while expansion can build economies of scale such as increasing scale and machinery inputs to maximise efficiency. A landholder could also decide to put compensation in a non-farm activity (e.g. bank deposit) when full potential (maximised productivity) has been attained by a current farming system (i.e. irrigated intensive farming system in Cecil Plains). This form of investment diversifies the farm enterprise and spreads the risk of managing the system and mitigates the risk of future uncertainty (Reardon, Crawford & Kelly 1994). These business options are simplified strategies in the short-term due to the limitations of the parameters and conditions at a simulated environment.

4.1.1.1 Intensification: On-farm investment

The main intent of farmers in dryland areas is to maximise productivity while minimising production risk. This entails optimising crop rotation in order to efficiently capture and utilise rainwater (Hochman, Prestwidge & Carberry 2014). Management practices such as plant density (Wade & Douglas 1990) and skip row configurations (Whish et al. (2005) have been adopted in order to better manage seasonal variability.

The study simulates an intensified cropping production by modifying the agronomic management for the dryland area at Chinchilla and Dalby. APSIM is used to simulate the effect of an augmented supply of nitrogen and early sowing on the productivity of the indicative farms with a wheat-sorghum rotation. The parameters used in the APSIM simulation is based on the works of Hochman, Prestwidge and Carberry (2014). Intensification as a business strategy excludes other elements, such as technological, genetic, physiological, and capital form of intensification in agriculture.

In particular, the simulated fertiliser input intake at sowing is increased from 130kg/ha to 150kg/ha (Table 4-1), providing an additional 9kg/ha of nitrogen (at 46 % nitrogen in Urea) for improved crop yield. An intensified cropping system also models a different sowing trigger. The sowing trigger offers a planting 'opportunity' for dryland areas, which are dependent on the availability of water from rainfall and the soil water. The 'Manager' module of APSIM defines the trigger level of sowing. An intensified cropping system for wheat is modified to have a sowing trigger of 120 millimetres of soil moisture. The amount of rainfall (over 3 days) required for sowing is lowered from 25 millimetres to 15 millimetres (Table 4-1). Another parameter that demonstrates an opportunity for planting is the sowing period. Intensification entails extending the sowing period, as manifested for sorghum crop having a sowing window from 60 to 100 days. These parameters imply that the window for planting happens during low soil water availability in order to maximise the utilisation of available rainfall.

Table 4-1. Parameters used for simulating wheat-sorghum rotation by average baseline and intensified production

Parameters	**Baseline Production**		**Intensified Production**	
Crop	Wheat	Sorghum	Wheat	Sorghum
Cultivar	Hartog	Buster	Hartog	Buster
Plant Population (/m^2)	100	6	100	6
Plant available water required for sowing (mm)	100	150	120	150
Date of the start of sowing window	1-May	15-Sept	1-May	1-Oct
Date of the end of sowing window	30-Jun	14-Nov	30-Jun	10-Jan
Management costs ($/ha)	28	36	28	36
Rainfall (previous 3 days) required for sowing (mm)	25	25	15	15
Amount of N at sowing (soil+ fertiliser) (kg/ha)	130	130	150	150
Grain Price ($/t)	235	175	235	175
Fertiliser N Price ($/kg N)	1.17	1.17	1.17	1.17
Volume Cost ($/t)	11	9	11	9
Operational Cost ($/ha)	180	212	180	212
Cost of managing missed planting ($/ha)	43	86	43	86

4.1.1.2 Expansion: Acquisition of another farm field

This investment option is consistent with the mantra in agriculture of ‘either get bigger or get out’, which means increasing the physical area of production and building economies of scale. Economies of scale facilitates the spreading out the fixed (overhead) costs across additional output produced as well as reducing the variable cost per unit of production through efficiency gains. Growth in farm size is associated with increasing return to scale of the production function. The assumption is that large farms are operating more efficiently as compared to small farms, particularly in developed countries (Kislev & Peterson 1996; McClelland, Wetzstein & Musser 1986; Raup 1969).

The study provides the option of utilising the compensation payment to purchase another adjacent parcel of land in order to achieve economies of scale in future production. The new parcel of land would have the same biophysical characteristics and size as the areas currently leased by the gas company (200 hectares), but would not be impacted by CSG operations. Its acquisition is through bank loan amortised at an interest rate of 5 percent (ABARES 2015). An expansion option increases the assets for the landholder. It is assumed that the productive capacity of that new parcel of land would have the same rate of gross margin as the baseline agricultural production of the simulated leased area by the gas company.

4.1.1.3 Diversification: Non-farm investment

There is limited literature on off-farm investment. Most related studies conducted are based on simulated optimisation of long-run investment scenarios (Just 2003). Diversification for this study is associated with investments that are non-agricultural in nature. It supposes that a farm has achieved its maximum potential in production and is highly intensive (e.g. Cecil Plains) prior to CSG development. Therefore, the investment option of agricultural intensification is excluded for irrigated farming systems.

Non-farm investment activities provide supplementary income for the farm and form part of the overall business returns. It also becomes an alternative source of wealth, in the case of low returns such as a poor harvest or lost crop due to drought. Hence, diversification of investment not only increases potential profitability of a business but also serves as a risk management strategy.

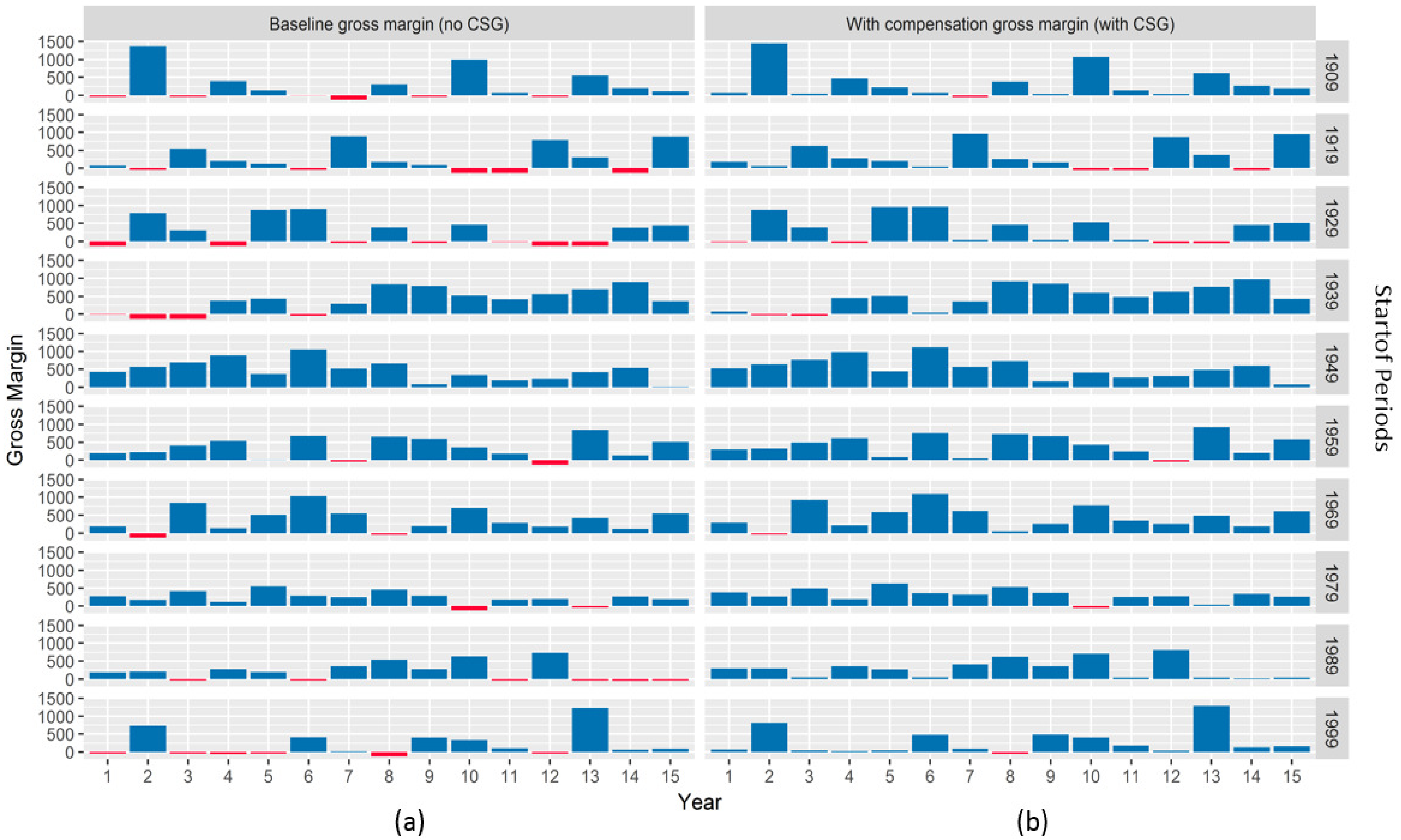
The expected cash flow from compensation is compounded as a fixed interest rate. It assumes that the compensation payment is invested (e.g. bank deposits, savings) at a rate of three percent (based on existing bank savings rates) to project the future value of the simulated cash flows of a farming system. Compounding allows earnings from the principal amount of money and its previously earned interest. It determines the value of an investment opportunity at a specific future date. This derived cash flow is compared to expansion options to determine the most economically efficient investment decision.

4.2 Results and Discussion

4.2.1 Comparison of cash flow

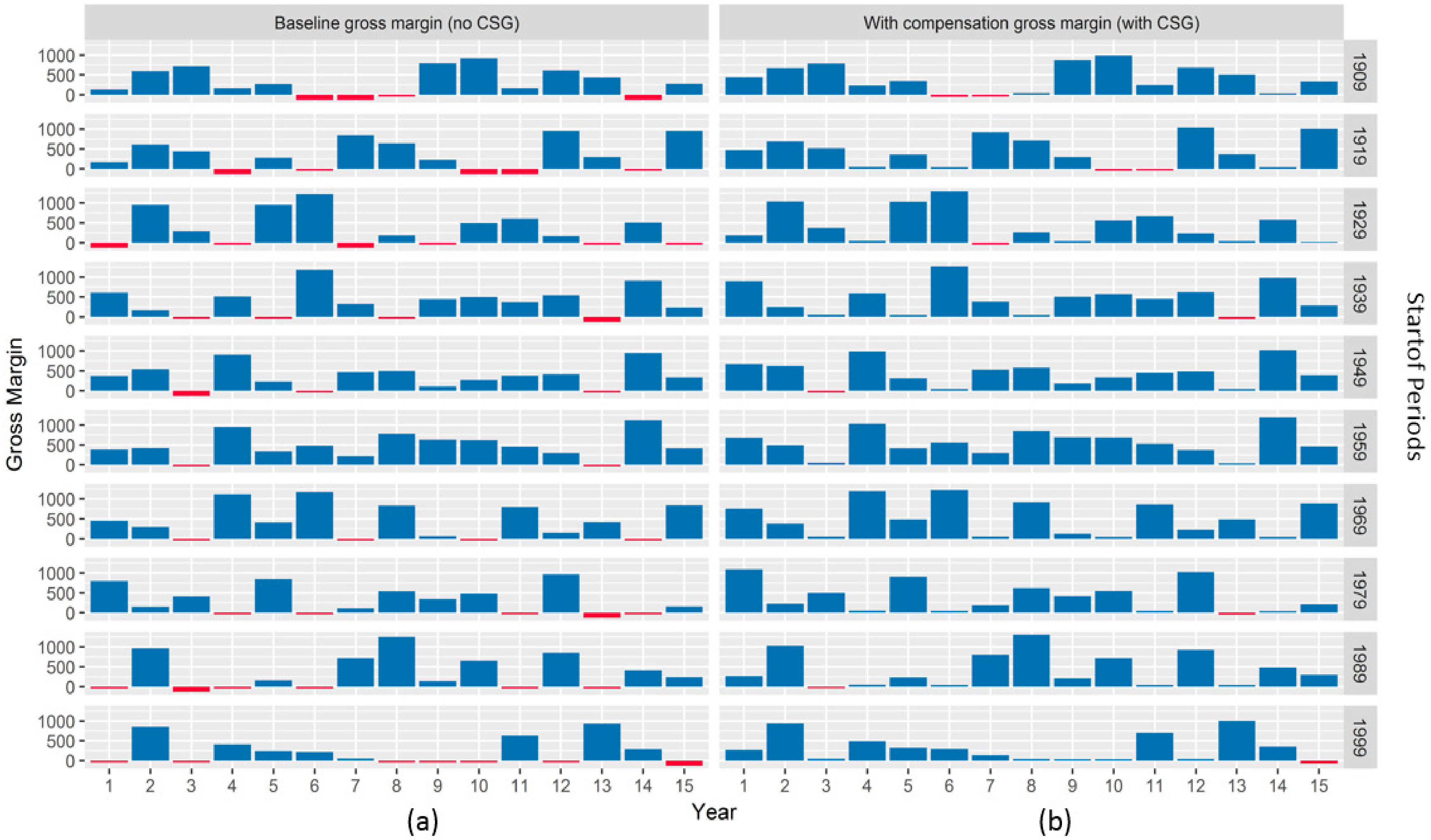
The pattern of sparklines for the 15-year simulated 'Startof' climatic periods indicates that the cash flow has generally improved with the advent of compensation from gas companies. The left side of Figure 4-1, Figure 4-2, and Figure 4-3 point out the financial performance of the farm enterprise before CSG development (baseline). The red columns on the charts represent substantial periods of negative gross margins due to losses attributed to lack of production (e.g. fallow or crop failure because of drought).

The trend changes with additional cash stream from compensation for the farm. The charts on the right side of Figure 4-1, Figure 4-2, and Figure 4-3 show an improvement in the performance of the cash flows, exhibited by the reduction in red columns or negative gross margin values. These observations are similarly found in all three sites of the study area. This signals that a compensation payment serves as a cash 'buffer' in periods of expected losses in production. Appendix D, Appendix E, and Appendix F illustrate in detail the trend of the cash flow of each 'Startof' periods, including the 'With wells but without compensation' scenario.



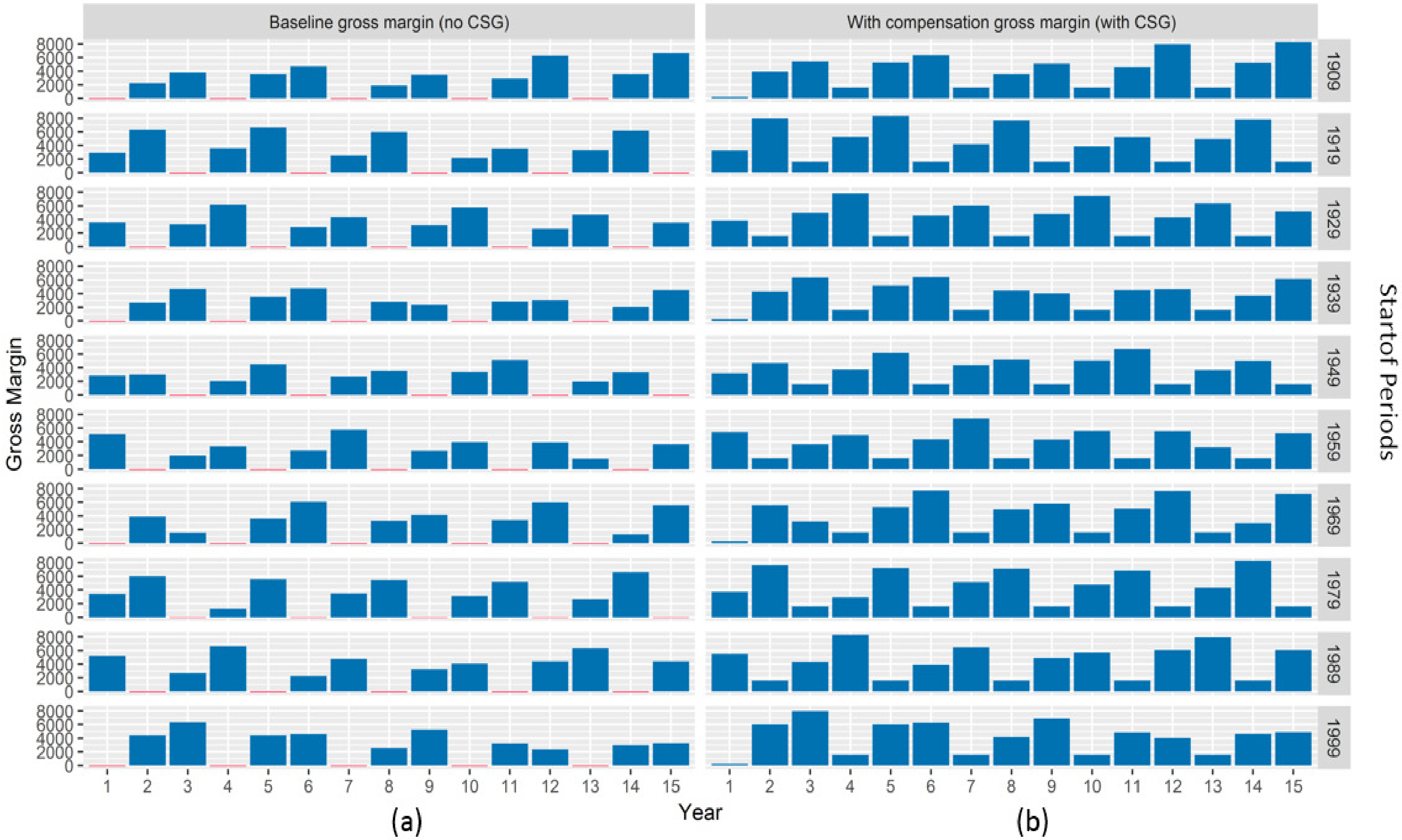
Note: (a) Baseline (before CSG) production; (b) With wells and compensation from CSG

Figure 4-1. Cash flow distribution of Chinchilla throughout CSG years of operation at different simulated Startof periods



Note: (a) Baseline (before CSG) production; (b) With wells and compensation from CSG

Figure 4-2. Cash flow distribution of Dalby throughout CSG years of operation at different simulated Startof periods



Note: (a) Baseline (before CSG) production; (b) With wells and compensation from CSG

Figure 4-3. Cash flow distribution of Cecil Plains throughout CSG years of operation at different simulated Startof periods

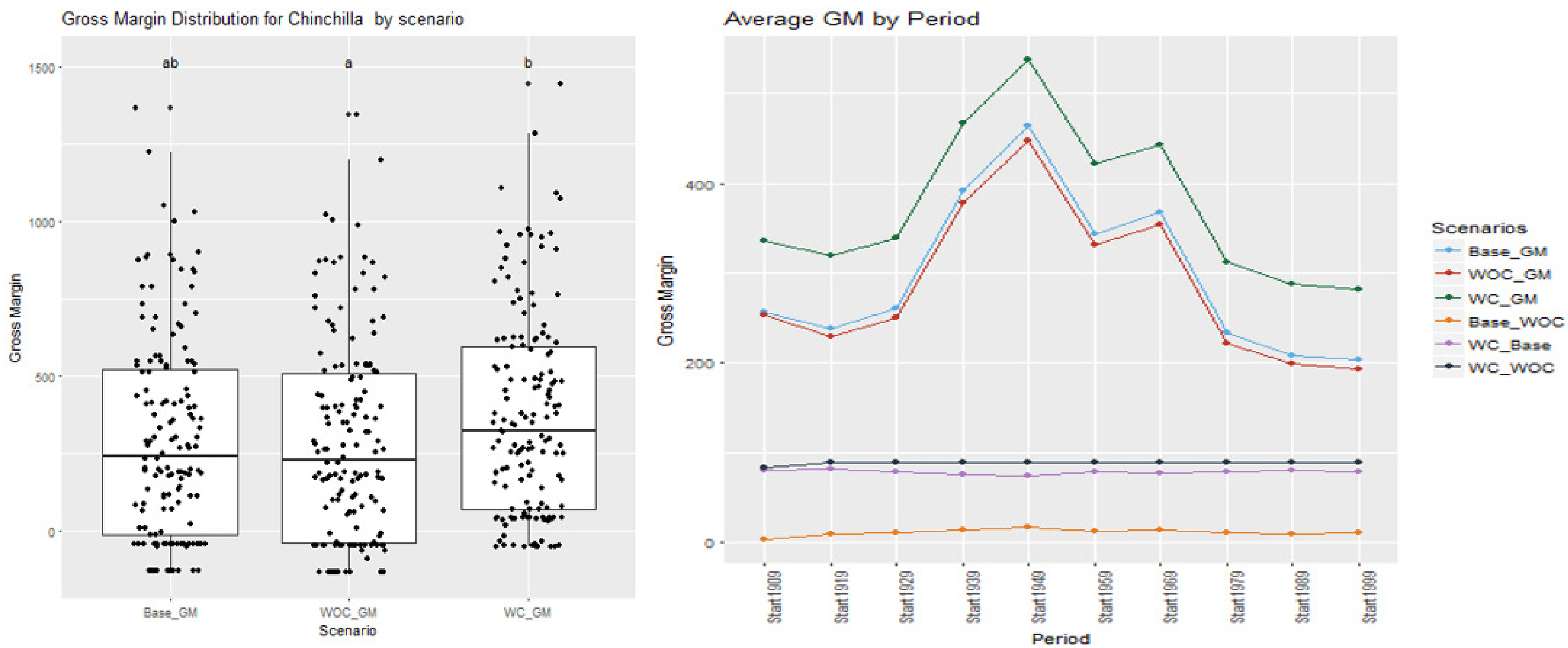
Figure 4-4, Figure 4-5, and Figure 4-6 signify the statistical results as illustrated by the boxplots and line graphs. The ANOVA of the gross margin in Chinchilla and Dalby shows that there is a significant difference (at 1%) among the scenarios analysed by the study. The boxplot for the distribution of the gross margins throughout the simulated years of Chinchilla and Dalby are somewhat similar, as illustrated by the dots in the boxplot. Both dryland areas denote that compensation improved the financial performance of the farm enterprise by generally shifting the gross margin distribution upwards, resulting to higher values. This finding is exhibited by the increase in the median of the gross margins of 'with wells but without compensation (WOC_GM)' and 'with wells and compensation (WC_GM)' scenarios for both Chinchilla and Dalby. It is also related to the distribution of the lower limit and upper limit of the gross margin values are indicated by the first quartile and upper whiskers of the boxplots. Figure 4-4 and Figure 4-5 shows that the first and fourth quartiles distribution of the gross margins in Chinchilla and Dalby are larger value if landholders are compensated, as compared to other scenarios.

