Modelling Fertiliser Use in the Glenelg Hopkins Catchment

A thesis submitted in fulfillment of the requirements for the degree of Master of Applied Science

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Declaration of Originality

Except where otherwise stated, this thesis is my own work. This thesis has not previously been submitted for a degree or diploma in any institution of higher education.

Parts of chapters 6, 7 and 8 have been published in the proceedings of the International Congress on Modelling and Simulation (MODSIM), held in Christchurch, New Zealand in 2007.

Signed: Date:

Certification

This is to certify that the above statements made by the candidate are correct to the best of our knowledge.

Signed: Date:

This thesis is based on research undertaken by a team of researchers from RMIT University under the supervision of Dr Sergei Schreider: The team consists of Prof. Panlop Zeephongsekul; Dr Afshin Alizadeh Shabani; Mr Matthew Fernandes and Ms Julia Schlapp across several disciplines including mathematics, geospatial sciences and agricultural science.

The thesis contains a description of the work undertaken by myself as part of the team and the application and the relevance that the results have had on the game theory model developed by Dr Schreider, Prof Zeephongsekul and Mr Fernandes.

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Abbreviations:

BGA	Blue-Green Algae
BMP	Best Management Practice
CALP	Catchment and Land Protection
CFA	Country Fire Authority
CMA	Catchment Management Authority
DPI	Department of Primary Industries
DSE	Department of Sustainability and Environment
d.s.e	Dry Sheep Equivalent
EBMP	Environmental Best Management Practice
EPA	Environment Protection Authority, Victoria
FIFA	Fertiliser Industry Federation of Australia
FNLI	Farm Nutrient Loss Index
GA	Greening Australia
GHCMA	Glenelg Hopkins Catchment Management Authority
GHNMP	Glenelg-Hopkins Nutrient Management Plan
GIS	Geographic Information System
DAP	Di Ammonium Phosphate
MAP	Mono Ammonium Phosphate
P	Phosphorus
PBI	Phosphorus Buffering Index – dependent on soil type
PP	Particulate Phosphorus
SEPP	State Environment Protection Policy
SOA	Sulphate of Ammonia
SWFMP	South West Farm Monitor Project
TP	Total Phosphorus
VWQMN	Victorian Water Quality Monitoring Network
WFP	Whole Farm Plan

Abstract

The improvement of water quality in the streams of the Glenelg Hopkins catchment is a priority of the Glenelg Hopkins regional strategy until 2009. A major source of water pollution in the region is associated with agricultural activities and the extensive use of fertilisers by local farmers. High nutrient levels are associated with blue-green algae (BGA) together with lowered water flows and raised water temperature. The incidence of blue-green algae in the Glenelg Hopkins region has the potential to increase, with the changes to land use that are occurring in South Western Victoria. Reduced rainfall, more frequent extreme rainfall events and higher temperatures associated with climate change are likely to exacerbate this trend.

The 2001 audit of nutrient loads to Australian rivers and estuaries estimated that the total export of phosphorus is estimated at 1.9 times the natural export that occurred before European settlement. Water testing data of the Total Phosphorus (TP) levels in the Hopkins River and at other sites within the Hopkins Catchment also indicate increasing incidence of TP above the Environment Protection Authority's target levels of 0.0325mg/l P for longer periods of each year.

Earlier research indicated that phosphorus in runoff increases when pasture fertility increases and that fertiliser management practices should be considered as an element of preventative action for reducing nutrient pollution. During our research, a survey was undertaken in the Hopkins River catchment, to determine the current management of phosphorus (P) fertilisers on grazing and mixed enterprise farms, the attitude of farmers to natural resource management and their understanding of nutrient pollution. The survey also gathered information on the way farmers made fertiliser management decisions. If cooperation relating to phosphorus fertiliser application could be facilitated between groups of farmers, it may be possible to reduce nutrient runoff into the Hopkins waterways.

Cooperative game theory has successfully been used worldwide in the resolution of environmental problems where there is an economic impact to the decision making process. In this project, the amount and the timing of phosphorus application were the parameters to be explored in the cooperative game theory model. However, in the final analysis the project was limited to the parameter 'the amount of fertiliser applied on farm' being used in the model. Dependent on the payoff function, the potential for cooperative action on phosphorus management by groups of farmers, is assessed in this work.

Analysis of the results of the survey included their use in game theoretic modelling, and the practicality of cooperative action based on the trade off between the economic cost of pollution to the region waterways and the economic production benefits to the individual. The outcome of this work will be individual optimal strategies for fertiliser application, allowing individual farmers to reduce the impact of agricultural production on the health of the catchment.

Involving the farmer groups, while undertaking the project, raised awareness amongst the farming population of the regional nutrient pollution caused by runoff from agricultural land, and enlisted their assistance towards adopting a cooperative approach to the problem. This supports the programs developed by Glenelg Hopkins Catchment Management Authority (GHCMA) to reduce nutrients in streams, principally TP, over 20 years beginning in 2002. In addition, the results have been mapped using a Geographical Information System (GIS) for visual presentation and to demonstrate the use of this process in natural resource management with the farmer groups.

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Chapter 1: Introduction

1.1 Outline of the Problem

Water is the life of the country; it provides sustenance for the natural environment and is essential to the community and for the economies of industry. Past practices of land clearing, drainage and excessive water extraction have led to a decline in the health of the waterways, with a lowering of water quantity and quality. The Glenelg Hopkins regional strategy calls for actions leading to the improvement of water quality in the streams of the Glenelg-Hopkins catchment as a major priority (Glenelg Hopkins Catchment Management Authority, 2003). While there is not a serious problem with blue-green algae outbreaks currently, there are indications of nutrient load problems within the waterways which potentially may lead to an increase in the number of blue-green algae (BGA) blooms within the catchment.

A major source of water nutrient pollution in the region is associated with agricultural activities and the extensive use of fertilisers by local farmers, which raises the levels of soil nutrients and increases the potential for nutrient pollution of waterways due to runoff and erosion. Prior to the local ‘agricultural revolution’ in the 1960s when super phosphate began to be added to the soils, together with the introduction of ‘improved’ pasture species, the properties in south west Victoria were based on low input, native pastures which did not require high soil phosphorus levels and ran only 1to 4 sheep/ha. Economic pressures dictated a move to higher output from the same area: changing land practices to high input grazing (prime lamb mostly), cropping and forestry were accompanied by an increase in fertiliser application.

This research focuses on the mitigation strategies to prevent rising phosphorus loads within the Hopkins River catchment which have the potential to increase the number of BGA outbreaks occurring. The phosphorus load in the streams of the Hopkins catchment may be influenced by different managerial strategies of the farmers within the region. An effective way of reducing the nutrient pollution therefore may be obtained through a community of farmers coordinating their fertiliser application schedules in a way that satisfies both the Catchment Management Authority (CMA) targets for pollution reduction in the region, and the fertiliser demands of crops or pasture. This led to the initial research question:

> ‘Is it possible to develop cooperative strategies for fertiliser applications amongst a community of farmers to minimise nutrient pollution of waterways in the region?’

For this project data collected from farmers was used to develop a Game Theory model which incorporated production economics and the cost to the environment. Dependent on the payoff (utility) function, the potential for cooperative action on phosphorus management by groups of farmers is assessed. Game theory has been used successfully in resolution of environmental problems worldwide. Where there is an economic impact on the decision making process, it offers the development of a cooperative approach to problem solving in resource management rather than a competitive approach to natural resource use. The outcome is the recommendation of an optimal amount and timing regime of fertiliser application for each individual farmer, allowing the farmer to reduce the impact of his agricultural production on the health of the catchment. Due to difficulty with obtaining precise 'timing' data on fertiliser application it was felt that initially the 'amount' of fertiliser would be used in the model described in this work.

Economics and the environment are inextricably connected, with natural resources becoming increasingly scarce and the impact on them by human activity often detrimental. Current economic accounting rarely includes the 'cost to the environment' in the final figures(Mahendrarajah and Warr, 1993). The project seeks to address this in relation to phosphorus management on mixed farming properties.

1.2 Aim of the Research

The aim of this research is to produce information on decision making in relation to fertiliser use. This information can be used in the Game Theory model to calculate optimal strategies on phosphorus fertiliser application amounts for the individuals within the group. If the results indicate a benefit to the individual and the community as a whole, and are seen as practical, then on a catchment wide basis this should lead to changes in management practices that will minimise phosphorus pollution of the Hopkins River catchment's waterways.

To model current fertiliser (phosphorus) application practices on a variety of properties with differing acreage, soil types, rainfall, land uses, nutrient loads and farmer attitudes to natural resource management several farmer groups in the catchment were consulted. The decision making process was examined and the potential for farmers to participate in cooperative action on nutrient pollution was assessed. A Game Theory approach was employed to model farmer behaviour in a competitive situation (Nash Equilibrium Profile) in comparison to a cooperative situation (Pareto Optimum), in order to assess the possible economic benefits of cooperative behaviour with reference to varying the amount of phosphorus application.

An Arcview™ Geographic Information System (GIS) has been developed to convey a visual representation of survey data and the Game Theory Modelling results. This will complement the research that has been undertaken and will add to the knowledge within the local region through greater awareness of tools available to the community for environmental and agricultural problem solving.

The work was undertaken to determine if it is possible to urge a local community of farmers to work together to bring about a change to a regional environmental problem where there are benefits for the greater community. If this can be demonstrated, then the benefits to the greater community through cooperative behavior at the individual level would impact on the approach to environmental problem solving. Community environmental problems impact on the economics of rural families and businesses, therefore cooperative community actions that assist in solving the problem, have both an economic benefit and a community benefit.

1.3 Thesis Outline

This thesis presents the use of Game Theory modelling as a means of cost benefit analysis for the application of phosphorus in a rural catchment and to develop recommendations on fertiliser application decision making. Data collected directly from farmers in the Hopkins River catchment was used for calculations. Below is a description of this thesis by chapter.

Chapter 1: Introduction

Chapter 1 presents a brief description of the background to the problem, the aims and scope of the research and an outline of the chapters.

Chapter 2: Description of Hopkins Catchment

Chapter 2 describes the biophysical and economic characteristics of the Hopkins River catchment in the context of the research which provides an idea of the land use, hydrological systems and economy driving the sustainability of the catchment. A description of the topography, geology and soils and climate which impact on the formulation of the Game Theory model are also given.

Chapter 3: Literature Review

Chapter 3 presents a literature review of the existing research into phosphorus pollution and the use of Game Theory in solving environmental problems. The chapter touches on current research regarding farmer attitudes to change of management practices that are required for sustainable farming.

Chapter 4: Background Documentation

Chapter 4 provides an overview of the Federal, State and Industry documents supporting reduction in nutrient pollution. The chapter explains the targets of the Glenelg Hopkins Catchment Management Authority (CMA), the fertiliser industry 'Codes of Practice', the Department of Primary Industries (DPI) recommendations and industry based recommendations on fertiliser use.

Chapters 2, 3 and 4 set the scene for the thesis, providing a description of the location, supporting documents and literary review of current research into the problem.

Chapter 5: Survey Descriptions

Chapter 5 presents a description of the data collection from three surveys and several workshops undertaken during the research and will describe the collation of mapping data used to support the project. This survey is a necessary part of the overall project, without it further practical implementation of the model is not possible.

Chapter 6: Survey Results and Discussion

The results of the surveys will be presented in Chapter 6 with a discussion of their use in the Game Theory model. A discussion of the response of the farmers to the Game Theory model recommendations completes the chapter.

Chapter 7: Game Theory Model Design

Chapter 7 describes the development of the Game Theory model. The use of data collected in the surveys and taken from other research documents, are coupled with the parameters selected for the model.

Chapter 8: Game Theory Model Results and Discussion

Results from the Game Theory model will be given in Chapter 8 with the GIS visual presentation. A discussion of the limitations and potential benefits of the Game Theory model are also given.

Chapter 9: Conclusion

Chapter 9 includes the concluding remarks on the survey results, the Game Theory model and the possible future directions for the research project. Potential conflict areas in natural resource management (NRM) and agriculture, where Game Theory modelling has an application in partnership with farmers, are also presented.

Appendices

Appendices 1, 2 and 3 contain the original Surveys 1, 2 and 3 with questions in full. Appendix 4 has the Game Theory formulation for phosphorus pollution of waterways.

Chapter 2: Hopkins River Catchment Profile

2.1 Introduction

The Hopkins River catchment was chosen as the study area, as representative of a rural catchment with environmental problems. As part of the research, which was conducted in conjunction with the Hamilton campus of RMIT University, and the Glenelg Hopkins Catchment Management Authority, which funded the study, a detailed survey of the region was undertaken. It was important to understand the biophysical attributes of the catchment as they contribute to the vulnerability of the catchment to future potential problems.

This section details a description of the Hopkins River catchment with reference to factors that impact on the parameters used in the Game Theory model and on the decision making that is undertaken by farmers in their annual nutrient management.

2.2 Biophysical Description of the Hopkins River Catchment

2.2.1 Location

The Hopkins River Catchment is found in the south west of Victoria, Australia. It "covers an area of 10,096 km² and extends approximately 160 km from its northern boundary to the Southern Ocean and is approximately 60 km wide" (Glenelg Hopkins Catchment Management Authority, 2004). The Great Dividing Range forms the northern slopes of the catchment. The catchment lies between latitudes 37º 20' and 38º 50'S and longitude 142º 30' and 143º75'E. Maps of Australia and Victoria with the Hopkins River catchment indicated are shown in Figure 2.1.

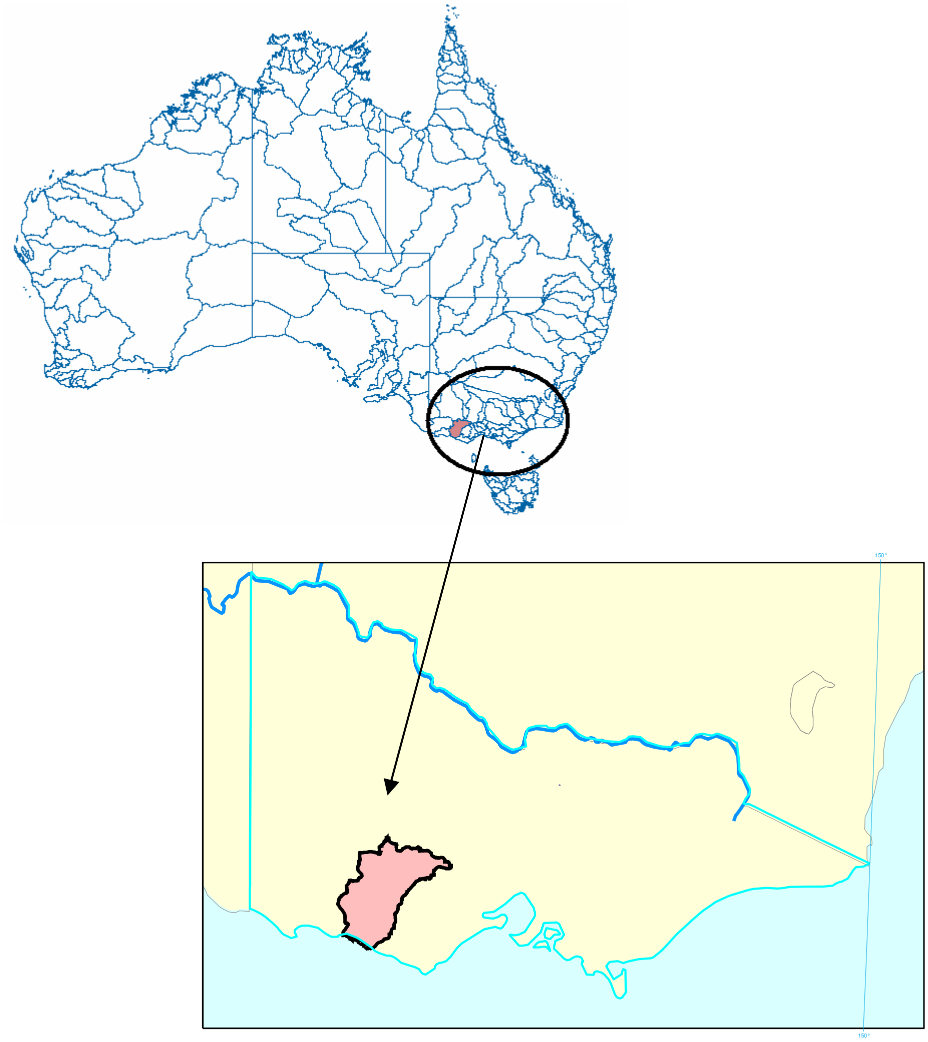


Figure 2.1: Maps of Australia and Victoria with the Hopkins River catchment marked

2.2.1.1 Towns

The main towns within the catchment are: Ararat (population 11,000) in the north, Warrnambool (population 32,000) in the south and Ballarat (population 85,000) in the east, although only a section of Ballarat falls within the Hopkins catchment. The region has numerous small rural towns ranging in population from 150 to 1,100. These can be seen at the conjunction of roads as shown in Figure 2.2.

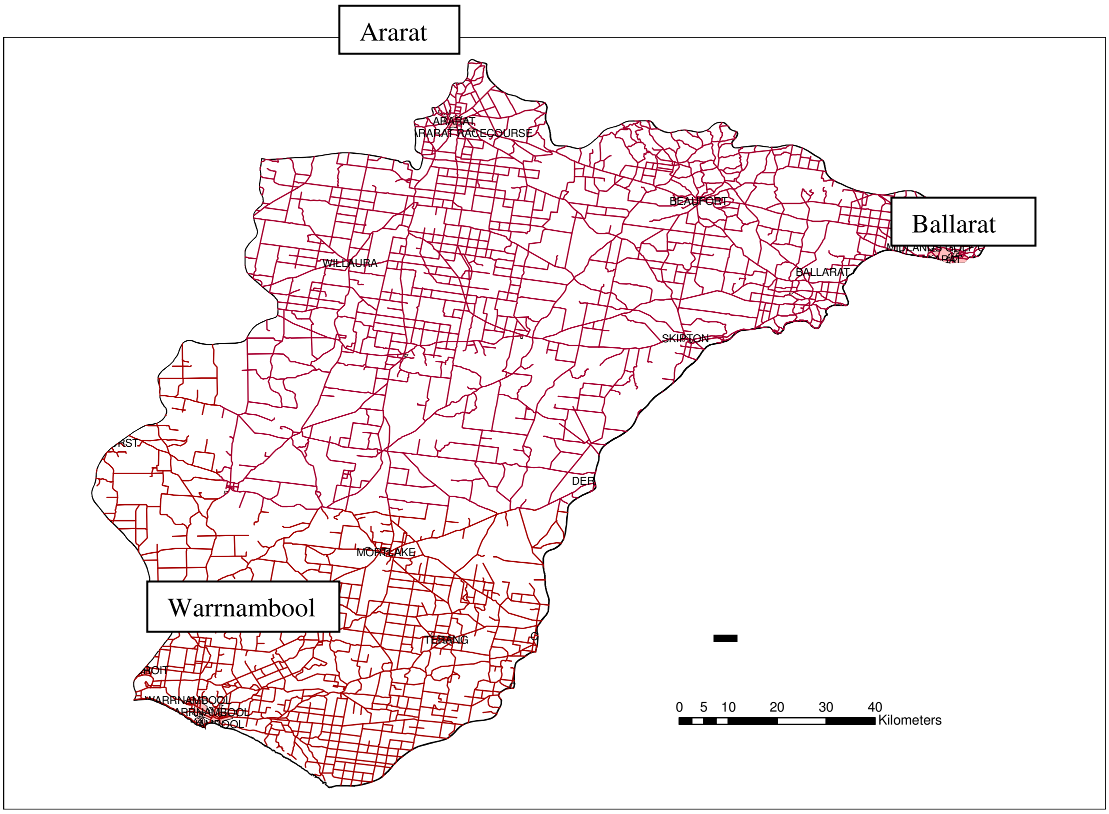


Figure 2.2 The Hopkins River catchment roads and towns

2.2.1.2 Water supplies

Water quality within the catchment is marginal to poor (see Figure 2.10) so the towns within the catchment are supplied with drinking water piped in from the Grampians range (to the north-west of the catchment) and the Otway Ranges (to the south-east of the catchment). Rural properties collect rainwater for domestic supplies and stock water is supplied by dams, bores or from unfenced access to the river and its tributaries. The water quality varies throughout the year, depending on the rainfall and subsequent flow rate; often high salt levels (3500-15000+ Electrical Conductivity (EC) units) are present, particularly in the summer months (much of the groundwater throughout the catchment also suffers from high salinity levels). Irrigation water for dairy and horticulture is accessed from the Otways and occasionally from groundwater if the quality is high enough. Groundwater monitoring is undertaken throughout the catchment with the main emphasis on salinity rather than nutrients.

2.2.2 Climate

The climate of western Victoria is considered to be Mediterranean, with cold wet winters and hot dry summers. It is characterised by winter temperatures of 3-7°C and summer temperatures of 23-26°C. Frosts occur frequently inland from April to September. The past ten years have shown a distinct drying pattern with average rainfall dropping by up to 10% and an increase in longer dry autumns and winter following summer thunderstorms. This is consistent with the predicted climate change data and will exacerbate any future potential BGA problems. The coastal plains do not show the variation in temperature and rainfall that is apparent inland due to moisture coming in off the ocean with the southwesterly weather patterns. Rainfall, as shown in Figure 2.3 varies in range from 550mm to 1100mm with an average of 700mm. The area of lower rainfall is consistent with the effect of a rain-shadow produced by the Grampians range, on the northwest edge of the catchment.

In calculating the Game Theory model, total annual rainfall was used for the animal (sheep and beef) enterprises and a proportion based on the crop growing period was used for the crop enterprises.

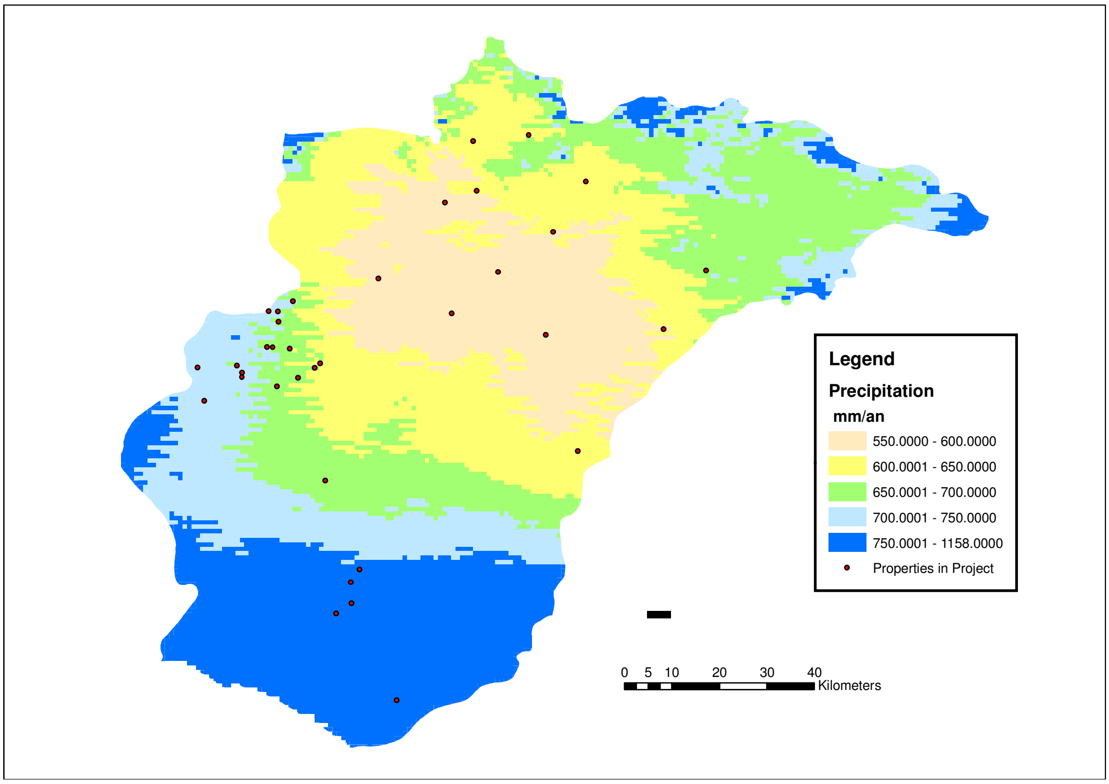


Figure 2.3 The Hopkins River catchment average precipitation map

Bureau of Meteorology rainfall intensity charts give a 'return rate' (i.e. the frequency in years) of intense rainfall events but do not indicate at which time of the year it is likely for intense rainfall events to occur. Rainfall intensity is relevant to the likelihood of nutrient runoff within four days of fertiliser application.

2.2.3 Topography

The Hopkins River catchment begins in the north on the southern slopes of the range which runs through the middle of Victoria. The highest point in the catchment rises to an elevation of 910metres and slopes southward to the Victorian volcanic plains (VVP) and finally to the Warrnambool coastal plain. The contour and digital elevation maps shown in Figures 2.4 and 2.5 indicate areas of steep hills and valleys in the north, west and a small area in the east. These areas are prone to erosion due to the slope and the underlying soil types, many of which have sodic B horizon characteristics. These areas also correspond to different vegetation bioregions.

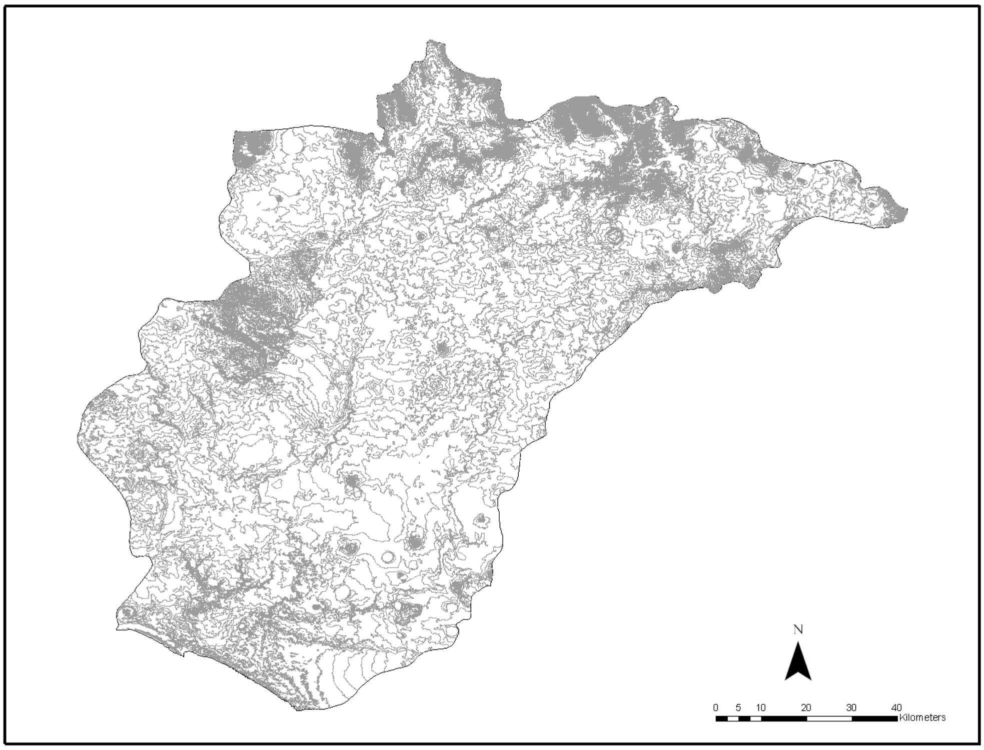


Figure 2.4: The Hopkins River catchment with elevation contour lines

The volcanic plains area of the river catchment is well punctuated with low areas that form wetlands. These may be permanent or ephemeral, and are often saline, with plant communities tolerant to salinity and water logging. Nutrient runoff from exposed paddocks is likely to concentrate in these low areas, many of which have been drained previously for cropping and grazing. Scoria cones, remnants of the volcanoes that formed the plains, are scattered across the region and the streams form deep creek beds cutting down into the easily eroded sub-soils. Removal of streamside vegetation, in-stream logs and the constant presence of stock have accelerated up the process of erosion, thereby exacerbating the problems with nutrient pollution, through release of nutrients from stream banks and sediments into the water.

The digital elevation map shown in Figure 2.5 gives an indication of the various aspect of slopes found within the catchment area. When calculating the proximity factor (β_{ij}) in the Game Theory model, elevation and slope together with position of the property in relation to wetlands and waterways will be used for future calculations.

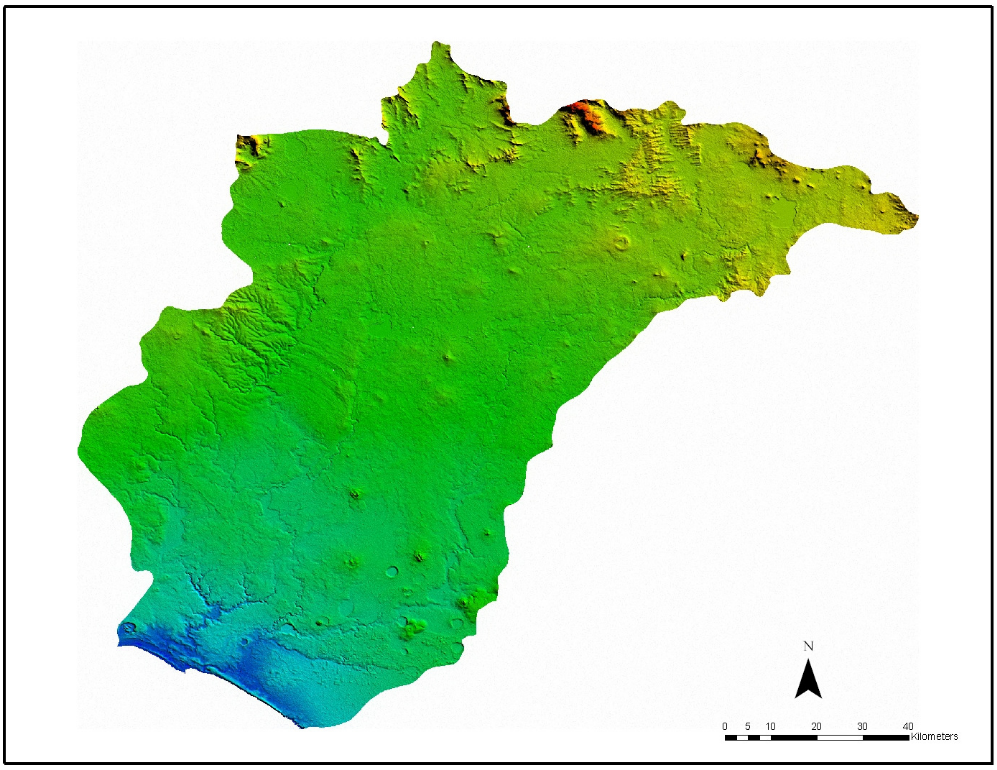


Figure 2.5: Digital Elevation Map
(Alizadeh Shabani et al, 2007)

2.2.4 Geology and Soils

The underlying geology of the catchment is shown in Figure 2.6. There is a mixture of parent geology from granite intrusions to sedimentary siltstones and sandstone and some alluvial deposition. Basalt from the volcanic period covers a large percentage of the region and was laid down during the Tertiary and Quaternary periods as were the coastal sedimentary soils and areas of marl. The sedimentary and granitic soils south of Glenthompson are older, from the Cambrian period, as are the sandstones of the Great Dividing Range near Beaufort. These older soils are prone to erosion particularly when adequate groundcover is not maintained. The area described as Glenthompson Duricrust has a high percentage of sand and sandy loams formed in the Cainozoic period. These soils are prone to wind erosion and are less likely to retain phosphorus, increasing the likelihood of ‘runoff’.

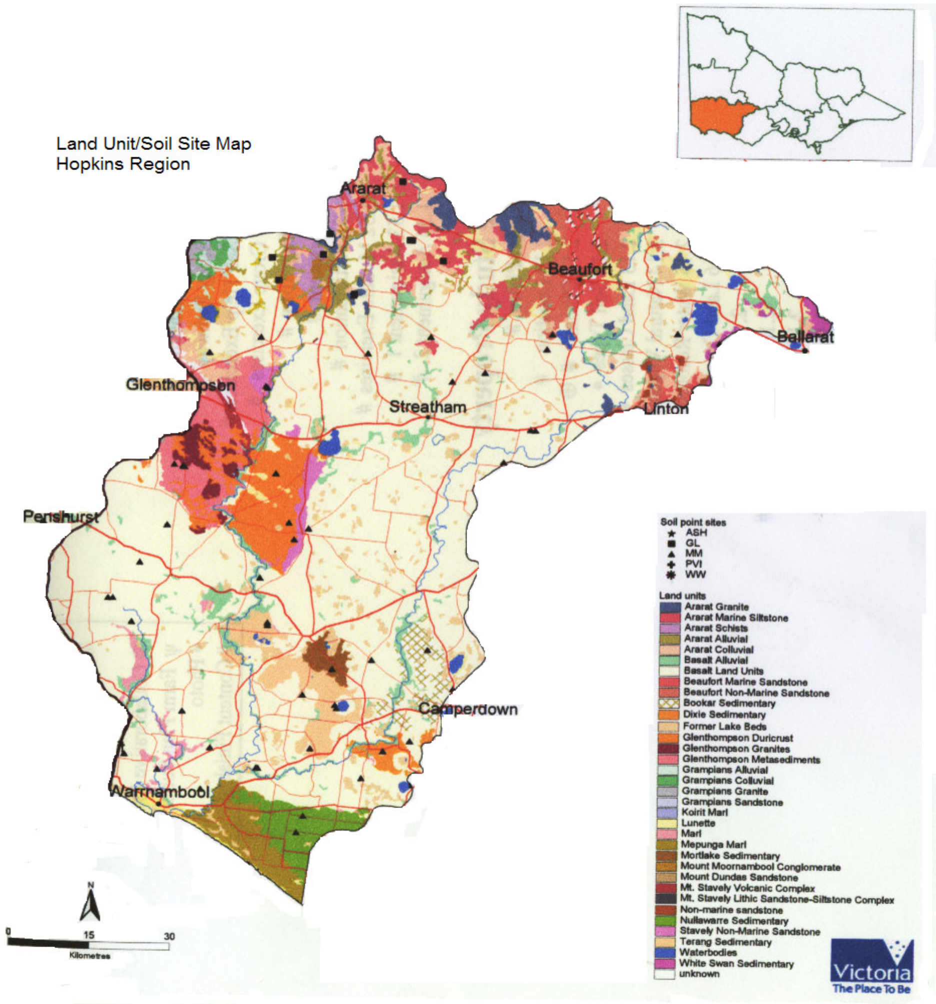


Figure 2.6 Soils Map

(Department of Primary Industries, 2004)

Most soils in the region are considered to be arable, hence the high percentage of land use for agriculture, although there are areas prone to erosion based on slope and soil type. Surface soils of the participating farms range from granite sands, sandy loam, loam and clay loam through to medium clays. The latter are often found in association with water-logging and salinity in low lying areas. Figure 2.7 shows the surface soil descriptions which can be corroborated with the landholders own observations. The basalt soils have a greater level of clay component which reduces the potential for erosion and nutrient runoff. The sedimentary soils generally have a higher sand component and as a result are freer draining and therefore may be prone to nutrients leaching into the groundwater.

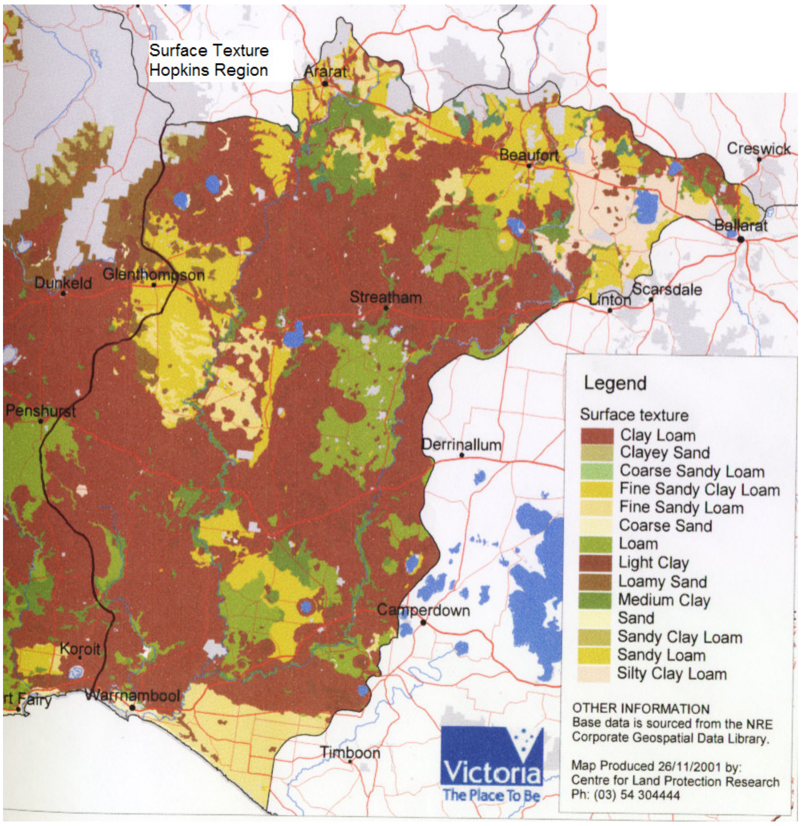


Figure 2.7 Soils – Surface Texture
(Department of Primary Industries, 2004)

2.2.5 Hydrology

> 'The mean annual flow of the Catchment is approximately 400,000ML, almost 2% of the state of Victoria's total discharge' (Glenelg Hopkins Catchment Management Authority, 2004)

The Hopkins River begins near Ararat (in the north) and flows south to enter the ocean at Warrnambool, after travelling 259 km. Its major tributaries are Mt Emu Creek – flowing from the north-east near Ballarat, and Fiery Creek which flows from the north into Lake Bolac and continues its journey south as Salt Creek to join the Hopkins River just south of Hexham. The Merri River is an independent river within the Hopkins catchment. It starts near Penshurst and flows in a south-easterly direction to join the ocean near Warrnambool. Figure 2.8 shows the hydrology of the catchment with the main tributaries labelled.

The wetlands scattered throughout the volcanic plains are a feature of the region. Many of these have high salinity readings and are closed systems hence phosphorus runoff will concentrate in these areas. Many of the original wetlands have been drained for agricultural pursuits.

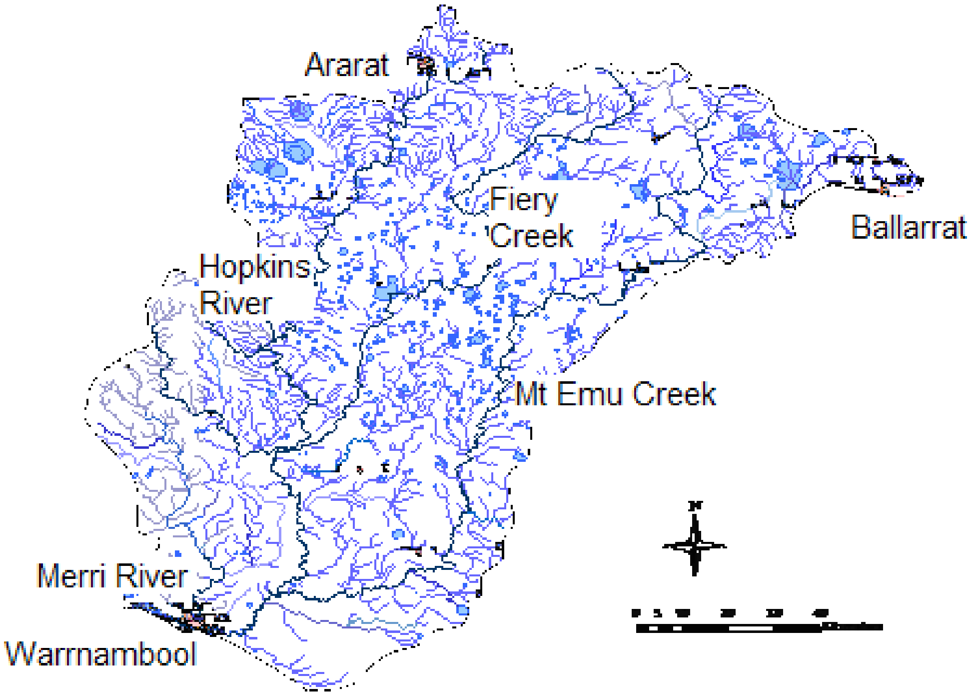


Figure 2.8 The Hopkins River catchment streams and wetlands

2.2.5.1 Monitoring Sites

Surface water monitoring has been undertaken at ten sites within the catchment, however regular monitoring of phosphorus has only been undertaken at seven sites, indicated in Figure 2.9. Groundwater testing is undertaken at numerous bores within the region, but does not include for Phosphorus. Readings from these sites are discussed in Section 2.2.5.2.

This lack of consistent monitoring throughout the catchment makes it difficult to assess the results of changes to management on farms over a short period of time and within specific sub-catchments. The increased interest in the environment and environmental auditing by State and Federal government departments should lead to more monitoring being undertaken in the future.

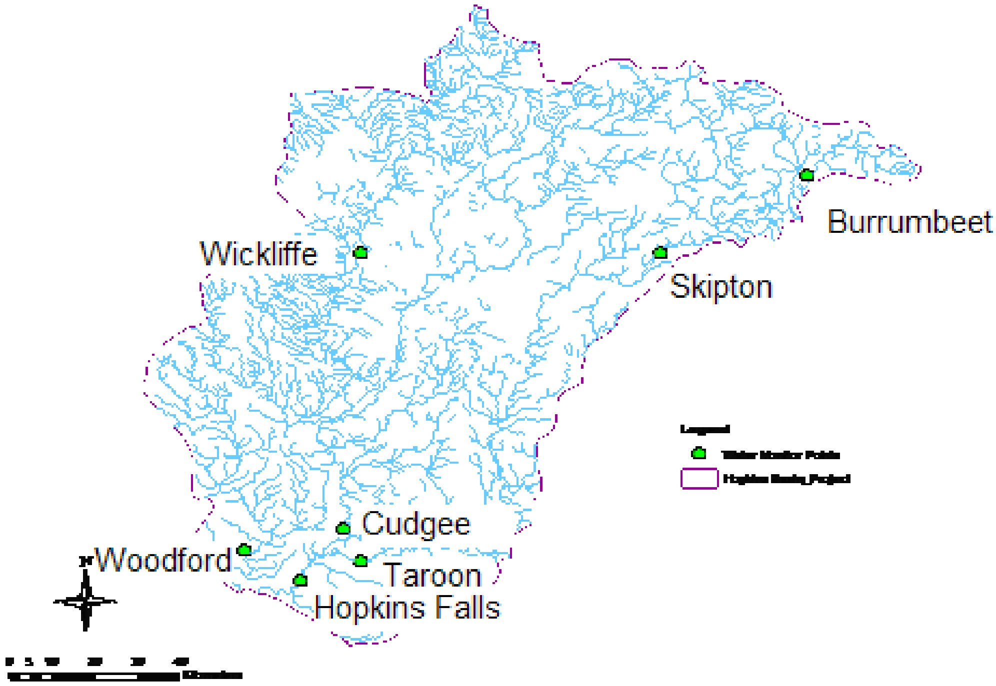


Figure 2.9 The Hopkins River catchment surface water quality monitoring sites

2.2.5.2 Environmental Condition of the Hopkins Catchment

The water quality of the Hopkins River catchment is generally poor. Naturally high salinity levels and clearing along the waterways since European settlement has led to increased erosion and high turbidity of the water. Removal of logs and snags from the river has exacerbated the erosion and hastened the loss of riparian vegetation. Although salinity has been a part of the system historically, levels are thought to have risen due to land clearing practices.

'Landcare', a community approach to land restoration, has had an impact on the region within the past 25 years with many farmers becoming involved in the planting of native vegetation along streams. This vegetation provides stock with shelter and at the same time adds to biodiversity and increases the level of perennial vegetation in the catchment. Water quality generally improves when the speed at which the water flows through a catchment is reduced and allowed to filter through vegetation. The Glenelg Hopkins Catchment Management Authority (GHCMA) has encouraged the fencing off of waterways and planting of native vegetation within the area, to address the problems of erosion and lack of biodiversity, with the aim of improving water quality. Figure 2.10 shows the current water quality ranking of the rivers and tributaries of the Hopkins River catchment.

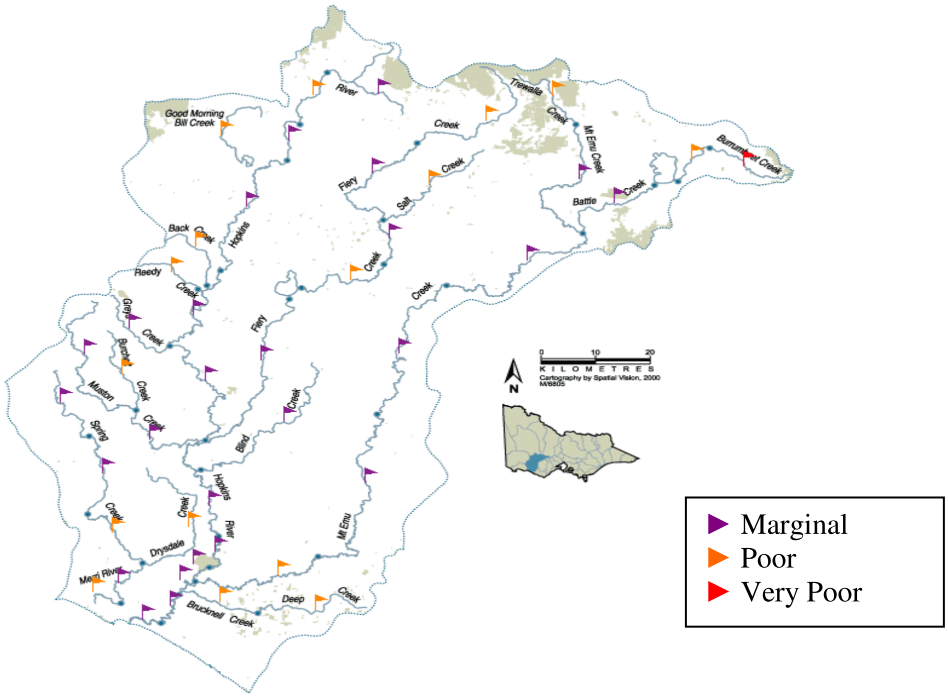


Figure 2.10 Water quality assessment of the Hopkins River catchment
(Victorian Water Data Warehouse, 2006)

In the Hopkins region, the Environment Protection Agency's (EPA) Total Phosphorus (TP) target levels are 25-40µg/L, depending on the nutrient region (see Section 3.2.3). Water phosphorus levels taken at the monitoring sites in the Hopkins River catchment, and available on the Victorian Water Data Warehouse website, are shown in Figures 2.11(a –g). The figures indicate that the TP levels in the Hopkins River and its tributaries are increasingly above the EPA target levels. Figure 2.11(h) shows the declining water flows experienced from 1996 to 2006.

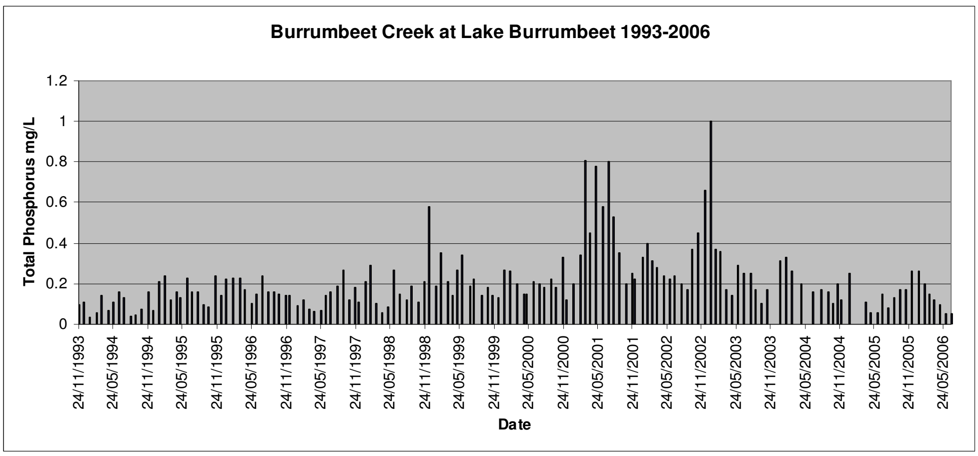


Figure 2.11 (a) Total Phosphorus levels. Burrumbeet Creek at Lake Burrumbeet

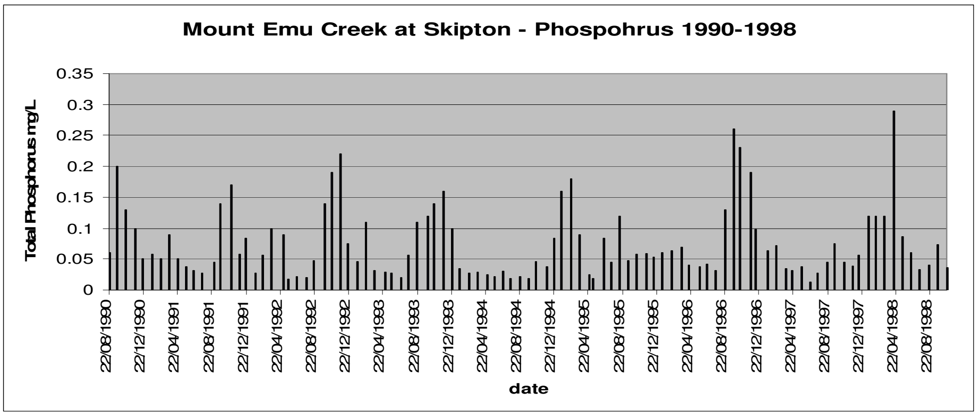


Figure 2.11(b) Total Phosphorus levels. Mount Emu Creek at Skipton

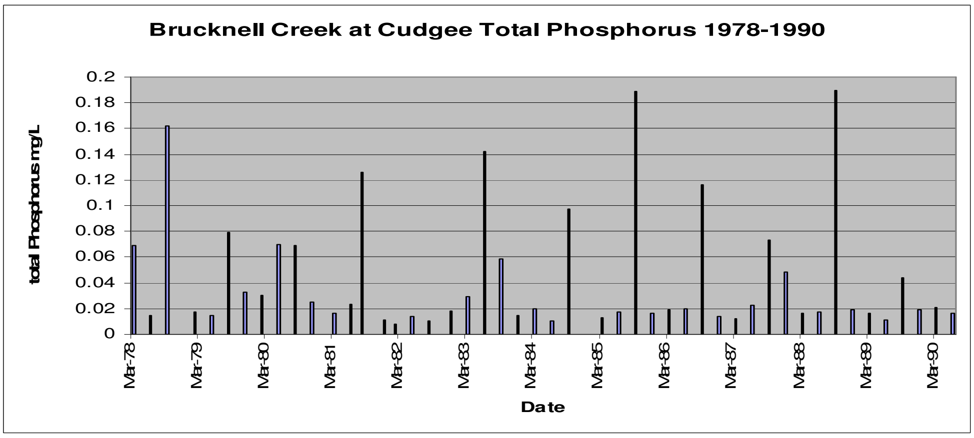


Figure 2.11(c) Total Phosphorus levels. Brucknell Creek at Cudgee

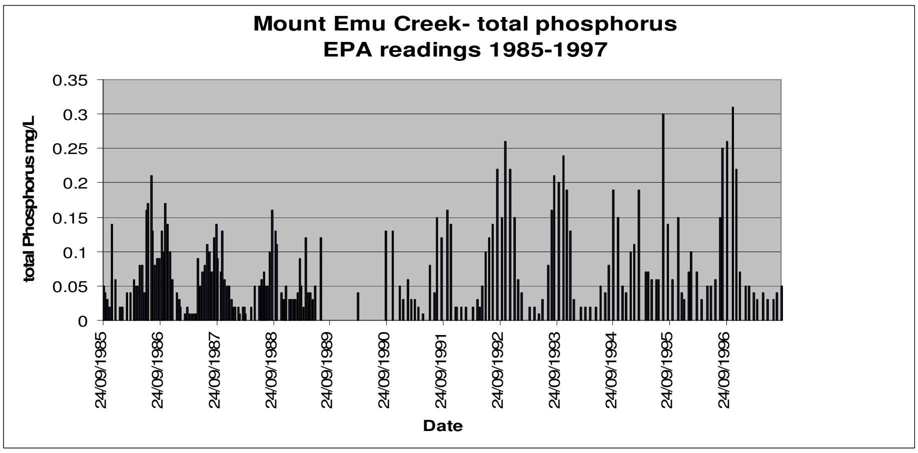


Figure 2.11 (d) Total Phosphorus levels. Mount Emu Creek (EPA readings)

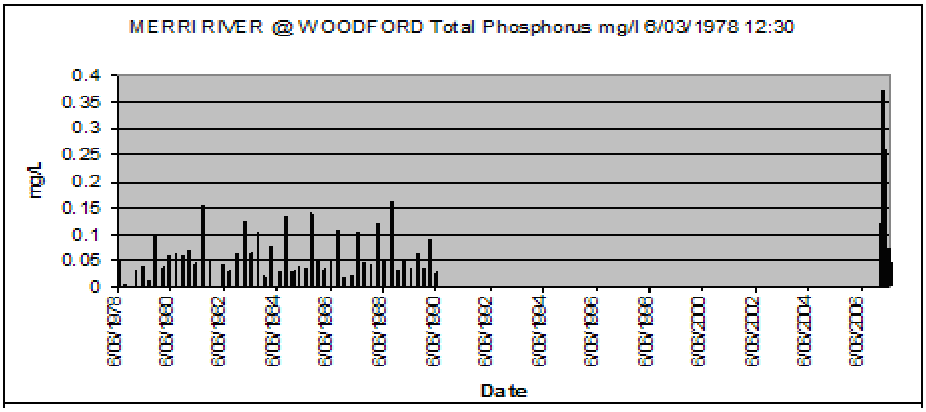


Figure 2.11 (e) Total Phosphorus levels. Merri River at Woodford

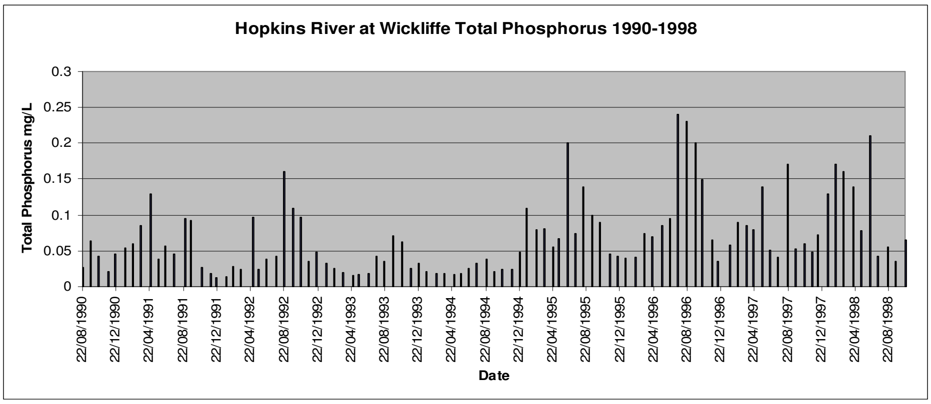


Figure 2.11 (f) Total Phosphorus levels. Hopkins River at Wickliffe

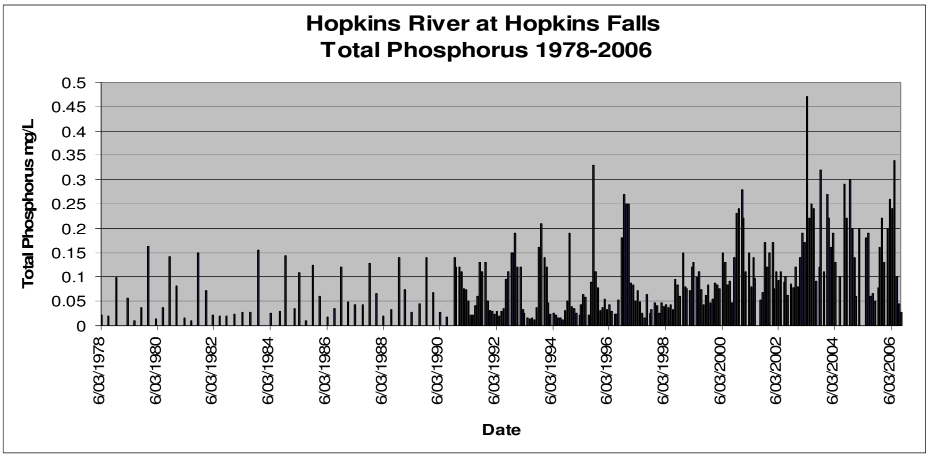


Figure 2.11 (g) Total Phosphorus levels. Hopkins River at Hopkins Falls

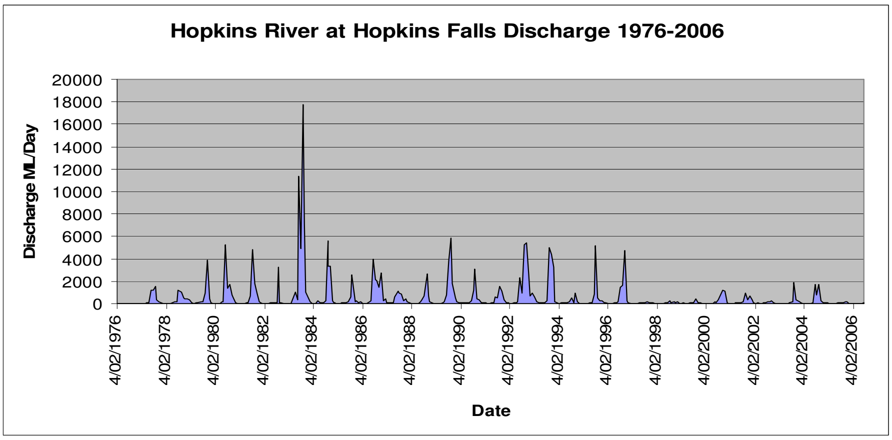


Figure 2.11 (h) Discharge of Hopkins River at Hopkins Falls

Figures 2.11 (a) to (g) indicate fluctuations in TP levels at numerous sites within the Hopkins River basin. The theory that phosphorus is stored in the stream sediments and released by water disturbance during high water flow events is supported by the high TP levels recorded during spring and/or autumn rainfall events (Baldwin, 2002).