The line graphs in Figure 4-4 and Figure 4-5 demonstrate a large gap in the trend of gross margins between the above two scenarios. Therefore, the result of the Tukey HSD tests for both Chinchilla and Dalby reveal that there is a five percent significance difference in the paired comparison of the scenarios 'With wells but without compensation versus With wells and compensation' (WC_WOC) at p-value of 0.045 for Chinchilla and 0.044 for Dalby.

On the other hand, the boxplot for Cecil Plains exhibits a distinct pattern, such that the gross margin distribution of the scenarios 'baseline (Base_GM)' and 'with wells but without compensation (WOC_GM)' is almost identical. It infers that installation of wells has no significant impact on agricultural production and farm enterprise profitability. This is because of the multiple-well pad design for well spacing, which lessens the CSG footprint and machinery inefficiency in an intensive farming system such as irrigated areas. Gross margins are only statistically significant when landholders are compensated. This is shown in the p- adjusted results of the Tukey HSD test in scenarios 'baseline versus with wells and compensation (WC_Base)' and 'with wells but without compensation versus with wells and compensation (WC_WOC)'.

Figure 4-7 demonstrates the distribution of the gross margins for all the study sites at different scenarios using the density plots. The spread of gross margin distribution of scenarios 'baseline (Base_GM)' and 'with wells but without compensation (WC_WOC)' in Chinchilla are parallel, where there is presence of negative gross margins per hectare. These are the periods when landholders do not have harvest or production, but incur costs from maintaining their farms. As compensation is introduced, the gross margin is shifted to the right, a higher probability of an increased gross margin values. This observation is also apparent in Dalby, where gross margin distribution also shifted to the right.

The probability distribution of gross margin is highest in Cecil Plains when valued at zero and around $3,000 per hectare at 'baseline (Base_GM)' and 'with wells but without compensation (WC_WOC)' scenarios. The probability distribution is shifted with compensation, leading to gross margin value per hectare of between $1,000 to $2,000 if the landholder does not have production, and around $5,000 per hectare if there is a favourable harvest.



Analysis of Variance of gross margin (GM)

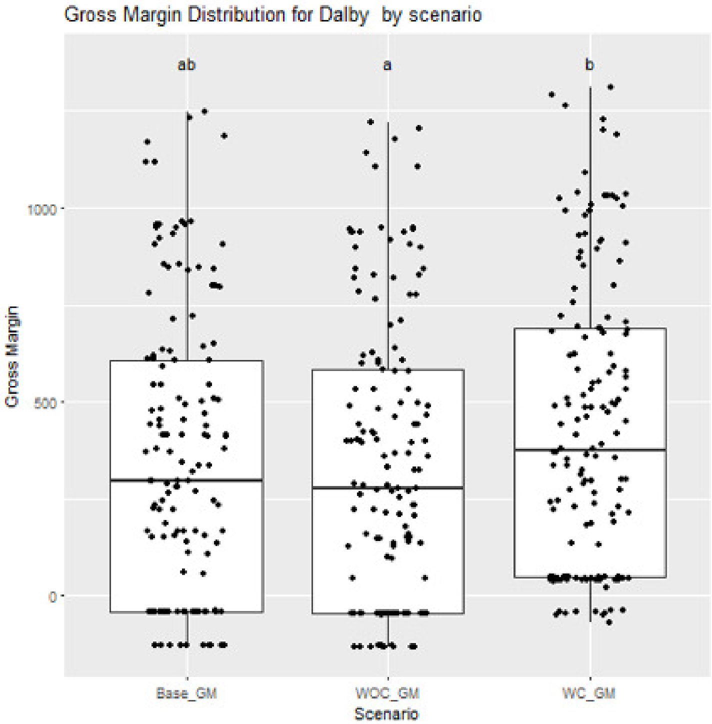
Variables	Means	Std. Error	F value
Scenarios		37.08	0.034*
Baseline (Base_GM)	296.6		
With wells but without compensation (WOC_GM)	285.7		
With wells and compensation (WC_GM)	374.4		
Startof Periods		67.70	0.000***

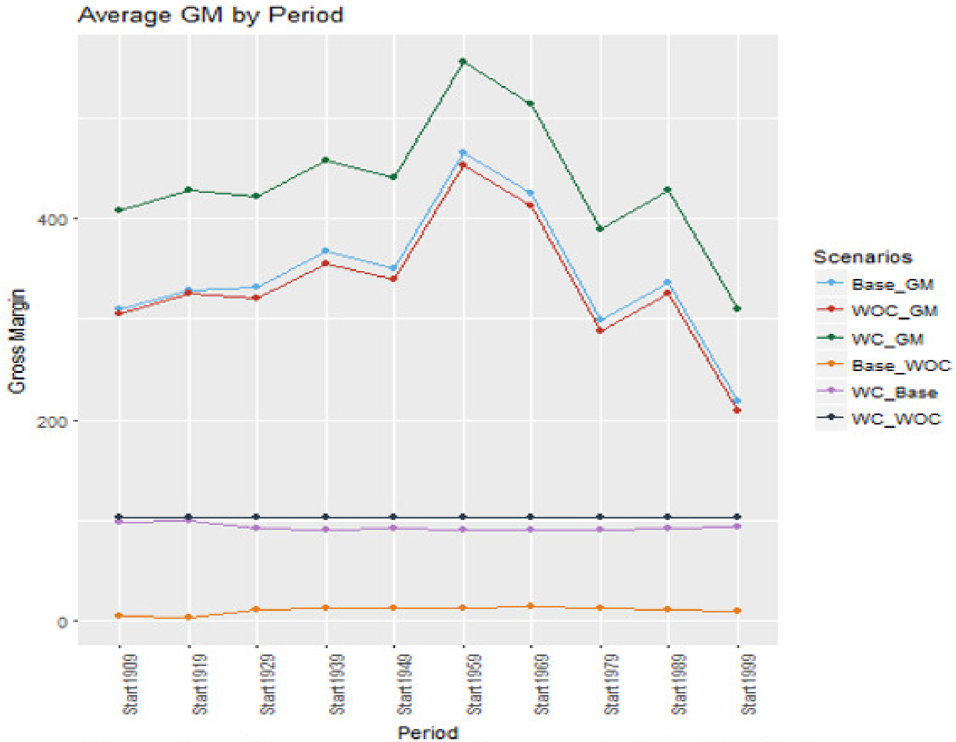
Comparison of gross margin (GM) means using Tukey HSD test

Scenarios	Difference	P adjusted
Baseline versus With wells but without compensation (Base_WOC)	-10.898	0.954
Baseline versus With wells and compensation (WC_Base)	77.849	0.091
With wells but without compensation versus With wells and compensation (WC_WOC)	88.747	0.045^

Significance codes: 0 (***); 0.001 (**); 0.01 (*); 0.05 (^)
Note: similar letters on top of whiskers of the boxplot indicates no significant relationship (at 5%)

Figure 4-4. Gross margin distribution and statistical tests of Chinchilla





Analysis of Variance of gross margin (GM)

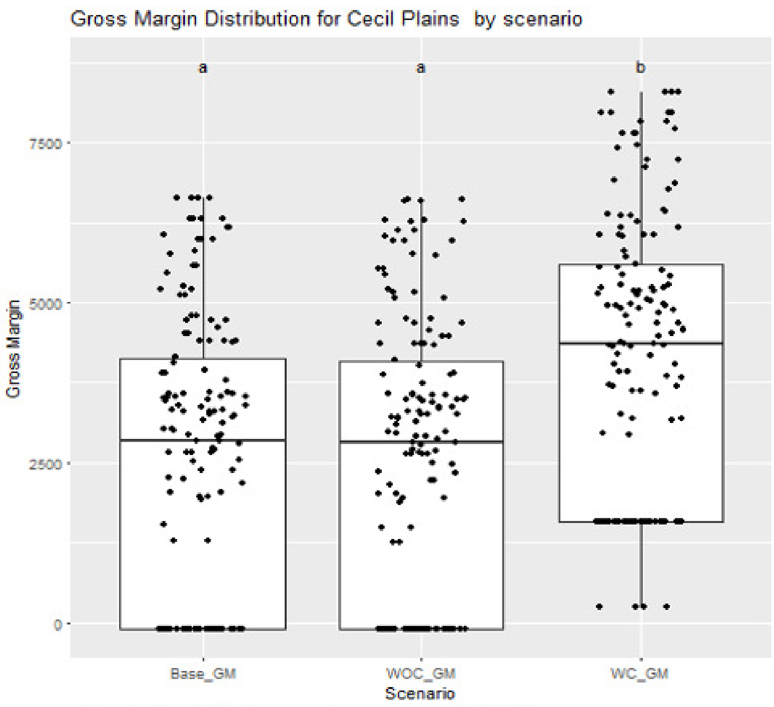
Variables	Means	Std. Error	F value
Scenarios		42.63	0.031*
Baseline (Base_GM)	343.6		
With wells but without compensation (WOC_GM)	333.9		
With wells and compensation (WC_GM)	436.0		
Startof Periods		77.83	0.148

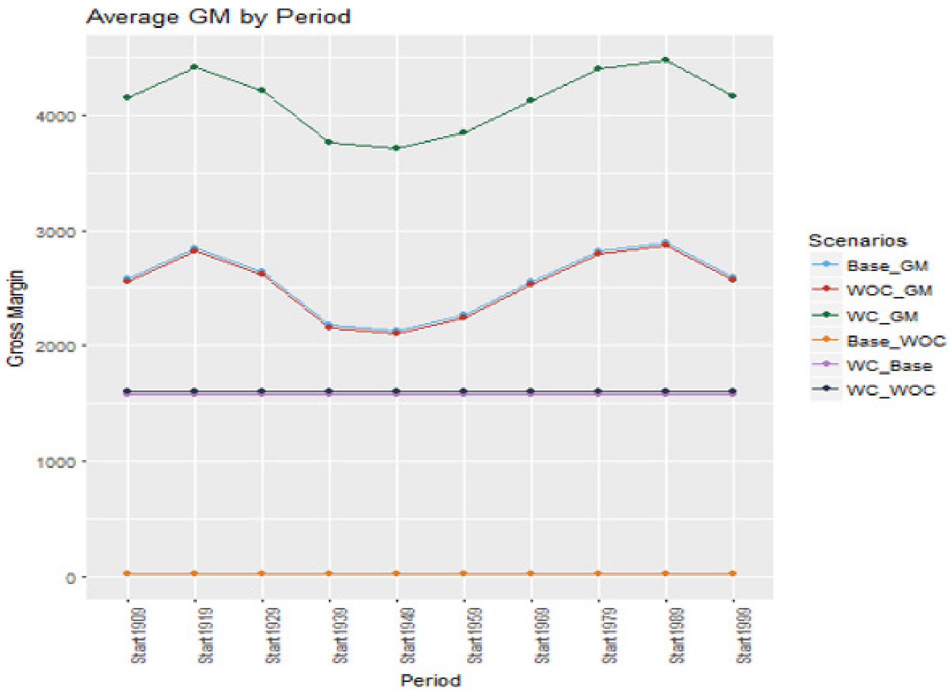
Comparison of gross margin (GM) means using Tukey HSD test

Scenarios	Difference	P adjusted
Baseline versus With wells but without compensation (Base_WOC)	-9.766	0.971
Baseline versus With wells and compensation (WC_Base)	92.393	0.078
With wells but without compensation versus With wells and compensation (WC_WOC)	102.159	0.044^

Significance codes: 0 (***); 0.001 (**); 0.01 (*); 0.05 (^)
Note: similar letters on top of whiskers of the boxplot indicates no significant relationship (at 5%)

Figure 4-5. Gross margin distribution and statistical tests of Dalby





Analysis of Variance of gross margin (GM)

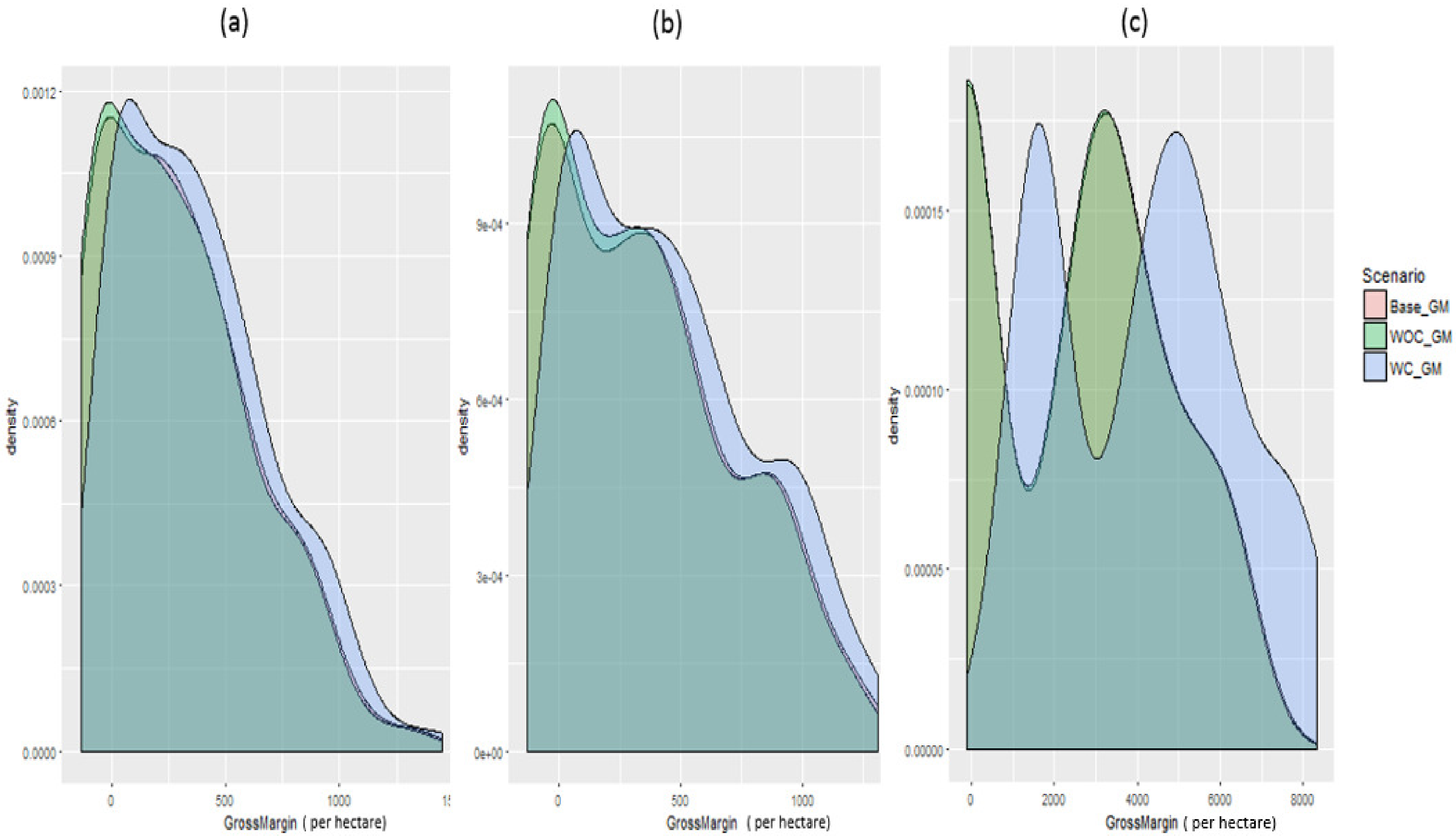
Variables	Means	Std. Error	F value
Scenarios		255.7	25.81***
Baseline (Base_GM)	2550		
With wells but without compensation (WOC_GM)	2527		
With wells and compensation (WC_GM)	4129		
Startof Periods		466.8	0.69

Comparison of gross margin (GM) means using Tukey HSD test

Scenarios	Difference	P adjusted
Baseline versus With wells but without compensation (Base_WOC)	-22.85	0.995
Baseline versus With wells and compensation (WC_Base)	1579.31	0.000
With wells but without compensation versus With wells and compensation (WC_WOC)	1602.16	0.000

Significance codes: 0 (***); 0.001 (**); 0.01 (*); 0.05 (^)
Note: similar letters on top of whiskers of the boxplot indicates no significant relationship (at 5%)

Figure 4-6. Gross margin distribution and statistical tests for Cecil Plains



Note: (a) Chinchilla, (b) Dalby, (c) Cecil Plains

Figure 4-7. Density plot of gross margins per hectare for all study sites

4.2.2 Business strategies

4.2.2.1 Chinchilla dryland farming: Intensification or Expansion

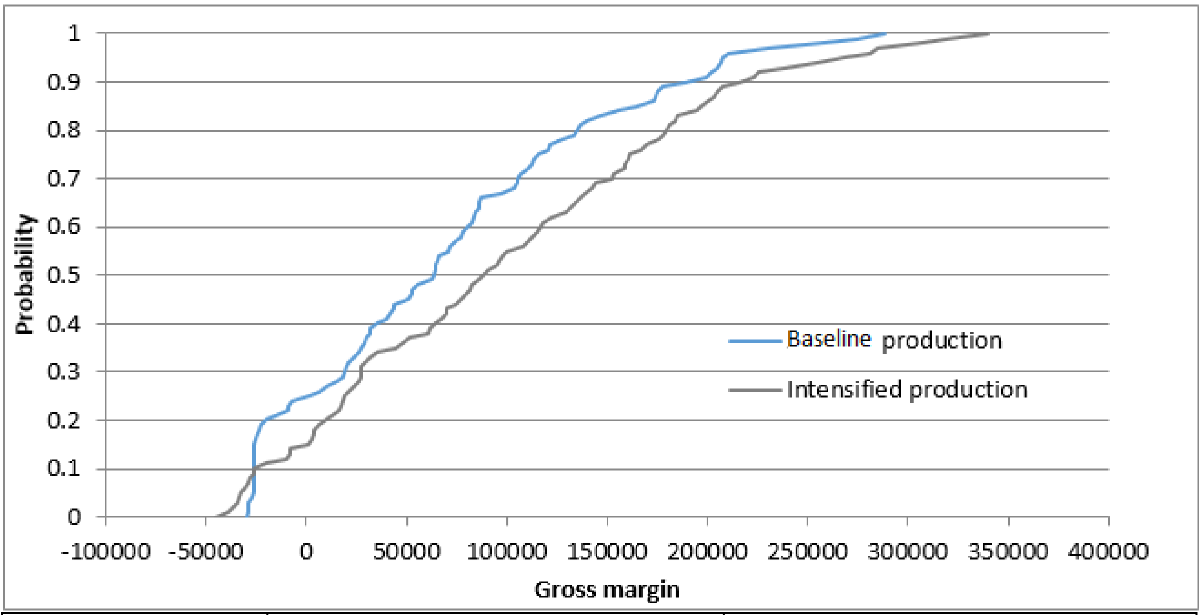
An indicative compensation structure of the Chinchilla area is evaluated before any investment decision is made. The land value of the area leased by the gas company is set at $1,350 per hectare. An upfront payment of $14,365 per farm paddock ($3,591 per well) is assumed. The total compensation for the construction phase is $22,132 per farm paddock ($5,533 per well) and operation phases is $19,130 per farm paddock ($4,783 per well) (Table 4-2).