2.2.5.3 Occurrence of blue-green algae outbreaks in the Hopkins catchment

There have been documented occurrences of blue-green algae outbreaks in the Hopkins River catchment in the period from 1920 - 2000; however it is unknown how many small outbreaks may have not been documented because they have occurred on private property that have not impacted beyond the boundaries of the property. Table 2.2 gives the location and the species of BGA present in each outbreak, with the response or treatment undertaken to deal with the problem. Figure 2.12 shows the position in the catchment of the recorded BGA outbreaks.

Drainage Catchment	Location	Algae	Comments and action
Hopkins	Alexander Lake	*Anabaena* and *Microcystis*	
	Caramut Reservior	*Chroococcus*	Ongoing monitoring
	Caramut Water Supply	*Ulothrix* and *Euglena*	Ongoing monitoring
	Deep Lake	*Microcystis*	Warning signs in place
	Green Hill Lake, Ararat	*Microcystis*	Drinking, recreation facilities banned
	Hopkins River, Boonerah	Unicellular green	Ongoing monitoring
	Lake Burrumbeet	*Microcystis* and *Oscillatoria*	Closed to recreation
	Lake Cartcarrong	*Anabaena*	
	Lake Gellie	*Oscillatoria*	Warning signs in place
	Lake Gillear	*Anabaena*	Warning signs in place
	Lake Terrinallum	*Oscillatoria*	Warning signs in place
	Mt Ewen Reservoir	*Anabaena*	CuSO4 treatment
	Tank Hill Reservoir	*Struastrum*	CuSO4 treatment

Table 2.1: Occurrence of blue-green algae outbreaks in the Hopkins catchment 1920 - 2000

(Glenelg Hopkins Catchment Management Authority, 2002)

Figure 2.12: Occurrence of blue-green algae outbreaks in the Hopkins catchment 1920 - 2000

(Department of Primary Industries, 2006c)

2.2.6 Remnant Native Vegetation

The Hopkins catchment supports a wide range of agriculture from cropping and grazing in the north to dairy and horticulture in the south. The remaining natural vegetation remnants only occur in any measure, in the north of the catchment along the southern side of the Great Dividing Range and infrequently in pockets throughout the rest of the catchment, generally in association with the waterways or as remnants along the road system. Native grasslands, which once dominated the plains, have been decimated and less than 1% remains. Figure 2.13 shows the areas of larger remnant vegetation such as forest and woodlands. The map does not indicate native grasslands as many occur as pockets on private property, along roadsides and rivers.

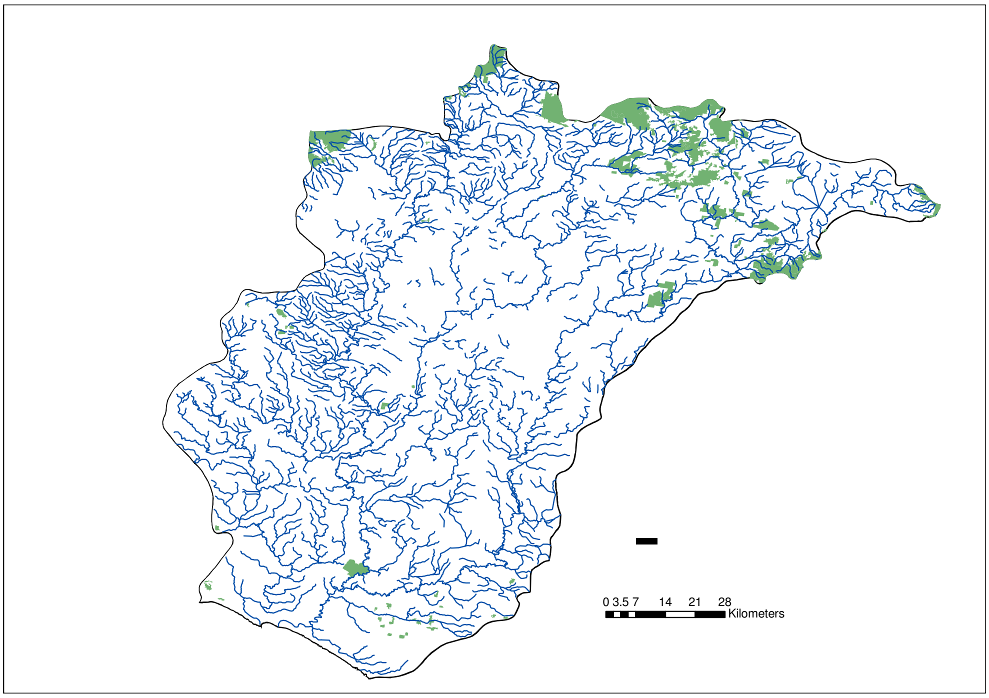


Figure 2.13: Map of remnant vegetation cover in the Hopkins catchment

2.3 Description of Farming Community

2.3.1 Landuse

As indicated previously, 94.8 % of the Hopkins River catchment supports a wide range of agriculture practices including cropping, prime lamb, wool, beef, dairy and horticulture (generally potato growing). There are approximately 1350 farming properties within the Hopkins River catchment and average farm size is 976ha (D Borg, DPI, personal communication).

According to Read et al, 1999 the predominant agricultural activity in the Glenelg Hopkins catchment in 1999 was dryland grazing, accounting for 755,029ha (68.2%), and cropping accounting for 58,982ha (5%). Since the 1990s there has been a swing away from dryland grazing into cropping and other activities. Recent research indicates a swing of 13.06% across the Glenelg Hopkins region away from dryland grazing (Ierodiaconou et al, 2004) and a 6.88% increase in acreage of grain crops. There has also been a marked increase in bluegum plantations for wood chip production, which occurs predominantly in the Glenelg and Portland catchments due to more suitable rainfall and soil types. However, this industry is now moving into the lower and eastern Hopkins region.

Horticulture, predominantly potato growing, accounts for 891ha is undertaken near Koroit in the south and near Ballarat in the east, with the use of groundwater for irrigation. Dairying is undertaken in the higher rainfall region in the south on the Warrnambool Plains and accounts for 225,789ha, 20.4% of all agricultural land (Read et al, 1999). These activities are supported with irrigation water from the Otway Ranges.

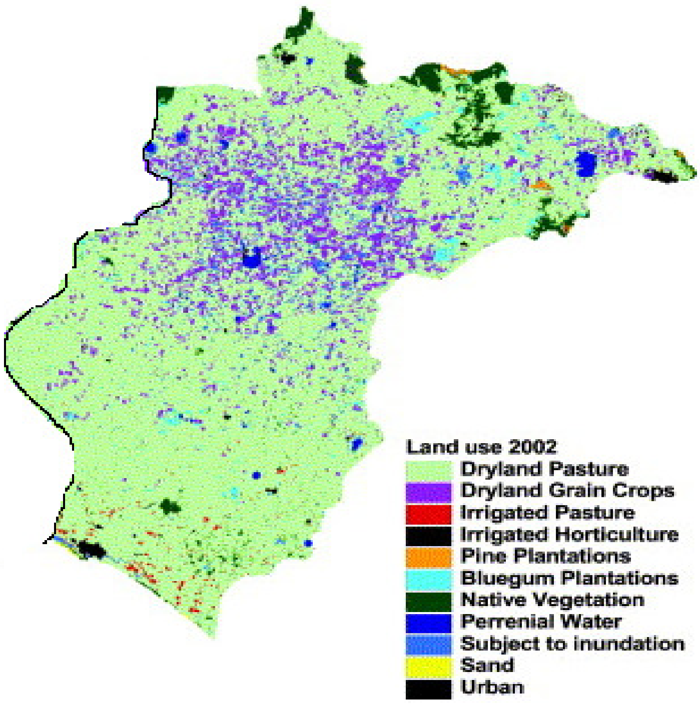


Figure 2.14 Landuse
(Ierodiaconou et al, 2004)

The Hopkins catchment also supports an eel industry, which is concentrated on the Salt Creek system with Lake Bolac as an important habitat refuge. However, as a result of the past ten years of dry climate, Lake Bolac has been suffering lower water levels and the industry has been substantially reduced.

2.3.2 Economic Information

It is difficult to establish the actual population of the Hopkins River catchment, as the statistics do not fit neatly into the area. The Bureau of Statistics indicates that the population of the Hopkins region is 33,122 (2004), however the city of Warrnambool is quoted as 32,000 and Ararat as 11,000. Terang has a population of 1,100 and Mortlake, Skipton and Beaufort each have 200 to 400 in population and there are other smaller towns besides. The northern section of Ballarat falls into the Hopkins catchment but it is not possible to estimate the number of people that live within that specific egion, as separate from the total population of Ballarat.

Statistics indicate that approximately 4,728 people in the region are employed in the agricultural sector. This equates to 36.5% of the total population (12,025) of the Hopkins region in employment in 2006 (Bureau of Statistics, 2006).

VALUE OF AGRICULTURAL PRODUCTION –
Hopkins Region (year ended 30 June 2001)

Value of crops	$m 111.9
Value of livestock slaughtering and other disposals	$m 197.7
Value of livestock products	$m 507.1
Total value of agriculture	$m 816.7

Table 2.3 Value of agricultural production 2001
(Bureau of Statistics, 2006).

2.4 Farmer Groups

Department of Primary Industries (DPI) extension services have operated within the Hopkins region for many years and in the 1980s there was an effort to improve on-going professional development of the farming community. As a result, a number of farmer groups that are active in supporting the community with research, education and awareness of new technology have been established.

The South West Farm Monitor Project (SWFMP) group is a benchmarking program that began in the 1970s. Farmers are able to anonymously compare their financial data with other farmers with similar enterprises. In any one year, 30 to 40 properties are involved, filling in a standardised form with their financial information. A report is generated which enables the farmer to compare his inputs, production figures, gross margins, profitability and return on assets with other properties. The properties can run a mixture of enterprises and can compare each enterprise individually. Farm 500 is a similar organisation of groups that focus on the financial data of the farming operations, although it is usually locally based and the members meet to share financial data therefore the data does not remain anonymous within the group.

The Bestwool / Best Lamb groups were formed under the umbrella of the DPI and the Victorian Farmers Federation (VFF) with the aim of improving the productivity of wool and meat sheep properties. Each group is able to choose its facilitator and the topics that are investigated. For example, in the Glenthompson region the group originally ran a ‘Paired Paddock Program’ (Triple P), which enabled farmers to make changes on paired paddocks and follow the changes in production through the group. This has led to a range of further programs, including addressing social issues such as succession planning, change of enterprise issues, research (e.g. into lambing problems), professional development and ongoing education (Bestwool/Bestlamb, 2008).

Southern Farming Systems (SFS) arose out of a need for farmer-initiated on-ground research into cropping practices in higher rainfall regions. The organisation commissions practical research to be undertaken on farm land within the regions. Research into cropping and grazing has been initiated and issupported by industry groups such as the Meat and Livestock Association (MLA), Australian Wool Innovation, Grains Research and Development Corporation, and the government through research grants (Southern Farming Systems, 2008).

The Landcare movement began at St Arnaud, just north of the Hopkins catchment and the concept spread south through the region throughout the 1990s. The community - based groups developed to address environmental degradation within a local area; each group focusing on local problems and undertaking measures to resolve them themselves. Technical support is provided by the Department of Sustainability and Environment (DSE), the Department of Primary Industries (DPI), Greening Australia (GA) and Landcare Australia. Financial help in the way of government grants is now administered by the Catchment Management Authority (CMA) in each region. Although not official education groups, they also have a role in disseminating information regardingtechniques for effective tree planting, pest and weed control and environmental best practice. In this region the Environmental Best Management Practices (EBMP) Program was initiated by the DPI and trialled with the Landcare groups in 2002 and 2003.

Chapter 3: Literature Review

3.1 Introduction

This project set out initially to assess the decision-making process adopted by the farm managers of one catchment area in regard to fertiliser usage (specifically phosphorus fertilisers). Applying Game Theory modelling to this information, optimal strategies on the amount of phosphorus fertiliser to be applied could be calculated. If the result of the modelling were both beneficial and practical for the individual and the community as a whole, a change in management practices could be expected, thus minimising phosphorus pollution of the waterways.

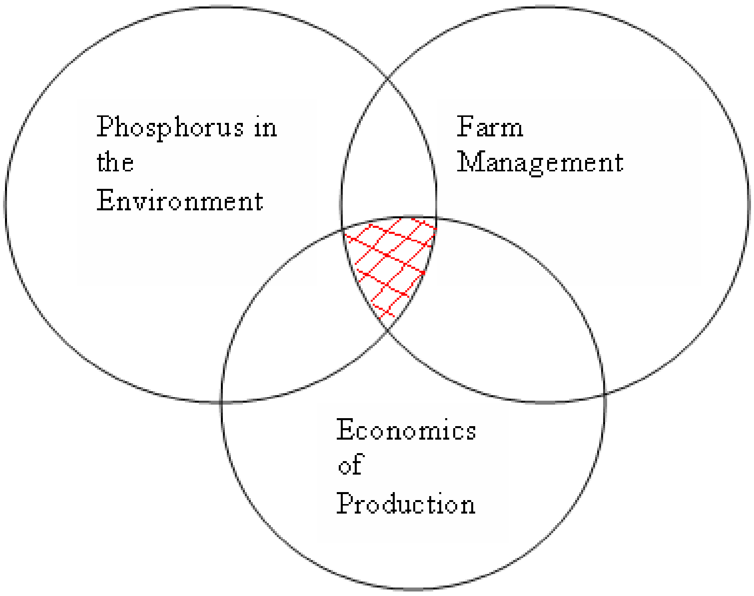


Figure 3.1 Thesis overview

Figure 3.1 represents the research diagrammatically,namely, the interaction of the 'problem to be solved', the 'means of achieving it' and the 'economic impact on production'. The research is concerned with modelling this interaction (the hatched section) so that recommendations can be made to farm managers that are economically sound in terms of production, but also take into account minimising the physical impact on the environment.

Cooperative game theory has successfully been used in resolution of environmental problems worldwide where there is an economic impact to the decision-making process. Most environmental problems present as a variation of the 'Tragedy of the Commons'. The metaphorical account of individually using public common land for their stock, and not realising the effect of adding ‘just one more of their own stock’ until the impact of each in the group adding ‘just one more’ leads to overgrazing of the common land as a whole and ultimately the breakdown of the system, with the individual suffering economically and the environment destroyed. The conflict between the individual usage and the impact on a ‘public resource’ is thus described.

> “In economic jargon, the costs are externalized. Individually rational behaviour deteriorates into collective ruin”(Ridley and Low, 1993).

Environmental conflicts tends to arise through‘resource sharing and overuse’ or ‘pollution produced by one group impacting on others’. In the case of the Hopkins catchment, each farmer is contributing to the impact of nutrient pollution of the rivers in the region through actions that benefit his/her own production.

The literature review begins with the background to the problem of phosphorus enrichment of waterways from non-point sources. The principles of Game Theory as applied to natural resource management are then outlined. Research into attitude’s of the farming community to changing management practices necessary for the good of the environment will be described with a view to identifying the likely uptake of new management techniques as recommended by the research results.

3.2 Background to Phosphorus as a Potential Pollutant to the Environment

Phosphorus is an essential nutrient in biological systems, being critical for the replication of cells. In agriculture, it is cycled through the soil plant system and is removed through products leaving the farm. Australian soils are very old and usually low in phosphorus, hence the need for farmers to add phosphorus to agricultural soils for improving production. Department of Primary Industry soil tests in the 1970s on un-fertilised soils indicated Colwell P levels of 3-11mg P/kg (Department of Agriculture, 1975). To avoid depleting the agricultural system of phosphorus, it must be replaced artificially, with food additives for animals, or chemical fertilisers and/or manures added to the soil. Generally this occurs annually. The addition of nutrients inappropriately may lead to excess runoff into catchment water systems, resulting in lowered water quality and a detrimental effect on environmental habitats. In extreme cases, this may promote the growth of undesirable algae and cause toxic algal blooms leading to widespread undesirable economic and environmental impact.

Testing of soil phosphorus is commonly used by farmers as the basis for assessing the amount of phosphorus to be applied as fertiliser. Soil type, crop requirements and climatic conditions govern the critical soil value for optimum crop yields (Leinweber et al., 2002). There are more than ten different soil tests available for calculating soil phosphorus (P), although in Australia the common tests used in agriculture are the 'Olsen P' and 'Colwell P'. The Phosphorus Buffer Index (PBI) is also reported in soil test results (Burkitt et al, 2002). The PBI gives an indication of the soil's ability to tie up phosphorus, ie make it unavailable for plant use. Soils with high aluminum, iron and manganese have a high PBI as sorption of phosphorus occurs making it unavailable for plant use. Sands tend to have a low PBI. Sandy soils with low phosphorus sorption capacities will demonstrate greater phosphorus movement and therefore are more susceptible to P loss (McDowell et al., 2002). Farm soil testing for P levels is not a good indicator of likely phosphorus runoff, due to the depth at which testing occurs, namely at 10 cm where it is more relevant for production yield than for runoff, which occurs from the top 2.5 cm.

3.2.1 Movement of P from soil to water

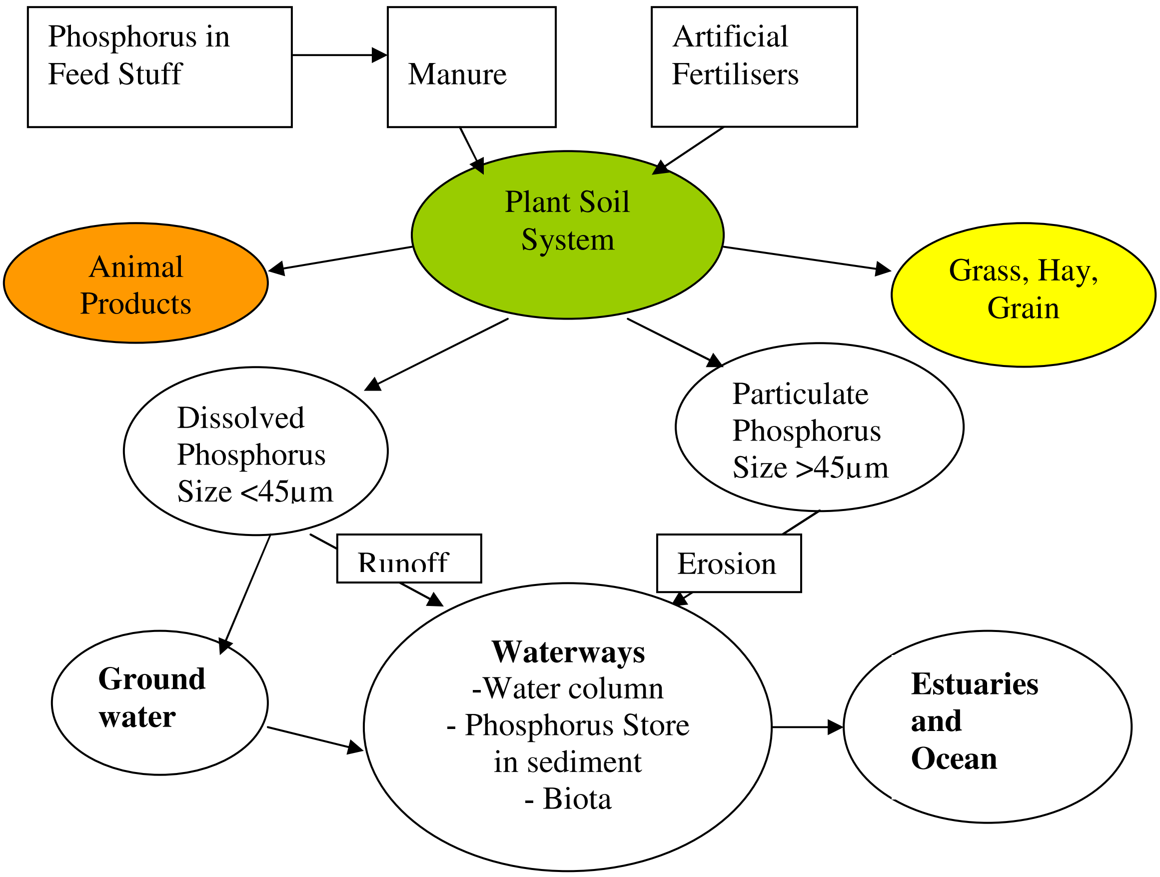


Figure 3.2 Movement of phosphorus through the plant soil system

The transfer of phosphorus from soil to water is described in general terms in Figure 3.2. It is complex and is influenced by many factors including:

- the form of phosphorus
- mechanism of release from soil

- transport processes (erosion, surface water runoff and subsurface water)
- soil type (sorption capacity)
- soil management – influencing erosion (vegetative cover)
- type of input (chemical or organic) (Haygarth and Jarvis, 1999, Leinweber et al, 2002, McDowell et al., 2002, Drewry et al, 2006).

TP in soils is made up of reactive phosphorus (RP) and unreactive phosphorus (UP). It is also defined by the size of the fractionation ie < 0.45µm or > 0.45µm. Generally speaking, dissolved phosphorus (DP) found in runoff is < 0.45µm and is readily available to aquatic organisms (Robertson and Nash, 2007). As much of the phosphorus found in runoff is in the dissolved form, it is unlikely that buffer areas along waterways will substantially reduce phosphorus entering the waterway, particularly as runoff occurs most when soils are saturated (Nash and Murdoch, 1997, McDowell et al, 2004). Drewry et al, (2006) suggest that riparian vegetation may have limited long term use in removal of nutrients and may eventually become a source of nutrient runoff from nutrient build up over time. Particulate phosphorus (PP), which is phosphorus attached to clay soil particles, is > 0.45µm and this becomes available over a longer period as de-sorption of the phosphorus from the clay particles needs to occur. Leinweber et al., (2002) describe the factors that affect de-sorption as pH, temperature, ionic strength, the rate of water movement through the soil and the equilibrium phosphorus concentration.

> The chemical composition of the sediments dictates number and type of P sorption sites…. Brinkman (1993) suggests that the most important sites for anion adsorption are surface coatings of Fe3+ and Al oxides and oxyhydroxides….the extent of binding will depend in part on the pH of the solution, the number of exchangeable hydroxyl groups per unit of area of sediment and the specific surface area of the sediment (Baldwin et al, 2002).

Phosphorus moves from farmland to waterways via several routes. It can travel overland in runoff when intense rainfall occurs within four days of fertiliser application; it can travel as PP due to soil erosion; as DP in surface water; and it can move through subsurface pathways into the groundwater (minimal). The amounts of phosphorus lost in runoff from farming depends on release and transport factors such as slope, vegetative cover, rainfall, rainfall timing in relation to fertiliser application (the half life of phosphate fertilisers in relation to export is four days), and soil type (see Section 3.2 'sorption capacity'). Most phosphorus available for export by overland flow is in the top 25mm of soil only (Nash, 2007, Nash, 2004). Fertilisers that have been applied in previous years are found to supply the bulk of the phosphorus used by crops and much of the nutrient runoff flow is the result of increased systemic P built up in the soil from past fertiliser applications (Robertson and Nash, 2007). Indeed, systemic P soil levels are already at a height which makes the EPA target levels in the waterways difficult to achieve (Nash, 2007). The DPI data from 1975 supports this view (see Section 3.2). The amounts of phosphorus exported from the paddock varies considerably from year to year depending on management (e.g. grazing pressure, vegetative cover, crop management) and seasonal conditions (Nash, 2004).

Poorly timed agricultural processes contribute to lossof soil from paddocks due to rill and gully erosion thereby increasing phosphorus loss from the paddock. An increase in the time a paddock is bare, due to cropping, may exacerbate the likelihood of erosion since periods of maximum rainfall can occur at the time of sowing and before the crop is established. A no-till cropping system reduces the potential for P loss because vegetative cover reduces overland water flow, and the addition of gypsum to soils improves drainage and has been shown to reduce P solubility without significantly reducing plant-available P (McDowell et al., 2002). Water logging during the winter period, when the crop uptake is small, may also increase soil to water P transfer. Artificial drainage has an overall effect of reducing P transfer from the land, by as much as 30% compared with undrained plots (Leinweber et al., 2002), however it may contribute to increases of P leaching into the groundwater.

Research into the impact of raised bed cropping on nutrient runoff is currently being undertaken in south west Victoria due to the drainage implications in the region and the likelihood of increased nutrient runoff due to reduced infiltration. There has been a major shift to this form of agriculture away from grazing. The changes to land use, mapped using satellite data from 1980 to 2002, show a 16% alteration to traditional farming practices (Ierodiaconou et al, 2004). Estimates of increased nutrient loading have been given for each sub-catchment. These are shown in Figures 3.3 and 3.4.

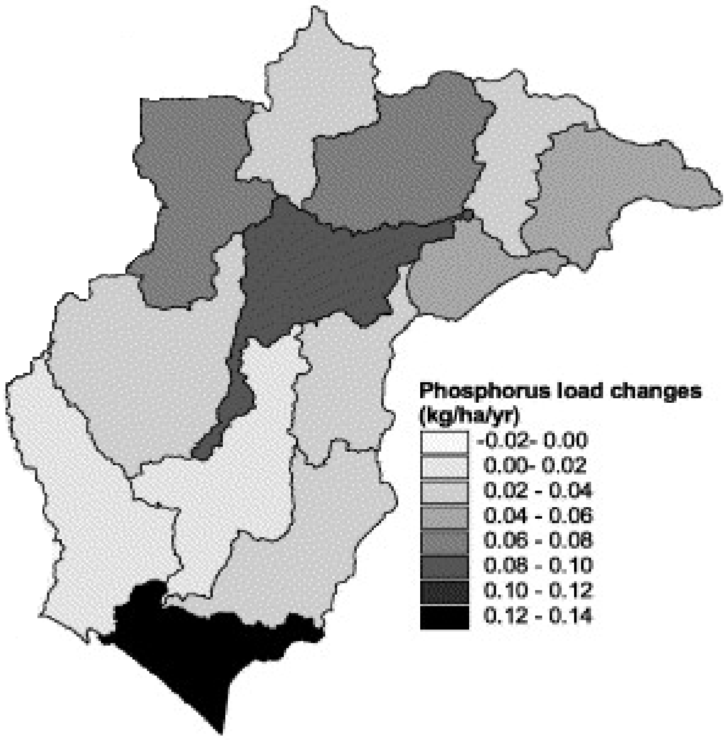


Figure 3.3 Phosphorus load changes in the Hopkins Catchment estimated to occur from 1980/2002

(Ierodiaconou et al, 2004)

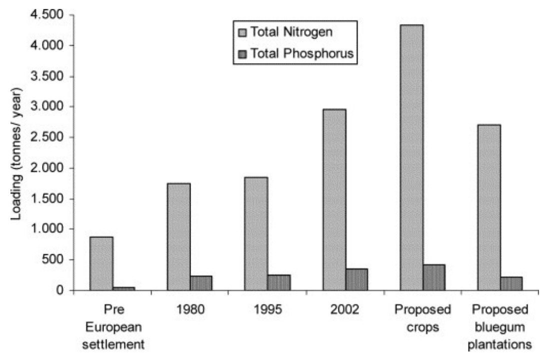


Figure 3.4 Future phosphorus load predictions for Glenelg Hopkins region

(Ierodiaconou et al, 2004)

The speed with which P loss occurs through groundwater is also dependent on soil type and structure (movement of P through the soil is via macropores), the source of P, soil typeand grazing management (Drewry et al, 2006). It appears that there is a 'change point' concentration, different for different types of soils, where the P concentration appearing in drainage rises dramatically. This may be due to different energy adsorption sites (Nash, 2004).

Stream banks are vulnerable to erosion due to the movement of water arriving at and within the watercourse. This contributes P to water through de-sorption from the clay particles. Livestock exacerbate erosion through trampling of the banks and add P directly to the water through their manure; hence catchment authorities have encouraged the protection of streams with funding for fencing and revegetation of buffer zones. The relative amount of surface soil and subsoil derived sediment in streams depends on the age of the stream channel network (i.e. how recently erosion has occurred).

The source of P used in the agricultural enterprise will influence its availability for immediate use by plants and algae e.g. manure products take longer to release P into the environment compared to artificial fertilisers and rock phosphate requires acidic soils to release its phosphate for plant use.

3.2.2 Phosphorus in Waterways

Phosphorus in the aquatic environment normally resides in one of the following four pools:

- dissolved in the water column
- associated with suspended sediments
- deposited in bed sediments
- incorporated into the biota (Baldwin et al, 2002).

Phosphorus may arrive already dissolved in water that runs into the waterway system, making it readily available for immediate use or it may dissolve out of the suspended sediment and stream bed deposition depending on pH of the water, temperature of the water, ionic strength of the water, the rate of water movement and the phosphorus equilibrium concentration of the stream, thus sediment deposition is a means of removing P from the water column (Baldwin et al, 2002). On the other hand, sediment re-suspension and transport may be an important instrument for the movement of phosphorus through the aquatic environment. Increased water movement through a catchment is likely to stir up sediments releasing phosphorus into the water column. Thus we observe increased TP levels in streams during spring when rainfall events flush the system and in streams that have been cleared of in-channel logs where water flow is increased causing turbulence in the water column.

> Sediments are often thought of as inert mixtures of minerals and recalcitrant organic matter. However, sediments contain a rich mixture of living organisms, which may include

macrofauna such as tube worms and other burrowing invertebrates, macro and micro algae and most importantly microorganisms, particularly bacteria. Therefore a substantial proportion of available sediment P may be bound in bacterial biomass (Baldwin et al, 2002).

Plant material in association with a catchment is also thought to have an impact on seasonally fluctuating P levels in waterways as plants grow and decay, releasing nutrients into runoff and streams (McDowell et al, 2002).

3.2.3 Setting Targets for Nutrients in Waterways

Eutrophication, whereby aquatic systems have become enriched with high nutrient levels can lead to increased growth of lgae and other microscopic plants impacting on whole ecosystems. TP levels above 50 µg P /l in streams are understood to be caused by human activity (Leinweber et al, 2002).

In Australia the fundamental sources of standards for monitoring and collecting data on water quality are the *Australian Guidelines for Water Quality Monitoring and Reporting* and the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. These guidelines use a risk based assessment approach, giving 'alert' threshold levels that require action and further monitoring. The target levels for upland rivers, fresh water lakes and reservoirs is 10µg P/l.; lowland river 50 µg P/l; estuaries 30µg P/l; and marine water 25µg P/l (Australian Government, 2008). Methods for determining turbidity and suspended solids are described in *Standard Methods for the Examination of Water and Wastewater* (Land and Water, 2008).

The Victorian Environment Protection Agency (EPA) is responsible for establishing maximum acceptable levels of potential contaminants in air, land and water in Victoria. In 2003 the agency released the *Nutrient Objectives for Rivers and Streams* with specific targets of nutrient levels for streams in seven regions of Victoria (Victorian Environment Protection Agency, 2003). A more recent approach is to present targets based on ecological goals, designed to protect the existing aquatic environment if the stream is healthy and to provide goals if a stream is impacted.

Victoria is divided into nutrient regions and objectives are set for each region based on the 75^{th} percentile of past data.

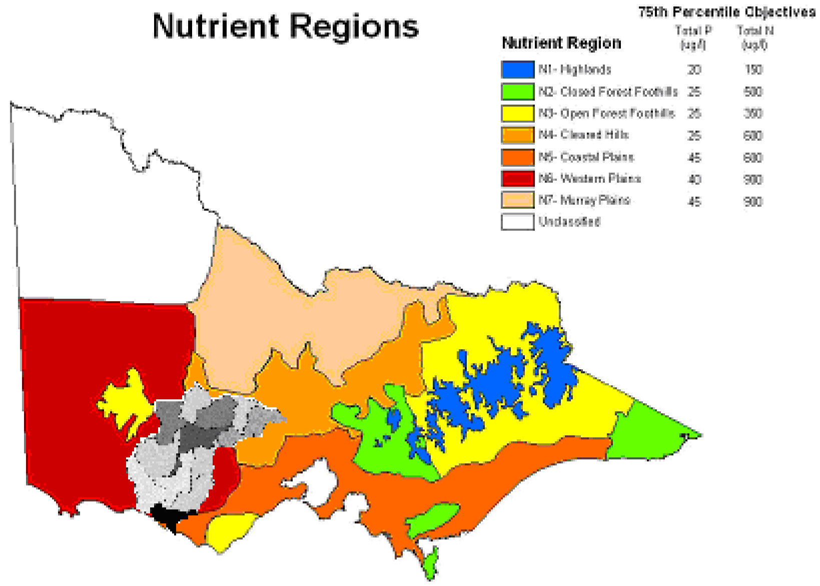


Figure 3.5 Nutrient regions of Victoria with the Hopkins Catchment overlaid (grey)
(Victorian Environment Protection Agency, 2003)

The Hopkins River catchment covers an area that falls over a section of the Western Plains (N6) and the Cleared Hills (N4). This is indicated by the grey section in Figure 3.5. The 75 th percentile objectives for phosphorus and nitrogen in the Western Plains Nutrient Region are:

- total phosphorus 40 µg/ l and total nitrogen 900 µg / l

In the Cleared Hills Nutrient Region the 75th percentile targets are:-

- total phosphorus 25 µg/ l and total Nitrogen 600 µg /l.

The average of these two levels is 32.5 µg P/l.

Nash, (2007) argues that the systemic soil levels (Olsen P levels of 1-5 mg P/kg) are contributing to runoff into streams, bringing the steam levels above the targets without the contribution of additional nutrients from non-point sources.

3.3 Effect of Phosphorus on the environment

Phosphorus, when present in excessive amounts, can affect the environment, in a number of ways. It can lead to excessive opportunistic plant growth in waterways, clogging the system, leading to a reduction in light availability for other plants and animals which ultimately results in a reduction in biodiversity. Subsequent decreases in available oxygen can kill aquatic animals and create unpleasant odours. Fish migration can be impeded by the extra plant growth and recreational fishing affected by a reduced supply of fish and disagreeable conditions. Finally, conditions can arise that stimulate algal growth to the extent that toxic blooms occur. These are poisonous to livestock and pose a serious risk to human health. This leads to restricting the use of these waters for recreation, fishing and drinking water. Blooms cause the depletion of oxygen in the water which results in further loss of desirable plants and animals thus depleting the habitat further (Victorian Environment Protection Agency, 2006).

3.3.1 Blue-green algae

Blue-green algae are primitive photosynthesizing micro-organisms able to reproduce asexually in a matter of days when the conditions are beneficial. Some species are able to adjust their position in the water column through collapsing their internal pockets of gas, enabling them to take advantage of light and nutrient levels. Others are able to fix nitrogen and store phosphorus until the conditions are favourable for growth (Smith, 1999 in(Glenelg Hopkins Catchment Management Authority, 2002). Algae play an important role in the ecosystem but if conditions arise that lead to an algal bloom, some BGA produce toxins that cause acute poisoning to animals, skin and eye irritations and at worst liver damage, tumour growth and paralysis leading to death (Flett and Thoms, 1994). Outbreaks of algal blooms in Australia have been recorded as far back as 1878.

Four species of BGA produce toxins, namely: *Anabaena* (present in lakes and slow moving rivers), *Microcystis* and *Cylindrospermopsis* (generally in lakes and dams), and *Nodularia* (in brackish waters).

The four main types of toxins produced by blue-green algae are:

Hepatotoxins produced by species of *Microcystis*, *Nodularia,* and *Anabaena* and can cause liver damage and gastrointestinal symptoms.

Neurotoxins produced by species of *Anabaena* and have been observed to cause muscle tremor, staggering, paralysis and respiratory arrest in animals. The neurotoxins produced by *Anabaena circinalis* in South East Australia have recently been shown to be the same compounds as those produced by dinoflagellates in the marine environment and are responsible for paralytic shellfish poisoning (PSP).

Cytotoxins produced by species of *Cylindrospermopsis* and can cause kidney damage. *Cylindrospermopsis* is more prevalent in tropical waters.

Endotoxins contact irritants produced by most species of blue-green algae and can cause skin rashes, eye irritation, allergic reactions and gastroenteritis. The toxins are released into the water following the death of blue-green algal cells and can remain potent for a period of several weeks after the algae have disappeared (Glenelg Hopkins Catchment Management Authority, 2002).

3.3.2 Conditions Appropriate for Algal Blooms

The key factors that encourage blooms are:

- increased nutrients (phosphorus and nitrogen)
- low river flow and calm conditions, more likely in summer and autumn and will increase with climate change if river flows decline as are predicted.
- high water temperatures
- light availability moderate turbidity favours blue-green algae
- disturbed ecosystems which are more likely to have conditions that promote BGA growth

3.3.3 Best Management Practices to Minimise Nutrient Pollution

Current best management practice (BMP) for the management of nutrients on farms encourages the farmer to:

- undertake soil and tissue testing to understand better the nutrient requirements for production
- use accurate calibrated spreaders for application of fertilisers
- use 20metre vegetative buffer strips along waterways to reduce nutrient runoff into streams
- undertake appropriate placement of nutrients on paddocks away from waterways
- undertake appropriate timing of fertiliser application to minimise the likelihood of nutrient loss due to rainfall events (ie not within four days of expected rain) (Department of Primary Industries, 2006a).

Chapter 4 gives a more detailed description of Federal, State and Local government documents produced in relation to reducing the potential for algal blooms.

3.4 Game Theory

3.4.1 Introduction

Game Theory modelling is used with games of strategy where the preferred outcome is known and can be defined clearly. It is used to determine optimal solutions that can be employed in negotiation of conflict situations, of course assuming rational behaviour and that the parties will act in their own best interests. Game Theory is a mathematical theory that analyses independent and interdependent decision making. Assuming two or more rational players, the basic assumption of the ‘game’ is that each player has an understanding of the expected rational behaviour of the other and will act accordingly in pursuit of their own goal. The players can be individuals or a group of individuals that act as a whole.

Game Theory and Game Theory modelling has been used in many disciplines including economics, psychology, philosophy, evolutionary biology and recently natural resource management to analyse situations of conflict and behaviour and to model solutions (Kelly, 2003).

Games can be defined as either:

- **Cooperative** where the players interact with one another to signal their purpose to the other players. The objective of each player is the same. Players are able to form coalitions and utilities (payoffs) are transferable (shared) between members of these coalitions. The main objective here is to understand how cooperation could lead to better distribution of benefits to all players.
- **Zero sum non-cooperative (competitive)** where each player or group of players is totally antagonistic, ie in a conflict situation, to each other. The main objective of non-cooperative games is to find the optimal strategies which players can use to optimise one or more utility (payoff) functions.
- **Mixed motive games (variable sum games)** where both players objectives are partly opposed and partly in agreement. In these games the sum of the utilities (payoffs) differs from strategy to strategy.

Figure 3.6 shows a diagram with the taxonomy of games as described by Kelly 2003. From the taxonomy schedule, this research is best described by the ‘prisoner’s dilemma game’ which falls into the category of two player, mixed motive: both players objectives are partly opposed and partly in agreement, with no optimal equilibrium point (the Nash strategy is dominant at the one and only equilibrium point) but this payoff is worse for both players than the alternative strategy (martyrdom).

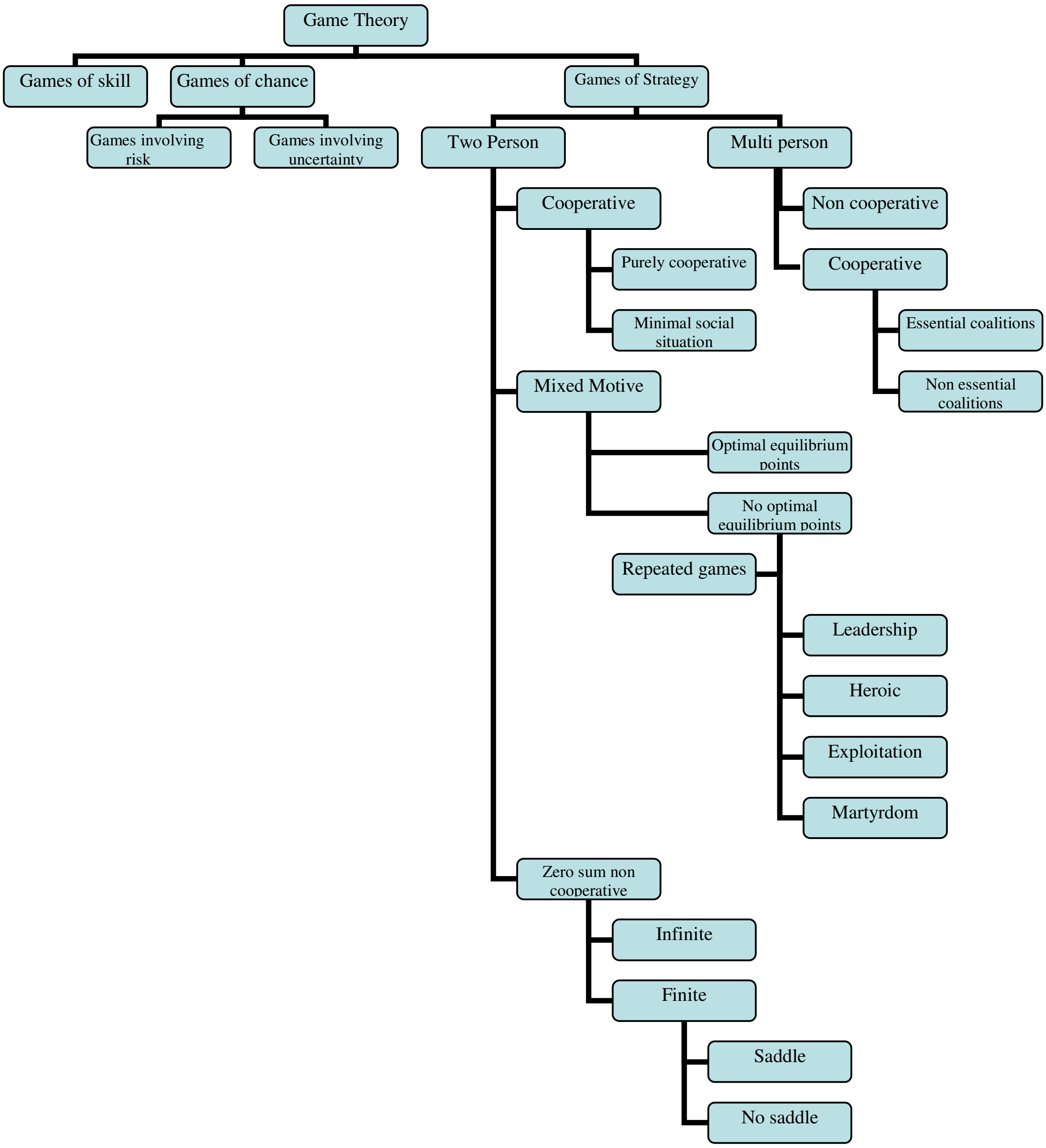


Figure 3.6 Taxonomy of Games
(Kelly, 2003)

3.4.2 Brief History of Game Theory

Game Theory was first conceived in the seventeenth century by mathematicians attempting to solve gambling problems (two person zero sum games). It was examined by **Zermelo** in 1913 who proved that every competitive two person game has a 'best strategy for both players'. Game Theory was further developed by **Borel** in 1921 and in 1926 **John von Neumann** proved the minimax theorem ie there exists a strategy for each player in a competitive game, such that none of the players regret their choice of strategy when the game is over. In the 1940s **Oskar Morgenstern** worked with **von Neumann** to produce the work *Theory of Games and Economic Behaviour*, which brought the discipline into the sphere of economics (Kelly, 2003).

The prisoner's dilemma game which represents a socio-political scenario in which everyone suffers by acting selfishly, though rationally, was unveiled in a lecture by **A W Tucker** in 1950 (Kelly, 2003). The prisoner's dilemma game is shown in Figure 3.8. In 1951 **John Nash** succeeded in generalising the minimax theorem by proving that every competitive game possesses at least one equilibrium point in both mixed and pure strategies. In the prisoner's dilemma game, the Nash Equilibrium is the decision where the player does the best given what its competitors are doing. 1957 saw *Games and Decisions* published by **Duncan Luce & Howard Raiffa.** This book brought Game Theory into the general arena of decision making. In 1967 **John Harsanyi** extended the theory to include games of incomplete information (Kelly, 2003).

Post 1960 Game Theory turned from the military arena to the socio-political arena and has since been used in other disciplines, as suggested in Section 3.4.1. including management theory, environmental negotiation and natural resource management (Kelly, 2003).

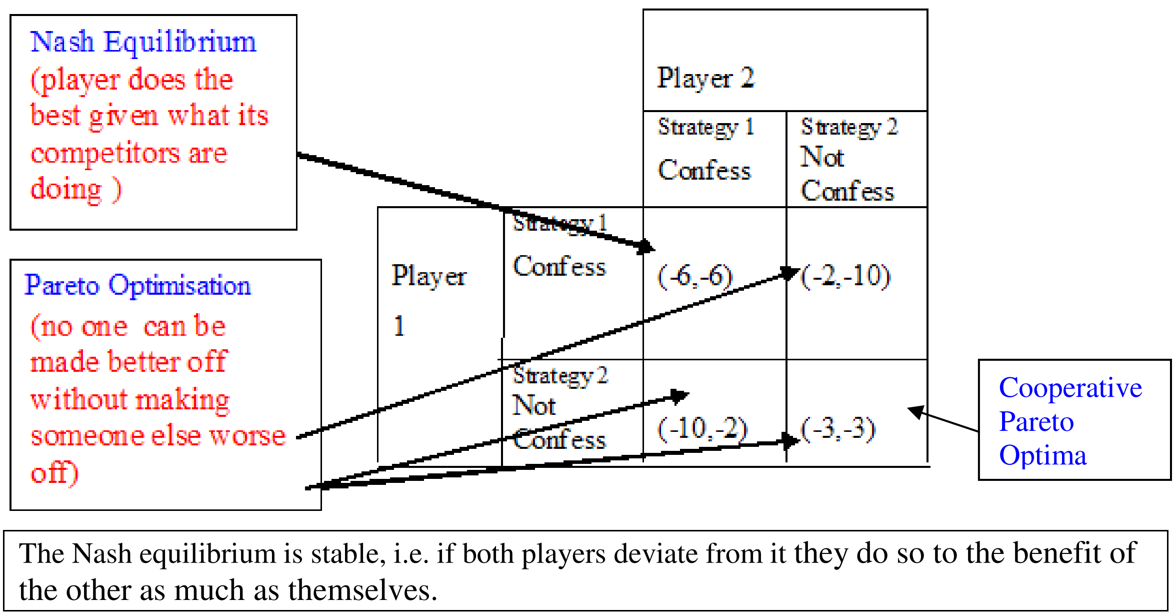


Figure 3.7: Prisoners Dilemma in economics: Illustration of Nash Equilibrium and Pareto Optimisations positions.

3.4.4 Reviewing the use of Game Theory in Solving Natural Resource Problems

Natural resource problems which have an economic impact are able to be modelled using Game Theory. These problems tend to be one of two types: two or more parties depleting a resource, e.g. fisheries or water, or two or more parties being impacted upon by pollution created externally which impacts on their natural resource bank, e.g. greenhouse gases or acid rain. In either case there is an issue of 'externality'. These problems may occur between countries, regions within one country, local neighbourhoods or different segments of society (e.g. city dwellers and farmers). In many instances the problem has an impact on the perpetrator as well as on the external party, creating a 'mixed motive game' situation, ie both parties will benefit from the action undertaken.

Game Theory has been used for analysing environmental problems and for modelling possible situations and solutions. It provides parties on opposite sides of the negotiation table with the benefit of models which have the potential to give the best case scenario with an outcome beneficial to all parties.

> The cooperative outcome in the resource problem is the outcome that maximises the sum of individual agents' net benefits. In this outcome each agent maximises its net benefits, internalizing the adverse effects of its action (strategy) on its own welfare and on the welfare of all other agents in the system (Pham Do, 2003).

When there are more than two parties involved in negotiation, it is possible that a variety of coalitions could form and these may do so under guidance of the scenarios represented by Game Theory models.

Generally, in modelling natural resource predicaments, the cooperative pareto optima is adopted from a non-cooperative game rather than from a cooperative game perspective, because the situation of 'externality' exists with the problem. The difference between the cooperative and non-cooperative outcomes is the gain to be had from collaborating. However, in a multiparty situation, some parties are likely to become 'freeloaders' on the system allowing others to carry the burden, even when understanding the benefit to the whole community. It can therefore be valuable to have some form of reinforcement in the way of taxes or laws as a disincentive to be a freeloader. This may work if the problem exists within one country but reinforcement is more difficult in an international sphere where taxes and laws do not apply and social pressure has less of an impact across boundaries.

Thurow (1998) found that lack of communication rather than lack of economic incentive influences community cooperation or non cooperation. He was supported by Zara et al (2006) who suggested that a lack of communication between parties is one of the main causes of non-cooperation at the international level but is less of a problem at the local level where networks are better established.

A large amount of research has been directed over the past 20 years towards common pool resources. The main environmental areas where Game Theory has been employed for the benefit of problem analysis and conflict negotiation are international fisheries (Pham Do, 2003; Zara et al, 2006), grazing rights (Gamini, 2006), forestry (Zara et al, 2006) and water resources (Lund and Palmer,1997; Dinar, 2004; Hermans, 2004; Gamini, 2006). Game Theory has more recently been employed in assisting the protection of endangered species. (Prato, 2005; Gamini, 2006).

An extensive review into the use of game theoretic models when negotiating cross boundary resources is presented by Zara et al (2006). The work concentrates on world fisheries but also includesGame Theory use in resolving other cross boundary problems such as acid rain, forestry, the placement of pipelines and noxious manufacturing plants. The use of Game Theory to resolve problems associated with pollution expelled from one country and impacting on other countries is also discussed (Zara et al 2006). Pham Do (2003) also reviews the use of Game Theory modelling in negotiation of regional fisheries agreements.

Many early applications of Game Theory modelling were in regard to the sustainability of water allocations and strategies to improve negotiation over water resource use by multiple parties. New demands for water, such as demand for recreation purposes, waste assimilation and environmental flows in addition to the traditional needs foragricultural, urban, flood control and power generation, have created further difficulties in water allocation and increased the need for negotiation.

Lund and Palmer (1997) put forward sound reasons for using the tools of Game theory to resolve conflict arising from management of water resources using the tools of Game Theory. They observed that Game Theory modelling has several potential roles:

- facilitate further understanding of the problem, including the development of computer models of water resource systems
- formalisation of performance objectives
- developing the promising alternatives
- evaluation of alternative strategies

- providing confidence in solutions
- providing a forum for negotiation (Lund and Palmer, 1997)

Lund and Palmer looked in more detail at various means of achieving desirable outcomes including a shared vision model where the stakeholders work together to develop the model. It was suggested in this work that in spite of the limitations, Game Theory modelling is likely to be more cost effective than other means of resolving conflicts (Lund and Palmer, 1997).

Supalla (2000) used Game Theory concepts to analyse the failure of earlier efforts to negotiate the allocation of water from the River Platte in the USA, with the aim of facilitating 'the resolution of this continuing water allocation problem'. Supalla concluded that the likelihood of success was greater through employment of Game Theory modelling because the players can assess the possible solutions simultaneously. The models are produced independently of the players themselves and they may return possible solutions not envisaged by the original people. Modelling also encourages players to consider incentives and strategic behaviour in bargaining.

Dinar (2004) evaluated the effectiveness of cooperation in managing trans-boundary water resources after more than ten years of research in the field. In the same year Hermans (2004) discussed the limitations and successes of employing a Game Theory approach to water resource management using different experiences in water management, citing examples from a range of countries.

Basaran and Bolen (2005) undertook research on the 'preferences and attitudes of different players taking part in the Nilüfer watershed' in Turkey. The work examined strategies of environmental protection and industrial development using a non-cooperative two-player game scenario. Environmental problems such as trans-frontier pollution (air or water) arising from industrial development are often multilateral and they affect all the agents in the economies of countries.

Research in the past two decades has also been directed at trans-boundary pollution where pollution produced by one party impacts on an external party. Game Theory has been used to model solutions to acid rain pollution, greenhouse gas emissions and non-point source pollution. Carraro and Filar (1995) brought together papers by a range of authors, discussing greenhouse warming, exogenous pollution and the use of Game Theory models to establish equitable outcomes.

Filar and Gaertner, (1996) demonstrated that co-operative Game Theory can be used to establish the equitable share of costs and benefits in modelling reductions in greenhouse gas emissions. The work considers different regions of the world, classified according to their production of CO_2, as players in a cooperative game and arrived at a fair allocation of emission reductions for each country, which would achieve an overall reduction in world atmospheric concentration of CO_2.

Romstad (2003) discussed the use of financial incentives (tradable permits) and disincentives (taxes or regulations) to change management practices on farms as a means of controlling non-point source (NPS) pollution. Tax is considered a blunt instrument, and slow to produce a noticeable change in NPS pollution, therefore Romstad proposed a team approach to reduce ambient NPS pollution using the principles of Game Theory to decide team ‘contracts’.

Cochard et al (2005) also examined the use of taxes and compared the efficiency of tax instruments to regulate NPS pollution. Input based tax, ambient tax/subsidy, ambient tax and group fine were assessed. Using Game Theory to model the four scenarios, they concluded that the input tax and ambient tax (on its own) are very efficient at regulating pollution, the group fine is fairly efficient and all improved pollution outcomes. Ambient tax/subsidy combined, however, decreases social welfare and is not very effective in reducing pollution. Game Theory has also been employed in natural resource management when examining decision making in regard to species protection. Prato, (2005) found that the minimax regret criterion selects the delisting decision that minimises the maximum loss likely to occur under alternative ecosystem states. When the cost of making a correct decision is less than the cost of making an incorrect decision, the minimax regret criteria indicate that delisting is the optimal decision.

Gamini (2006) provideda general overview of Game Theory applications to natural resource management including examples such as assessment of land privatisation and grazing rights, water allocation, safe minimum standards as applied to ecological problems. Species protection decisions were also discussed.

In conclusion, Game Theory provides a means to analyse natural resource management problems and to model various situations and solutions objectively. Models enable a cost effective method of comparing different scenarios and facilitates identification of the ‘best case scenario’ with an outcome beneficial to all parties.

3.5 Farmer Attitudes to Change and Natural Resource Management

Using Game Theory to resolve natural resource management problems initiates change of behaviour in the participants (individuals) to improve the benefits to all parties (the community). To gauge the likely uptake of the Pareto Optima result calculated by the model, background is given here to the attitude of rural populations change and natural resource management.

Change in rural regions is continual, with adaptation to changing markets, soil conditions, economic circumstances and climate an annual reality. At the individual level, psychologists have studied the decision-making process for many years and as in all societies the response to change in the rural community can be portrayed by a normal distribution with a small proportion of the farmers as early adopters, followed by a group of relatively early adopters who allow the early adopters to take the main risk and wait to see the results. These are the seond tier adopters followed by the 'majority', then the more 'conservative group' and lastly, if at all, 'the laggards'. This is demonstrated in Figure 3.9. The farmers that were approached to participate in this project are likely to be skewed towards the right half of the graph by virtue of already being associates of farming groups.