Table 4-2. Compensation structure for Chinchilla

Compensation structure	CCA payment ($/farm paddock)	Construction payment ($/farm paddock)	Operation payment ($/farm paddock)
Land value of leased area	13,365		
Gross margin		3,094	3,094
Other costs	1,000	19,038	16,035
Total	14,365	22,132	19,130

The first investment option entails intensifying the crop production of a wheat-sorghum rotation for a representative dryland farm paddock. The second scenario is the option to expand by acquiring a comparative farm paddock (200-hectare area) with traits similar to the area leased by the gas company. With these two options, the farmer has the potential to complement his cash flow by improving the cropping system or leveraging or by scaling up production.

Figure 4-8 illustrates the cumulative probability distribution of the gross margin for a simulated farm in Chinchilla at average baseline agricultural production without CSG production, compared to intensified agricultural production in the absence of CSG development as well. It shows that there is a 90 percent probability that intensification would improve profitability of the farming enterprise by as much as $250,000. The average gross margin of all 15-year simulated cycles at intensified agricultural production (before or without CSG production) is $86,290.61 for the whole farm paddock, a 32% increase compared with the average gross margin baseline agricultural production without CSG production.



Parameters	Average baseline production ($/paddock)	Average intensified production ($/paddock)
Income	138,821.63	183,300.08
Cost	79,510.91	97,009.46
Gross Margin	59,310.72	86,290.61

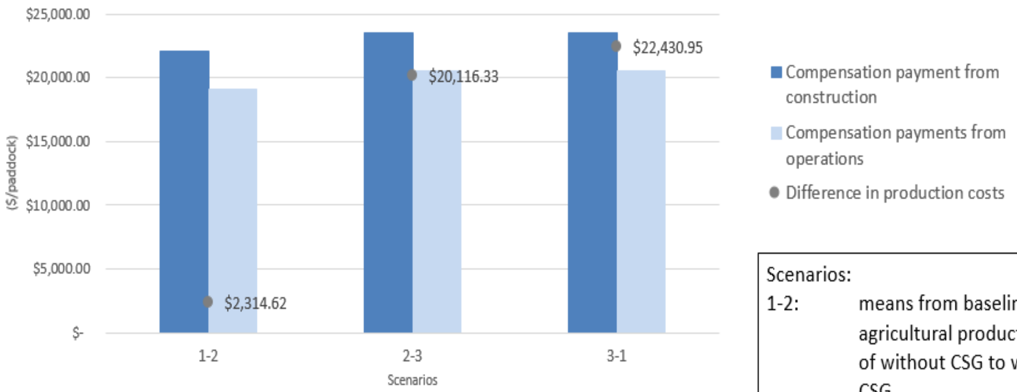
Figure 4-8. Cumulative probability distribution of the gross margin of baseline and intensified agricultural production before (without) CSG development in Chinchilla

Table 4-3 presents the changes in production performance of a representative farm paddock with the installation of four CSG wells in Chinchilla. The results corroborate the previous deduction that intensified cropping system provides a higher gross margin. The expected income and cost under baseline agricultural production is $694 and $397 per hectare. However, when CSG is introduced in the farm, the average income decreased by $27 per hectare due to reduced effective cropping area. Likewise, the operational cost increased by $21 per hectare, mainly due to decreased machine efficiency (e.g. fuel and oil cost or rental cost). Intensifying the production system under CSG coexistence has a positive impact on the gross margin. Under this system, the income is pegged at $881 per hectare against operational cost of $551 per hectare, for a gross margin of $371 per hectare, a 44 percent increase compared to coexistence without intensification. Therefore, there is more to lose if the landholder coexists with CSG but is not able to transition to intensified cropping system.

Table 4-3. Productivity performance of baseline and intensified agricultural production without and with CSG development in Chinchilla

Parameters	**Average baseline (without CSG) ($/farm paddock) (1)**	**Average baseline (with CSG wells) ($/farm paddock) (2)**	**Average intensified (with CSG wells) ($/farm paddock) (3)**	**Absolute percentage difference from (1) to (2)**	**Absolute percentage difference from (2) to (3)**	**Absolute percentage difference from (1) to (3)**
Income	138,821.63	133,489.92	176,265.60	4%	32%	27%
Cost	79,510.91	81,825.53	101,941.86	3%	25%	28%
Gross margin	59,310.72	51,664.39	74,323.74	13%	44%	25%

The ability to recoup losses in profit gauges whether compensation payments are beneficial in improving the financial aspect of the farm enterprise. Figure 4-9 shows the changes in production costs and net returns from construction and operation compensations. The compensation payment at construction phase of an average cropping production is at $22,132.35 per farm paddock, or $111 per hectare. This increases to $23,570.76 per farm paddock ($118 per hectare) when production shifts to intensified cropping. The compensation during operational phase is generally lower than at the construction phase. The operation phase compensation is pegged at $19,129.80 and $20,568.21 per farm paddock for average cropping and intensified cropping, respectively.



Scenarios	Compensation payment from construction per paddock	Compensation payment from operation per paddock
1-2	$ 22,132.35	$ 19,129.80
2-3	$ 23,570.76	$ 20,568.21
1-3	$ 23,570.76	$ 20,568.21

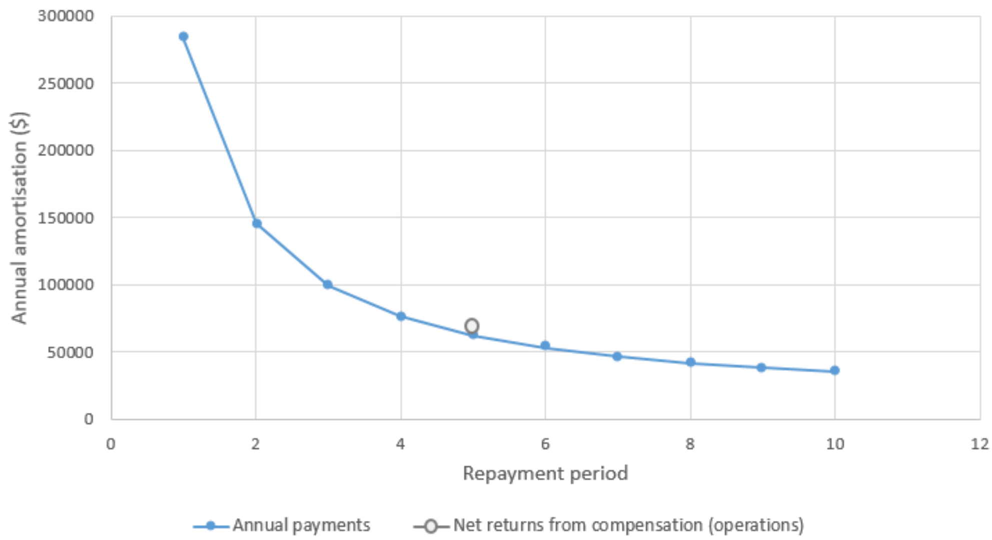
Scenarios:
1-2: means from baseline agricultural production of without CSG to with CSG
2-3: means from baseline agricultural production with CSG to intensified production with CSG
1-3: means from intensified production with CSG to baseline agricultural production without CSG

Figure 4-9. Compensation payments during construction and operations phase and difference in production costs under different scenarios in Chinchilla

The results show that the payments during the construction phase are enough to cover the increase in production cost associated with CSG coexistence under Scenarios 1-2, with a difference in production cost of $2,314.62 and Scenarios 1-3, with a difference in production costs $20,116.33. Furthermore, compensation from operation phase is also able to cover the production cost associated with CSG coexistence under Scenario 1-2, with a difference in production cost of $2,314.62. However, the compensation during operational phase is not sufficient to cover the increased production cost of farm intensification, by a margin of $1,862.74. Considering that operational phase may start on the 4th year, the landholder needs this additional amount from the 4th year onwards to finance intensification. The scenario highlights instances when landholders need to source out additional capital in pursuing investment options that could help maximise their profitability in light of coexistence.

An alternative investment strategy is the expansion in farming activity through the acquisition of another piece of land. The study determines whether landholders would be able to finance the amortisation payment for the other piece of property of 200 hectares at a lower compensation threshold during operations phase. It is assumed that the landholder would not want to invest yet on any agricultural development on this extended property until it is fully paid and owned.

The market price of a 200-hectare piece of land is $270,000. The mode of acquisition is through annual amortisation of the loan amount bearing a five percent annual interest. The first payment is assumed to be paid at the end of the year, in contrast to paying upfront. On the income side, the money available to pay off this acquisition comes from the net return derived from the gross margin of the leased area under baseline farming system, and the expected receivable from CSG compensation, all totalling $73,796.74 per farm paddock during construction and $70,794.19 per farm paddock during operation phase. It is expected that the loan will be paid up within five years, of which, the farmer pays an equal amount of yearly amortisation of $62,363.20. The analysis demonstrates that within this five-year period, the yearly net return from expansion is $11,433.54 per farm paddock during construction and $8,430.99 during operation, the amount of money left on the farmer's hands after paying the amortisation (Figure 4-10).



Acquisition cost (amount borrowed)($)	270,000
Interest rate (%)	5
Compensation + gross margin of the leased area by the gas company at baseline production	73,796.74 from construction 70,794.19 from operations
Repayment period (years)	5
Annual amortisation ($)	62,363.20

Figure 4-10. Annual amortisation and repayment using net returns from compensation in Chinchilla

At first glance, the farmer seems to be in a better financial situation if he decides to adopt intensification, instead of expansion. The expected net return for intensification is $97,894.50 per farm paddock during construction and $94,891.95 per farm paddock during operation. Whereas in the expansion, the net return is $11,433.54 per farm paddock during construction and $8,430.99 during operation after amortization for the first five years, and $70,794.19 from the sixth to 15th year.

Figure 4-11 shows the comparison of net returns from baseline scenario, intensification option, and expansion option for Chinchilla area. The result shows that intensified farming returns a higher cash on hand of $1,432,386.9 after 15 years. This is a 38 percent increase from the return of baseline production without CSG (business as usual). In contrast, the net cash return is $1,352,211.72 per farm paddock from expansion is lower than intensification. However, when accounting for the value of newly acquired land of $311,815.98 (the total amount of amortisation payments for 5 years for the repayment of loan), the actual net return for the expansion option amounts to $1,664,027.70.

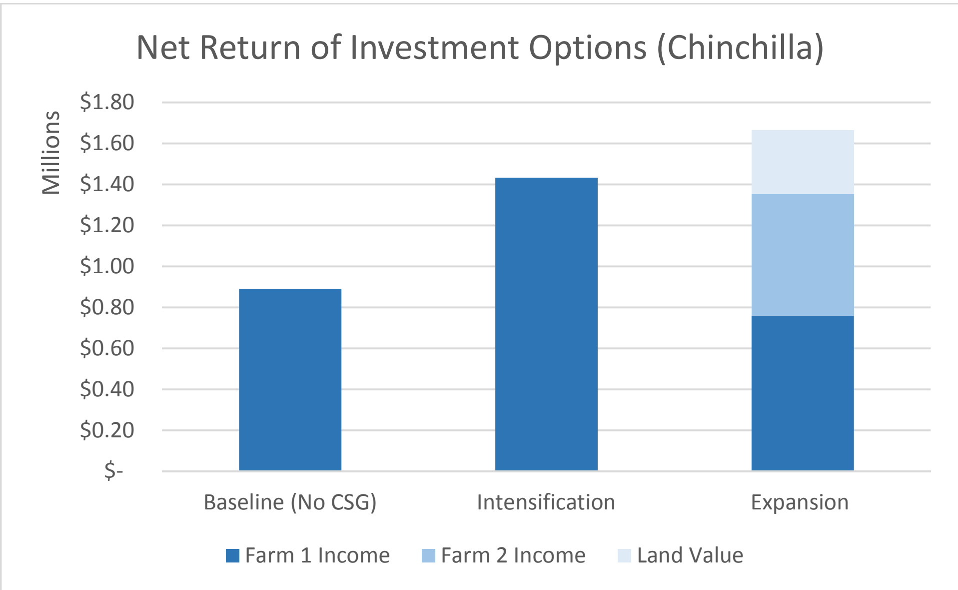


Figure 4-11. Comparison of net returns for Chinchilla under various scenarios

The result does not imply that landholders should maintain their current farming system or otherwise. This is only indicative of a rational decision-making exercise, given a compensation payment. Landholders could still decide to engage in intensification in instances where farming their current property is their primary priority and preference over other forms of investment. Others might be risk averse over the concept of land expansion due to lack of knowledge management, labour, and other uncertainties.

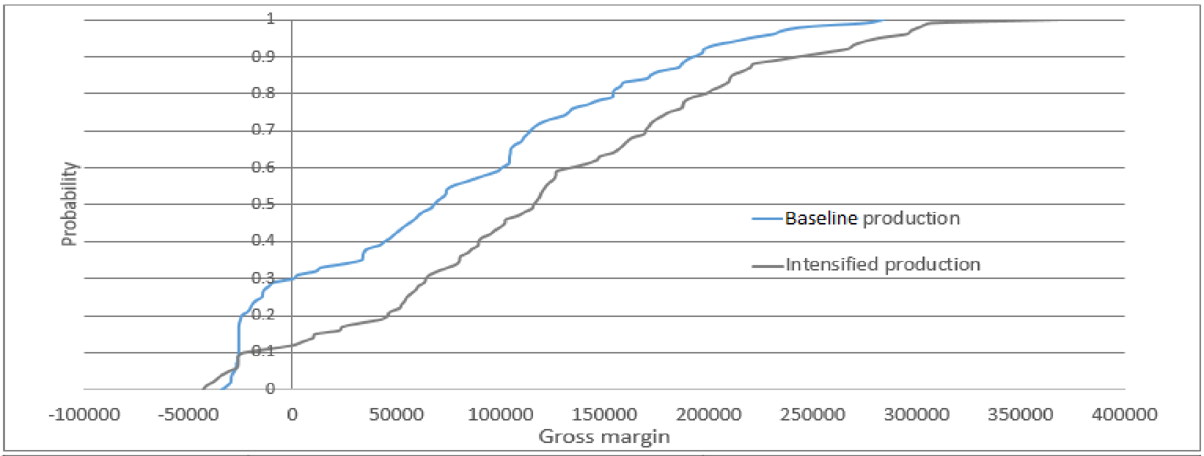
4.2.2.2 Dalby dryland farming: Intensification or Expansion

There are two investment options available for dryland leased area around Dalby. The indicative compensation structure utilised for this area is similarly related to that of Chinchilla. The market price for a parcel of land is $4,500 per hectare (suggested value from local real estate agent). Table 4-4 itemises the compensation figures as the basis for investment decisions. The upfront payment is $45,550 per farm paddock ($11,388 per well), while the annual compensation at construction phase is valued at $59,932 per farm paddock ($13,356 per well) and operation phase at $53,424 per farm paddock ($14,983 per well).

Table 4-4. Compensation structure for Dalby

Compensation structure	CCA payment ($/farm paddock)	Construction payment ($/farm paddock)	Operation payment ($/farm paddock)
Land value of leased area	44,550		
Gross margin		3,472	3,472
Other costs	1,000	56,460	49,952
Total	45,550	59,932	53,424

It is assumed that the level of yield will increase once landholders engage in intensified farming practices even before CSG well installation. There is a 90 percent probability that gross margin without CSG development at intensified production is higher than the average baseline production without CSG development (Figure 4-12). Simulated farm paddock run using APSIM shows that intensified production increased gross margin by 68 percent.



Parameters	Average baseline production ($/paddock)	Average intensified production ($/paddock)
Income	145, 657.57	215,332.58
Cost	76,934.03	100,769.66
Gross Margin	68,723.54	114,562.92

Figure 4-12. Cumulative probability distribution of the gross margin of baseline and intensified agricultural production in Dalby

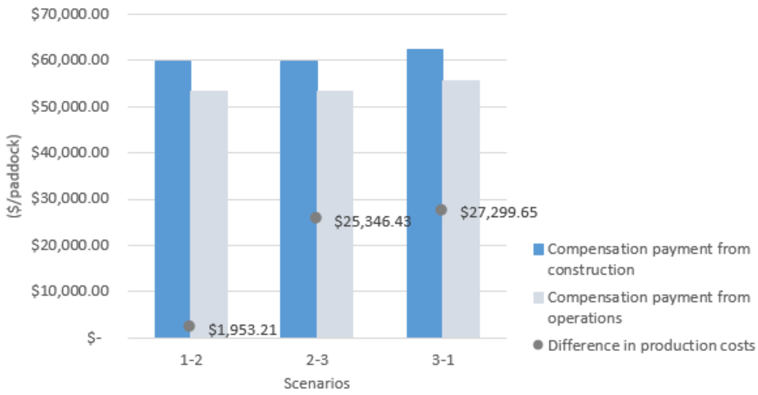
The gross margin of the baseline production is decreased by 11 percent once CSG is established. However, even with the presence of CSG wells in the leased area, intensified production system gross margin still managed to increase from $61,130.31 to $102,751.05 or a 68 percent improvement. This comes from an income increase of $66,967 (47%) against increase in the cost of production of $25,346 (32%). This improvement in income, and consequently gross margin, reiterates the importance of intensification in this agricultural environment (Table 4-5).

Table 4-5. Productivity performance of baseline and intensified agricultural production without and with CSG development in Dalby

Parameters	**Average baseline (without CSG) ($/farm paddock) (1)**	**Average baseline (with CSG wells) ($/farm paddock) (2)**	**Average intensified (with CSG wells) ($/farm paddock) (3)**	**Absolute percentage difference from (1) to (2)**	**Absolute percentage difference from (2) to (3)**	**Absolute percentage difference from (1) to (3)**
Income	145,657.57	140,017.55	206,984.72	4%	47%	42%
Cost	76,934.03	78,887.24	104,233.67	3%	32%	35%
Gross margin	68,723.54	61,130.31	102,751.05	11%	68%	50%

Figure 4-13 illustrates the difference between production costs and the net returns from compensation at the construction and operations stages in CSG development. Compensation during construction for baseline agricultural production is valued at $59,932.44 per farm paddock ($300 per hectare) and during operations is $53,423.94 per farm paddock ($267 per hectare). On farm intensification, the compensation amount is $62,210.01 per farm paddock ($311 per hectare) during construction and $55,701.51 per farm paddock ($279 per hectare) during operations phase.