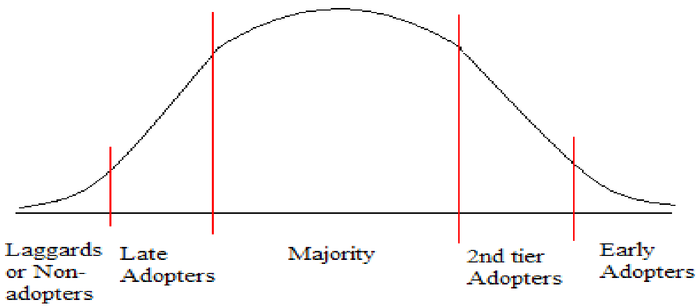


Figure 3.8: Distribution of adaptation to change

Research in a region of the Hopkins River catchment established that facilitated learning had a significant effect on knowledge, attitudes, skills and aspirations and led to increased production, environmental activities and social benefits. There was a corresponding increase in farmer satisfaction and a greater likelihood that farms would pass to the next generation. Much of the facilitated learning was production based, with opportunities to explore mainstream alternative enterprises. It appears that there is a flow on effect of groups of individuals getting together to learn and that facilitated learning in one arena opens the door to further opportunities and economic improvement which can lead to change in other areas such as the environment

(Trompf and Sale, 2006). The study also reported a higher landholder participation in Landcare groups within the research group than the non-participating group. These findings were supported by earlier research, indicating the importance of participation in learning and training groups for the individual to extend his own capacity for change (Lockie et al, 2002).

Curtis et al (2001), however found that the decision to adopt changes in land management practices to resolve an environmental problem is not solely related to awareness of the problem and the required solution (here the learning was narrowed down to the specific problem). It is more complicated, involving individual responsibility for the costs of work undertaken for the public good, lifestyle constraints (budget, time, age of landholder), and the economic sustainability of the land and the enterprises undertaken. There is a general saying in rural Landcare circles 'You can't be green if you are in the red'.

Lockie et al (2002) developed a discrete list of indicators which could be used as a model for judging capacity for change. They discussed 'capacity for change' from a regional perspective with key findings indicating the importance of social capital in the region. The study found that a diverse, vital, inclusive and supportive community, where communication between sections of the society is based on trust, sharing of resources, conflict resolution and acceptance of differences, leads to successful economic and cultural change.

In their discussion on the impact of land use change in South West Victoria, Petherham et al (2000) and Melland et al (2005) also emphasised the importance of trust and communication in acceptance of changes in a region. For example, the entry of corporate farming (Bluegums initially, and large corporate dairies subsequently) to the South-west region of Victoria has created some uncomfortable feelings, particularly amongst the farming fraternity. Good communication between the corporations and the community was not emphasized initially and the subsequent lack of trust created a negative image that has not yet been dispelled by the creation of jobs and economic wealth. Thurow (1998) stated that it is lack of communication rather than lack of economic incentive which drives community cooperation. The swing away from wool sheep to cropping does not appear to have created the same feelings due to the lower impact of cropping on the visual landscape compared with that of bluegum plantations.

The dairy industry has looked closely at farmers' attitudes to change in reference to natural resource management, in order to understand the social drivers that promote change and how the industry can best support it. They identified five interconnected factors:

1. A farmer's frame of reference, which determines what a farmer believes to be true about a particular issue, practice or intervention.
2. Aspirations, in terms of economics, technical, relational, cultural, emotional, moral and aesthetic properties.
3. Identity in a given situation, which informs the farmer's aspirations and his frame of reference.
4. Capacity for change including access to financial, physical and natural capital; learning capacity, perceptions of self efficacy and state of mind.
5. Social capital including networks and relationships, institutional support and trust in support organisations (Boxelaar and Paine, 2005).

On-farm change is best supported through a participatory approach ie where all the stake-holders are involved with the planning, goal setting and action for improvement (Boxelaar and Paine, 2005, Trompf and Sale, 2006).

Chapter 4: Water Quality Management and Nutrient Application - Supporting policy documents

4.1 Introduction

The factors that influence decision making in relation to phosphorus management by farmers are shown in Figure 4.1. Management practices have the potential to impact the waterways of the Hopkins catchment, as increased nutrient flows may lead to algal blooms.

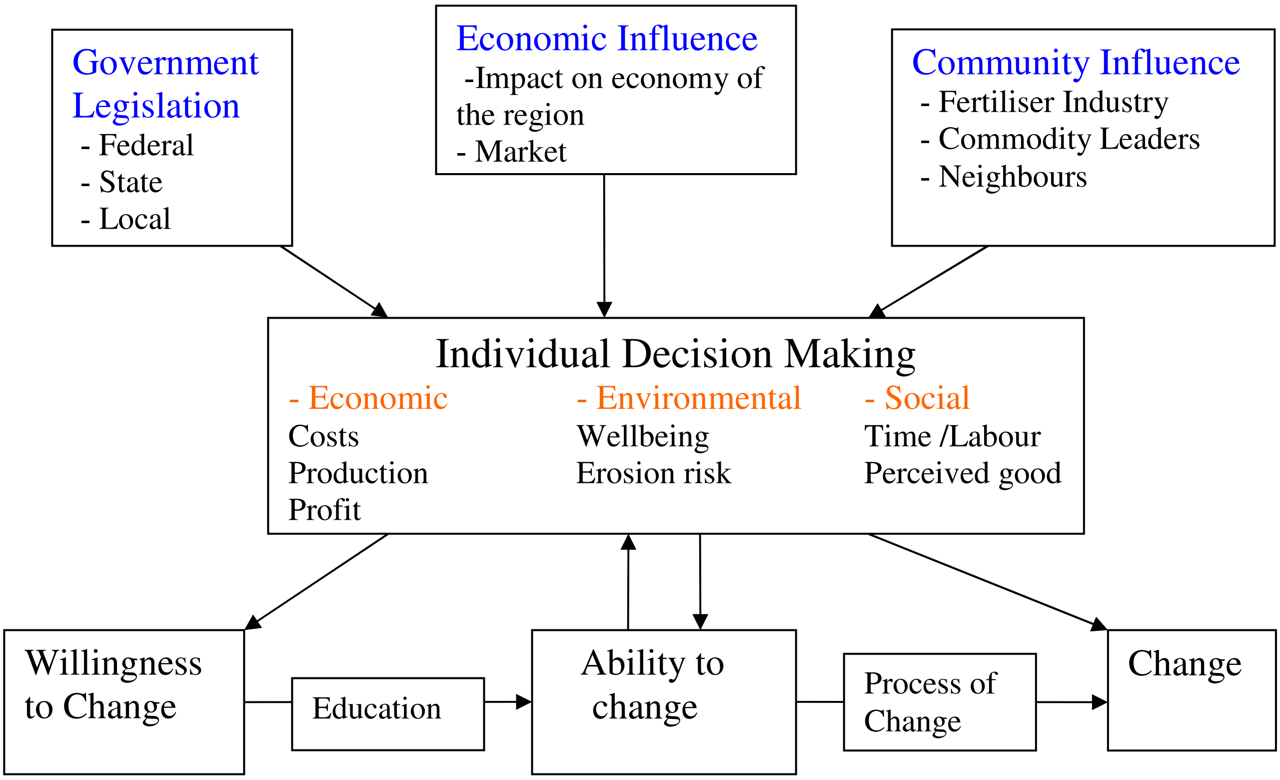


Figure 4.1 Factors that influence decision making in the management of phosphorus.

The Government legislation regulates and guides action on nutrient pollution and the industry bodies educate userson these guidelines. The farmer, meanwhile, is affected by social pressures from the community and regional economic factors. Within his/her own sphere of control he/she is influenced by the economics of his/her own production, the sense of well being about the environment, and time and labour management factors. Also, within the farmer, is the level of 'willingness to change' and the ability to change. All these factors can influence management actions. Game Theory modelling can be used to analyse the 'game of decision making' in such a situation and to contribute to the education of the individuals in the community by presenting optimal recommendations that enable a 'sustainable' solution to the problem.

The general design of Figure 4.1 is supported by Beegle et al (2002) who discussed the factors impacting fertiliser decisions, dividing them into economic, social and biological. Su XF et al (2005) also stated that the factors impacting decision making in relation to land use change include biophysical, economic and social factors. Biophysical factorsinclude: loss of biodiversity, soil degradation leading to changes in production (due to soil fertility factors), soil erosion and a decline in the health of the remaining vegetation and ecosystem.

A brief explanation of the authorities and their policy documents supporting the protection of environmentally sensitive natural heritage from nutrient pollution follows. Each level of government has legislation or policy documents targeting nutrient pollution in some form, although some local councils have placed greater emphasis on this than others.

4.2 Federal Legislation and Authorities

The role of the **Department of the Environment, Water, Heritage and the Arts** is to provide 'policy advice and program management which protects or promotes the protection of the environment and Australia's heritage' (Department of Environment, Water, Heritage and the Arts, 2008).

Under the *Environment Protection and Biodiversity Conservation Act*, the department manages and protects the principal national and internationally important ecological sites. It has developed a response to climate change and represents the Australian Government in international environmental agreements relating to the environment and Antarctica. Through the *Water Act 2007*, the department oversees the management of the Murray Darling catchment and other areas of national interest relating to water (Department of Environment, Water, Heritage and the Arts, 2007b).

The Department's principal objective under the 'National Water Quality Management Strategy', is to achieve sustainable 'use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development. It has developed guidelines for water quality management and benchmarks, ground water management, sewerage systems, effluent management and water recycling. The major environment and heritage programs are implemented through the National Heritage Trust's $3 billion trust fund.

At a Federal level, concern with agriculture and water quality is also dealth with by the **Department of Agriculture, Forestry and Fisheries** (DAFF) which oversees:

- National Land and Water Resource Audit (monitoring section)

- Land and Water (research section)
- Funding opportunities through the Landcare Program, Envirofund, National Action Plan for Salinity and Water Quality (NAP) and National Heritage Trust (NHT) to provide support for improvement to waterways
- Three databases: Australian Water Data Infrastructure Project; Australian Spatial Database; and Australian Natural Resources Library.

4.2.1 National Land and Water Resource Audit

A comprehensive National Land and Water Resources Audit was undertaken in 2001 to collate natural resource data across Australia and develop a framework for consistent collection of data on a regular basis. 'The National NRM Monitoring and Evaluation Framework (National M & E Framework) called for the identification of key topics or "matters for target". Each matter for target has a set of "indicators" that will be used to monitor and report on the topic' (Land and Water, 2008).

The key targets (bold) and the indicators used for monitoring are:

- **nutrients in the aquatic environment** nitrogen and phosphorus levels in flow leaving sub or whole catchment
- **turbidity and suspended surface water solids t**urbidity or total suspended solids (TSS) plus flow
- **surface water salinity in freshwater aquatic environments t**otal dissolved solids (TDS) plus flow or electrical conductivity (EC) plus flow

The source of standards for monitoring and data collection of water quality is discussed in Section 3.2.3.
The 2001 Audit of Nutrient Loads to Australian Rivers and Estuaries found that the 'Vic West' region, described as including 'the river catchments in an area of Victoria west of Melbourne which flow into the ocean and river catchments in South East of South Australia, which flow into the ocean', exported TP at 1.9 times the estimated natural levels.

Region	Hill slope (PP)	Gully (PP)	Bank (PP)	Point source (DP)	Run-off (DP)	Floodplain sediment-ation (PP)	Reservoir sediment-ation (PP)	Export (TP)	Export %	Times natural
Vic West	41	213	174	0	144	285	17	269	1	1.9

Table 4.1 Total phosphorus budgets (t/yr) Vic West region
(Land and Water, 2008)

In Table 4.1 the 'Export percent' is the region's export as a percentage of the assessment area total and 'Times natural' is the average increase in multiples of the pre-European TP load. This means that the runoff is almost twice the natural runoff of TP.

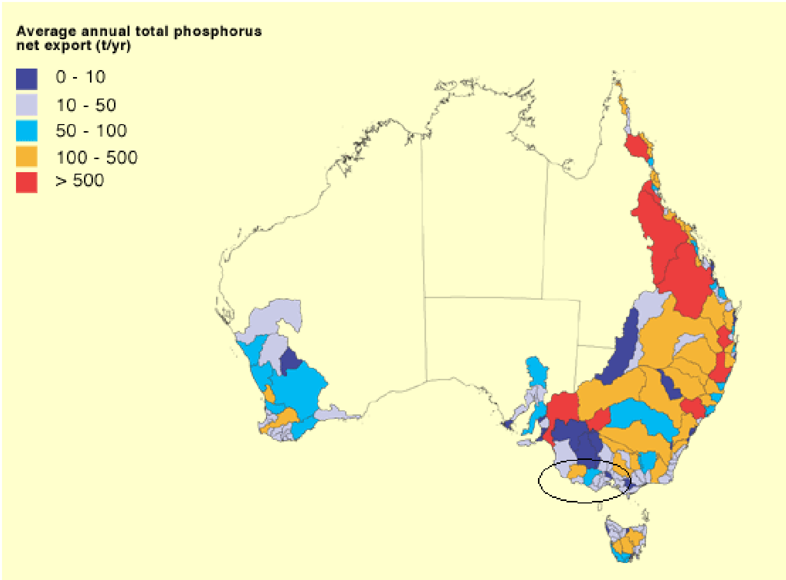


Figure 4.2: Map of Australia showing the average annual Total Phosphorus (TP) exported from the Hopkins River catchment (circled).

The total Australian annual export of TP is 1,894t P/an. As shown on the map the Hopkins region exports between 50-100 t P/an (Department of Environment Water Heritage and the Arts, 2007a). This is less than the figure used by Read et al in 1999 (144t P/an).

An assessment of the Hopkins River catchment found it to be substantially modified, particularly with reference to the nutrient and suspended load index. Mean annual runoff is 405,600ML/an with total surface water use of 13,570ML/an (with urban and industrial accounting for 53% and irrigation 46%) and storage volume of 205ML. It is fully developed with respect to water allocation, mainly due to the high salinity content of its waters (Department of Environment, Water, Heritage and the Arts, 2007b).

4.2.2 Land and Water Australia

Land and Water Australia is the research arm of DAFF. It collaborates with community, industry and government on many research programs aimed at sustainable agriculture often at the interface with environmental sustainability. Past research has produced guidelines on minimising the impact of agriculture on rivers and streams, looked at sustainable grazing systems, the management of algal blooms in the environment (see Section 3.3.2 and 3.3.3) and management of wetlands and riverine environments on private land. Collaboration with

Australian Wool Innovation has produced a series of practical tools to help wool growers manage natural resources sustainably. Grain and Graze is a project targeting sustainable grain production in collaboration with Grains Research and Development Corporation. The organisation also has a division investigating the impact of climate change on agricultural sustainability.

4.2.3 National Eutrophication Management Program

The National Eutrophication Management Program, which finished in 2001, led to an understanding of the processes that cause algal blooms, techniques available to minimise the frequency of them occurring and raised awareness about the conditions that exacerbate the problem.

> ‘Some of the management techniques developed through the Program included:
>
> - Managing flows to reduce the stratification in the water column that promotes blue-green algal blooms.
> - Managing light penetration within water bodies to control blue-green algal growth.
> - Using bio-manipulation to directly control concentrations and growth of blue-green algae.
> - Managing sediments in rivers, storages and estuaries so that the anoxic conditions favouring blue-green algae growth are avoided.
> - Managing nutrients so that they are not entering river systems in 'pulses' and promoting algal growth.
> - Controlling nitrogen to better manage algal blooms (Land and Water, 2001).

4.3 State Legislation and Authorities

The 1970 *Environment Protection Act* established the Environment Protection Authority in Victoria. ‘Its purpose is to protect, care for and improve the environment.’ (Department of Sustainability and Environment, 2007). It does this by administering the laws on air, land protection, waste, water, noise pollution and greenhouse gases. The *Victorian Conservation Trust Act 1972* established a process that enabled landholders to protect land of high conservation value on their title. It also enabled the government to purchase high conservation value land for preservation (particularly areas adjacent to waterways which still retained biodiversity value).

The State *Water Act 1989* established the responsibility of all parties in relation to water resources. It provided for integrated management of water resources for the environment and consumer. A significant State Act the *Catchment and Land Protection Act 1994 (CALP)*, established ten Catchment Management Authorities across the State to provide ‘integrated management and protection of catchments, and the process to encourage and support community participation in the management of land and water resources’ (Department of Sustainability and Environment, 2007).

An additional two other acts enable State and Federal government agencies to integrate management of nationally significant locations and develop environmentally sustainable policies. The Acts also require reports to be made on the environment and implementation of environmental management systems (EMS).

The State government published the ‘Nutrient Management Strategy for Victorian Inland Waters’ in 1995. The report provided for assessment of regional nutrient problems and the development of regional nutrient management plans. These wereundertaken by the Catchment Management Authorities in each region. Other linked strategies are the National Water Quality Management Strategy (NWQMS) and the State Environmental Protection Policy - Waters of Victoria (SEPP-WoV). The SEPP's goal is to attain and maintain levels of water quality that are sufficient to protect the beneficial uses of the surface waters of the policy area. Water quality targets relate to marine, estuarine and freshwater areas in conjunction withwith the beneficial use to which the waters are used (Department of Primary Industries, 2006).

4.3.1 Victorian Environment Protection Agency (EPA)

Victorian EPA programs that relate to waterways can be categorised into four sections:

1. Biological monitoring and assessment
2. River health/environmental condition reports
3. Environmental quality objectives
4. Lakes program.

Biological monitoring and assessment is now coordinated with monitoring undertaken by the CMAs and DSE. Results are recorded in a central database that is accessible to the public online at the Victorian Water Resources Data Warehouse (see Section 4.3.4) (Victorian Environment Protection Agency, 2006). Environmental condition reports are generated using the monitoring results and are collated for input into the Federal Governments ‘National Land and Water Resources Audit’ One additional task of the EPA is to develop targets for maximum levels of potential contaminants in air, land and water as discussed in Section 3.2.3.

4.3.2 Department of Primary Industries (DPI) and Department of Sustainability and Environment (DSE)

The DPI primarily develops extension programs promoting sustainable farming. Although there is a heavy emphasis on production efficiency in the animal, pasture and cropping sections, the Department promotes the Whole Farm Planning (WFP) and Environmental Best Management Programs (EBMP) and awareness of environmental issues through funding for Salinity remediation.

The role of DSE in the protection of water quality is in extension, education and management of water, forests, ecosystems and public land. It works closely with the DPI in rural regions to raise awareness of the links between environmental and agricultural sustainability.

4.3.2.1 South West Farm Monitor Project Data

The DPI has been collecting production and financial data from farmers in South West Victoria for 36 years through the South West Farm Monitor Project. It is a voluntary benchmarking project in which farmers input data and in return receive, anonymous financial information of farms with similar enterprises within the same region.

Farms vary in size from 120 to 3179 ha, and undertake prime lamb, wool, beef and/or cropping production. Traditionally, there was less cropping than other enterprises represented, however this is changing. Fertiliser costs per grazed ha are $42 (for the top 20% of farmers these costs are $56). The South West Farm Monitor Project has enabled an in-depth register of farming enterprise financial and production data to be used for research and by government departments. Table 4.2 shows data extracted from the 2005-2006 financial year when this project was undertaken. The data collected from the farmers in this project can be compared to that of the South West Farm Monitor Project for verification and to determine where in the commodity cycle each commodity lies. This impacts on the results from the Game Theory calculations and may explain why the use of phosphorus on particular enterprises is seen as more beneficial for any given year. The figures used in the Game Theory model were average application of fertiliser/ha; fertiliser cost/ha; output of commodity/ha; $/kg commodity and $/ha/100mm rainfall.

	Rainfall (mm)	Stocking Rate dse/ha	P applied Kg/ ha	Soil P mg/kg	Production Output-meat or crop $/ha	Production costs $/ha	Gross Margin $/ha	Top 20% gross margin $/ha	Historical Gross Margin $/ha	Commodity $/kg	Production Kg/ha
Prime Lamb	644	15.9	10.31	9.3	386	139	247	445	342	3.01 2.96	Lamb 95 Wool 34
Wool	618	14.9	8.86	8.5	236	117	119	227	269	7.78	Wool 30.3
Beef	658	15.2	13.46	12.1	515	336	179	513	188	1.70	400
Wheat	592	n/a	16.7	No data	622	289	333	No data	No data	0.16	3700
Canola	582	n/a	19.5	No data	641	601	40	No data	No data	0.29	1400
Oats	584	n/a	15.0	No data	659	379	280	No data	No data	0.15	3400

Table 4.2 Data extracted from South West Farm Monitor Project 2005-2006
(Department of Primary Industries, 2006b)

4.3.2.2 Long Term Phosphorus Experiment

For the past 25 years phosphorus the Hamilton long term phosphorus experiment has operated on the basalt plains. This project was set up to demonstrate the potential of improved pasture with adequate phosphorus for growth. Measurements of wool quality, and quantity, stocking rates and soil and pasture attributes have been recorded. The main findings are:

- applying more phosphorus and running more stock per hectare can dramatically increase profitability
- pasture composition, nutritive value and pasture growth all improved with increased fertiliser application.
- to profit from using extra fertiliser, animal production systems must utilise the additional fertiliser
- running more stock /ha does not increase animal health problems provided livestock weights and condition scores are not allowed to drop below normal targets.
- to maintain soil P, fertiliser needs to be applied at a rate of 10-20 kgP/ha annually, depending on current soil tests
- at the Hamilton site (basalt soils) 80-90% of the P is still in the topsoil
- soil sustainability indicators suggest no major environmental problems with this P level on basalt soils.

- at Hamilton, the amount of P required for maximum profit varies with the stocking rate. About 1 kg of P per ewe (~0.8 kg P/dry sheep equivalent (dse)) is needed in this environment)
- on this soil type the level of P applied does not affect the surface soil pH
- set stocking at high rates can lead to deterioration of botanical composition (Department of Primary Industries, 2003)

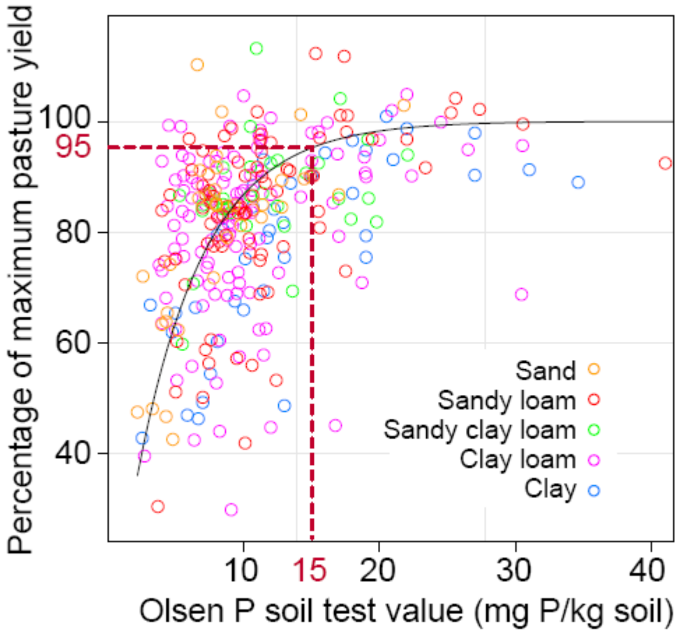


Figure 4.3 Graph of the soil Phosphorus levels required to maximise pasture production (Department of Primary Industries, 2007)

Figure 4.3 indicates the amount of soil P levels required to maximise pasture production which flows through to maximizing animal production given no other limiting factors.
Profitability is linked to productivity and the DPI has graphed the gross margins for different stocking rates based on the phosphorus input. These are shown in Figure 4.4.

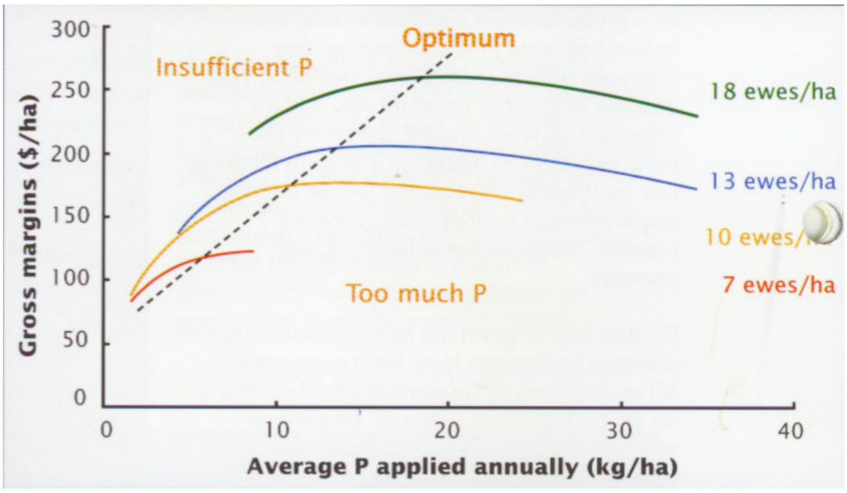


Figure 4.4 Gross margins estimated for sheep production relative to phosphorus inputs (Department of Primary Industries, 2003)

A further determinant of productivity relates to the breeding management of the stock by the farmer and his/her management of pastures which enables the farmer to take advantage of the carrying capacity of the land.

> On an animal production farm, neither crop production nor fertiliser use is directly connected to the output of such farms. Farm performance depends on the animal husbandry skills of the farmer (Beegle et al., 2002).

DPI recommendations on fertiliser use for grazing properties

The DPI has calculated the factors associated with thephosphorus requirements of sheep and beef cattle enterprises, according to the soil type, terrain and grazing management. Using these factors, a table has been created for easy estimation of phosphorus requirements (kg) based on a dry sheep equivalent (dse). Table 4.3 takes into account soil loss factors, animal loss factors, pasture and rainfall. A landholder is able to estimate the phosphorus requirements per hectare if the carrying capacity of the area is known.

Soil loss factors (See column 1 of Table 4.3)

1. Recent alluvial soils and loam soils in a low rainfall region are designated a low soil loss factor
2. Podzols, clay-loam and redzinas have a medium soil loss factor
3. Acid sands, krasnozems and other clays and organic soils display a high soil loss factor.

Animal management loss factors (based on management factors and slope, see column 2 of Table 4.3)

1. Under an intensive rotational grazing management on flat rolling country the loss factors are very low; intensive rotational grazing management on easy hills rate as low; and intensive rotational grazing management on steep hills rate as medium.

2. Under set stocking management on flat rolling country the loss factors are low; set stocking management on easy hills rates as medium; and set stocking management on steep hills rates as high

Calculating how much phosphorus fertiliser is needed per hectare for a particular paddock is achieved by selecting the appropriate kg P/dse from Table 4.4 and calculating the amount from the equation shown.

$$\text{Fertiliser/ha} = \frac{100 \times \text{P/d.s.e} \times \text{Stocking Rate}}{\text{Phosphorus Content \%}}$$

		Poor pasture Rainfall			Improved Pasture Rainfall		
Soil Loss factor	Animal Loss factor	400mm	600mm	800mm	400mm	600mm	800mm
Low	Very low	0.38	0.42	0.44	0.40	0.44	0.48
	Low	0.50	0.52	0.56	0.50	0.56	0.62
	Medium	0.60	0.64	0.70	0.62	0.68	0.76
	High	0.72	0.76	0.82	0.72	0.82	0.90
Med	Very Low	0.56	0.60	0.64	0.58	0.64	0.70
	Low	0.66	0.72	0.76	0.68	0.76	0.84
	Medium	0.78	0.84	0.88	0.80	0.88	0.98
	High	0.88	0.94	1.00	0.92	1.02	1.12
High	Very Low	0.74	0.78	0.84	0.76	0.84	0.92
	Low	0.84	0.90	0.96	0.86	0.96	1.06
	Medium	0.94	1.00	1.08	0.98	1.08	1.20
	High	1.06	1.14	1.20	1.08	1.20	1.32

Table 4.3 Predicted kg P/dse for maximum profit for a range of conditions
(Department of Primary Industries, 2001)

Using Tables 4.4 and 4.5 and Figures 4.5 and 4.6, the future soil Olsen P levels can be predicted when the current Olsen P levels and the amount to be applied are known. This differs according to soil type. From these Tables landholders can calculate the amount required to maintain soil P levels or increase them to a desired level for maximising production.

Basalt Soils – clay loam

Phosphorus applied in fertiliser (kg/ha)						
Current Olsen P mg/kg ↓	0	5	10	20	40	80
25	21	21	22	23	25	29
20	17	17	18	19	21	25
15	13	13	14	15	17	21
10	9	9	10	11	13	17
5	5	**5**	6	7	9	13
3	3	3	4	5	7	11

Table 4.4 Basalt Soils predicted Olsen P for given amounts of applied P

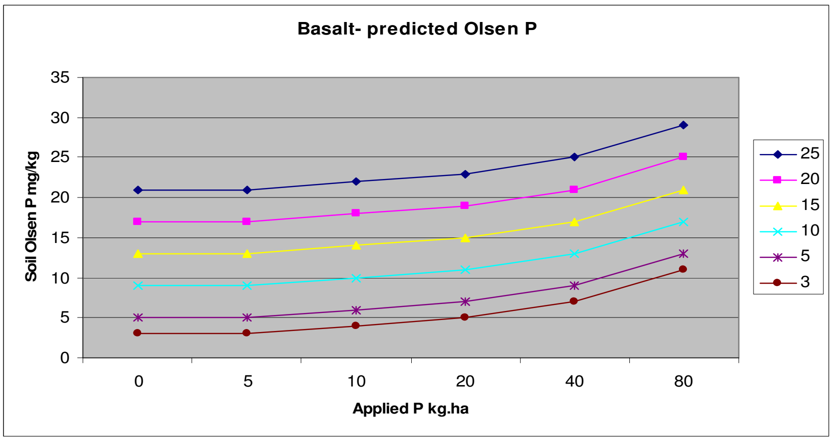


Figure 4.5 Basalt Soils predicted Olsen P for given amounts of applied P

Dundas Tablelands- duplex loam derived from rhyolite

	Phosphorus applied in fertiliser (kg/ha)					
Current Olsen P mg/kg ↓	0	5	10	20	40	80
25	20	21	22	23	27	33
20	16	17	18	19	23	29
15	12	13	14	15	19	25
10	8	9	10	11	15	21
5	4	5	6	7	11	17
3	3	3	4	6	9	15
1	1	2	3	4	7	14

Table 4.5 Dundas Tablelands - predicted Olsen P for given amounts of P applied

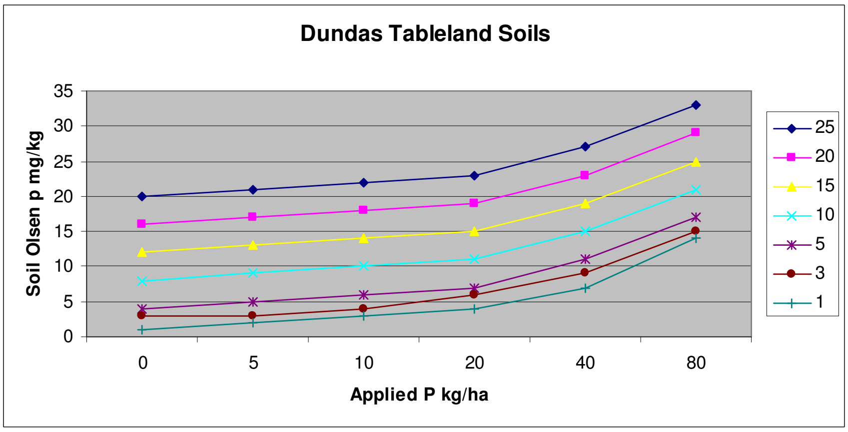


Figure 4.6 Predicted Olsen P after different amounts of fertiliser were applied
(Department of Primary Industries, 2001)

If the soil has a current level of 15mg P/kg, and the farmer applies 40kg P/ha according toTable 4.4 the soil P level will rise to 17kg P/kg. To maintain the soil at 15 kgP/kg the farmer would need to apply 15-20 kg P/ha. The information gained from such research was delivered to the farmer population via extension programs and decision support tools such as 'Making Sensible

Fertiliser Decisions', which advises farmers on the appropriate fertiliser application rates for particular soil types, rainfall and stocking rates. 'The Farmer Nutrient Loss Index' (see Section 4.3.2.3) has been developed more recently, building on the Long Term Phosphorus Experiment and recent research (Melland et al, 2007).

4.3.2.3 Farm Nutrient Loss Index (FNLI)

A group of scientists from the DPI with the support of the fertiliser industry (FIFA) and State and Federal government departments has spent the last four years developing the Farm Nutrient Loss Index (FNLI). It is an index which:

> draws together current knowledge on how nutrient loss occurs in a simple to use computer program… The FNLI identifies the average annual risk of N and P loss from paddocks within a pasture based grazing system to waterways, groundwater and the atmosphere. (Melland et al, 2007)

Factors identified in the FNLI are divided into two parts and weights are given to each factor to identify an overall risk ranking for the paddock. Using this information together with soil testing data and nutrient budgeting, landholders are able to identify suitable management options for individual paddocks. The factors are as follows:

> **Source factors** soil P; fertiliser amount; timing of application; pasture type; ground cover; stocking rate; effluent rate and timing; Phosphorus Buffering Index (PBI) and nutrient hotspots.
>
> **Transport factors** surplus water and storm likelihood; soil profile type; slope; land shape; water logging; groundcover; pasture type; groundwater depth; proximity to waterway and runoff modifying features (Melland et al, 2007).

4.3.2.4 Cropping phosphorous decision making

The DPI has developed a series of booklets relating to management of environmental issues, including *Phosphorous Loss Management on Farms* which relates to removal of phosphorus in product. Figure 4.7, reproduced from this booklet, calculates the amount (kg) of P removed in plant products, and therefore needing to be replaced annually by fertilisers or manure. This table can also be used to calculate relative risk to the environment from phosphorus application. The fertiliser companies also have similar tables of crop nutrient usage.

A	B	C	D	E	F	G
Crops	**kg P removed per tonne of product**	**Insert your target crop yield (t/ha)**	**Calculated P requirem't *(B x C)***	**Intended P application *(kg P/ha)***	**P balance Positive or negative balance *(E-D)***	**RISK SCORE* *(see below)***
Eg wheat	*3.0*	*4.0*	*12*	*15*	*+3*	
Wheat	3.0					
Barley	2.5					
Oats	2.5					
Canola	6.0					
Lupins	3.0					
Peas	3.5					
Faba	4.0					
Chickpeas	3.0					
Hay	1.8					

* To calculate your risk score (Column G) use the following guidelines.

- For Olsen P* 8 mg/kgor less and negative, zero or positive P balance, score VERY LOW RISK (1).
- For Olsen P* 8-18 mg/kg score and negative or zero P balance, score VERY LOW RISK (1).
- For Olsen P* 8-18 mg/kg score and positive P balance, score LOW RISK (2).
- For Olsen P* above 18 mg/kg and negative or zero P balance, score MEDIUM (3)
- For Olsen P* above 18 mg/kg and positive P balance, score HIGH (4)

Figure 4.7 Table used to calculate the amount of Phosphorus required to replace phosphorus removed in product

(Department of Primary Industries, 2005)

The average targets for crop yields in the mid Hopkins region are:

- Wheat 5t/ha (P requirement from Figure 4.7 would be 15 kg P/ha)
- Barley 5t/ha (P requirement from Figure 4.7 would be 12.5 kg P/ha)
- Canola 2.5t/ha (P requirement from Figure 4.7 would be 15 kg P/ha)(D McInnes, personal communication).

4.3.2.5 Dairy Extension Centre

The DPI's online service, the Dairy Extension Centre has produced a number of resource manuals including the *Fertilising Dairy Pastures Manual* (Department of Primary Industries, 2005). It provides the current research information on nutrient management, interpretation of soil and tissue tests, how to budget nutrient use, use of effluent on paddocks and advice on timing of fertiliser application.

4.3.2.6 Environment Best Management and DairySAT Programs

By 2000 the Australian Federal government was encouraging the Departments of Primary Industry in all states to develop Environmental Management Systems (EMS) for agricultural production. The systems were to be based on the International Standards Organisation's ruling ISO 14001 with several stages to be developed to facilitate achievement of full accreditation. In response the Victorian Government encouraged farmers to assess their farms from the environmental perspective, as the first level of an EMS. Called 'Environmental Best Management Practices project (EBMP)', the self assessment program proceeds through a number of questions relating to eleven major management areas with environmental impacts on the property, thereby raising awareness of best management practices in regard to management of water, soil, vegetation, chemicals, pest weeds, pest animals, effluent, farm waste, nutrients, green house gas and property planning. The program is delivered as a one to one extension program and links to wider information resources and extension officers..

DairySAT is a similar program aimed at Dairy farmers, and covers effluent, soils, chemicals, nutrients, biodiversity, pests and weeds, irrigation and drainage, farm waste, air and energy. The tool allows farmers to audit themselves on these environmental issues, set targets for improvement and provides links to begin to address the higher priority issues through the Department's extension officers.

4.3.3 Glenelg Hopkins Catchment Management Authority

The plans and strategies of the Glenelg Hopkins Catchment Management Authority (GHCMA) covered in this section include:

- Regional Catchment Management Strategy 2003/2007
- River Health Strategy 2004/2009
- Nutrient Management Plan
- Other Plans and Strategies
- Benefits and Costs of Nutrient Management in the GHCMA Region (Read and Sturgess Report).

4.3.3.1 Regional Catchment Management Strategy

The Glenelg Hopkins Catchment Management Strategy has six key areas of regional focus:

- regional sustainability
- biodiversity
- water health and water quality
- soil decline and salinity
- pest plants and animals
- coastal areas.

Within each focus area the CMA has developed targets for improvement based on the key indicators.

In the area of water health and water quality the objective is to 'maintain and enhance the ecological health of the region's water resources and waterways while maintaining economic and social development'(Glenelg Hopkins Catchment Management Authority, 2003).
This includes protecting fresh water quality, restoring river and wetland health, managing groundwater, drainage, floodplains and wastewater and sharing water equitably. The GHCMA also considers important its role in developing strategies and plans, supporting research, raising awareness and supporting on ground works through administering Federal and State funding. In addition, the GHCMA monitors, evaluates and reports on various programs.

4.3.3.2 River Health Strategy

There are three Catchments in the Glenelg Hopkins Region:

- Glenelg River catchment
- Hopkins River catchment
- Portland Coastal catchment.

The River Health Strategy is concerned with the current state of the rivers in the Glenelg Hopkins Catchment Management region and the threats to river health. Risk assessments are undertaken on a catchment and a sub catchment basis, priorities set and actions planned to alleviate threats. Threats described include degradation of vegetation, pest plants and animals, loss of in-stream habitat, bank and bed instability, poor water quality, algal blooms and flow deviation. The actions described include re-vegetation, control of pest plants and animals, placement of in-stream habitat and adopting the nutrient management plan (NMP) (see Section 4.3.3.3) to prevent high nutrient inputs leading to algal blooms.

4.3.3.3 Nutrient Management Plan

The Glenelg Hopkins Nutrient Management Plan provides a 'strategic framework for nutrient management across the region. The actions identified will assist in reducing nutrient loads entering the region's waterways'.

Objectives of this plan are to:

- to reduce the risk of blue-green algal blooms, nutrient concentrations and sediment loads in the waterways
- to maintain and improve the quality of waters (surface and ground) and riverine environments
- to develop a greater understanding of the movement of nutrients in the catchment and availability of nutrients to algal growth

- to foster regional development by ensuring supplies of high quality water for industries and communities (Glenelg Hopkins Catchment Management Authority, 2002).

The annual cost of toxic algae blooms to the environment in the Hopkins River Catchment is estimated at $1,014,032 by Read et al (1999). This will be discussed in section 4.3.3.5

Nutrient Reduction Targets

The GHCMA has developed targets for nutrient reduction in streams, principally TP, over the 20 years beginning 2002. A number of programs are being developed to enable this to occur. For dry-land agriculture the targets for a reduction in TP are as follows:

- TP entering waterways through gully protection 22%
- TP entering waterways through streambank protection 11%
- TP entering waterways from adoption of Best Management Practice 12%
- TP entering waterways through effective effluent systems being adopted 2.5%

Within the whole catchment a reduction target of 54% is set, including sources from forestry and urban areas.

On-ground activities are chosen based on the environmental values to be protected and minimising the risks to priority areas. The priority areas have high nutrient concentrations, active erosion, poor water quality, past multiple algal blooms and/or high salinity. Actions that deliver the greatest benefit to cost ratio and programs that complement current on-ground works are given precedence. Programs in place, funded by the Federal government through the National Heritage Trust (NHT), involve fencing and revegetating river and creek banks, and support of the EBMP. As a result of these programs, awareness of nutrient runoff has been raised and management of dairy effluent, storm water and public road drainage has been improved.

The greatest benefit to cost ratio is in the urban areas, followed by forestry and public lands. As the region is 98% agricultural however, activity in these areas has limited impact on the whole catchment water quality. Within the dryland agriculture sector, the greatest benefit to cost is in farm nutrient management (0.36) followed by gully erosion control (0.25) and streambank stabilisation (0.14).

4.3.3.4 Other Policy Documents

The GHCMA has developed a number of other strategies and plans that interact with the NMP, with actions taken on behalf of one strategy being likely to improve outcomes for other issues. The **Salinity Strategy '**discusses interception and re-direction of surface water as a potential method for controlling salinity. It recommends the development of a drainage policy that, amongst other things, establishes standards for drainage water disposal and identifies methods for protecting wetlands and other environments that may be affected by drainage' (Glenelg Hopkins Catchment Management Authority, 2003). Actions that aid reduction of salinity, such as fencing out and revegetating, are likely to also reduce erosion and intercept nutrient flow.

The **Drainage Strategy** deals with management of regional rural drains with the aim of achieving a 'sustainable balance between land-use and the environment'. This encompasses downstream environmental impacts of the drainage waters which may carry high nutrient runoff from agricultural land. The **Floodplain and Waterway Management Strategy** and the **Regional Wetland Strategy** both deal with management of wetlands, swamps and floodplains. The region has 44% of Victoria's wetlands, 90% of which are on private land. Protection of wetlands and swamps through fencing off and rehabilitation of habitat will improve the health of the wetlands which act as filters for the catchment. Re-instatement of wetlands which have been drained for agricultural reasons would have a beneficial impact on the whole catchment health, however this is unlikely due to the drying climate and increased use of raised bed cropping techniques within the region (Glenelg Hopkins Catchment Management Authority, 2003).

4.3.3.5 Benefits and Costs of Nutrient Management in the GHCMA Region

Read et al (1999) were commissioned to produce the report *Benefits and Costs of Nutrient Management in the GHCMA Region* prior to the development of the Nutrient Management Plan by the GHCMA. The estimated future frequency of algal blooms was to be considered as potential only. The report estimates the potential financial impact of algal blooms on human activity associated with waterways but does not account for the cost to native animals and native habitat.

Based on the past thirty years, if no strategy for water improvement is developed, the expected number of weeks over the next 30 years that lakes in the Hopkins catchment will be affected is 84 (major blooms) and 273 (minor blooms). Streams in the Hopkins catchment will be affected for 18 weeks (major blooms) and 48 weeks (minor blooms). For farm dams the figure is 6132 weeks for major blooms and 9198 weeks for minor blooms. Algal cell counts above 15000 cells imply that water should not be used for drinking or animal use (Read et al, 1999).

The cost of these blooms in the Hopkins catchment in 1999 was predicted to be $67,990 (6.7%) for stream impact, $469,211(46.3%) for impact onlakes and $476,831 (47.0%) for impact on dams. In total $1,014,032, which is $0.92/ha based on GHCMA's estimate of 1,096,000 ha in the Catchment (or $1.08/ha based on Read et al, 1999. figure of 940,000 ha). According to area, the percentage impact is:

- Farm dams 55%
- Eel production 16%
- Urban water supplies 9%
- Amenity of foreshore residents 8%
- Recreation and tourism 7%
- Management agencies 3%
- Irrigation water supplies 2%

In 1999 the main contribution to nutrient loads in the catchment was thought to be dryland farming (69%), due to the high percentage of catchment land use for this purpose, intensive industries (10%), stormwater (20%) in urban areas, and runoff from roads and logging in forested areas (1%). Read et al (1999) estimated phosphorus loads in the Hopkins catchment as 144,214 kg/annum. This equates to 0.146 kg P/ha/an.

Read also calculated the benefits and costs for each potential nutrient reduction activity within the catchment. In its Nutrient Management Plan (NMP), the GHCMA has adopted the report's recommendations in regard to which area to focus on for greatest impact on the catchment as a whole (see Section 4.3.3.3).

4.3.4 Water Data Warehouse Data on Total Phosphorus in water monitoring

The 'Water Data Warehouse' was initiated by the EPA as a central database to hold biological monitoring and assessment data collected by the EPA, CMAs, State departments and other research bodies. Within the Hopkins River catchment there are 11 locations where data has been collected in the past. Of these, seven have data on TP levels. Graphs of the TP readings are found in Section 2.2.5.2.

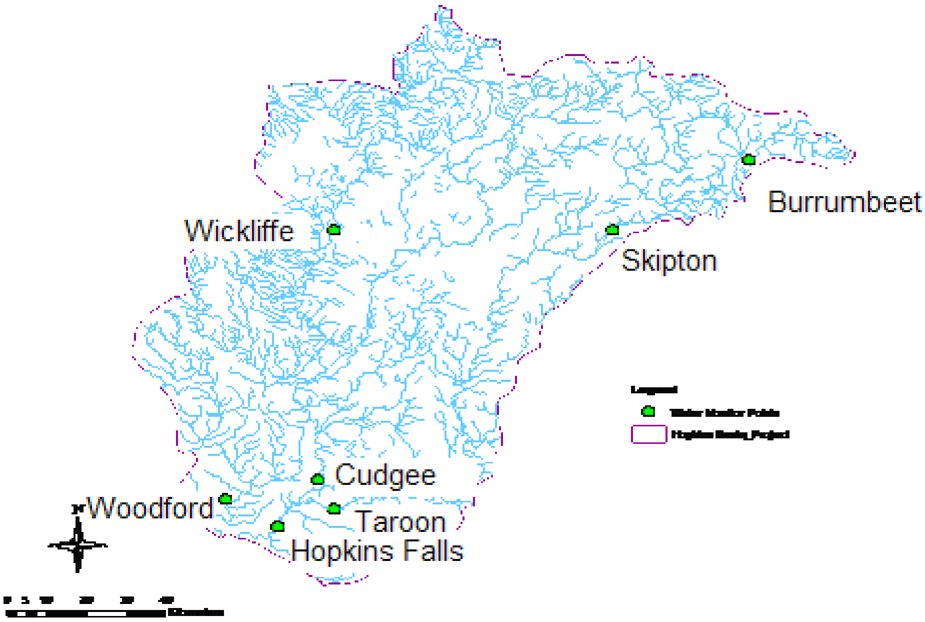


Figure 4.8 Total phosphorus monitoring points within the Hopkins River catchment

4.4 Local Councils and Policy Documents

The Hopkins River Catchment crosses four shire boundaries: Moyne, Ararat, Corangamite and Ballarat. Each Shire has its own strategies, plans and targets for dealing with environmentally sensitive problems.

4.4.1 Moyne

Moyne has an environmental sustainability strategy plan which provides a reference point for 'the protection and management of all key environmental assets within the Shire'. Within this strategy targets have been set to improve:

1. water quality and conservation
2. soil quality and conservation
3. level of greenhouse gas emissions
4. waste management practices
5. Biodiversity management
6. Education and awareness (Moyne Shire Council).

As part of the Environmental Sustainability Strategy, a Priority Action Plan was developed to be reviewed and updated every two years. The Moyne Shire also works in collaboration with the DPI and GHCMA to support the Environmental Best Management Practices program to raise awareness of best water management practices on farms. A storm water management plan to improve the quality of urban storm water discharge into local waterways covers three towns in the Hopkins catchment.

4.4.2 Ararat Rural City Council

In 2007 the Ararat Rural City Council developed Environment Local Law 2007 which in principle provides a safe and healthy environment for the residents of the district. A section of this law is targeted at water courses, where activities which are detrimental to the water quality or water course are prohibited. An urban storm water management plan is also in place for the city of Ararat (Ararat Rural City, 2007).

4.4.3 Ballarat City Council

The Ballarat City Council adopted an Environment Sustainability Strategy and the LiveSmart Ballarat Policy in October 2007. The Environment Sustainability Strategy provides for over 100 actions and initiatives orientated around the following themes:

- biodiversity (flora and fauna)
- water quality and quantity
- energy
- waste recycling and re-use
- air quality

The key objectives of the strategy are to:

- provide a clear direction to the City of Ballarat and its community regarding sustainability as well as the protection and enhancement of the natural environment.
- develop a focus on sustainability across the organisation and achieve best practice environmental management in respect to council's operation.
- continue to raise awareness and increase the community's participation and partnership in environmental issues (Ballarat City Council, 2007).

4.4.4 Corangamite Shire Council

The Corangamite Shire Council has a waste water policy in reference to sewered and un-sewered properties. An environmental strategy has not been developed as yet.

4.5 Fertiliser Industry Codes of Practice

The Fertiliser Industry Federation of Australia (FIFA) board endorsed an eco-efficiency agreement with Environment Australia (EA) in 2002, with the aim of achieving better environmental outcomes, reduced costs and increased competitiveness through:

- increased implementation of environmental management systems consistent with ISO 14001
- increased promotion and policy involvement with environmental management issues
- development of environmental standards in the form of an environment code of practice for the industry and benchmarking environmental inputs and outputs (Fertiliser Industry Federation of Australia Inc, 2005).

The industry is encouraging members employed in the fertiliser service industries to undertake FERTCARE modules which instruct participants about product knowledge and employing best practice in transport, storage and spreading. In addition, members are encouraged to have their spreading machines accredited under ACCUSPREAD. A program for the testing of fertiliser spreading machines to ensure that they are accurate in spreading fertiliser evenly across a paddock.

Codes of Practice (Australian Fertiliser Services Association)

Storage

- Fertiliser products will be confined within the storage perimeter and there will be minimisation of drift of dust, spillage and runoff outside the storage area.
- Storage dumps on farms can be located to prevent runoff into environmentally sensitive sites.
- Each specified fertiliser product will be kept in a separate storage area.
- Contact between fertiliser products, people and animals will be minimised.
- Equipment to be used within established safety limits and principles of sound practice observed.

Transport

- Fertiliser product will be free of contamination, contained within the tray or bin (no spillage).
- Appropriate OH&S standards observed.
- Sound practice observed with minimised environmental impact.
- Driver will advise customer as to the suitability of any proposed farm fertiliser dump to minimise the likelihood of fertilisers being blown or washed from the site.

Spreading

- Fertiliser products will be spread only on the land that has been contracted to, operator will ask owner if it is acceptable to spread if there is visible drift.
- Operator will not begin spreading when rain is imminent and soil tracking off the area being spread is unacceptable.
- Fertiliser products will be contained on the land area contracted and will not breach State department guidelines on what buffer zones are set to allow minimal fertiliser runoff into waterways, dams and drains. Groundcover and slope will be taken into consideration.
- The operator will be familiar with the range of fertiliser rates common in a district and query the customer if it is above the rate, to avoid leaching into groundwater.
- Machinery will be clean on and clean off the property.
- High OH& S standards and sound practice will be observed to minimise adverse environmental impact.

Product knowledge

- All members will understand the basic principles concerned with the products being marketed and the uses of the products within the industry.
- All members will explain to clients where they may be able to give advice and demonstrate that they are qualified to do so.

4.6 Industry Papers

The main agricultural peak bodies have been working towards encouraging farmers to factor environmental sustainability into their enterprises. These are outlined in the following subsections.

4.6.1 Meat and Livestock Association (MLA)

The Meat and Livestock Association (MLA) has produced a number of fact sheets advising growers on the best practice in natural resource management. These include *Managing groundcover to reduce runoff and water loss* which addresses appropriate fertiliser application timing to reduce runoff and erosion, and management of groundcover. Other fact sheets deal with increasing biodiversity, retaining native vegetation, improving pasture management and reducing weeds (Meat and Livestock Association, 2008).

4.6.2 Australian Wool Innovation (AWI)

Australian Wool Innovation (AWI) has undertaken a trial survey with the MLA on environmental and livestock management practices. The aim is to collate data on current producer management practices and compare this to ‘best practice’. The AWI has also collaborated with Land and Water in their program 'Land, Water and Wool'. This program gives practical advice on managing waterways and gullies to improve water quality through reducing sediment and nutrient runoff (Australian Wool Innovation, 2008).

4.6.3 Dairy Australia

Dairy Australia has been working with researchers at The University of Melbourne and the DPI to encourage dairy farmers to utilise fertilisers in a sustainable, efficient manner that will minimise runoff and leaching into waterways. A number of research papers have been produced aimed at improving water quality and increasing biodiversity under the banner of 'Dairying for Tomorrow'. They are pro-active in extension services promoting sustainable dairying and are endorsing better effluent management to reduce nutrient pollution and improve the image of dairying.

Economic data for the dairy properties was obtained from a 2004/2005 report of a survey and analysis of data undertaken by the Australian Bureau of Agricultural and Resource Economics into the financial performance of Australian dairy farms. The results shown in Table 4.6 are an average over 3 years from 2001 to 2004. This data will be used in the future when the Game Theory model is applied to a dairy enterprise.

	Rainfall	Stocking Rate dse/ha	Gross Margin Per ha	Milk production L / ha	Water per cow ML
Dairy	700-900 mm	17.6	$ 574.71	8607	1.77

Table 4.6 Dairy Production data extracted from Dairy Australia
(ABARE and Dairy Australia, 2005)

4.6.4 Grains Research and Development Corporation

The Grains Research and Development Corporation supports an educational program called 'Fertiliser decisions: Show me the money' aimed at helping growers make informed decisions on nutrient use. In August 2007 the corporation produced a supplement in the *Groundcover* magazine detailing information gained through its nutrient research projects (Grains Research and Development Corporation, 2007).

Chapter 5: Project Survey Description

5.1 Introduction

Survey data on the actual amount of fertiliser applied to properties and the decision making process had not been collected throughout a whole catchment region prior to this research. Five groups of farmers in the Hopkins River catchment were invited to participate in a survey collecting data on the use of fertilisers in the region. Presentations were given to two of the groups and 210 surveys were distributed to all the members in all groups. In total 39 surveys were returned, however four were rejected due to being outside the Catchment or contained unusable information.

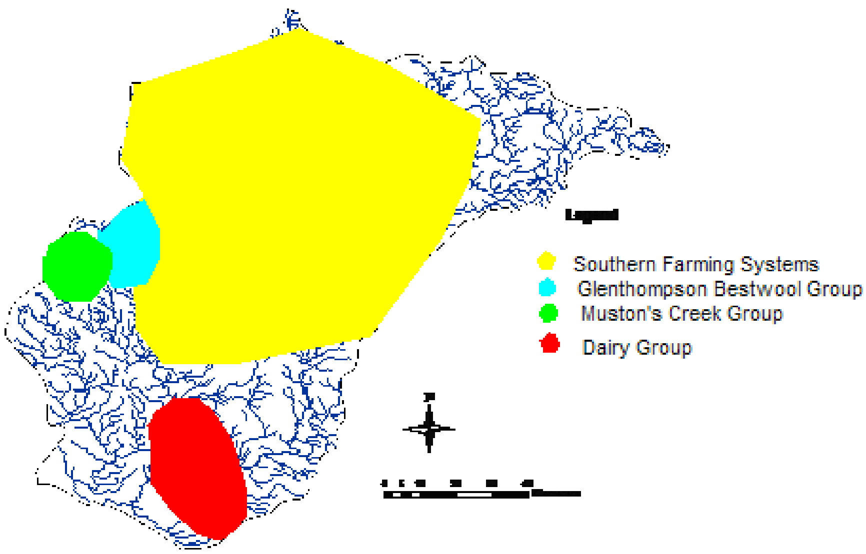


Figure 5.1 Farmer Groups targeted in the Hopkins River Catchment

The returned surveys were from individual farmers scattered throughout the catchment although primarily they were in the north (see Figure5.1). Farmers in a dairy discussion group were approached initially but were unwilling to participate. Contacts in the DPI's Environmental Best Management Project (EBMP) led to a second group being approached with some success in the second year. This area is outside the local region in which the researcher is known and may explain why there was some reluctance to participate. Ten dairy properties were approached and Five returned their surveys.

5.1.1 Selection of Groups of Farmers in the Hopkins River Catchment.

The five groups of farmers in the Hopkins River catchment approached were the Glenthompson Bestwool/Bestlamb Group, the Streatham Branch of Southern Farming Systems, Mustons Creek Landcare Group, Bushy Creek Landcare Group and the South Eckland Dairy Discussion Group. The participants in the Bushy Creek Landcare Group that chose to participate were also members of the Southern Farming Systems Group or the Glenthompson Bestwool/Best Lamb group hence they were reclassified into the other groups.

5.1.2 Getting the Groups Together

Initial considerations

- Should the whole Glenelg Hopkins catchment region be used or just part of it?
- Initial contact was made with several farmers when the project was proposed -who and where are these people in the catchment?
- Should the existing farmer groups be used or a general mail out (letter drop)?
- How do we get farmers interested in the project? Will it only be those interested in conservation?
- From the above will there be a problem with skewed data?
- What is the time frame for the first survey?
- What is a workable group size?
- Total number of participants for statistical use of information?
- Different enterprises, soil types, region of catchment, rainfall?