The gap between the production costs and the amount of compensation granted to landholders at different scenarios denotes the expected level of net returns. The lower the difference in production costs, the higher the net returns from compensation. Scenario 1-2, is when CSG coexist but the farmer does not change his production system (baseline). The production cost in this scenario increased by $1,953.21 per farm paddock and income decreased by $5,640.02 per farm paddock, or a total gross margin reduction of $7,593.23 per farm paddock, of which, the landholder gets a compensation of either $59,932.44 (construction phase) or $55,701.51 (operations phase). This means that coexisting with CSG will result to increase in gross margin of $52,339.21 during construction and $45,830.71 during operation phase.



Scenarios	Compensation payment from construction per paddock	Compensation payment from operation per paddock
1-2	$ 59,932.44	$ 53,423.94
2-3	$ 62,210.01	$ 55,701.51
1-3	$ 62,210.01	$ 55,701.51

Scenarios:

1-2: means from baseline agricultural production of without CSG to with CSG

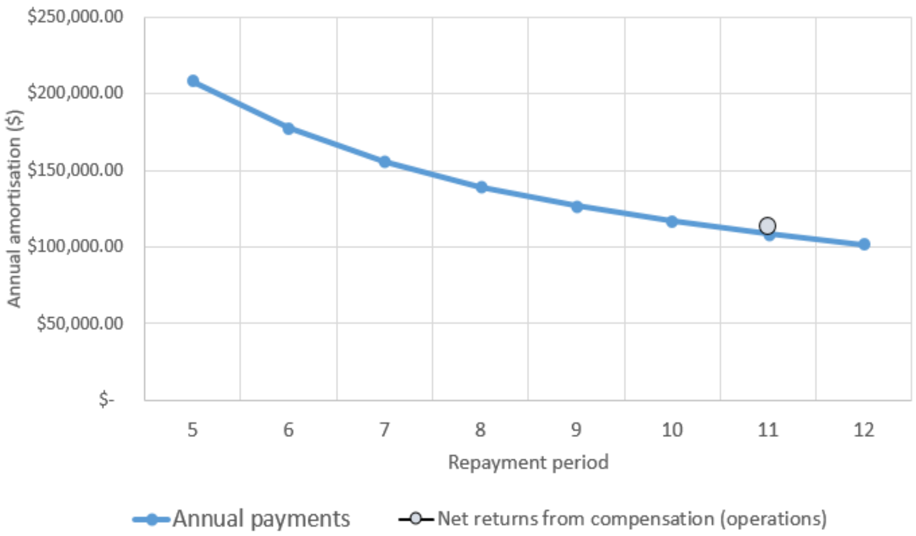
2-3: means from baseline agricultural production with CSG to intensified production with CSG

1-3: means from intensified production with CSG to baseline agricultural production without CSG

Figure 4-13. Compensation payments during construction and operations phase and difference in production costs under different scenarios in Dalby

Scenario 2-3 compares the gross margin under CSG coexistence with baseline production versus intensified production. In this scenario, the farm income per farm paddock increased from $140,017.55 to $206,984.72, and the cost per farm paddock increased from $78,887.24 to $104,233.67. This leads to a gross margin increase of $41,620.74. The net return of intensification per farm paddock with CSG, taking into consideration the farm income and the compensation, is $103,830.75 during construction phase and $97,322.25 during operations phase more than from baseline production with CSG.

On the other hand, the option to expand necessitates the acquisition of another parcel of land of 200 hectares valued at $900,000 in the Dalby area. It is assumed that the interest rate is five percent. The available money from baseline production gross margin and CSG compensation at construction phase is $121,062.75 and at CSG operation phase is $114,554.25. The new land acquisition will be fully paid in 11 years, with an annual amortisation of $108,350. The net return for expansion option during this period is $12,712.75 during construction and $6,204.25 during operations phase. However, in the 12th to 15th year, the net return is $114,554.25 (Figure 4-14).



Acquisition cost (amount borrowed)($)	900,000
Interest rate (%)	5
Compensation + gross margin of the leased area by the gas company at baseline production	121,062.75 from construction 114,554.25 from operations
Repayment period (years)	11
Annual amortisation ($)	108,350.00

Figure 4-14. Annual amortisation and repayment period using net returns from compensation in Dalby

Figure 4-15 shows the comparison of net returns from baseline scenario, intensification option, and expansion option from coexistence with CSG mining for Dalby area. The result shows that intensified farming provides a higher return of $2,396,313.90 per farm paddock after 15 years. This is a more than twice the return of baseline production without CSG (business as usual). In contrast to expansion, the net return including value of the land purchased is only $2,012,733.41. This suggests that, within the 15-year period, landholders in Dalby may be better off pursuing intensification, rather than acquiring new land for expansion.

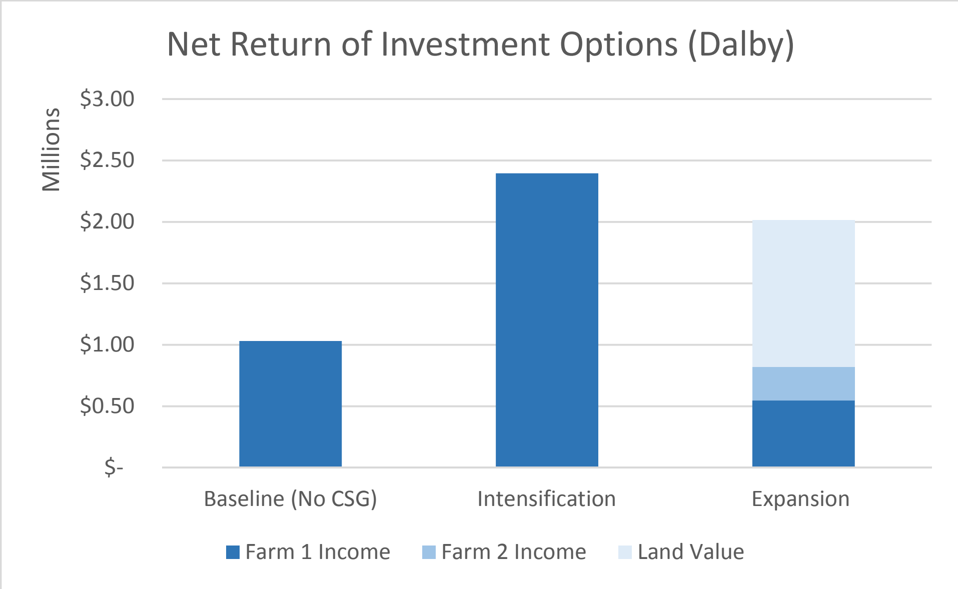


Figure 4-15. Comparison of net returns for Dalby under various scenarios: a) Baseline-No CSG, b) Intensification with CSG, c) Expansion with CSG

The evaluation of both options for investment in the Dalby area suggests that it is more rational for a risk-neutral landholder to intensify cropping rather than to engage in expansion through the acquisition of a piece of land of a comparable size to the leased area mainly due to a better return. This business decision is consistent with the result in Study One, classifying Dalby as one of the areas with tenement that have a high productive value and are suitable for intensification.

These results are, once again, a representative decision-making process given the parameters and assumptions undertaken by the study and should not be taken as a definitive investment solution. Landholders with a preference for 'risk taking' could opt to expand their farm sizes as this increases their property assets and family legacy.

4.2.2.3 Irrigated farming: Expansion or Diversification

A different set of assumptions are used for an irrigated farming system. An irrigated farm is already characterised as an intensive production system. It is more productive and profitable compared to other farming systems (i.e. dryland). Hence, the intensification investment option is left out and business strategies such as expansion or diversification into non-farm options are considered instead.

The study simulates an irrigated farming system in the Cecil Plains area. Compensation for this area is based on an optimal 'farm-well' design (the multiple well pad), which means that all the wells are centralised to a smaller footprint, reducing the access track (right of way) by 2,000 metres. It is estimated to be one-fourth of the footprint of previously surveyed CSG well designs. The multiple-well pad footprint is 100 metre x 150 metre with a right of way (ROW) of 18 metre (including tracks). The overall gross margin per farm paddock from having four wells at the conventional (surveyed) well spacing is $461,181.96 per year at 96 percent machinery efficiency. While a multi-well pad design enables gross margin to increase to $488,132.75 per year, assuming that the there is a 98 percent machinery inefficiency.

The compensation structure for irrigated cropping in Cecil Plains, with a multiple well pad design, is comprised of a land market value of $8,500 per hectare. The compensation payment for this area is the highest amongst the three case sites. A landholder could expect to receive a maximum amount of $67,600 per farm paddock or $16,900 per well during the construction phase (Table 4-6).

Table 4-6. Compensation structure for Cecil Plains

Compensation structure	**CCA payment ($/farm paddock)**	**Construction payment ($/farm paddock)**	**Operations payment ($/farm paddock)**
Land Value Area Used	43,350		
Gross margin		12,580	12,580
Other Costs	1,000	55,020	45,420
Total	44,350	67,600	61,000

The first business strategy is the expansion option. Acquiring a 200-hectare area in Cecil Plains would require $1,700,000 at an interest rate of five percent. The repayment period to acquire the property is within four years. This is a relatively short period of time, since compensation from CSG operations phase and the gross margin of the leased area are sufficient to fund the annual amortisation of $479,420 per farm paddock or $2,397 per hectare, resulting in a net return of $76,312.63 during the first three years $107,192.81, $69,712.63 in the fourth year and $549,132.75 in each succeeding years (Table 4-7).

Table 4-7. Parameters for option to expand investment strategy for Cecil Plains

Parameters for expansion business strategy	**Values**
Acquisition cost (amount borrowed) ($)	1,700,000
Interest rate (%)	5
Compensation + gross margin of the leased area by the gas company at baseline production ($) (1)	555,732.75 (Construction) 549,132.75 (Operation)
Repayment period (years)	4
Annual amortisation ($) (2)	479,420.12
Net returns ($) (1) -(2)	$76,312.63 (Year 1-3) $69,712.63 (Year 4) $549,132.75 (Year 5-15)

This investment decision would offer a long-term business profit from increased production through economies of scale before the end of the lifespan of CSG development. That implies that the landholder would still have other opportunities to invest in other business and management strategies to improve crop production using compensation payments.

Table 4-8 further provides information on the cumulative net return from engaging in agricultural production on the newly purchased piece of land commencing at Year 5 upon full equity of the property. This information is based on the premise that similar productivity would be derived from the same cropping rotation in the new 200-hectare of property and no CSG development is in the farm paddock. The study refers to Farm 1 as the area currently leased by the gas company, and Farm 2 as the newly acquired piece of land. It also considers the future value of production on this new property as gains from compensation.

Cumulative losses are incurred during the first six years of agricultural production mainly due to the amortisation payment for acquiring Farm 2. Starting Year 7, the landholder realizes a positive net return of $58,836.37 from agricultural production in Farm 2 supplemented with compensation. The succeeding years show increasing net cumulative returns from expansion as Farm 2 becomes productive. At the end of CSG operation (15 years), the net cumulative return from expansion is valued at $4,626,081.25.

Table 4-8. Whole farm paddock cumulative net return from expansion option in Cecil Plains ($)

Year	CSG compensation from construction and operation phase	Farm 1 gross margin	Land Payment	Farm 2 gross margin	Net Return (Farm 2 + Compensation)	Net Return Cumulative
1	67,600.00	488,132.75	-479,420.12		-411,820.12	-411,820.12
2	67,600.00	488,132.75	-479,420.12		-411,820.12	-823,640.23
3	67,600.00	488,132.75	-479,420.12		-411,820.12	-1,235,460.35
4	61,000.00	488,132.75	-479,420.12		-418,420.12	-1,653,880.46
5	61,000.00	488,132.75		509,905.61	570,905.61	-1,082,974.85
6	61,000.00	488,132.75		509,905.61	570,905.61	-512,069.24
7	61,000.00	488,132.75		509,905.61	570,905.61	58,836.37
8	61,000.00	488,132.75		509,905.61	570,905.61	629,741.98
9	61,000.00	488,132.75		509,905.61	570,905.61	1,200,647.59
10	61,000.00	488,132.75		509,905.61	570,905.61	1,771,553.20
11	61,000.00	488,132.75		509,905.61	570,905.61	2,342,458.81
12	61,000.00	488,132.75		509,905.61	570,905.61	2,913,364.42
13	61,000.00	488,132.75		509,905.61	570,905.61	3,484,270.03
14	61,000.00	488,132.75		509,905.61	570,905.61	4,055,175.64
15	61,000.00	488,132.75		509,905.61	570,905.61	4,626,081.25

Another investment strategy for a representative irrigated farm around Cecil Plains is through non-farm diversification. This entails placing the returns from compensation in investments other than agriculture. As a hypothetical example, we propose that compensation payments throughout the 15 years are invested in a term deposit with fixed interest rate of three percent. This annuity invested amounting to $61,000.02 per farm paddock (value of compensation at operations phase) would have a future value of $1,163,619.18.

In this instance, a landholder would have to consider the time value of money in determining which investment option to undertake in order to maximise returns using compensation. Figure 4-14 demonstrates the future value out of the expected returns from expansion and diversification over the CSG life span. Comparison of the returns from investment in diversification and expansion in Cecil Plains show that between Year 1 to 7, the value of money is higher when invested in banks. This is because agricultural production takes time to grow and be able to recoup investment. Future value of profit from farm expansion soared after Year 8, valued at $774,503.20, which strengthens the argument that it is rational and sustainable to reinvest in agricultural enterprise.

Table 4-9. Future value of returns from expansion and diversification options for Cecil Plains

Year	Future Value (Cumulative Net Return) of Expansion per farm paddock	Future Value (Compensation Invested in Banks) of Diversification per farm paddock
1	-$ 622,914.88	$102,251.07
2	-$ 1,209,543.45	$201,523.94
3	-$ 1,761,471.04	$297,905.38
4	-$ 2,289,357.35	$382,343.65
5	-$ 1,455,427.64	$464,322.55
6	-$ 668,134.21	$543,913.71
7	$ 74,532.15	$621,186.68
8	$ 774,503.20	$696,208.99
9	$ 1,433,636.01	$769,046.18
10	$ 2,053,715.69	$839,761.90
11	$ 2,636,458.03	$908,417.94
12	$ 3,183,511.96	$975,074.28
13	$ 3,696,462.07	$1,039,789.18
14	$ 4,176,830.91	$1,102,619.18
15	$ 4,626,081.25	$1,163,619.18

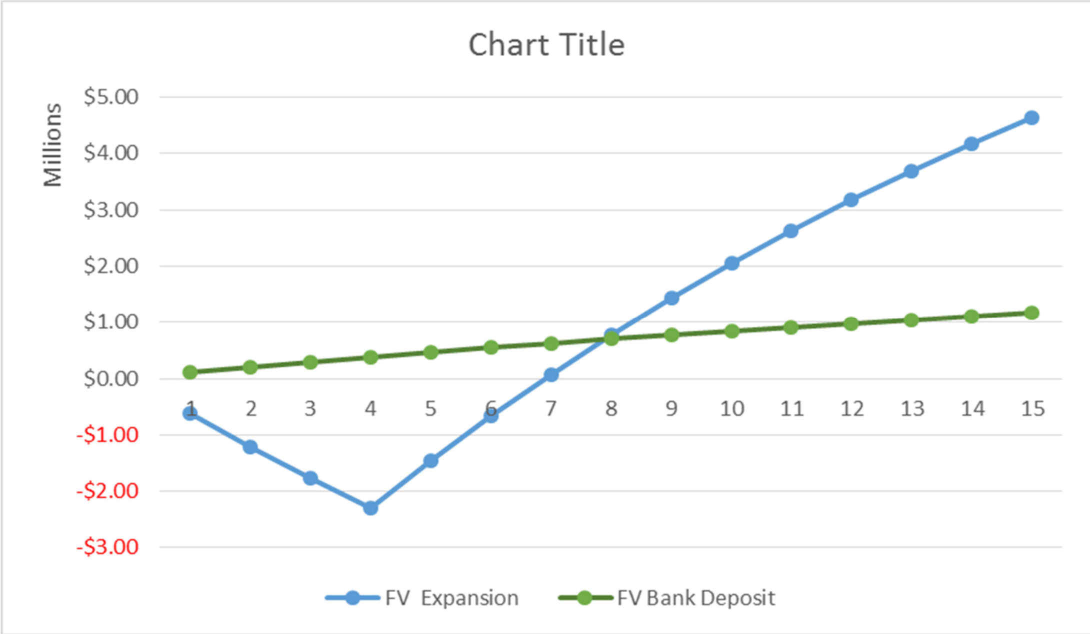


Figure 4-16. Comparison of the returns from investment in diversification and expansion in Cecil Plains

Note: FV denotes future value

4.3 Summary and Conclusion

The study presumes that coexistence, between gas companies and farmers in the Surat Basin, is imminent and inevitable, affecting agricultural production and profitability. The theory of cooperation advocates that it is economically efficient for landholders to negotiate or bargain for a sound settlement rather than compete or resist gas companies. Therefore, an enabling mechanism is necessary to manage this set-up, which is enacted through compensation.

Existing information regarding compensation is characterised as being asymmetric and subjective. This study is not designed to provide an absolute quantitative figure of the amount of the compensation that should be paid. Rather, the study provides indicative values of the potential capital investment that landholders could undertake in developing agriculture based on the returns from compensation. The investment strategies are intended to create synergy out of the coexistence relationship.

The overall financial performance of the farm enterprise in all simulated farming systems improved with the advent of compensation payments. Compensation became a ‘buffer’ income able to cover the losses from production of the farm. The two-way ANOVA and Tukey post-hoc test shows that there is a significant difference in the comparison of means of the gross margin in scenarios when well installation are compensated for all simulated areas. This result implies that compensation payments are adequately important. The statistical test supports the claim that impacts of CSG, even at the farm enterprise level, could benefit from additional cash inflow since landholders regard every dollar spent at a practical perspective.

The study undertook a simplified financial assessment to evaluate whether the compensation payment is of potential benefit. The indicative compensation structure used by the study shows that compensation amount of Dalby and Cecil Plains at higher values than Chinchilla. These compensation amounts were based on the CSG footprint and land market value.

The decision of which business strategies to employ is based on the highest returns from investment after recouping all losses from the CSG footprint. The option to expand through purchasing another parcel of land is an investment strategy available across all farming systems. Other strategies include intensification for dryland farming and diversification (to non-farm activities) for irrigated farms.

The study concludes that the indicative compensation payment received by the landholder is enough to restore profitability to baseline production levels prior to CSG development, in general. The more feasible investment for dryland farms around the Chinchilla area is to expand farm size, while the rational investment decision for areas around Dalby is to intensify cropping production. These results corroborate the findings from previous studies of Study One and Study Two on areas where landholders intensify production based on its biophysical attributes and extent of climate variability, given additional financial resources. Study One classifies both Chinchilla and Dalby areas to have high productive value. However, farms around Chinchilla area experience a more variable climate, resulting in lower and unstable gross margins as compared to Dalby.

The study reveals that investments related to agricultural development is the most profitable investment option. This business strategy is highlighted in the case of irrigated farming. Though the landholder of an irrigated system could assume to invest in non-farm activities that could have initial higher pay offs than agriculture, such a decision defeats the concept of compensation and theory of conservation of resource loss, indicating that individual welfare can be achieved when resource lost is regained by a damaged party. This means that compensation is regarded as a mechanism in restoring the 'original' state or condition of the affected party. The results of the study reveal that the decision to expand and engage in agricultural production provides long-term returns from investment. Thus, it is appropriate that compensation should be used to recuperate the damage to agriculture if CSG development imposes an impact on farming. Otherwise, CSG would not only impair agriculture but also eliminate it if the landholders decide to move out of farming or invest in non-farm activities.

The study demonstrates an alternative perspective on the relationship and coexistence of farming and gas production. While most literature dwells on the negative consequences of CSG on farming and the level of fairness of compensation payments, this research highlights compensation as a financial opportunity to stabilise the farm enterprise's cash flow by maximising benefits and minimising losses in a coexistence scenario. However, the outcomes of the study are suggestive and business decisions are dependent on the risk behaviour of the landholder, as all investment strategies prove to be feasible. Hence, there is no 'one size fits for all' strategy.

Part 3: Conclusion and Implications

The thesis examines the relationship between two important sectors contributing to the economic development of rural regions, which are agriculture and CSG development. Landholders and gas companies are in contention for the claims and rights to land use and development over the same area. Landholders (who hold title to the land) privately own the land, while gas companies are granted permits to access farms (by acquiring mining tenements from the state government). Moreover, the intricacies of the negotiation and compensation agreements are variable and asymmetric. Mutual trust and synergy between landholders and gas companies could be achieved by having an objective and evidence-based information.

5 Introduction

The thesis explores the coexistence between farming and gas mining under the context of spatial overlap, financial impact, and investment strategies. Each of these topics is investigated through the case studies discussed in Part 2. Part 3 of the thesis reiterates the preceding chapter findings and outlines the research implications, which starts by summarising the conclusions from the research questions, and finishes with the directions of future research.

Part 1 of the thesis provided the general overview of the research. It outlined both the background of the research problem and the research questions that steered the overall discussion throughout the thesis. Relevant literature regarding the theoretical, conceptual, technical, and legislative context of coexistence has been investigated. The literature underpins the justification for the research that led to the framing of the methodology and its delimitations to achieve the research objectives.

Table 5-1 summarises what Part 2 of the thesis addressed. It relates to the research questions, the research methodology applied to address them, and their key elements.

Table 5-1. Summary of the basic components of the thesis

Case Studies	Research Question	Methodology	Key elements
1- Agricultural Land Productivity Assessment of Areas within CSG tenements	What are the physical characteristics and productive value of the farming areas within CSG tenements in the Surat Basin?	Fuzzy logic spatial analysis	Knowing the space where coexistence exists
2- Farm Systems Modelling of the Impacts of CSG Footprint on Farm Enterprise	What are the effects of CSG operations on agricultural production and enterprise in different farming systems in the Surat Basin?	Gross margin analysis	Estimating the value of impacts of coexistence
3- Strategic Coexistence Management	What are the local farm investment strategies that would enable coexistence between agriculture and CSG?	Scenario modelling	Setting a balanced evaluation of the losses and benefits from coexistence

As discussed earlier in the thesis, there is a knowledge gap in terms of the scale at which coexistence has been analysed to date. There is also a sense of 'bias' towards the impacts and adverse consequences of coexistence, overlooking the additional income derived from the financial cash inflow from compensation. Literature reviewed in this thesis shows that the agricultural sector is being threatened by gas mining in terms of its tendency to cause harm to the natural resource environment, affecting the fertility of the land. Social issues and concerns also affect the community at a regional level. However, there is a lack of information on the effects of CSG development on agricultural productivity of the farming enterprise on farm or area basis. The thesis provides a 'window' to fill the prevailing literature gaps for a holistic understanding of coexistence through the concepts and hypotheses developed.

This research considers that coexistence between agriculture and CSG development is inevitable, due to the legal rights to the land granted by the state government to both the private owners and the resource sector. The thesis underscores an exploratory positivist research framework, which objectively examines the consequences of coexistence using simulation models to derive the losses and prospects of landholders' engagement with gas companies. It aims to serve as an information tool for managing the farm enterprises strategically and efficiently whilst coexisting with CSG exploration.

Part 2 is the core of the thesis. It is composed of three interdependent case studies representing the objectives of the thesis investigating coexistence in the Surat Basin. Each of these studies has a distinct methodology, technical framework, findings, and implications. The first chapter identifies the spatial location and biophysical characterisation of the areas within the CSG tenements of the study area. The second chapter quantifies the CSG footprint impact on both farming operations and the financial performance of the farm enterprise. The last chapter deals with the investment opportunity from compensation to improve the agricultural enterprise of the landholders.

This concluding part of the thesis recapitulates the findings gathered throughout the research, giving exclusive conclusions per research objective and comparing them to the literature. The following discussions also assess whether the literature gaps were addressed. It also evaluates the contribution of the thesis and the implications of the findings in practices, methodology, and policy. Lastly, this part highlights the limitations of the thesis and possible related future research directions.

5.1 Conclusions related to research question 1

The first research question the thesis addresses is: *'What are the physical characteristics and the productive value of the farming areas within CSG tenements in the Surat Basin?*

Study One addresses this issue by identifying the biophysical characteristics of the areas with tenement within the Surat Basin. Three major biophysical factors have been utilised for the study: climate, topography, and soil types. Proxy indicators were selected to represent these factors, grouping the areas of tenement according to their agricultural productive value.

The study identifies cropping and grazing areas that are either inherently limited or have potential for agricultural intensification from a biophysical perspective. These areas were categorised using soil pH, aridity, slope, and PAWC, by using a spatial fuzzy logic membership. The findings of the study are consistent with other forms of spatial output by the Queensland Government such as the SCL and QALA. The study provides indicative means for landholders on areas of different productive value to utilise the financial income from compensation for management of their farm enterprise.

The main conclusion from Study One that relates to Research Question 1 is that the agricultural systems where CSG deposits lie cannot be generalised. Aside from differences in farming systems (i.e. cropping and grazing), these areas within CSG tenements have inherent characteristics that determine their current and potential agricultural development. Therefore, the consequences of coexistence cannot be oversimplified, as landholders are expected to react differently according to the possible effects that CSG development poses to their land value, farming productivity, and enterprise profitability. The information derived from Study One enhances landholders' negotiating skills for compensation from gas companies, by having a realistic notion of the productive capacity of their land. More productive lands, which are capable of intensified production, attract higher compensation since CSG mining has a greater potential impact on more intensive agricultural production systems.

5.2 Conclusions related to research question 2

The next research question the thesis dealt with is: *'What are the effects of CSG operations on agricultural production and enterprise in different farming systems in the Surat Basin?*

Study Two dealt with this question by examining the spatial overlap of the CSG footprint and farming operations, particularly in cropping areas within CSG tenements. Chinchilla, Dalby and Cecil Plains were chosen as case studies for the yield and farm management simulation through APSIM of a farm enterprise at a farm paddock scale. The study investigates the changes in cropping area as a result of the displacement of farming, which leads to an 'income effect' as it decreases production yield. Conversely, the 'cost effect' is influenced by the obstructions in farming implements by CSG infrastructures, decreasing machinery efficiency. There are three conclusions resulting from Study Two.

The preliminary finding is that the actual CSG footprint is more than just the area leased for well installation. Other key CSG footprints identified by the study include access roads and pipelines. These forms of infrastructure impose different degrees of impact that vary over the project phase, affecting yield and farm income. On the other hand, farm costs are affected by CSG operations. The study reveals that with CSG development undertaken even during periods of no agricultural production (i.e. fallow and drought), landholders still incur costs of maintaining soil health of the farm. However, during no or low agricultural production, farm losses are also minimal. Hence, CSG operations should ideally coincide during these periods of less farming operation. Information on the nature of the infrastructure, operations, and impact typology of the CSG development is imperative to farm management so that landholders and gas companies can plan and agree on the timing of each of their own operations to minimise overlapping activities.

The study also shows that the production cost is a major driver of the change in gross margin of a farm enterprise coexisting with CSG development. The increase in variable costs, brought about by additional time of machinery operations, is referred to as the 'cost squeeze'. This result should be a significant component of the compensation framework where production costs are not currently fully covered. The study indicates that cost is a more suitable basis for remuneration rather than gross margin to recoup the auxiliary expenses incurred by the landholders due to the impacts of CSG infrastructure on farm operations and logistics.

The conclusion of the study is that well placement is an important consideration for efficient negotiations, as strategic well spacing can minimise potential losses and maximise agricultural returns under coexistence. This was exemplified for a representative farm paddock around Cecil Plains, where there is a smaller CSG footprint due to a multiple-well pad design.

5.3 Conclusions related to research objective 3

The last research question addressed by the thesis is: *'What are the local farm investment strategies that would enable coexistence between agriculture and CSG?*

Study Three deals with the strategic management of coexistence, taking into consideration the financial opportunity from compensation to invest in enterprise development. There are three financial options that the study provided as an investment management decision: intensification, expansion, and diversification. Both intensification and expansion options are geared towards cultivating agricultural development, while diversification denotes exploring gains other than agriculture, such as those found in banking.

The study sets out an indicative compensation structure to determine the implications of an additional cash flow or financial opportunity to the farm enterprise. This information approximates the compensation payment taken from the information gathered from gas companies, since actual details of the negotiations and agreements are confidential. Hence, the results of the study provide the best estimate of the financial performance of the farm enterprise and rational investment decisions to be taken by landholders.

The study concludes that there is a statistical significant difference in the means of gross margin of different scenarios in all simulated areas and the net returns from (estimated) compensation is substantial. Landholders are provided with investment capital to improve their farm situation. The study also demonstrated that farming systems require a tailored investment management strategy. However, overall findings imply that agricultural development is the most plausible and sustainable investment option for all the case studies undertaken. Compensation not only serves as a buffer for production, but also an income prospect that promotes synergy between landholders and gas companies.

5.4 Contributions of the research

There is a paucity of empirical evidence pertaining to the improvement of the relationship between landholders and gas companies. The findings of the thesis contribute to the enrichment of knowledge and understanding of the coexistence between agriculture and CSG mining. The research addresses the gaps in the literature by providing a more holistic and balanced perception of the impacts and prospects of the interrelationship of the two industries. The contribution of the research is highlighted by the scope and context of the thesis.

The findings of the study are comparable to the general results of existing literature, particularly of Clarke (2013) on compensation amounts and Marinoni and Garcia (2015) on CSG footprint. However, the results of the study are referenced at a per hectare or per farm paddock basis to provide landholders with indicative insights into the potential financial consequences of a CSG footprint on their farm enterprise at a practical unit of measurement.

The thesis also postulates a straightforward presentation of the research topic. It does not just demonstrate the possible losses that could be incurred from coexistence (which is what most of the previous literature had examined), it also examines potential opportunities from the cash inflow from compensation that gas companies provide to landholders. The research provides indicative measures of whether compensation is sufficiently able to recoup losses from a CSG footprint and finance investment for agriculture development.

This research evaluates coexistence objectively under the premise of hard systems thinking, which was the centre of the conceptual model of the thesis. Many studies conducted on the overlap between agriculture and CSG development focus on the perceived social impacts on stakeholders and the projected environmental damages alongside coexistence. However, the findings of such studies are often variable, uncertain and individualised, and contentious. The thesis provides a simplified objective approach using empirical models to provide insights into the potential financial consequences of coexistence.

5.5 Implications of the research

The findings of this thesis have implications for the management of agriculture and CSG development at the methodological, practical and policy perspective. This offers stakeholders a clearer understanding into some of the key underlying issues of coexistence as well as the intricacies of improving a 'CSG-farm' relationship in the future.

5.5.1 Methodological implications

Most of the literature (Collins et al. 2013; Fleming & Measham 2013; Huth et al. 2014; Walton et al. 2013; Williams & Walton 2013a) engages both the qualitative and quantitative analysis in investigating the constructs of coexistence. However, this issue is 'clouded' with controversy and exhibits variability, uncertainty and confidentiality. Because negotiation agreements are kept private between gas companies and landholders, information on the implementation and operationalisation of the compensation payments and other logistic designs are not disclosed or documented. Generalised conclusions from previous studies related to this issue are also limited because of its specificity considerations. This makes primary data collection (i.e. interviews and surveys) difficult to manage and take longer, especially when individuals are investigated.

Thus, the thesis offers an alternative methodology for gaining insights into coexistence. The characterisation of the farming systems under coexistence is simulated. Simulation is an experimental procedure of relating variables and events to arrive at an explanation of the behaviour of the system. It provides information to researchers on testing the feasibility and practicability of a process without investing resources prior to actual implementation (Khan et al. 2011).

Simulation is the appropriate and logical technique for the research, given the limitations in data, resources, and timespan of the study. The use of APSIM for projecting the effect of a CSG footprint on the financial performance of a farming enterprise is considered innovative both at the practical and research standpoints. Integrating the information on the potential crop production and estimates of the spatial and machinery impacts gathered through geospatial survey provides an empirical, though indicative, estimate of the costs and benefits of engaging in coexistence. The findings of the thesis build a strategic guide that could be emulated by stakeholders undertaking comparable investigation of the same phenomena.

5.5.2 Practice and policy implications

The findings described in this thesis provide information for improving the negotiation process, land use planning, and legislative actions. The implications of the research are linked with the existing policy and program developments undertaken by the Queensland Government. This also serves as an information tool for landholders, gas companies, rural stakeholders, researchers, and policy makers.

The foremost implication is related to the results derived from Study One regarding the productive value of the areas within CSG tenements. The output of the study supports the objectives of the RPI Act 2014 (Queensland Government 2014d) of protecting interest areas of agricultural development, which are identified based on biophysical attributes and productive capacity. The study reveals that the current land valuation of cropping and grazing areas is based on the existing productive performance of the farming system and not the inherent or its potential agricultural capacity. Landholders would be able to sustain and improve their farming enterprise if gas companies could arrange remuneration based on productive value. This process would not only cover the present impacts of CSG in farming, but also its future consequences, since the CCA is registered along with the land title. Also, considering future agricultural potential of an area harmonises with the aims of legislation (such as the RPI Act 2014) on environmental and natural resource preservation.

Meanwhile, the contentious issue of coexistence stems from the lack of social licence to operate, insufficient transparency, and variable information within the negotiation process. The establishment of an independent agency, the GasField Commission, which has the initiative to be a third-party negotiator facilitating cooperation between agriculture and resource development, is a significant step towards synergistic relationship. A concrete action towards a good relationship between landholders and gas companies is the proposal for a standard CCA by the Commission. Although there is an existing guideline for CCA, landholders find it too legalistic, complex, and structured. Hence, other stakeholders, including the AgForce and the Australian Petroleum Production and Exploration Association (APPEA), also led to initiate this undertaking. Technical legal terms and customised conditions are to be formalised when signing contracts in order for the landholders to minimise time and transaction costs. This also includes the CSG operational logistics and infrastructure designs that landholders should be aware.

The results from Study Two could be an important input to this process of standardising CCA. The thesis detected that machinery impact, which affects the cost component of the gross margin, is as much an issue as spatial displacement caused by CSG infrastructure, and should be recompensed. However, there is limited documentation about this. The thesis serves as a fundamental documentation of estimates of CSG activity in agriculture.

The requirement for confidentiality in negotiations may be creating further conflicts between landholders and gas companies. Data on the factors included in compensation calculations are lacking. The inconsistency and ambiguity in compensation raises uncertainty, confusion, and contention to landholders. This issue was raised in the 2012 Land Access Review (Scott 2016).

The purpose of this thesis is to provide a balanced assessment of the effects of coexistence. The thesis presented a hypothetical compensation structure and highlighted the financial opportunities gained from compensation aside from the losses to production. Specifically, the investment strategies indicated by the thesis imply that coexistence could lead to synergy in the form of partnership, rather than competition, between agriculture and CSG mining. The objective estimates derived from the thesis could be used as a pattern for negotiating the compensation amounts.

5.6 Directions for future research

The case studies of the thesis primarily centre on cropping areas within CSG tenements. This is intended to demonstrate the impact threshold of coexistence and the possibility of enterprise synergy on highly intensive productive areas. It is a preliminary model for undertaking related studies for other farming systems, such as grazing. The research recommends that similar assessment should be provided for the western areas of the Surat Basin, where there is predominance of grazing areas with high potential for intensification and of existing less intensive farming. It is important to explore the dynamics of coexistence on grazing areas, as it is the predominant land use within CSG tenements.

Moreover, the results of the research suggest that the financial impact of the CSG footprint on cash flows range from four percent to 17 percent, when impacts of lost land and reduced machinery efficiency are accounted for. However, there are many other impacts, which are not considered. This study reinforces the recommendations from other related studies that the intangible effects of CSG mining (i.e. future risk and uncertainty, stress, health, landscape), aligned with the expression of 'resource loss' from the Literature Review of Part 1, should also be quantified and considered in determining compensation. Another intangible parameter affected by coexistence is time. Research on opportunity and transaction costs incurred by landholders should be considered. This includes valuing the landholder's misappropriated time in dealing with gas companies instead of farming. In addition, the salvage and replacement costs of machinery and risk premium for accidents caused by CSG obstructions are not accounted in negotiation agreements, but need to be further investigated.

These highlight the cost component of the compensation structure as the driver of profitability and should be the centre of enterprise analysis under coexistence. Other aspects of impacts brought about by CSG development on farms, including changes in product quality of farm commodities and changes in land values, could be of interest for further studies.

5.7 Overall Findings

The thesis therefore concludes that coexistence between farming and gas mining could result in the enterprise synergy needed to improve farm financial performance. This is important for landholders and gas companies undertaking negotiations and contract agreements. The simulation model demonstrated in the research indicates the extent of financial impacts and opportunities at the basic level of a farming system. The research contributes to a holistic analysis of coexistence, fundamentally addressing the practical issues of typical landholders.

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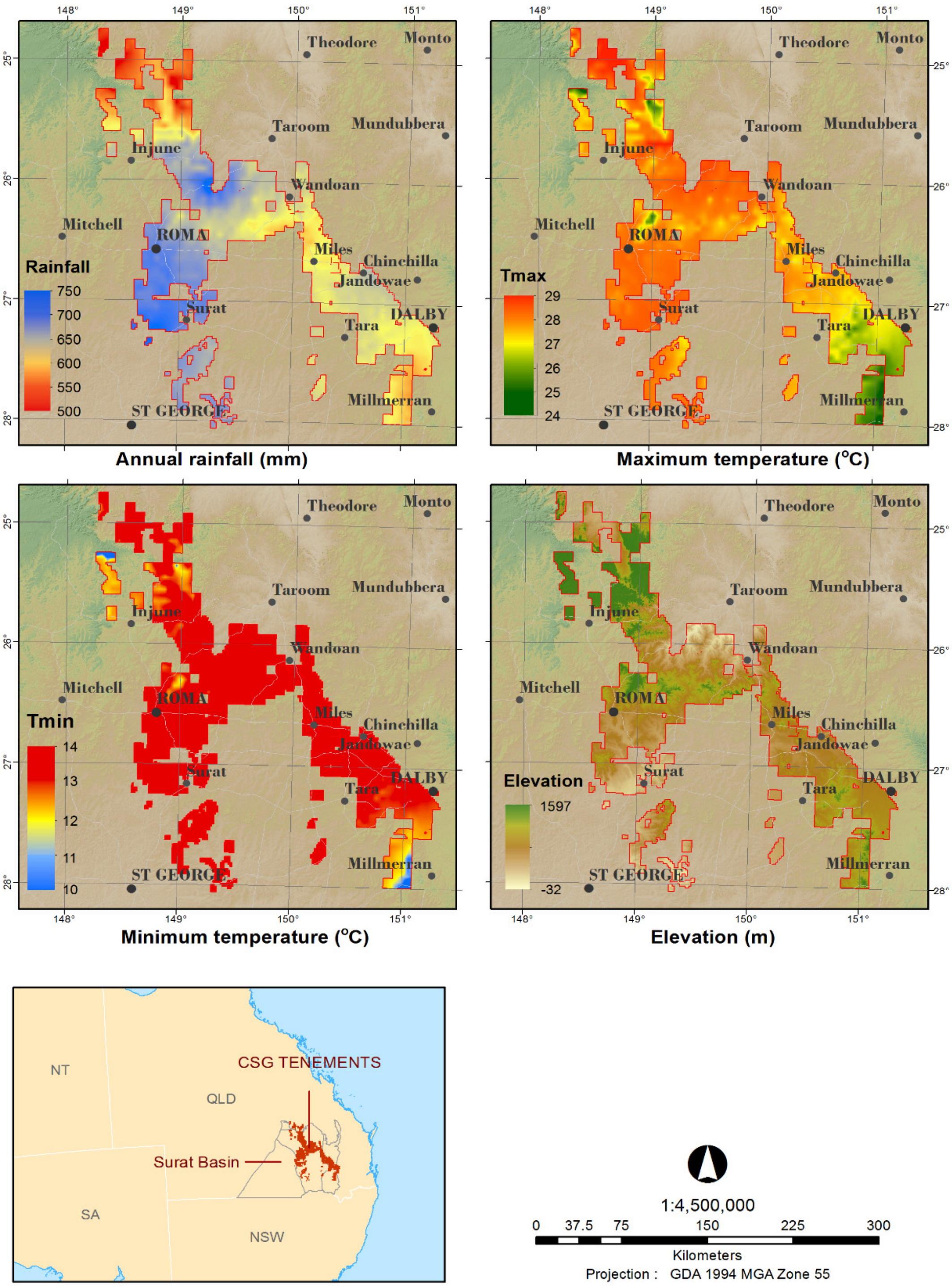
7 Appendices