Possible groups to target

- Landcare groups – Muston's, Woodhouse Nareeb, Bushy Creek, Chatsworth, Woorndoo and Mortlake.
- Environmental Best Management Project groups – would involvement of these groups produce some bias?
- Bestwool/Bestlamb group
- Dairy discussion groups
- Topcrop group
- Personal networks
- Landcare facilitators at the CMA
- People originally contacted when project was proposed.

The possibility of mailinga 'letter to the farmer' was considered as it would make contact with a broad spectrum of farmers but the question was 'would they complete the survey' when the researcher was unknown and the survey appeared out of context. This method would also be costly. Initial approaches were made with local group facilitators to arrange a 15 to 20 minutes to talk to the local Bestwool and Landcare groups. To increase the return rate of the survey a reward was offered for completing the survey in the form of a cash payment to a local organisation/ business. The Country Fire Association (CFA) was selected as the recipient organisation as most farmers belong to it and it is apolitical. The chairman of Southern Farming Systems facilitated the use of their database of 167 members in the Hopkins catchment area in sending out the surveys. The secretary sent out initial letters so that the privacy laws were not breached. In light of this the research area was confined to the Hopkins River Catchment. Surveys were sent out to Muston's Creek and Bushy Creek Landcare groups, Glenthompson Bestwool / Bestlamb group and the Southern Farming Systems Group in August 2006, and were returned by the end of September 2006.

Discussions with contacts in the dairy industry led to a meeting and presentation to the dairy discussion group. However, the reception was defensive as the group felt that dairy farmers were always being targeted in regard to their fertiliser application management. There were no returned surveys from this group. After failing with the first dairy group an approach was made to contacts in the EBMP Project who work within the dairy region. Through them, ten dairy farmers were contacted in June 2007 and invited to be involved in the project. A survey incorporating both the first and second survey questionnaires (refer to appendicies 1 and 2) was sent out and five surveys were returned.

5.2 Survey Design Overview

The initial survey was designed to collect data on property size, type of enterprise, position within the catchment and information on fertiliser use, knowledge of nutrient runoff and attitudes to nutrient pollution. The surveys were sent out in August and collected over two months in August/September 2006. A second survey was sent out in June 2007 to the initial participants to clarify some questions. The delay was due to the drought of 2006/2007 as it was felt inappropriate to impose on people under stress. The second group of dairy farmers was surveyed in June 2007 (incorporating questions from the second survey sent out to the initial farmers). A third survey was conducted by interview in May/June 2008 to gauge a response to the recommended phosphorus amounts as calculated by the Game Theory model. Full copies of the survey questions are found in the appendicies 1, 2 and 3.

The data were collated in an Excel spreadsheet with private information removed, once the position of properties within the Hopkins catchment had been determined. The numerical data was analysed using Minitab™ and Excel data analysis. ArcGIS™ wasused to produce maps of enterprise analysis, phosphorus use and Game Theory results.

5.2.1 Survey 1

The aim of survey 1 was to gather information for the Game Theory equations and to understand how farmers make decisions about how much and when fertiliser is applied. An additional objective the aim was to gain an understanding of the farmer's attitude to changing those practices that contribute to environmental degradation. Primary information enabled the identification of farmer clusters for use in the cooperative Game Theory model. The survey was structured as follows.

Primary Information

Name and contact details.
Farm size; Type of farm enterprises and breakdown of each enterprise by percentage;
Soil types; Average annual rainfall; Pasture type and coverage and the presence of waterways.

Fertiliser Application Questions

What type of fertilisers are used? Specify what they are used on and how frequently they are used? How much is applied and when is it applied? Does the type and amount vary from year to year? Are granular or liquid fertilisers used? Is a contractor used to spread the fertiliser? (important when considering altering the timing of fertiliser application) Do you follow the recommendations of the 'Codes of practice' for the fertiliser industry? How do you decide the amount applied? Do you use soil tests or tissue tests to determine how much fertiliser to spread on pastures or crops? If a heavy rain occurs immediately after fertilizing the farm, are fertilisers reapplied? What margin would you put on the benefit you get by applying fertiliser? What is the cost of fertiliser expressed as a percentage of your annual farm costs?

Nutrient Pollution Questions

What is your understanding of nutrient pollution of waterways? How does this affect you and your region? Are you concerned with the long term effect of nutrient pollution on the wider catchment? What monetary value do you place on the benefits of a healthy catchment? What agricultural activities contribute to nutrient pollution? What percentage of your waterways and wetlands have been fenced and revegetated to at least 10m from the edge of the water? Is it possible for you to contribute to solving the problem of excess nutrient pollution in waterways? What frustrates you most in discussions of environmental issues and agriculture? Why?

5.2.2 Survey 2

The aim of this survey was to investigate the current fertiliser targets (which influence fertiliser management decisions) that the landholders have and to clarify questions from the first survey. This survey was structured as follows.

Questions

What is your soil P target? What percentage of your production areas are at or near this target?
Does the amount that you are using reflect where you are aiming for in soil P target?
Was the amount indicative of what was applied over the whole farm? Was it specific to certain paddocks with the aim of raising soil P? If so what percentage of the farm was this?
Indicate in which month/s you apply Phosphorus fertiliser. C-Crop and P- Pasture
At what distance from the waterway are the fences? Have you observed an improvement in water quality in streams? Would you allow this to be mapped on a GIS for the purposes of the project? What are the local attitudes on fencing waterways and wetlands? Do you use land class fencing to manage low lying areas of your farm? Are you an active member of a landcare group?

5.2.3 Survey 3

The aim of the final survey was to obtain the response of the farmers to the recommendations from the Game Theory calculations and what was the farmer's response to the doubling and tripling in price of fertiliser products in 2008? This survey was structured as follows.

Does knowing that there is a problem with rising phosphorus levels in the Hopkins River alter your decision making with regard to phosphorus fertiliser application? What do you predict would be the production response in 3to 5 years if you raised/ lowered the amount of P (kg/ha) according to the recommendation arising from the research? Are you likely to follow the recommendations?

What impact has the doubling in cost of fertiliser had on your decision making this year?
Did this alter the timing of fertiliser application? Has this altered the amount of fertiliser applied? Has this altered the mix of enterprises that you are planning to produce? Has this altered the mix of crops that you are planting this year? How?

5.3 Workshops Methodology

During the project several workshops were conducted. The first workshop was a presentation to the groups to discuss the project and participants were invited to be involved. The second round of workshops included presentations of the results from the first survey and the initial findings from the literature research. A final presentation was made to the GHCMA on the completion of the project.

5.3.1 Workshop 1: Presentation of Proposed Project

A power point presentation was made to the Glenthompson Bestwool/Bestlamb, the Bushy Creek Landcare and the South Eckland Dairy Discussion Groups separately, inviting the members to participate in the proposed research project. The group facilitator/secretary was contacted and a presentation time allotted at the next meeting to be held. This coincided with the time frame of the project. The Bestwool/Bestlamb presentation was delivered at Cuming's wool shed on 4 May 2006 to a group of twelve farmers. The presentation to the South Eckland Dairy Discussion Group was held at Mac's dairy on 8 August 2006 to a group of 35 farmers and the presentation to the Bushy Creek Landcare Group was held at the McInnes property on 23 August 2006 with twelve people in attendance.

5.3.2 Workshop 2: Feedback of Survey 1 Results

A poster presentation was delivered to Southern Farming Systems displaying the preliminary results of the project at their annual research workshop held at a property south of Beaufort on the 3/4th November 2006.

Preliminary results were presented to the Glenthompson Bestwool/Bestlamb group at the Glenthompson Fire shed on 15 June 2007. The timing coincided with a scheduled meeting and with sending out the second survey. There was some delay in the process due to the drought that had a major impact on the region. Discussion took place concerning current research on the impact of phosphorus on the catchment, the cost benefit analysis being undertaken and the practicality of the Game Theory calculation.

5.3.3 Workshop 3: Presentation of Game Theory Recommendations

Initially it was intended to run a workshop for each of the farmer groups to discuss the results of the Game Theory model. However, due to problems with a delay in the final numbers it was felt more appropriate to interview a smaller group of individual farmers to gain their response on the results. During the past twelve months the price for commodities changed due to the drought, and the cost of fertiliser rose between 100/300% (at the end of the drought). A corresponding rise in the price received for commodities has not yet been realized and the questionnaire was given to gauge how farmers react to sudden cost rises. The drought and rising fuel costs have altered the market dynamics compared to the original year of the project, a factor that would be reflected in the Game Theory model results if they were re-calculated at present.

The final presentation was made to members of the GHCMA, with some DPI researchers in attendance. A discussion was had of the practical lessons learned that were of value to the GHCMA.

5.4 Collating Material for Maps

Interest in modelling environmental systems has greatly increased in the past decade. At the same time appropriate techniques, computer resources, and data of suitable quality have become widely available, so that the gap between the desirable and feasible in environmental modelling keeps decreasing. Geographic Information Systems (GIS), with their power to integrate diverse databases, undoubtedly play a key role in this development and have become the core technology of environmental research.

In this study, where the cooperation of farmers in decreasing the effects of nutrients on surface waters was investigated, various GIS data sets from different sources wereused. The outcome will assist in visually expressing the recommended changes to quantities of fertiliser to be used. This section will present the data that has been collected and used to create maps required for information in the study area. The necessary conversions and modification of each layer has been made as required.

5.4.2 Material and Methods

The underlying mapping was collated by Afshin Alizadeh (RMIT University) using different GIS packages based on the nature of the data and/or their conversions. The main software used to produce the final maps was ESRI® ArcGIS™ (version 9.1) due to its high capability with vector based layers.

Global Mapper (version 6.08) was used to view, convert, and extract raster-based layers such as Digital Elevation Models (DEM) and satellite images. In addition, it was used to re-project those layers which had differing geographical projections to the main data layers.
DIVA GIS (version 5.2.0.2) was employed to import the rainfall and elevation data, which was then converted to GIS files to be used in ArcGIS™.

5.4.2.1 GIS Base Data Layers

Raster data

Raster data are demonstrated in the form of grid cells, in which the information is stored. In other words, each cell contains information about the area that the cell covers. The 9 second Digital Elevation Model layer is derived from RMIT's School of Mathematics and Geospatial

Science data library. Its resolution is 9” x 9” cells (latitude/longitude) ~250m, vertical accuracy ~25m, derived from 1: 100,000 spot heights with enhancements.

The average yearly precipitation was extracted from the DIVA Bioclimatic Database. Individual data was also collected from the property owners participating in the research.

Vector data

The vector data layers are made of polygons, lines, or points. Most of the spatial data used to produce the maps were vector data. The data layers are briefly described below.
The Hopkins River catchment polygon covers the extent of the study area and it was extracted from the Victorian Catchments’ layer. This polygon was mainly used to clip the essential data from other layers, and to adjust the geographical projection among different layers.

The rivers and surface water data comes in the form of lines and polygons. Each feature contains information about the length, type (water course, canal, wetland), and name. This layer is especially useful to visualise the position of the properties in relation to the surface water.The elevation contour lines layer contains intervals of twenty metres. Along with the DEM layer, different aspects and slopes of the region can be calculated to find out the transportation rate of fertilisers within the area (Alizadeh Shabani et al., 2007).

5.4.2.2 Development of the maps from collated farmer data for visual presentation

Using the base maps as a guide, two vector data layers were produced with information collected from the property owners and the Game Theory model.

Property Layer

The attributes for the property layer include property size, owner code, enterprise, phosphorus amount applied to pasture, phosphorus amount applied to crops, use of soil testing and use of contractors.

Game Theory Modelling Layers

The Game Theory model layer has attributes indicating the data from the Nash equilibrium and Pareto Optima calculations for each property and for three enterprises namely prime lambs, wool and crops (see Figures 8.1, 8.2 and 8.3).

A second layer has the data giving the difference between the Nash equilibrium and Pareto Optima calculations providing visual presentation of the benefit of undertaking cooperative decision making compared to competitive decision making (see Figures 8.4 (a) – (f)).

Chapter 6: Survey Results

6.1 Introduction

Actual data from properties throughout a catchment was collected for use in the Game Theory model to enable the provision of realistic figures for the model and to understand the process of managing fertilisers on those farms, which have multiple enterprises. These decision processes could later be factored into the model as necessary.

The DPI reports that the number of farm properties in the Glenelg Hopkins catchment region is 3850 (D Borg, Personal Communication). There is no data on actual farm numbers in the Hopkins catchment alone however, as the Hopkins catchment is approximately 40% of the Glenelg Hopkins region, a reasonable estimate of the number of properties in the Hopkins catchment is 1540. Of these 35 property owners were surveyed, which equates to 2.2%. The area of the properties we have surveyed is 25770ha (Cropping 9969 ha, Grazing 15344 ha) which is 2.5% of the Hopkins catchment area.

The average size of the properties in the projectwais 736 ha, whereas the average property in the catchment was 640 ha. The difference is attributed to the small number of dairy properties represented in the project.

6.2 Survey 1

The aim of the first survey was to gather primary information on the farmers in the group and material to be used directly in the Game Theory model. We used the data to identify farmer clusters for use in the cooperative Game Theory model.

The survey data collected and shown in Table 6.1 indicates that most farms have mixed enterprises, except for the dairy landholders who exclusively run dairy cattle. Approximately 39% of the region is under crop; 60% is pastured for some form of animal production (milk, meat or wool) and 1% is used for other activities (forestry, fodder production).

6.2.1 Primary Information

	Enterprise %							Area			
	Wool	Prime Lamb	Beef	Crop	Hay	Forestry	Dairy	Total area	**Ha grazing**	**Ha crop**	Ha other
1	70	30						300	300		
2	20	10		70				2446	733.8	1712.2	
3	50			50				1200	600	600	
4	40	40		20				800	640	160	
5		50		50				970	485	485	
6	60			40				1400	840	560	
7	20	20		60				400	160	240	
8				100				400	0	400	
9	35			65				1400	490	910	
10	20	15		65				440	154	286	
11	25	25		50				1100	550	550	
12		25		60	15			788	197	580	12
13	30	6	4	60				1200	480	720	
14	33	34		33				1040	686.4	343.2	
15	33			67				96	31.68	63.36	
16	30	20	50					200	200		
17	97			3				1350	1309.5	40.5	
18		100						240	240	0	
19	30	60			10			234	209		25
20	60	40						250	250		
21	50	15	15		5	15		1500	1200		300
22	100							325	325	0	
23		33		67				2000	660	1320	
24	55	10	10	25				950	712.5	237.5	
25	100							425	425	0	
26	10	35	35	20				800	640	160	
27	95	4	1					413	413	0	
28	74	5		21				387	305.73	81.27	
29		40	20	40				1300	780	520	
30	70				30			297	207.9		89.1
31							100	280	280		
32							100	300	300		
33							100	159	159		
34							100	212	212		
35							100	168	168		
							Totals	25770	15345	9969	426.1

Table 6.1 Area and Enterprises of the Farmer Group

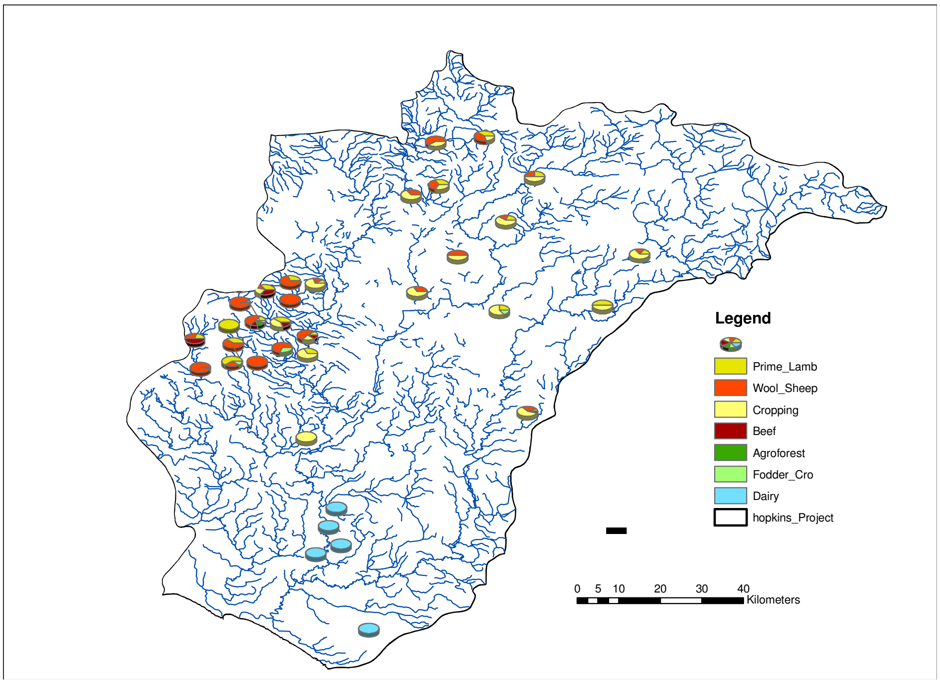
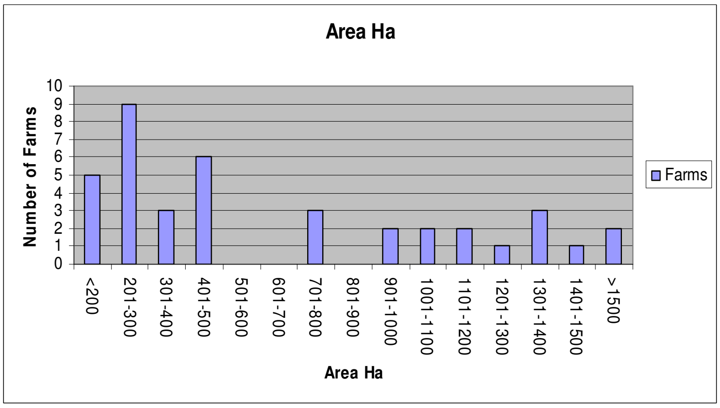


Figure 6.1 Positions of Properties in Project by Enterprise

Figure 6.1shows that the dairy properties are located in the south of the catchment which equates to the higher rainfall region (see Figure 2.3). The mixed enterprise properties undertaking cropping and prime lamb or wool tend to be found in the north of the catchment in the lower rainfall region and in the region of moderate slope. The grazing only enterprises are found in the area with average rainfall, and the region with steep slopes where continuous cropping may present soil erosion problems.



Area	
Mean	736.2857
Standard Error	97.862
Median	425
Mode	300
Standard Deviation	578.9594
Sample Variance	335194
Kurtosis	0.826935
Skewness	1.097916
Range	2350
Minimum	96
Maximum	2446
Sum	25770
Count	35
Confidence Level(95.0%)	198.8795

Figure 6.2 Statistics of acreage distribution

The histogram in Figure 6.2 indicates a skew towards the smaller holdings in the project group; this is a productive region with a range of rainfall patterns, with a greater number of smaller farms in the high rainfall, high land value areas.

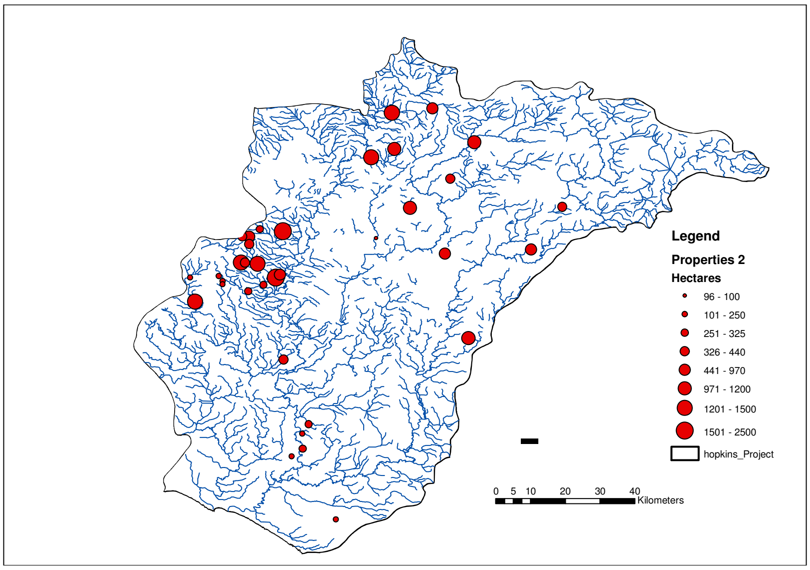


Figure 6.3 Properties by Size

In a region with even climate and soil types this would not be as apparent. The largest properties are in the mid to northern section of the catchment as indicated in Figure 6.3.

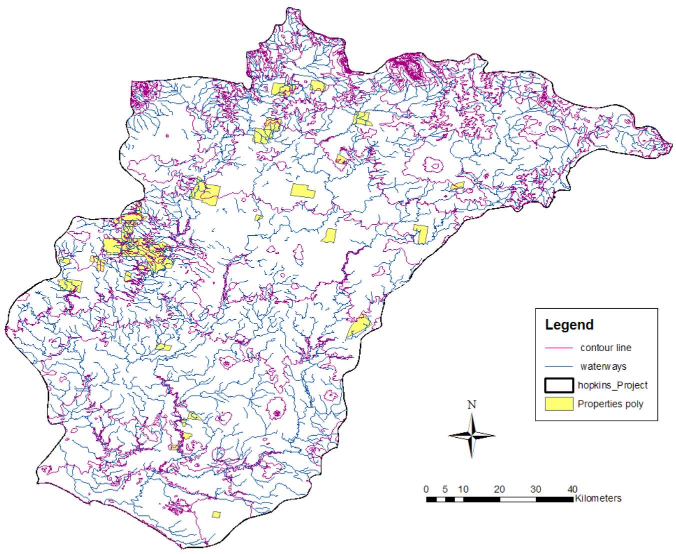


Figure 6.4 Position of Properties within the Hopkins Catchment

Initially the proximity factor (β) in the model, which is described in Chapter 7, has been calculated as the distance between neighbouring properties. Figure 6.4 gives the relative position of the properties to each other and their position in the catchment. Information from this map will be used in future calculations when the β value is calculated using distance to waterways and property position in relation to elevation and slope rather than distance from closest participating property. This is discussed in Section 8.3.2.2.

FARM	Pasture Type: Native %	Introduced %	Annual %	Perennial %	% Creek Lines fenced	Soil Type: Soil Types	Rainfall (mm)	Elevation (m)
1	5	95	0	100	90	SL	600	150
2	5	95	0	100	5	SL-CL	525	200
3	10	90	100	0	0	gr-L-C	500	250
4	5	95	20	80	100	BA	575	350
5	5	95	30	70	0	L, B/S	600	250
6	10	90	50	40	2		590	300
7			20	80	50	B/S Br L	550	300
8					100	BA	625	100
9	5	95	50	50	40	BA	500	250
10	80	20	20	80	2	gr-L -C	630	250
11	50	50	25	75	50	CL	625	350
12	10	90	20	80	0	gr-L	500	300
13		100	0	100	25	gr-C red-L	600	200
14		100	30	70	10	gr-L red-br E	600	150
15		100	100	0	50	CL	580	250
16		100	50	50	90	B-L	640	200
17	5	95	60	40	50	B-L	630	200
18		100	30	70	70	B-L	700	200
19		100	20	80	0	HB	675	250
20		100	30	70	100	B-CL	680	200
21	20	80	30	70		SL	700	200
22	8	92	0	100	100	SL	590	300
23		100	0	100	60	SL	514	200
24	3	97	15	15	45	SL	550	200
25	10	90	70	30	90	S-SL	600	200
26	5	95	50	50	90	SL	650	300
27	4	96	4	96	100	S	700	300
28	8	92	20	80	90	gr-SL	635	300
29	0	100			90	SL	600	300
30	0	100	30	70	100	Granite SL/SL	578	250
31	0	100	0	100	100	B S/R	750	250
32	10	90	20	80		B S/R	800	100
33	50	50	25	75	100	CL	750	100
34	1	99	10	90		L	750	100
35	1	99				SL	750	100
Ave	6.939	87.61	28.15	66.39	64.25		624	50

Key: SL – Sandy Loam; CL - Clay Loam; BA – Basalt; C – Clay; B/S – Buckshot; S/R –Stoney Rises; gr – grey; br – brown

Table 6.2 Pasture Type, Soil, Rainfall and Elevation

Table 6.2 indicates a high level use of introduced pastures as would be expected in a region that has been cleared for agriculture for over 150 years. Only one property indicated a greater proportion of native pasture than introduced pasture. Most also indicated a high level of perennial to annual pasture, which is consistent with DPI figures for farms involved with agricultural extension groups (Trompf, 2000). Four properties indicated more than 50% annual to perennial pasture. Table 6.2 also presents the owner's information on soil types, rainfall and the elevation calculated from Figure 6.4.

6.2.2 Fertiliser Application Results

Fertilisers used in the district vary from property to property. The range includes Single Super, MAP, DAP, Urea, SOA, Lime, Gypsum, Dolomite, Trace Elements Cu Mo Zn B, Potash, Pig manure, Hay booster, Emfert, Goldphos blends and High analysis pasture fertiliser (triple super).

Generally the phosphate fertilisers, lime, potash, gypsum and trace elements (if required) are applied in the late summer to early winter period, with the cropping fertilisers drilled in at sowing. The nitrogen fertilisers are customarily applied to crops, hay and fodder crops in early spring, or maybe applied in a split application. One dairy property applied fertiliser once a year in spring, the rest followed the above practices. Crop and pasture fertilisers (phosphorus, nitrogen) are applied annually with potash, lime and dolomite applied every three to five years and trace elements every five to ten years as required. Farmers indicated that they apply fertilisers on grain crops (65.776%), pasture (80%), hay crops (48.5%) and other (2.8%). The results are greater than 100% due to multiple enterprises being run by many properties.

The statistics for phosphorus (kg /ha) applied to pastures and crops are shown in Table 6.3. There is a statistically significant difference between the amount applied to crops and the amount applied to pastures. The cropping properties had higher average use of phosphorus per hectare as shown in Table 6.3

Pasture (all enterprises)		**Crop**	
Minimum	4.55	Minimum	7.0
Maximum	23.1	Maximum	31.28
Mean	12.93	Mean	19.7

Table 6.3: Statistics for Phosphorus Application

.

	Total pasture	Total crop	Prime Lamb growers Pasture	Prime Lamb growers Crop	Wool growers Pasture	Wool growers Crop	Beef Pasture	Beef Crop
1	17.05		17.05		17.05			
2	13.9	13.9	13.9	13.9	13.9	13.9		
3	9.1	21.9			9.1	21.9		
4	10.50	21.9	10.50	21.9	10.50	21.9		
5	15.3	18.1	15.3	18.1				
6	13	31.28			13	31.28		
7	11.375	27.38	11.375	27.375	11.375	27.375		
8		13.14						
9	15	20			15	20		
10	5.16	11.93	5.16	11.93	5.16	11.93		
11	17.91	17.91	17.91	17.91	17.91	17.91		
12	19.45	19.45	19.45	19.45				
13	14.76	30.27	14.76	30.27	14.76	30.27	14.76	30.27
14	13.25	19.06	13.25	19.06	13.25	19.06		
15	4.55	10.9			4.55	10.9		
16	15.11		15.11		15.11		15.11	
17	7.76				7.76			
18	18.96		18.96					
19	13.96		13.96		13.96			
20	18.2		18.2		18.2			
21	10.7		10.7		10.7		10.7	
22	13.65				13.65			
23	18.2	21	18.2	21				
24	13.65	27.38	13.65	27.375	13.65	27.375	13.65	27.38
25	10				10			
26	9.1	21.8	9.1	21.8	9.1	21.8	9.1	21.8
27	16.22		16.22		16.22		16.22	
28	7.75	20.01	7.75	20.01	7.75	20.01		
29	7	7	7	7			7	7
30	11.85				11.85			
31	5							
32	15							
33	23.1							
34	10.8							
35	22							
Ave	12.996	19.7	13.40	19.79	12.23	21.12	12.36	21.61

Table 6.4 Phosphorus Application in kg P/ha

Table 6.4 presents the individual application rates for the farms based on the enterprises in production. A comparison of histograms of P use on grazing and cropping properties (Figures 6.5 and 6.6) indicates that cropping properties show a greater standard deviation (SD) compared with the grazing properties. The lowest value for a grazing property was for a small farm of 96 ha which maybe considered a 'hobby farm' and not representative of a commercial situation.