APPENDIX A. Annual rainfall, temperature and elevation of areas within CSG tenements



Note: Average values from 1961 to 1990 data

APPENDIX B. Agronomic parameters, expected farm income and farm costs for simulated farm in Chinchilla, 1990-2013

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
17/10/1900	wheat	4.345	59	0	1021.164	344.88
14/11/1900	summerfallow	0	59	0	0	86
23/10/1901	wheat	3.737	88.5	0	878.169	372.628
14/11/1901	summerfallow	0	88.5	0	0	86
30/06/1902	winterfallow	0	88.5	0	0	43
14/11/1902	summerfallow	0	88.5	0	0	86
8/10/1903	wheat	5.706	0	0	1340.943	290.768
11/02/1904	sorghum	3.466	123.8	0	606.518	448.048
23/10/1904	wheat	2.711	118.3	0	637.109	396.203
14/11/1904	summerfallow	0	118.3	0	0	86
10/10/1905	wheat	2.298	69.5	0	540.061	334.649
14/11/1905	summerfallow	0	69.5	0	0	86
18/10/1906	wheat	6.146	39.3	0	1444.346	341.612
14/11/1906	summerfallow	0	39.3	0	0	86
19/10/1907	wheat	2.065	61	0	485.326	322.099
14/11/1907	summerfallow	0	61	0	0	86
30/06/1908	winterfallow	0	61	0	0	43
14/11/1908	summerfallow	0	61	0	0	86
30/06/1909	winterfallow	0	61	0	0	43
15/02/1910	sorghum	7.885	0	0	1379.931	342.968
21/10/1910	wheat	3.288	77.6	0	772.729	354.936
14/11/1910	summerfallow	0	77.6	0	0	86
30/06/1911	winterfallow	0	77.6	0	0	43
8/02/1912	sorghum	3.671	51.2	0	642.459	364.982
28/10/1912	wheat	2.27	63.3	0	533.371	327.042
14/11/1912	summerfallow	0	63.3	0	0	86
20/10/1913	wheat	2.303	51.2	0	541.183	313.225
14/11/1913	summerfallow	0	51.2	0	0	86
4/11/1914	wheat	1.749	70.5	0	411.125	329.732
14/11/1914	summerfallow	0	70.5	0	0	86
30/06/1915	winterfallow	0	70.5	0	0	43
14/11/1915	summerfallow	0	70.5	0	0	86
6/11/1916	wheat	2.75	0	0	646.348	258.255
14/11/1916	summerfallow	0	0	0	0	86
30/06/1917	winterfallow	0	0	0	0	43
30/01/1918	sorghum	8.635	26.6	0	1511.134	380.808

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
30/06/1918	winterfallow	0	26.6	0	0	43
14/11/1918	summerfallow	0	26.6	0	0	86
14/10/1919	wheat	2	53.2	0	470.045	312.243
14/11/1919	summerfallow	0	53.2	0	0	86
30/06/1920	winterfallow	0	53.2	0	0	43
8/02/1921	sorghum	5.617	58.6	0	983.045	391.175
30/06/1921	winterfallow	0	58.6	0	0	43
19/01/1922	sorghum	4.423	113.6	0	774.041	444.705
30/06/1922	winterfallow	0	113.6	0	0	43
14/11/1922	summerfallow	0	113.6	0	0	86
27/10/1923	wheat	1.926	0	0	452.678	249.189
14/11/1923	summerfallow	0	0	0	0	86
30/06/1924	winterfallow	0	0	0	0	43
28/01/1925	sorghum	7.907	22.5	0	1383.67	369.471
30/06/1925	winterfallow	0	22.5	0	0	43
14/11/1925	summerfallow	0	22.5	0	0	86
10/10/1926	wheat	2.372	40	0	557.502	300.917
14/11/1926	summerfallow	0	40	0	0	86
27/10/1927	wheat	2.294	101.6	0	538.984	372.08
14/11/1927	summerfallow	0	101.6	0	0	86
30/06/1928	winterfallow	0	101.6	0	0	43
14/11/1928	summerfallow	0	101.6	0	0	86
30/06/1929	winterfallow	0	101.6	0	0	43
14/11/1929	summerfallow	0	101.6	0	0	86
7/10/1930	wheat	4.922	0	0	1156.715	282.144
14/11/1930	summerfallow	0	0	0	0	86
4/11/1931	wheat	3.29	102.6	0	773.168	384.266
14/11/1931	summerfallow	0	102.6	0	0	86
30/06/1932	winterfallow	0	102.6	0	0	43
14/11/1932	summerfallow	0	102.6	0	0	86
5/11/1933	wheat	5.038	19.4	0	1183.971	306.168
2/03/1934	sorghum	5.706	121.1	0	998.622	465.022
9/10/1934	wheat	3.713	126.5	0	872.51	416.821
14/11/1934	summerfallow	0	126.5	0	0	86
30/06/1935	winterfallow	0	126.5	0	0	43
11/02/1936	sorghum	5.267	81.3	0	921.688	414.559
30/06/1936	winterfallow	0	81.3	0	0	43
14/11/1936	summerfallow	0	81.3	0	0	86
30/06/1937	winterfallow	0	81.3	0	0	43

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
24/02/1938	sorghum	4.652	0	0	814.147	313.87
30/06/1938	winterfallow	0	0	0	0	43
3/02/1939	sorghum	2.022	83.3	0	353.8	387.642
7/11/1939	wheat	2.085	111.6	0	489.995	381.5
14/11/1939	summerfallow	0	111.6	0	0	86
30/06/1940	winterfallow	0	111.6	0	0	43
14/11/1940	summerfallow	0	111.6	0	0	86
30/06/1941	winterfallow	0	111.6	0	0	43
14/11/1941	summerfallow	0	111.6	0	0	86
11/10/1942	wheat	3.219	25.3	0	756.568	292.966
14/11/1942	summerfallow	0	25.3	0	0	86
27/10/1943	wheat	3.769	80.6	0	885.768	363.771
14/11/1943	summerfallow	0	80.6	0	0	86
30/06/1944	winterfallow	0	80.6	0	0	43
19/01/1945	sorghum	4.291	91.9	0	750.912	418.09
30/06/1945	winterfallow	0	91.9	0	0	43
22/01/1946	sorghum	7.489	79.1	0	1310.64	431.99
30/06/1946	winterfallow	0	79.1	0	0	43
19/01/1947	sorghum	4.094	76.8	0	716.371	398.697
21/10/1947	wheat	4.1	114.6	0	963.551	407.141
14/11/1947	summerfallow	0	114.6	0	0	86
2/10/1948	wheat	4.227	91.3	0	993.273	381.296
14/11/1948	summerfallow	0	91.3	0	0	86
26/10/1949	wheat	3.292	78.4	0	773.58	355.974
18/02/1950	sorghum	3.569	121.6	0	624.596	446.386
15/10/1950	wheat	3.323	108.9	0	780.944	391.944
6/03/1951	sorghum	7.365	110.4	0	1288.828	467.478
30/06/1951	winterfallow	0	110.4	0	0	43
14/11/1951	summerfallow	0	110.4	0	0	86
1/10/1952	wheat	5.389	0	0	1266.342	287.276
14/11/1952	summerfallow	0	0	0	0	86
7/10/1953	wheat	3.166	101.7	0	744.061	381.868
25/02/1954	sorghum	5.076	119.9	0	888.223	457.93
5/10/1954	wheat	4.362	108.9	0	1025.033	403.412
10/02/1955	sorghum	3.336	125.3	0	583.838	448.653
29/09/1955	wheat	3.622	99.9	0	851.088	384.704
14/11/1955	summerfallow	0	99.9	0	0	86
10/10/1956	wheat	4.821	90.1	0	1132.953	386.485
14/11/1956	summerfallow	0	90.1	0	0	86

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
31/10/1957	wheat	1.981	37.8	0	465.647	294.048
14/11/1957	summerfallow	0	37.8	0	0	86
28/10/1958	wheat	3.252	71.2	0	764.164	347.034
14/11/1958	summerfallow	0	71.2	0	0	86
17/10/1959	wheat	2.679	78.6	0	629.556	349.389
14/11/1959	summerfallow	0	78.6	0	0	86
5/11/1960	wheat	2.681	46.2	0	629.919	311.55
14/11/1960	summerfallow	0	46.2	0	0	86
22/10/1961	wheat	3.224	70.8	0	757.74	346.329
20/02/1962	sorghum	5.994	124.5	0	1049.03	471.561
30/06/1962	winterfallow	0	124.5	0	0	43
18/01/1963	sorghum	3.207	104.4	0	561.221	423.063
30/06/1963	winterfallow	0	104.4	0	0	43
14/11/1963	summerfallow	0	104.4	0	0	86
23/10/1964	wheat	4.398	0	0	1033.431	276.373
14/11/1964	summerfallow	0	0	0	0	86
30/06/1965	winterfallow	0	0	0	0	43
17/01/1966	sorghum	6.344	73	0	1110.251	414.509
30/06/1966	winterfallow	0	73	0	0	43
1/02/1967	sorghum	6.128	95.3	0	1072.337	438.638
30/06/1967	winterfallow	0	95.3	0	0	43
5/02/1968	sorghum	4.758	98.1	0	832.72	429.548
30/06/1968	winterfallow	0	98.1	0	0	43
26/01/1969	sorghum	4.08	79.7	0	714.02	401.993
30/06/1969	winterfallow	0	79.7	0	0	43
14/11/1969	summerfallow	0	79.7	0	0	86
30/06/1970	winterfallow	0	79.7	0	0	43
14/11/1970	summerfallow	0	79.7	0	0	86
16/10/1971	wheat	5.441	51.7	0	1278.541	348.338
14/11/1971	summerfallow	0	51.7	0	0	86
30/10/1972	wheat	2.187	110.6	0	514.047	381.43
3/03/1973	sorghum	5.841	120.6	0	1022.183	465.617
30/06/1973	winterfallow	0	120.6	0	0	43
13/01/1974	sorghum	6.301	117.3	0	1102.603	466.001
26/10/1974	wheat	3.621	86.4	0	851.008	368.869
14/11/1974	summerfallow	0	86.4	0	0	86
31/10/1975	wheat	4.151	56.5	0	975.372	339.745
14/11/1975	summerfallow	0	56.5	0	0	86
30/06/1976	winterfallow	0	56.5	0	0	43

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
23/01/1977	sorghum	4.038	72.4	0	706.603	393.001
13/10/1977	wheat	1.395	103.9	0	327.924	364.88
14/11/1977	summerfallow	0	103.9	0	0	86
1/11/1978	wheat	5.004	88.2	0	1175.929	386.275
14/11/1978	summerfallow	0	88.2	0	0	86
25/09/1979	wheat	3.053	79.8	0	717.367	354.92
14/11/1979	summerfallow	0	79.8	0	0	86
13/10/1980	wheat	2.439	46	0	573.248	308.667
14/11/1980	summerfallow	0	46	0	0	86
15/10/1981	wheat	3.695	84.8	0	868.238	367.844
14/11/1981	summerfallow	0	84.8	0	0	86
26/10/1982	wheat	2.386	91.1	0	560.706	360.876
14/11/1982	summerfallow	0	91.1	0	0	86
23/09/1983	wheat	4.331	92.2	0	1017.842	383.485
14/11/1983	summerfallow	0	92.2	0	0	86
6/11/1984	wheat	3.009	60.8	0	707.107	332.233
14/11/1984	summerfallow	0	60.8	0	0	86
28/10/1985	wheat	2.879	69.7	0	676.638	341.201
14/11/1985	summerfallow	0	69.7	0	0	86
25/09/1986	wheat	3.879	86.5	0	911.643	371.853
14/11/1986	summerfallow	0	86.5	0	0	86
8/10/1987	wheat	3.09	73.3	0	726.095	347.757
14/11/1987	summerfallow	0	73.3	0	0	86
30/06/1988	winterfallow	0	73.3	0	0	43
14/11/1988	summerfallow	0	73.3	0	0	86
28/10/1989	wheat	2.421	36.8	0	568.853	297.639
14/11/1989	summerfallow	0	36.8	0	0	86
18/10/1990	wheat	2.873	107.2	0	675.226	385.079
14/11/1990	summerfallow	0	107.2	0	0	86
30/06/1991	winterfallow	0	107.2	0	0	43
7/02/1992	sorghum	3.834	44.5	0	670.974	358.563
30/06/1992	winterfallow	0	44.5	0	0	43
20/02/1993	sorghum	4.261	97.7	0	745.719	424.646
30/06/1993	winterfallow	0	97.7	0	0	43
14/11/1993	summerfallow	0	97.7	0	0	86
30/06/1994	winterfallow	0	97.7	0	0	43
13/02/1995	sorghum	4.191	21.6	0	733.367	334.983
26/10/1995	wheat	1.715	100.9	0	402.991	364.888
14/11/1995	summerfallow	0	100.9	0	0	86

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
20/09/1996	wheat	4.15	64.1	0	975.352	348.602
14/11/1996	summerfallow	0	64.1	0	0	86
28/09/1997	wheat	3.013	73.9	0	707.98	347.587
14/11/1997	summerfallow	0	73.9	0	0	86
23/09/1998	wheat	4.714	92.6	0	1107.804	388.246
14/11/1998	summerfallow	0	92.6	0	0	86
30/06/1999	winterfallow	0	92.6	0	0	43
12/02/2000	sorghum	7.294	65.6	0	1276.458	414.37
30/06/2000	winterfallow	0	65.6	0	0	43
14/11/2000	summerfallow	0	65.6	0	0	86
30/06/2001	winterfallow	0	65.6	0	0	43
1/03/2002	sorghum	2.471	51.3	0	432.468	354.279
30/06/2002	winterfallow	0	51.3	0	0	43
14/11/2002	summerfallow	0	51.3	0	0	86
30/06/2003	winterfallow	0	51.3	0	0	43
2/02/2004	sorghum	4.045	4.6	0	707.835	313.767
26/09/2004	wheat	2.085	116.5	0	489.868	387.212
14/11/2004	summerfallow	0	116.5	0	0	86
23/10/2005	wheat	1.923	82.1	0	452.012	345.19
14/11/2005	summerfallow	0	82.1	0	0	86
30/06/2006	winterfallow	0	82.1	0	0	43
14/11/2006	summerfallow	0	82.1	0	0	86
23/10/2007	wheat	3.205	0	0	753.278	263.26
14/11/2007	summerfallow	0	0	0	0	86
18/10/2008	wheat	3.378	93.5	0	793.746	374.547
14/11/2008	summerfallow	0	93.5	0	0	86
3/10/2009	wheat	2.39	95.5	0	561.727	365.998
14/11/2009	summerfallow	0	95.5	0	0	86
30/06/2010	winterfallow	0	95.5	0	0	43
5/02/2011	sorghum	8.229	67.7	0	1440.113	425.314
10/10/2011	wheat	3.015	127.6	0	708.432	410.507
14/11/2011	summerfallow	0	127.6	0	0	86
22/10/2012	wheat	2.241	103.1	0	526.73	373.322
14/11/2012	summerfallow	0	103.1	0	0	86
5/10/2013	wheat	2.261	84.8	0	531.229	352.048
14/11/2013	summerfallow	0	84.8	0	0	86

APPENDIX C. Agronomic parameters, expected farm income and farm costs for a simulated farm in Dalby, 1900-2013

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
20/10/1900	wheat	4.111	73.7	0	966.125	359.447
14/11/1900	summerfallow	0	73.7	0	0	86
23/10/1901	wheat	4.222	98.6	0	992.226	389.789
14/11/1901	summerfallow	0	98.6	0	0	86
30/06/1902	winterfallow	0	98.6	0	0	43
14/11/1902	summerfallow	0	98.6	0	0	86
10/10/1903	wheat	6.302	0	0	1480.935	297.32
2/03/1904	sorghum	3.736	124	0	653.829	450.707
22/10/1904	wheat	3.16	116.6	0	742.608	399.188
14/11/1904	summerfallow	0	116.6	0	0	86
9/10/1905	wheat	3.115	91.9	0	732.136	369.807
14/11/1905	summerfallow	0	91.9	0	0	86
30/06/1906	winterfallow	0	91.9	0	0	43
16/02/1907	sorghum	9.594	25.5	0	1678.978	388.2
30/06/1907	winterfallow	0	25.5	0	0	43
14/11/1907	summerfallow	0	25.5	0	0	86
30/06/1908	winterfallow	0	25.5	0	0	43
10/02/1909	sorghum	3.229	0	0	565.122	301.063
30/06/1909	winterfallow	0	0	0	0	43
14/11/1909	summerfallow	0	0	0	0	86
27/10/1910	wheat	3.802	26.4	0	893.438	300.67
13/03/1911	sorghum	7.019	116.5	0	1228.37	471.534
30/06/1911	winterfallow	0	116.5	0	0	43
8/02/1912	sorghum	2.966	108.4	0	519.129	425.539
4/11/1912	wheat	2.163	84.3	0	508.2	350.378
14/11/1912	summerfallow	0	84.3	0	0	86
16/10/1913	wheat	2.777	33.2	0	652.579	297.396
14/11/1913	summerfallow	0	33.2	0	0	86
30/06/1914	winterfallow	0	33.2	0	0	43
14/11/1914	summerfallow	0	33.2	0	0	86
30/06/1915	winterfallow	0	33.2	0	0	43
14/11/1915	summerfallow	0	33.2	0	0	86
30/06/1916	winterfallow	0	33.2	0	0	43
22/02/1917	sorghum	6.687	0	0	1170.199	332.182
30/06/1917	winterfallow	0	0	0	0	43
31/01/1918	sorghum	8.583	88.1	0	1502.073	452.359

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
30/06/1918	winterfallow	0	88.1	0	0	43
14/11/1918	summerfallow	0	88.1	0	0	86
15/10/1919	wheat	2.232	16.1	0	524.611	271.445
14/11/1919	summerfallow	0	16.1	0	0	86
31/10/1920	wheat	4.555	82.3	0	1070.497	374.419
14/11/1920	summerfallow	0	82.3	0	0	86
27/10/1921	wheat	3.788	84.1	0	890.14	368.05
14/11/1921	summerfallow	0	84.1	0	0	86
30/06/1922	winterfallow	0	84.1	0	0	43
14/11/1922	summerfallow	0	84.1	0	0	86
28/10/1923	wheat	2.644	0	0	621.39	257.086
14/11/1923	summerfallow	0	0	0	0	86
30/06/1924	winterfallow	0	0	0	0	43
28/01/1925	sorghum	7.391	60.7	0	1293.368	409.479
30/06/1925	winterfallow	0	60.7	0	0	43
21/02/1926	sorghum	6.916	91.2	0	1210.339	440.94
30/06/1926	winterfallow	0	91.2	0	0	43
14/11/1926	summerfallow	0	91.2	0	0	86
29/10/1927	wheat	2.654	48.5	0	623.726	313.989
14/11/1927	summerfallow	0	48.5	0	0	86
30/06/1928	winterfallow	0	48.5	0	0	43
14/11/1928	summerfallow	0	48.5	0	0	86
30/06/1929	winterfallow	0	48.5	0	0	43
14/11/1929	summerfallow	0	48.5	0	0	86
10/10/1930	wheat	5.716	8.3	0	1343.356	300.646
14/11/1930	summerfallow	0	8.3	0	0	86
5/11/1931	wheat	3.3	111.3	0	775.485	394.569
14/11/1931	summerfallow	0	111.3	0	0	86
30/06/1932	winterfallow	0	111.3	0	0	43
24/01/1933	sorghum	8.238	81.8	0	1441.644	441.859
30/06/1933	winterfallow	0	81.8	0	0	43
4/02/1934	sorghum	7.16	98.3	0	1253.021	451.492
8/10/1934	wheat	3.962	122.3	0	931.066	414.653
14/11/1934	summerfallow	0	122.3	0	0	86
30/06/1935	winterfallow	0	122.3	0	0	43
14/11/1935	summerfallow	0	122.3	0	0	86
27/10/1936	wheat	2.229	0	0	523.774	252.517
14/11/1936	summerfallow	0	0	0	0	86
30/06/1937	winterfallow	0	0	0	0	43

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
21/02/1938	sorghum	5.213	48.9	0	912.306	376.091
30/06/1938	winterfallow	0	48.9	0	0	43
28/02/1939	sorghum	5.672	92.4	0	992.596	431.142
10/11/1939	wheat	2.175	108.9	0	511.188	379.386
14/11/1939	summerfallow	0	108.9	0	0	86
9/10/1940	wheat	2.6	88.4	0	610.921	360.015
14/11/1940	summerfallow	0	88.4	0	0	86
30/06/1941	winterfallow	0	88.4	0	0	43
3/03/1942	sorghum	5.703	31	0	998.004	359.625
30/06/1942	winterfallow	0	31	0	0	43
14/11/1942	summerfallow	0	31	0	0	86
30/06/1943	winterfallow	0	31	0	0	43
15/02/1944	sorghum	9.114	10.7	0	1594.9	366.541
30/06/1944	winterfallow	0	10.7	0	0	43
23/01/1945	sorghum	3.381	123.8	0	591.667	447.231
1/11/1945	wheat	2.811	120.5	0	660.625	399.88
14/11/1945	summerfallow	0	120.5	0	0	86
30/06/1946	winterfallow	0	120.5	0	0	43
21/01/1947	sorghum	2.889	38.2	0	505.57	342.689
25/10/1947	wheat	3.124	90.2	0	734.045	367.898
14/11/1947	summerfallow	0	90.2	0	0	86
6/10/1948	wheat	4.044	77.3	0	950.289	362.914
14/11/1948	summerfallow	0	77.3	0	0	86
29/10/1949	wheat	3.487	81	0	819.427	361.175
14/11/1949	summerfallow	0	81	0	0	86
18/10/1950	wheat	4.327	95.2	0	1016.888	387.022
14/11/1950	summerfallow	0	95.2	0	0	86
30/06/1951	winterfallow	0	95.2	0	0	43
14/11/1951	summerfallow	0	95.2	0	0	86
2/10/1952	wheat	5.445	0	0	1279.618	287.897
14/11/1952	summerfallow	0	0	0	0	86
5/10/1953	wheat	3.002	105.9	0	705.366	384.918
14/11/1953	summerfallow	0	105.9	0	0	86
30/06/1954	winterfallow	0	105.9	0	0	43
15/02/1955	sorghum	4.476	87.2	0	783.228	414.298
21/10/1955	wheat	2.456	116.8	0	577.241	391.729
14/11/1955	summerfallow	0	116.8	0	0	86
13/10/1956	wheat	4.197	105.2	0	986.365	397.307
14/11/1956	summerfallow	0	105.2	0	0	86

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
2/11/1957	wheat	2.233	66.9	0	524.835	330.806
14/11/1957	summerfallow	0	66.9	0	0	86
30/10/1958	wheat	3.077	93.4	0	723.048	371.178
14/11/1958	summerfallow	0	93.4	0	0	86
21/10/1959	wheat	3.068	68.9	0	721.074	342.339
2/03/1960	sorghum	5.738	116.4	0	1004.214	459.848
30/06/1960	winterfallow	0	116.4	0	0	43
14/11/1960	summerfallow	0	116.4	0	0	86
30/06/1961	winterfallow	0	116.4	0	0	43
30/01/1962	sorghum	8.123	0	0	1421.443	345.103
30/06/1962	winterfallow	0	0	0	0	43
14/11/1962	summerfallow	0	0	0	0	86
18/10/1963	wheat	3.28	71.8	0	770.855	348.103
14/11/1963	summerfallow	0	71.8	0	0	86
3/10/1964	wheat	3.762	115	0	884.127	403.971
15/02/1965	sorghum	4.1	124	0	717.435	453.955
30/06/1965	winterfallow	0	124	0	0	43
22/01/1966	sorghum	7.456	123.3	0	1304.714	483.404
30/06/1966	winterfallow	0	123.3	0	0	43
13/02/1967	sorghum	5.578	85	0	976.214	421.619
30/10/1967	wheat	2.274	99.3	0	534.467	369.222
14/11/1967	summerfallow	0	99.3	0	0	86
7/10/1968	wheat	4.489	63.7	0	1054.918	351.948
14/11/1968	summerfallow	0	63.7	0	0	86
22/10/1969	wheat	3.831	77	0	900.31	360.19
14/11/1969	summerfallow	0	77	0	0	86
24/10/1970	wheat	3.114	74	0	731.868	348.804
14/11/1970	summerfallow	0	74	0	0	86
30/06/1971	winterfallow	0	74	0	0	43
14/02/1972	sorghum	9.055	59.4	0	1584.703	422.955
30/06/1972	winterfallow	0	59.4	0	0	43
18/02/1973	sorghum	5.127	107.2	0	897.161	443.511
30/06/1973	winterfallow	0	107.2	0	0	43
16/01/1974	sorghum	7.502	109.3	0	1312.9	467.401
26/10/1974	wheat	3.339	93.5	0	784.687	374.111
14/11/1974	summerfallow	0	93.5	0	0	86
30/06/1975	winterfallow	0	93.5	0	0	43
1/03/1976	sorghum	7.464	73.2	0	1306.134	424.842
30/06/1976	winterfallow	0	73.2	0	0	43

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
29/01/1977	sorghum	3.527	107.4	0	617.147	429.371
30/06/1977	winterfallow	0	107.4	0	0	43
14/11/1977	summerfallow	0	107.4	0	0	86
30/06/1978	winterfallow	0	107.4	0	0	43
16/02/1979	sorghum	4.543	31	0	795.02	349.106
3/10/1979	wheat	3.573	113.6	0	839.551	400.165
14/11/1979	summerfallow	0	113.6	0	0	86
15/10/1980	wheat	2.624	106.4	0	616.536	381.335
14/11/1980	summerfallow	0	106.4	0	0	86
18/10/1981	wheat	3.763	98.3	0	884.34	384.376
14/11/1981	summerfallow	0	98.3	0	0	86
30/06/1982	winterfallow	0	98.3	0	0	43
6/02/1983	sorghum	5.87	57.6	0	1027.182	392.207
25/09/1983	wheat	2.958	118.1	0	695.209	398.738
14/11/1983	summerfallow	0	118.1	0	0	86
30/06/1984	winterfallow	0	118.1	0	0	43
22/02/1985	sorghum	3.458	53.8	0	605.149	366.096
30/06/1985	winterfallow	0	53.8	0	0	43
14/11/1985	summerfallow	0	53.8	0	0	86
28/09/1986	wheat	3.998	33.9	0	939.612	311.697
14/11/1986	summerfallow	0	33.9	0	0	86
9/10/1987	wheat	3.429	94.8	0	805.715	376.573
14/11/1987	summerfallow	0	94.8	0	0	86
17/10/1988	wheat	4.152	119.1	0	975.829	413.054
14/11/1988	summerfallow	0	119.1	0	0	86
30/06/1989	winterfallow	0	119.1	0	0	43
19/02/1990	sorghum	6.446	91.5	0	1128.034	437.06
18/10/1990	wheat	3.225	114.9	0	757.979	397.894
14/11/1990	summerfallow	0	114.9	0	0	86
30/06/1991	winterfallow	0	114.9	0	0	43
14/11/1991	summerfallow	0	114.9	0	0	86
30/06/1992	winterfallow	0	114.9	0	0	43
26/02/1993	sorghum	3.35	0	0	586.264	302.151
30/06/1993	winterfallow	0	0	0	0	43
14/11/1993	summerfallow	0	0	0	0	86
30/06/1994	winterfallow	0	0	0	0	43
18/02/1995	sorghum	6.569	47.3	0	1149.574	386.427
30/06/1995	winterfallow	0	47.3	0	0	43
26/02/1996	sorghum	8.832	106.5	0	1545.625	476.12

Date	CropName	CropYield (kg)	CropFertiliser (kgN)	CropIrrigation (ML)	Income ($)	Cost ($)
28/09/1996	wheat	2.875	128.6	0	675.699	410.077
14/11/1996	summerfallow	0	128.6	0	0	86
4/10/1997	wheat	2.443	79.3	0	574.133	347.704
14/11/1997	summerfallow	0	79.3	0	0	86
26/09/1998	wheat	4.718	79.5	0	1108.78	372.91
14/11/1998	summerfallow	0	79.5	0	0	86
30/06/1999	winterfallow	0	79.5	0	0	43
11/03/2000	sorghum	7.903	48.2	0	1382.996	399.473
30/06/2000	winterfallow	0	48.2	0	0	43
14/11/2000	summerfallow	0	48.2	0	0	86
30/06/2001	winterfallow	0	48.2	0	0	43
8/02/2002	sorghum	5.511	85.5	0	964.462	421.639
30/06/2002	winterfallow	0	85.5	0	0	43
14/11/2002	summerfallow	0	85.5	0	0	86
23/10/2003	wheat	2.795	57.9	0	656.841	326.483
14/11/2003	summerfallow	0	57.9	0	0	86
28/09/2004	wheat	2.924	100.9	0	687.224	378.168
14/11/2004	summerfallow	0	100.9	0	0	86
25/10/2005	wheat	2	65.3	0	469.911	326.353
14/11/2005	summerfallow	0	65.3	0	0	86
30/06/2006	winterfallow	0	65.3	0	0	43
28/02/2007	sorghum	2.502	45.5	0	437.838	347.771
30/06/2007	winterfallow	0	45.5	0	0	43
14/11/2007	summerfallow	0	45.5	0	0	86
30/06/2008	winterfallow	0	45.5	0	0	43
24/01/2009	sorghum	6.465	36.2	0	1131.398	372.591
30/06/2009	winterfallow	0	36.2	0	0	43
14/11/2009	summerfallow	0	36.2	0	0	86
30/06/2010	winterfallow	0	36.2	0	0	43
11/02/2011	sorghum	8.039	75	0	1406.887	432.108
30/06/2011	winterfallow	0	75	0	0	43
4/02/2012	sorghum	5.053	128.5	0	884.191	467.806
30/06/2012	winterfallow	0	128.5	0	0	43
14/11/2012	summerfallow	0	128.5	0	0	86
30/06/2013	winterfallow	0	128.5	0	0	43
14/11/2013	summerfallow	0	128.5	0	0	86

APPENDIX D. Agronomic parameters, expected farm income and farm costs for simulated farm in Cecil Plains, 1900-2013

Date	CropName	CropYield (kg or bales)	CropFertiliser (kg N)	CropIrrigation (ML)	Income ($)	Cost ($)
24/08/1900	winterfallow	0			0	83
3/04/1901	cotton	9.65	233.3	288.566	5307.491	2230.141
24/08/1901	winterfallow	0	233.3	288.566	0	83
29/04/1902	cotton	12.675	170.4	334.354	6971.351	2365.451
12/11/1902	wheat	7.998	0	639.743	2247.408	806.823
16/03/1903	summerfallow	0	0	639.743	0	20
24/08/1903	winterfallow	0	0	639.743	0	83
22/04/1904	cotton	7.348	255.8	313.335	4041.631	2133.185
24/08/1904	winterfallow	0	255.8	313.335	0	83
4/06/1905	cotton	12.749	119.6	270.202	7011.932	2271.939
23/11/1905	wheat	9.565	0	559.396	2687.679	775.849
16/03/1906	summerfallow	0	0	559.396	0	20
24/08/1906	winterfallow	0	0	559.396	0	83
12/04/1907	cotton	9.07	244.8	219.217	4988.425	2167.121
24/08/1907	winterfallow	0	244.8	219.217	0	83
3/04/1908	cotton	7.396	104.9	238.283	4067.73	1914.477
18/11/1908	wheat	8.772	0	396.086	2464.956	669.144
16/03/1909	summerfallow	0	0	396.086	0	20
24/08/1909	winterfallow	0	0	396.086	0	83
10/04/1910	cotton	8.043	218.2	228.338	4423.596	2079.822
24/08/1910	winterfallow	0	218.2	228.338	0	83
29/04/1911	cotton	7.322	104.9	203.86	4027.224	1889.351
16/11/1911	wheat	8.48	0	509.561	2382.926	734.018
16/03/1912	summerfallow	0	0	509.561	0	20
24/08/1912	winterfallow	0	0	509.561	0	83
28/06/1913	cotton	10.825	222.6	295.638	5954.021	2292.337
24/08/1913	winterfallow	0	222.6	295.638	0	83
13/04/1914	cotton	9.423	154.9	338.856	5182.741	2154.914
20/10/1914	wheat	8.286	0	354.529	2328.247	638.859
16/03/1915	summerfallow	0	0	354.529	0	20
24/08/1915	winterfallow	0	0	354.529	0	83
16/03/1916	cotton	7.167	110.3	300.144	3941.807	1944.209
24/08/1916	winterfallow	0	110.3	300.144	0	83
8/05/1917	cotton	7.005	80.7	230.211	3852.666	1857.815
17/11/1917	wheat	7.609	44.2	328.181	2138.257	667.332
16/03/1918	summerfallow	0	44.2	328.181	0	20
24/08/1918	winterfallow	0	44.2	328.181	0	83
24/03/1919	cotton	9.423	186	294.479	5182.565	2164.645

Date	CropName	CropYield (kg or bales)	CropFertiliser (kg N)	CropIrrigation (ML)	Income ($)	Cost ($)
24/08/1919	winterfallow	0	186	294.479	0	83
1/05/1920	cotton	12.774	15.9	315.05	7025.912	2179.039
22/10/1920	wheat	7.466	0	370.764	2097.994	639.586
16/03/1921	summerfallow	0	0	370.764	0	20
24/08/1921	winterfallow	0	0	370.764	0	83
17/05/1922	cotton	10.817	221.2	295.267	5949.126	2289.903
24/08/1922	winterfallow	0	221.2	295.267	0	83
23/04/1923	cotton	13.012	113	534.054	7156.724	2438.334
1/11/1923	wheat	9.152	0	364.557	2571.734	654.407
16/03/1924	summerfallow	0	0	364.557	0	20
24/08/1924	winterfallow	0	0	364.557	0	83
23/04/1925	cotton	8.507	211.4	202.521	4678.784	2084.206
24/08/1925	winterfallow	0	211.4	202.521	0	83
24/05/1926	cotton	12.493	101.8	327.647	6871.278	2270.302
10/11/1926	wheat	7.764	0	612.35	2181.607	787.811
16/03/1927	summerfallow	0	0	612.35	0	20
24/08/1927	winterfallow	0	0	612.35	0	83
11/04/1928	cotton	7.881	200.8	274.923	4334.78	2077.808
24/08/1928	winterfallow	0	200.8	274.923	0	83
26/03/1929	cotton	6.709	77.9	240.982	3690.212	1843.304
15/11/1929	wheat	8.589	0	494.398	2413.547	726.119
16/03/1930	summerfallow	0	0	494.398	0	20
24/08/1930	winterfallow	0	0	494.398	0	83
31/05/1931	cotton	10.308	251.7	290.394	5669.252	2292.248
24/08/1931	winterfallow	0	251.7	290.394	0	83
5/06/1932	cotton	12.601	148.5	470.851	6930.492	2417.322
17/11/1932	wheat	8.618	0	563.349	2421.728	767.81
16/03/1933	summerfallow	0	0	563.349	0	20
24/08/1933	winterfallow	0	0	563.349	0	83
31/05/1934	cotton	9.366	206.7	263.039	5151.557	2166.607
24/08/1934	winterfallow	0	206.7	263.039	0	83
17/04/1935	cotton	8.659	147.9	347.845	4762.212	2106.243
16/11/1935	wheat	8.571	0	437.278	2408.501	691.65
16/03/1936	summerfallow	0	0	437.278	0	20
24/08/1936	winterfallow	0	0	437.278	0	83
13/05/1937	cotton	9.835	166.3	283.431	5409.093	2159.703
24/08/1937	winterfallow	0	166.3	283.431	0	83
22/04/1938	cotton	11.529	206.8	415.015	6340.918	2387.718
24/10/1938	wheat	9.061	0	435.748	2546.066	696.117
16/03/1939	summerfallow	0	0	435.748	0	20
24/08/1939	winterfallow	0	0	435.748	0	83

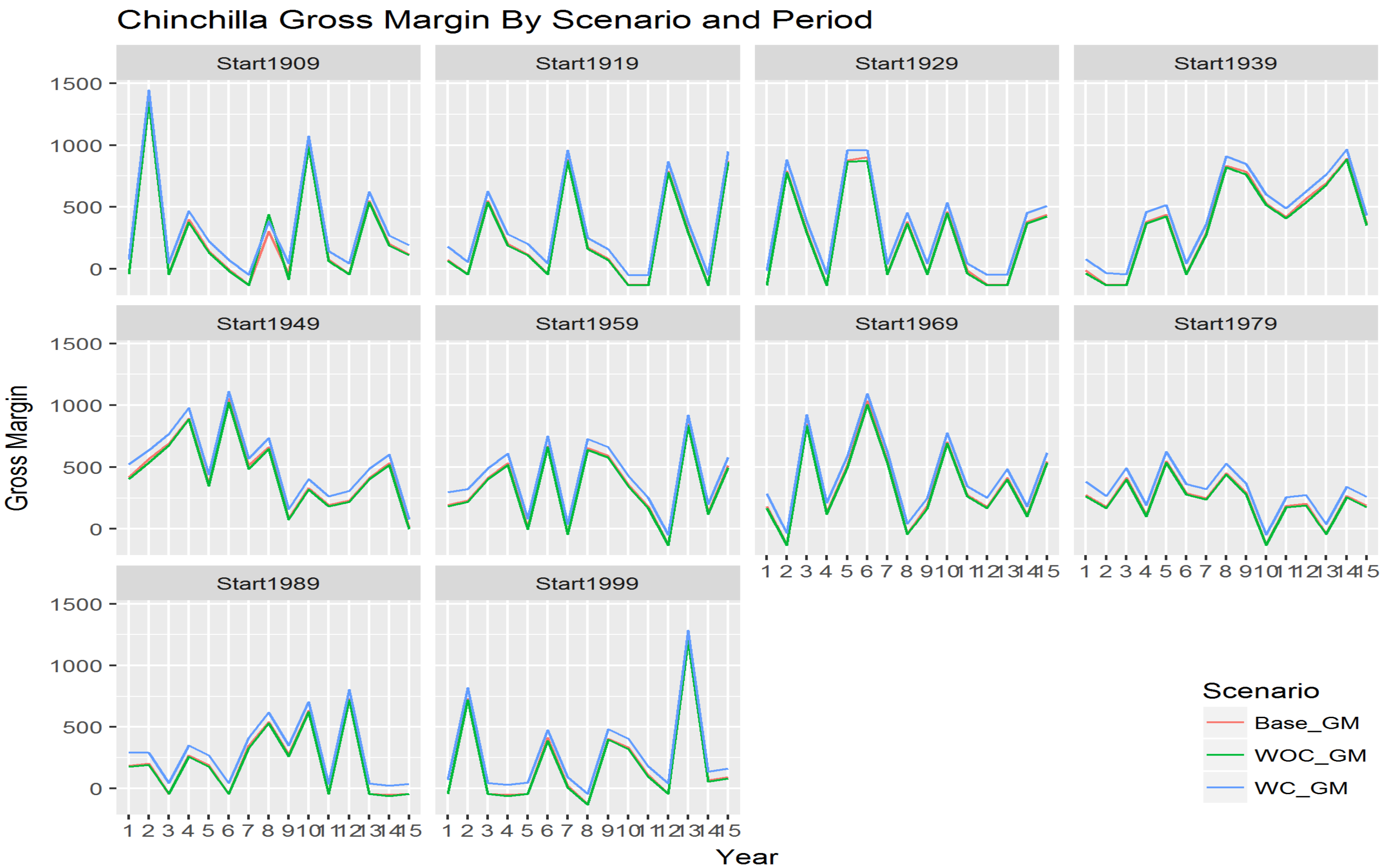
Date	CropName	CropYield (kg or bales)	CropFertiliser (kg N)	CropIrrigation (ML)	Income ($)	Cost ($)
19/05/1940	cotton	8.789	198.9	212.492	4833.942	2092.549
24/08/1940	winterfallow	0	198.9	212.492	0	83
21/04/1941	cotton	9.022	159.4	359.142	4962.326	2148.375
13/11/1941	wheat	9.52	0	557.642	2675.081	774.304
16/03/1942	summerfallow	0	0	557.642	0	20
24/08/1942	winterfallow	0	0	557.642	0	83
2/06/1943	cotton	10.626	205.6	270.861	5844.435	2245.586
24/08/1943	winterfallow	0	205.6	270.861	0	83
25/04/1944	cotton	9.668	175.6	369.85	5317.225	2212.392
15/11/1944	wheat	8.627	0	525.113	2424.073	744.961
16/03/1945	summerfallow	0	0	525.113	0	20
24/08/1945	winterfallow	0	0	525.113	0	83
27/04/1946	cotton	9.139	211.6	233.635	5026.682	2141.107
24/08/1946	winterfallow	0	211.6	233.635	0	83
19/03/1947	cotton	4.565	150.2	264.293	2510.847	1813.229
27/10/1947	wheat	8.156	0	315.945	2291.752	614.28
16/03/1948	summerfallow	0	0	315.945	0	20
24/08/1948	winterfallow	0	0	315.945	0	83
17/04/1949	cotton	9.111	175.5	197.945	5011.184	2075.834
24/08/1949	winterfallow	0	175.5	197.945	0	83
11/04/1950	cotton	7.427	61.9	171	4085.101	1825.612
19/10/1950	wheat	4.4	0	158.272	1236.539	478.368
16/03/1951	summerfallow	0	0	158.272	0	20
24/08/1951	winterfallow	0	0	158.272	0	83
19/03/1952	cotton	7.363	119.7	243.195	4049.722	1932.702
24/08/1952	winterfallow	0	119.7	243.195	0	83
19/04/1953	cotton	8.845	124.8	280.793	4864.929	2050.218
17/11/1953	wheat	8.609	0	488.707	2419.039	722.919
16/03/1954	summerfallow	0	0	488.707	0	20
24/08/1954	winterfallow	0	0	488.707	0	83
17/04/1955	cotton	9.023	219.3	290.417	4962.403	2177.204
24/08/1955	winterfallow	0	219.3	290.417	0	83
1/04/1956	cotton	6.137	111.4	148.602	3375.23	1792.679
3/11/1956	wheat	9.315	0	386.572	2617.615	669.412
16/03/1957	summerfallow	0	0	386.572	0	20
24/08/1957	winterfallow	0	0	386.572	0	83
25/05/1958	cotton	10.26	212.5	205.752	5643.048	2192.698
24/08/1958	winterfallow	0	212.5	205.752	0	83
30/05/1959	cotton	10.325	153.4	220.78	5678.732	2136.395
16/11/1959	wheat	8.12	0	479.302	2281.696	711.9
16/03/1960	summerfallow	0	0	479.302	0	20

Date	CropName	CropYield (kg or bales)	CropFertiliser (kg N)	CropIrrigation (ML)	Income ($)	Cost ($)
24/08/1960	winterfallow	0	0	479.302	0	83
7/05/1961	cotton	7.353	174.3	236.048	4044.304	1991.766
24/08/1961	winterfallow	0	174.3	236.048	0	83
11/04/1962	cotton	6.521	155.7	276.039	3586.464	1944.026
14/11/1962	wheat	8.396	0	398.521	2359.248	666.468
16/03/1963	summerfallow	0	0	398.521	0	20
24/08/1963	winterfallow	0	0	398.521	0	83
27/04/1964	cotton	8.976	228.7	200.103	4936.792	2131.233
24/08/1964	winterfallow	0	228.7	200.103	0	83
18/05/1965	cotton	11.946	123.6	342.504	6570.188	2271.843
16/11/1965	wheat	7.764	0	492.18	2181.811	715.717
16/03/1966	summerfallow	0	0	492.18	0	20
24/08/1966	winterfallow	0	0	492.18	0	83
27/04/1967	cotton	8.93	209.6	261.089	4911.428	2142.679
24/08/1967	winterfallow	0	209.6	261.089	0	83
27/05/1968	cotton	7.972	114.2	199.406	4384.663	1936.529
14/11/1968	wheat	7.874	0	491.824	2212.533	716.706
16/03/1969	summerfallow	0	0	491.824	0	20
24/08/1969	winterfallow	0	0	491.824	0	83
27/04/1970	cotton	11.314	189.7	229.104	6222.602	2243.208
24/08/1970	winterfallow	0	189.7	229.104	0	83
1/04/1971	cotton	3.508	157.1	208.572	1929.456	1724.481
13/11/1971	wheat	7.024	10.2	366.176	1973.712	643.853
16/03/1972	summerfallow	0	10.2	366.176	0	20
24/08/1972	winterfallow	0	10.2	366.176	0	83
13/05/1973	cotton	10.678	165.4	237.289	5872.885	2181.595
24/08/1973	winterfallow	0	165.4	237.289	0	83
27/05/1974	cotton	12.432	175.7	370.384	6837.47	2378.692
22/11/1974	wheat	8.116	0	421.134	2280.604	676.957
16/03/1975	summerfallow	0	0	421.134	0	20
24/08/1975	winterfallow	0	0	421.134	0	83
19/05/1976	cotton	10.089	226.3	161.758	5549.205	2172.164
24/08/1976	winterfallow	0	226.3	161.758	0	83
6/04/1977	cotton	8.167	172.1	349.648	4492.018	2106.212
19/10/1977	wheat	8.839	0	488.411	2483.71	725.274
16/03/1978	summerfallow	0	0	488.411	0	20
24/08/1978	winterfallow	0	0	488.411	0	83
1/06/1979	cotton	10.447	222.2	293.004	5745.799	2267.575
24/08/1979	winterfallow	0	222.2	293.004	0	83
2/05/1980	cotton	12.356	120.9	391.311	6795.571	2322.608
8/11/1980	wheat	8.173	0	577.006	2296.642	771.107

Date	CropName	CropYield (kg or bales)	CropFertiliser (kg N)	CropIrrigation (ML)	Income ($)	Cost ($)
16/03/1981	summerfallow	0	0	577.006	0	20
24/08/1981	winterfallow	0	0	577.006	0	83
26/03/1982	cotton	5.925	194.8	176.273	3258.763	1894.215
24/08/1982	winterfallow	0	194.8	176.273	0	83
11/04/1983	cotton	11.424	49.4	322.867	6283	2141.954
23/10/1983	wheat	7.205	43	221.066	2024.581	597.22
16/03/1984	summerfallow	0	43	221.066	0	20
24/08/1984	winterfallow	0	43	221.066	0	83
7/06/1985	cotton	10.699	238	323.663	5884.201	2319.586
24/08/1985	winterfallow	0	238	323.663	0	83
12/05/1986	cotton	11.371	137.3	290.37	6254.196	2222.129
14/11/1986	wheat	7.634	0	482.463	2145.213	708.454
16/03/1987	summerfallow	0	0	482.463	0	20
24/08/1987	winterfallow	0	0	482.463	0	83
20/04/1988	cotton	9.699	187.6	198.763	5334.69	2125.769
24/08/1988	winterfallow	0	187.6	198.763	0	83
21/04/1989	cotton	9.734	156.8	300.908	5353.667	2152.981
18/11/1989	wheat	9.549	0	405.123	2683.331	683.115
16/03/1990	summerfallow	0	0	405.123	0	20
24/08/1990	winterfallow	0	0	405.123	0	83
1/04/1991	cotton	8.948	245.7	236.905	4921.388	2171.469
24/08/1991	winterfallow	0	245.7	236.905	0	83
20/05/1992	cotton	13.485	110.5	332.051	7416.69	2342.585
24/10/1992	wheat	8.028	0	468.296	2255.756	704.281
16/03/1993	summerfallow	0	0	468.296	0	20
24/08/1993	winterfallow	0	0	468.296	0	83
29/03/1994	cotton	7.791	153.8	162.55	4285.089	1949.959
24/08/1994	winterfallow	0	153.8	162.55	0	83
12/05/1995	cotton	9.642	49.9	200.509	5303.096	1962.162
2/11/1995	wheat	7.745	0	522.34	2176.419	733.602
16/03/1996	summerfallow	0	0	522.34	0	20
24/08/1996	winterfallow	0	0	522.34	0	83
31/05/1997	cotton	10.122	232.1	260.871	5566.964	2240.406
24/08/1997	winterfallow	0	232.1	260.871	0	83
26/03/1998	cotton	9.653	162.1	419.645	5309.116	2225.574
7/11/1998	wheat	5.259	0	193.981	1477.895	509.242
16/03/1999	summerfallow	0	0	193.981	0	20
24/08/1999	winterfallow	0	0	193.981	0	83
21/05/2000	cotton	12.185	129.5	230.379	6701.504	2225.793
24/08/2000	winterfallow	0	129.5	230.379	0	83
25/05/2001	cotton	12.914	112	427.516	7102.492	2367.321

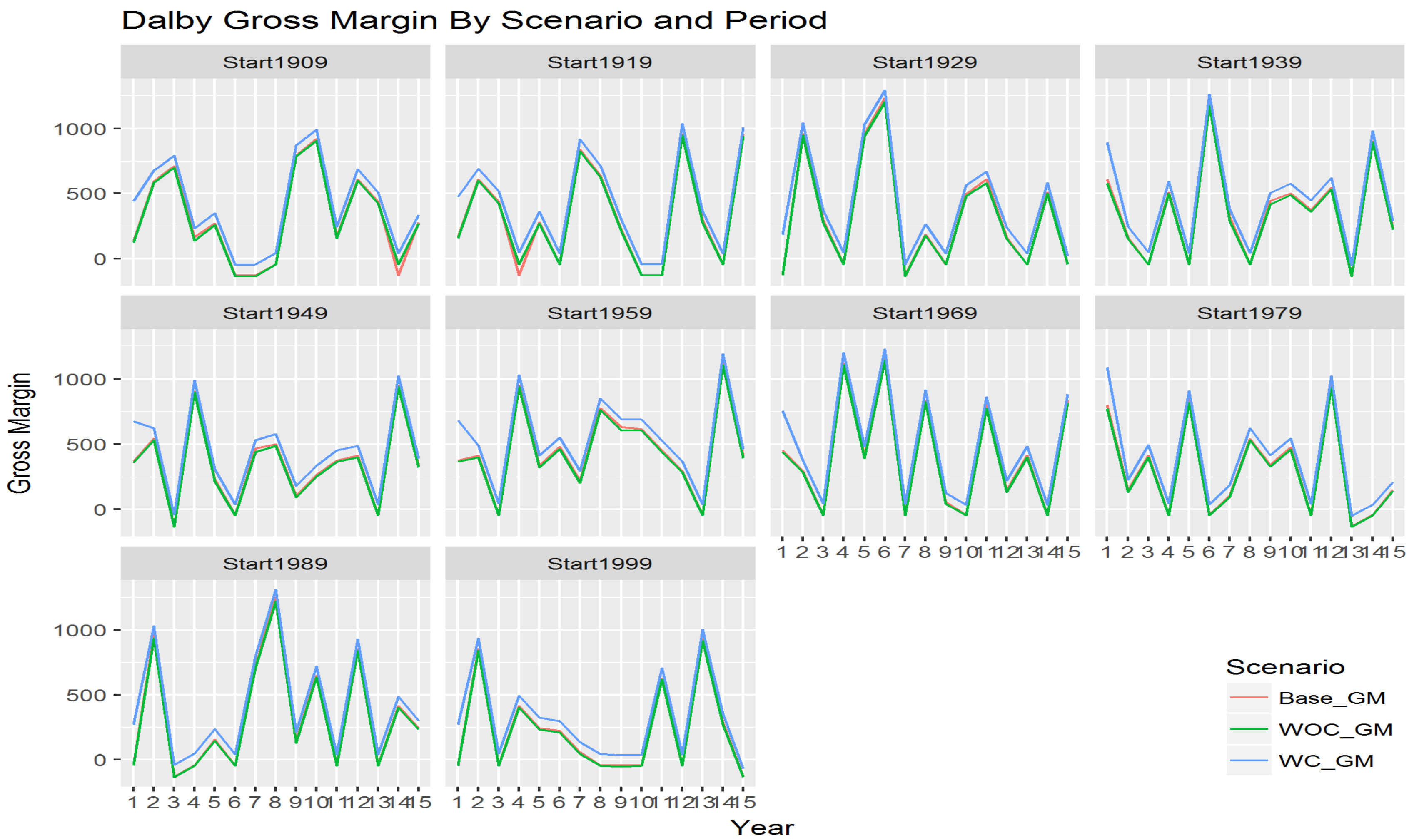
Date	CropName	CropYield (kg or bales)	CropFertiliser (kg N)	CropIrrigation (ML)	Income ($)	Cost ($)
12/11/2001	wheat	8.071	21.1	397.931	2267.926	687.201
16/03/2002	summerfallow	0	21.1	397.931	0	20
24/08/2002	winterfallow	0	21.1	397.931	0	83
17/05/2003	cotton	12.273	134.8	291.821	6749.929	2274.217
24/08/2003	winterfallow	0	134.8	291.821	0	83
18/05/2004	cotton	9.359	138.4	256.16	5147.392	2082.17
10/11/2004	wheat	8.368	28.5	569.297	2351.386	802.012
16/03/2005	summerfallow	0	28.5	569.297	0	20
24/08/2005	winterfallow	0	28.5	569.297	0	83
23/03/2006	cotton	8.537	151.9	305.983	4695.291	2078.5
24/08/2006	winterfallow	0	151.9	305.983	0	83
8/05/2007	cotton	10.893	52.6	290.038	5990.964	2094.157
27/10/2007	wheat	7.249	10.1	438.063	2037.107	689.355
16/03/2008	summerfallow	0	10.1	438.063	0	20
24/08/2008	winterfallow	0	10.1	438.063	0	83
5/05/2009	cotton	9.923	173.7	255.785	5457.762	2157.128
24/08/2009	winterfallow	0	173.7	255.785	0	83
17/03/2010	cotton	5.767	108.2	382.386	3172.008	1907.062
13/11/2010	wheat	5.74	0	156.147	1612.986	491.83
16/03/2011	summerfallow	0	0	156.147	0	20
24/08/2011	winterfallow	0	0	156.147	0	83
6/05/2012	cotton	9.555	201.3	271.488	5255.01	2176.64
24/08/2012	winterfallow	0	201.3	271.488	0	83
22/03/2013	cotton	6.93	115.2	271.419	3811.353	1918.38
5/11/2013	wheat	7.382	0	486.953	2074.367	708.375

APPENDIX E.

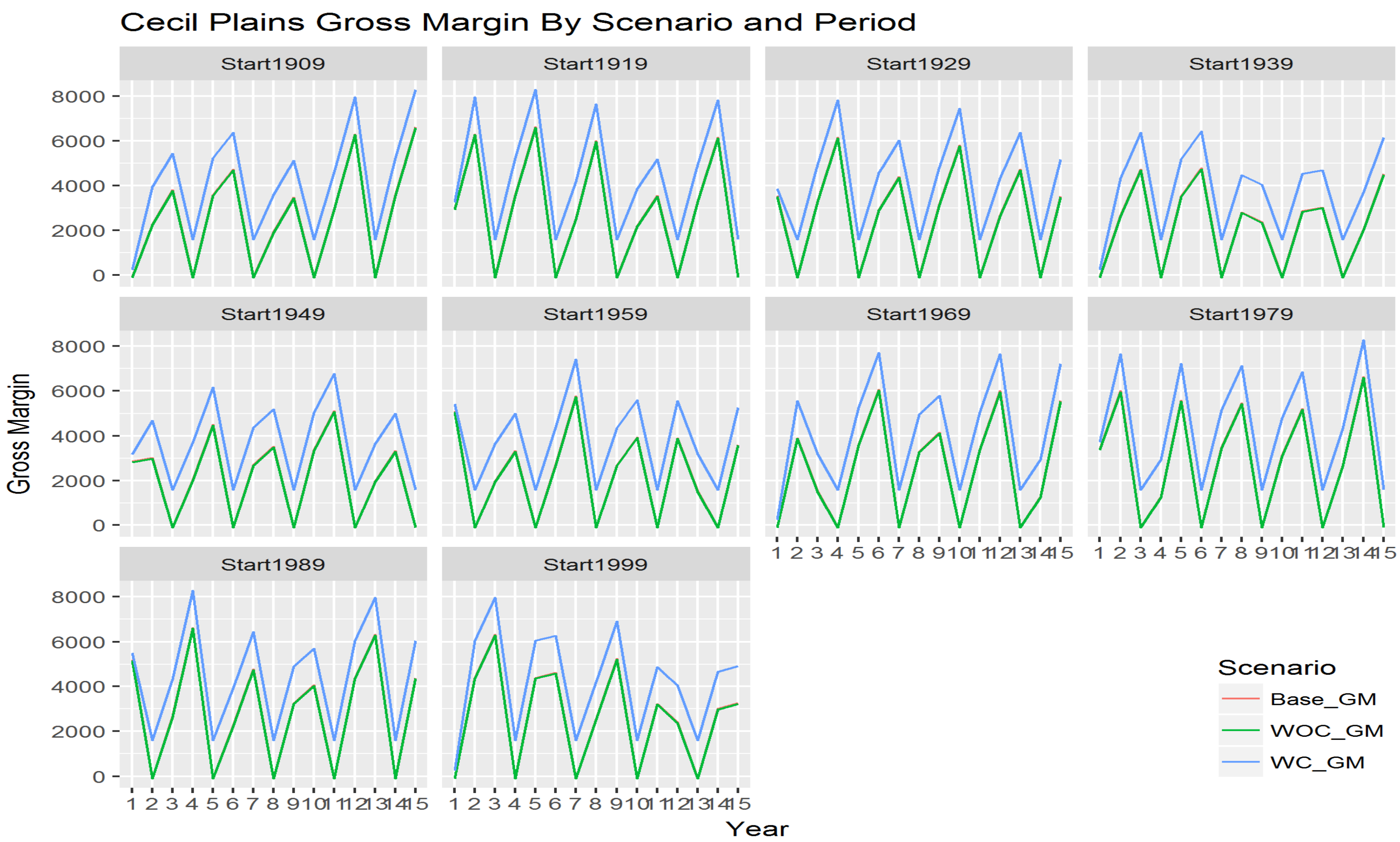


Chinchilla Gross Margin By Scenario and Period
Start1909
Start1919
Start1929
Start1939
Start1949
Start1959
Start1969
Start1979
Start1989
Start1999
Gross Margin
0
500
1000
1500
Year
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Scenario
Base_GM
WOC_GM
WC_GM

APPENDIX F.


Dalby Gross Margin By Scenario and Period
Start1909
Start1919
Start1929
Start1939
Start1949
Start1959
Start1969
Start1979
Start1989
Start1999
1000
500
0
Gross Margin
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Year
Scenario
Base_GM
WOC_GM
WC_GM

APPENDIX G



Cecil Plains Gross Margin By Scenario and Period
Start1909
Start1919
Start1929
Start1939
Start1949
Start1959
Start1969
Start1979
Start1989
Start1999
Gross Margin
Year
Scenario
Base_GM
WOC_GM
WC_GM