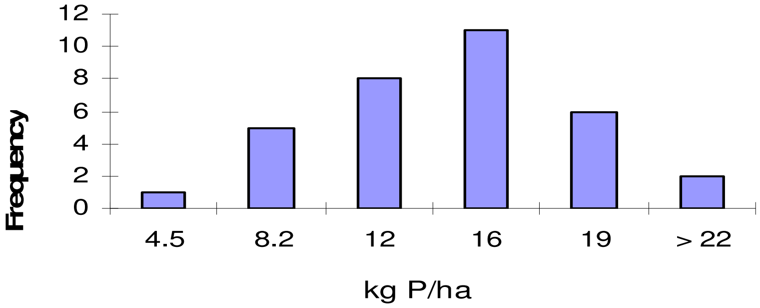


Figure 6.5 Average Pasture kg P/ha

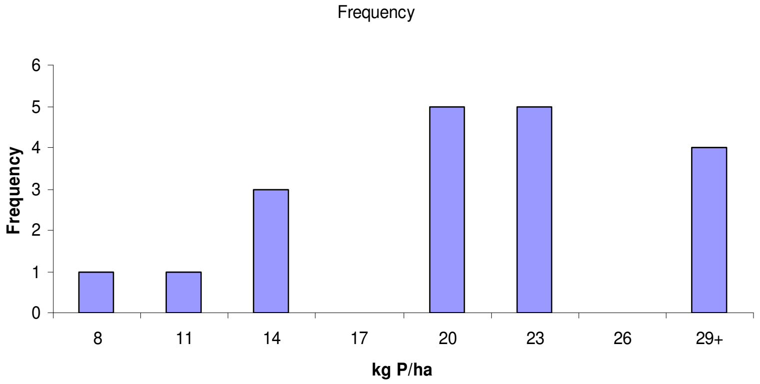


Figure 6.6 Average Crop kg P/ha

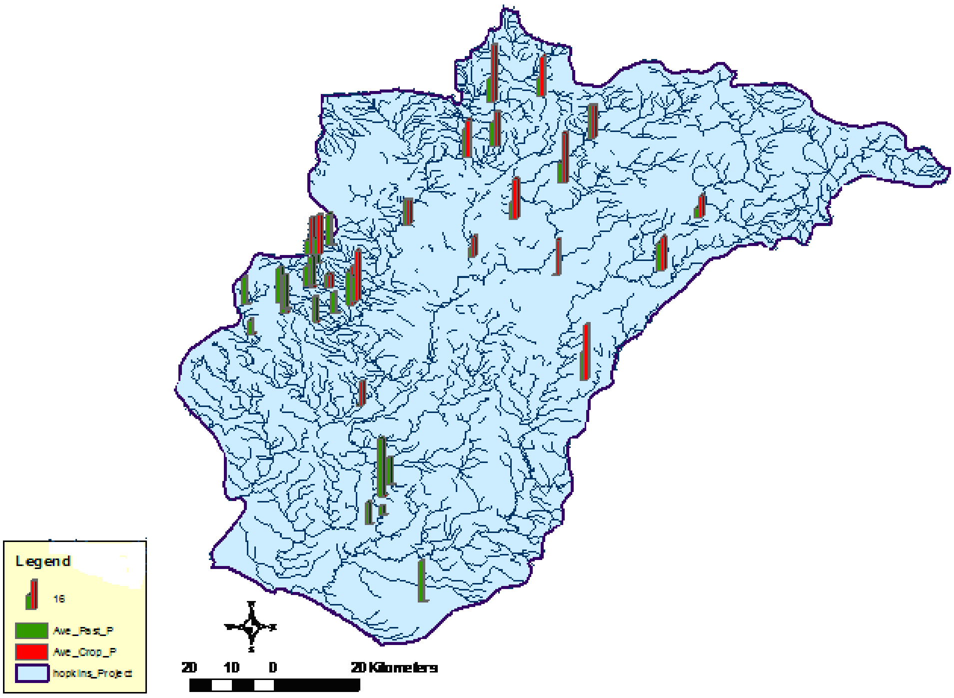


Figure 6.7 The Hopkins Catchment with Charts of Average Pasture and Crop P (kg/ha)

Figure 6.7 presents a comparison of the average P kg/ha applied to pasture and crops for each property. The height of the bars gives an indication of the quantity of P applied per ha. When examined in relation to proximity to water courses and elevation, it also gives some indication of the risk of phosphorus runoff.

Factors influencing the decision regarding the amount of fertiliser to be used includebased on advice by agronomists (66.6%), DPI (20%), previous farming experience (30%), tradition, ie handed down through the family (13%), the season, soil tests and other factors (13.3%) and the budget (10%). The use of agronomists has increased in the past 20 years as the terms of trade have declined and landholders are turning to specialists for advice.

The farmers indicated that any variation in fertiliser use from year to year is primarily due to **c**limate (43.3%), budget (33.3%), soil tests (20%) and the stocking rate (d.s.e./ ha) or the area to be committed to cropping (16.6%). The climate has the largest impact as it influences the stocking rate or crop species that are grown.

Thirty percent of the farmers were willing to look at alternative types of fertiliser from those that are currently used eg foliar sprays and/or ‘organic’ as opposed to chemical fertilisers. This became apparent in the third survey after fertiliser price rises.

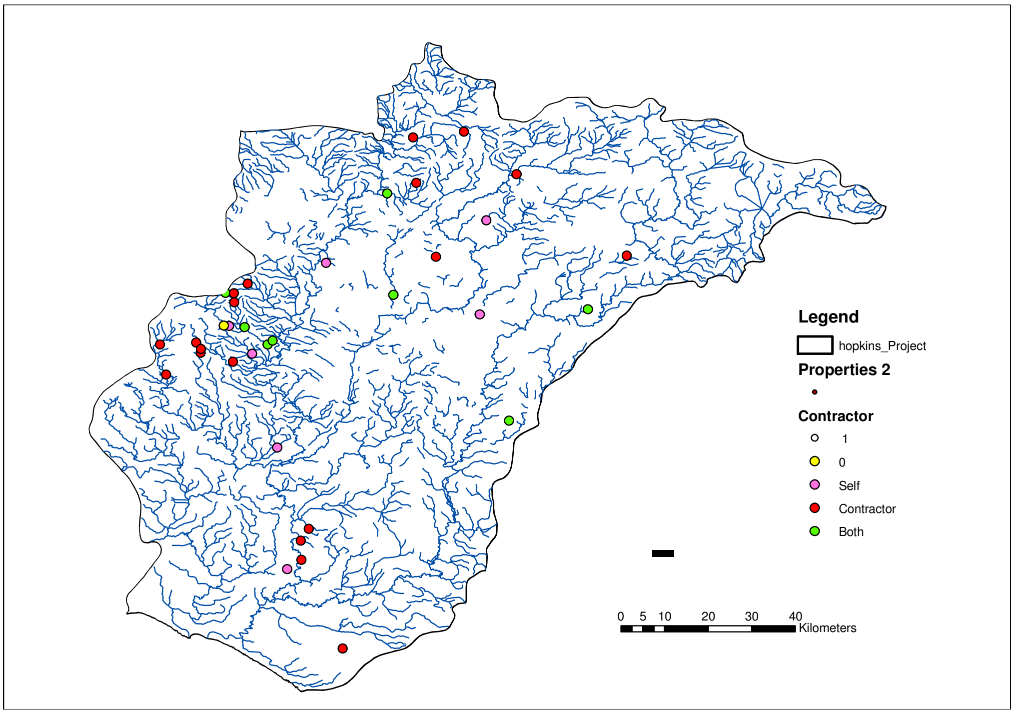


Figure 6.8 Representation of ‘Who Spreads’ the Fertiliser

The survey indicated that 76.6% of the spreading of phosphorus fertilisers is undertaken by contractors with only 20% of farmers still applying their own, as indicated in Figure 6.8. The reasons for this include time constraint and cost of equipment. These percentages align with the breakdown into granular and foliar application. Foliar application is undertaken with a sprayer, which is more common on individual farms than machinery required for super spreading, although it is too great an assumption to say that foliar spraying is not contracted out. Foliar sprays are often used to adjust nutrient demands during the growing of the crops. Of the total 48% of landholders either were not aware of the fertiliser industries 'codes of practice' (COP) or they relied on the spreading contractor to know them. The COP have been described in Section 4.5.

It was established that 85% of the participating farmers use either soil tests or tissue tests to determine how much fertiliser to spread on pastures or crops. Cropping properties in particular use tissue tests to monitor crops through the growing season and no farmers re-apply fertiliser after rain, due to the high cost of fertiliser.

A range of estimates (1.75 to 8) were given to the question on the margin of benefit gained by applying fertiliser. The cost of fertiliser expressed as a percentage of the annual farm costs varied from 10 to 30% with 10% of property owners not having calculated the cost as a percentage of their total costs. These results could indicate a lack of detailed business knowledge or a lack of wishing to share detailed knowledge with outsiders.

6.2.3 Nutrient Pollution Questions

A range of answers was given to the nutrient pollution questions however; they indicated that 76% of the participants have an acceptable understanding of nutrient pollution and the agricultural practices that contribute to it. 18.5% of participants had observed the detrimental effects of nutrient pollution (10% if dairy farmers are not included in the project). Dairy properties are in the lower reaches of the Hopkins catchment and are more likely to encounter the results of nutrient pollution within the total catchment. In keeping with this, 80% of participants did not view nutrient pollution as relevant to them and their community nevertheless, 60% were concerned with the possible long term effect of nutrient pollution.

The answers given in relation to how landholders could contribute to solving the problem of nutrient pollution supported the above evidence ie that they have a good knowledge of practices that contribute to reducing nutrient pollution and many are already fencing creeks and wetlands according to government advice. The survey indicated that 28.5% of participants put a high monetary value on a healthy catchment yet this may not reflect the true value of the catchment to the participants as 57% found the question difficult to answer. Only 10% of the participants gave little value to a healthy catchment. The survey indicated that 17.3% of the property owners have all of their waterways fenced and revegetated to at least 10 m from the edge of the water, 17.3% have no waterways fenced, and 32% have somewhere between 5 and 90% of their waterways fenced.

There were various responses to 'what frustrates you most in discussions of environmental issues and agriculture?' that loosely fell into a number of areas:

- city/rural divide in attitudes and responsibility
- perception that the time frames needed to repair environmental degradation are unrealistic
- environmental/agricultural research divide where not enough information is shared between the two
- over allocation of water from our rivers and groundwater
- too many regulations imposing on farming management
- unfair division of environmental cost placed on the farmer
- ignorance of the issues, problems and solutions by all sides
- long term use of herbicides
- unrealistic view of farming organisation leaders representing farmers as conservationists when it is not necessarily so
- contribution of soils, pasture and trees on farms not being accounted for in carbon calculations of greenhouse gas inputs and outputs from farms.

6.2.4 Survey 1 Discussion

One of the main tasks of the initial survey was to identify farmer clusters for use in the cooperative Game Theory model. Clusters are important because they identify groups within the catchment, with similar traits and objectives, which form the separate 'players' that will possibly form coalitions for cooperation. In this project there was no spatial basis for forming clusters therefore the clusters have been chosen on the basis of enterprise ie wool, prime lamb or crop. Adding complexity to this project is that the majority of landholders undertake mixed agriculture and some may practice all three enterprises. At this stage calculations for beef, agroforestry and dairy as separate enterprises have not been carried out. Detailed information on dairy production per ha per 100mm rainfall was not immediately available for the research project.

Two properties indicate 50%:50% native to introduced pasture which may be likely in one of the properties but less likely in the dairy property. Dairy properties are usually more developed than other enterprise properties due to the high value of the land. Past experience indicated that it is common for farmers to mistake degraded annual pasture as native pasture and the dairy property indicates a high use of phosphorus (in kg/ha) which would be detrimental to any native pasture as it is adapted to low phosphorus. In this case it is more likely to be 50% degraded pasture and 50% improved pasture. The property that indicated 80% native pasture indicated an appropriately low phosphorus use per hectare. The relevance of this in relation to the Game Theory model will be discussed in Section 8.3.2.2.

There were nine properties that indicated less than 10kg P/ha applied per annum. Of these 44.4% had >50% annual pasture but 56% have a higher proportion of perennial introduced pasture. Therefore, there appears to be no direct correlation between type of pasture and the amount of P applied except for the property owner with a large proportion of native perennial pasture which required a low P soil level. Soil P targets may have a greater role than the direct measure of pasture production. This factor was explored further in Survey 2.

There was an unexpectedly wide range of fertiliser amounts applied to pastures and crops. Information on participants in further education groups led us to expect a higher level of 'high production' landholders (Trompf, 2000) which may have skewed the results but there appears to be a relatively normal distribution of amount spread, refer to Figures 6.5 and 6.6.

Total Ave Pasture	Total Ave Crop	Prime Lamb-Pasture	Prime Lamb-Crop	Wool-Pasture	Wool-crop	Beef-Pasture	Beef-Crop
12.996	19.7	13.40	19.79	12.23	21.12	12.36	21.61

Table 6.5 Phosphorus Application in kg P/ha for Each Enterprise Group

Table 6.5 shows the break-down of phosphorus use (kg/ha) according to properties that have prime lamb and crops, wool and crops or beef and crops. There is no statistical difference between amounts of phosphorus applied to prime lamb pastures or wool pastures or between phosphorus applied to crops on prime lamb properties, and wool properties. There were not sufficient numbers of beef properties to make a statistical comparison with prime lamb and wool properties, nor a sufficient sample for comparison between cropping properties and pasture properties.

Information extracted from the SWFMP Group (refer to Section 4.3.2.1) puts the average fertiliser amount applied to pastures and crops on those farms as:

Wool 8.86 kg/ha Prime Lambs 10.31 kg/ha Beef 13.46 kg/ha
Cereal Crops 15.85 kg/ha Oil Crops 19.5 kg/ha

These values are lower for each enterprise compared to that of the participants in this project, suggesting that the research may strive to perform higher than the 'average' district farmer. L Beattie (Personal Communication) who has worked for the SWFMP, suggests that the landholders that participate in the project also perform above the average farmer. The surprising factor in this is that many property soil tests and application amounts are relatively low compared to other countries (Haygarth and Jarvis, 2002). In the model the production figures were based on the gross margins of the average SWFMP, therefore if the higher production levels of the top 20% of farmers were used the figures in the model would reflect a different result.

The high use of agronomists (66%) and DPI information (20%) for advice to aid in farm management decision making, together with past experience, indicates an awareness of seeking outside educational and extension services. These landholders showed openness to new and alternative ideas. The uptake of soil and tissue testing is also a positive indication of adopting new ideas.

The high use of contractors to spread phosphorus fertilisers (76.6%) will impact on the application of the game theory model results in practice. Initial plans were to examine varying the timing of fertiliser application throughout the year to minimise runoff potential. This is only practical if the contractors are involved in the planning as the DPI has done with the fertiliser industry and when calculating the Farm Nutrient Loss Index (FNLI).

The question on the margin of benefit gained by applying fertiliser produced results that indicated the farmers found it difficult to estimate the direct benefit. The wide range of estimates (1.75 to 8) suggested that landholders have not considered the cost of applying fertiliser on the gross margin and have concentrated on other factors in their business when reducing costs. Through its extension services, the DPI has promoted high inputs of fertiliser to improve production and profit. Considering the low P levels of Australian soils prior to the 1980s it has been important for continual production growth. As indicated in Survey 2 the soil P levels would still be considered low by European standards (Haygarth and Jarvis, 2002) and in many cases the soil tests have not yet reached the DPI recommendations for maximum profit. Soil targets for maximum production drives the amount of fertiliser used on many farms together with the budget and the season.

The SWFMP results indicate a margin of benefit of 2.99 to 8.07, ie for every dollar spent on fertiliser there is a gain in income of $2.99 to $8.07, however this calculation is very dependent on where in the economic cycle the commodity is. For 2006, when the data were obtained, the commodities of wool, prime lamb, beef and cropping were all down on average. This data will be discussed in Section 8.3.3.

The answers given to the nutrient pollution questions in Survey 1 indicate that farmers have a good awareness of nutrient pollution and its causes. Many landholders have taken the recommended steps to reduce nutrient runoff (fencing of waterways and better placement of fertilisers), due to concern regarding the effect on the environment and the potential waste of a cost to production. Most landholders were concerned by the factual information on the high levels of P in the waterways such as that provided by Leinweber et al (2002), who demonstrated the benefits of buffer zones, using figures from Kämppaet et al (2000) it was shown that TP concentrations decreased by 27 to 97% with the use of buffer zones, depending on their width. More recent information from the DPI research indicating that the size of particles in the runoff was too small to be trapped by buffers, had not yet reached the landholders and the high levels of phosphorus in the local rivers was also unknown prior to this project. Few landholders were able to 'value' a healthy catchment. This was a very subjective question and the results should not be taken critically.

The final set of answers indicates the spread of issues that create frustration amongst landholders in relation to discussions about the environment. They are not specific to the rural population but do indicate obstacles for environmental researchers working in a rural environment.

> To establish successful management options for reducing P losses to watercourses, it is necessary that farmers, other stakeholders and politicians are aware of the problem and accept that improper P use in agriculture is a main reason for surface water pollution with P (Leinweber et al, 2002).

6.3 Survey 2 Results

The aim of the second survey was to investigate the current soil phosphorus targets and assess whether they influence fertiliser management decision making. Survey 2 was designed to obtain more accurate data on timing of fertiliser application and landcare action.

Table 6.6 presents the data gathered from Survey 2. It shows the soil P levels targeted by the participants in the research, indicates what percentage of the farm is at these target levels and if the application amount reflects the aim to achieve the soil target. In summary, the average soil P targets were:

- Crop: 17.1 mg P/kg Range: 15 to 30mg P/kg

- Sheep and beef pastures: 16.35mg P/kg Range:7 to 23 mg P/kg
- Dairy pastures: 25.8 mg P/kg Range:20 to 35 mg P/kg
- Overall Range 7 to 35mg P/kg

Information on the precise month of fertiliser application was also collected but with mixed results. Some landholders indicated specific months but others either had the fertiliser spread during several months or at some stage during autumn or winter. The cropping landholders were able to be more precise about timing because the fertiliser is applied with the crop.

	Target Soil Olsen P	% at target	Month of application	Application reflects target
1	15	0	P - Feb to May Hay - Oct	Yes
2		85	P- Feb to May C – Apr to Jun	maintenance
3			Autumn	
4	12 to 15	75	P - April C - May to Jul	maintenance
5				
6				No. spread lime also
7			C – Apr to Jun	
8	16-20	100	C - Jun	Yes
9				Yes
10				
11				
12				
13	12 to 15	35	P – Apr to May, C – May to Jun	Yes
14	20	80	C – May to Jun	Yes
15			Autumn	
16	15	75	P - Apr Fodder C -Sept	maintenance
17	15	80	P-Mar C-May	No
18	12	80	P - Mar and Aug	Yes
19	18	100	P - Mar C- May and Sept	Yes
20	14 to18	20	P- Mar	Yes
21			P - Autumn Hay - Spring	
22	15-18	100	P - Autumn	
23	15-18	80	P – Autumn C-Apr to Jun	Yes
24	20-30	80	P and Hay – Autumn C –Apr to Jun	Yes
25	15-20	0	P - April	Yes
26	15	0	P - April and Sept C - May	No
27	20	80	P- Mar to Apr	Yes
28			Autumn, Winter Spring	
29	22		Autumn	Yes
30	7 to 15	100	P Mar C-Apr	Yes
31	25-30	35	P - May to June	Yes
32	23	100	P - Sept Oct Nov	Y -maintenance
33	>20	80	P - March	Yes
34	25-35	100	P – Feb to Apr C - Aug to Sept	No
35	20-35	80	P-Mar C-Aug	Yes

Table 6.6 Soil Test Targets and Month of Application

The term 'maintenance' implies that the landholder is applying the amount of phosphorus that is removed from the paddock through production, thus maintaining the soil phosphorus levels.
A summary of the months in which fertiliser is spread is shown in Table 6.7.

Month	Pasture	Crop
February	2	
March	11	
April	19	3
May	13	12
June	3	11
July		2
August	1	3
September	3	4
October	2	
November	1	

Table 6.7 Summary of Fertiliser Application Months (Number of Landholders)

Survey results indicated that 15% of landholders had fenced up to 25% of their waterways, 15% of landholders had fenced between 25 and 50% of their waterways, 20% of landholders had fenced 50 to 75% of their waterways, 25% of landholders had fenced 75 to 99% of their waterways, and 25% of landholders had creeks fenced 100% of their waterways.

The survey indicated that 25% of landholders had waterways fenced at a distance of <10m from the water; 50% had waterways fenced at a distance of 10-20m from the water; 10% had waterways fenced at a distance of 21-50m from the water and 5% of landholders had waterways fenced at a distance of more than 50m from the water. 35% felt that there had been an improvement in water quality whereas 47% had not observed an improvement in water quality.

Landholders indicated that local attitudes to environmental work were 35% positive while 45% had a varied response, mainly due to share of cost, time and responsibility. Land class management, where land of different soil types and vulnerability to erosion has been fenced separately for management purposes, has been undertaken by 60% of landholders. Although the farmers indicate a high level of environmentally sensitive farm management, 54% of were not currently in a Landcare group.

6.3.1 Survey 2 Discussion

The soil test targets for most enterprises undertaken by the participants are the same as those suggested by the DPI:

- Cereal Crops: 13.5-15.5 kg P/ha
- Canola Crop: 17.5 kg P/ha (this is dependent on tons/ha targeted to be harvested),
- Pastures: 10-20 kg P/ha (this is dependent on the d.s.e.).

The range 7-35 kg/ha goes higher than would be recommended by the DPI for pasture (plant) production targets (Figure 4.3) particularly for dairy. From this it may be concluded that the DPI information on a levelling out of gross margins in relation to ever increasing P input is not necessarily being adopted by the farmers, ie some landholders are still targeting soil P levels at a higher rate than is necessary. Dairy producers tended to have a higher level range. (Refer to Sections 4.3.2.2 and 4.3.2.3 for an explanation of the basis of DPI recommendations). The landholders indicated that 70.25% of soils were at target. However, only six of the 23 responding properties (26%) had their soil P at the required level; the other properties are still working towards their target.

Most farmers did not vary the fertiliser amount from paddock to paddock. However, on some farms individual paddocks were targeted for a higher rate if the pastures were of better quality and likely to produce more, and some paddocks were targeted to increase baseline P levels to bring production up to increase economic viability. Many cropping properties adjusted fertiliser according to leaf analysis during the growing season.

Timing of fertiliser application was based primarily on climate factors, then according to availability of contractor and budget. Pastures were predominantly fertilised in March to May and crops in May and June, at the time of sowing, fertiliser being applied in the conjunction with the seed. Rainfall averages per month for a property in the middle of the catchment (Figure 6.9) show January to March as relatively dry with >50 mm rainfall per month from April to November. When compared to the months in which fertiliser is spread there is significant overlap in these higher rainfall months.

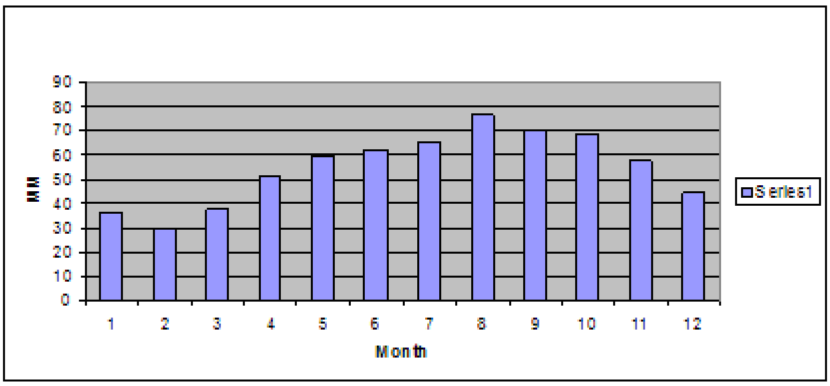


Figure 6.9 Average Rainfall at ‘Goodwood’ Caramut

Crops are fertilised at sowing (using a combine machine) hence fertiliser application occurs after the autumn break from April to September, the specific time depending on the acreage being sown, time management and crop selection. This will impact on the flexibility of adjusting fertiliser application timing for cropping enterprises.

Responses to the questions regarding fencing of creeks, land class fencing and membership in a Landcare group all indicated active participation in activities leading to improved environmental outcomes. There was considerable variation in answers, with 70% of participants having half their waterways already fenced, yet only 15% are fenced at the distance at which the GHCMA would prefer. The desired outcome, ie improved water quality was apparent to only 37% of those that responded (although this is most likely a visual appraisal and not scientifically tested). Membership of landcare is not necessarily a sound parameter when judging likely environmental action as the dynamics of landcare groups have changed in the 15 years since their inception and environmental funding is not tied to membership as it was in the 1990s. Results showed a 55% indication of a positive attitude towards environmental action and land class management had been undertaken by more than half the participants.

6.4 Survey 3 results

The objective of Survey 3 was to collate responses from the farmers regarding the recommendations calculated by the Game Theory model for their individual farm and the impact of the doubling of fertiliser prices in 2008 on the farmer's management decision (this would be equivalent to imposing additional tax on fertiliser input). Survey 3 was undertaken as a person to person interview rather than the planned group demonstration and discussion. The responses are presented in Tables 6.8 and 6.9.

In summary, from Table 6.8, six landholders were recommended to raise their phosphorus amount applied levels. Of these, two recommendations were to raise the amount applied to crops, four to raise application amounts on prime lamb pastures and three to raise the application amounts on wool pastures.

Four landholders were recommended to lower the amount of phosphorus applied. Of these, two were to lower the amount applied to crops, five to lower application amounts on prime lamb pastures and four to lower the application amounts on wool pastures.

Farm	Does high river P levels alter your decision making	Current use	Pareto Recom-mendation	Predicted Production Response	Would you follow the suggested recommendation
2	I will review placement of P. Creeks already fenced.	13.9	11.21 (w) 12.8 (pl) 14.38 (c)	Increased if raised, reduced if lowered.	Cropping would be fine, not likely to reduce P on pastures due to decrease in soil P and production over time.
17	Possibly. Current soil P levels at 9-10 would like to increase them.	15.11(g)	13.0 (w) 14.85 (pl)	I would not reach my target soil P levels for a long time.	Price of P will already reduce P amount put out. I will look at alternatives.
18	No	7.76	13		No- because the native pasture would be destroyed.
19	No- creeks are already fenced	18.96	14.85	Would go backwards in production.	Already reduced due to price.
20	Possibly	18.2	13 (w) 14.85 (pl)	Down over time.	Would look at alternative sources of P .
21	Already putting out lower level	10.7	12.12 (w) 13.82 (pl)	Raising P may increase production.	We put out according to soil tests and DPI recommendation. Sandy soils need P each year.
22	Possibly – but creeks already fenced at 100m	13.65	12.11	Down due to rundown in base soil P.	No- we feel more comfortable using soil tests to calculate the P input.
23	Possibly	18.2(g) 21.0(c)	13.82 (pl) 15.51 (c)	Depends on other limiting factors.	Have reduced P input as crops were not yielding as predicted- not limiting factor.
24	Not answered	13.65(g) 27.38 (c)	12.11 (w) 13.82 (pl) 15.51 (c)	Probably drop back after a few years.	Maintain Crop and lamb because prices are good for these commodities. May change commodity mix.
25	Not answered	10(g)	12.11 (w)	Production should go up, depends on other limiting factors.	Better to put out some every year than putting out a lot in one year only.
28	Already putting on a low amount.	7.55(g) 12.29(c)	12.29 (w) 14.03 (pl) 15.66 (c)	Increased if all other nutrients OK.	Only if budget would allow.

c – crop; w – wool; pl – prime lamb; g – grazing

Table 6.8 Response of Landholders to the Pareto Optimum Recommendations

Farm	Impact of fertiliser hike?	Alter timing of fertiliser application	Alter amount of fertiliser applied	Alter the mix of enterprises	Alter the mix of crops to be grown
2	Nil	No	Not on crops	No	No –in rotation
17	Cut back to $ amount ~ 13kg P/ha applied	No	2/3 P amount compared with normal	No	N/A
19	Reduced fertiliser this year to same $ amount	2 weeks later	2/3 of amount	Put in extra paddock of crop	No
18	Nil	No	No	No	N/A
20	Reduced amount. More soil testing	No	Amount reduced by 1/3 but soil tests indicate that it is OK.	Yes - some red wheat planted in 1 of 10 paddocks	Yes – but on regular annual basis
21	It was a shock, but it is necessary for production	No	No – we use soil tests	No	N/A
22	Use of guano instead of super-phosphate	Ordered early to reduce impact as much as possible No	Not kg P /ha	Yes –stud only retained, rest leased out for cropping	Canola's potential income will be higher than other crops
23	Huge impact on budget	Will reduce amount until impact felt.	Already decided to reduce it	No	No. Regular rotation undertaken
24	Purchased early. Used more single super and less MAP on crop	Ordered early so price rise not too bad	More single super, less MAP	Yes- slightly more crop, and prime lambs	No
25	Put out potash/super 4:1- slightly reduced P	Ordered early so price rise not too bad	2 months earlier due to availability	No	No
28	Same $ but less P in kg/ha	No	Crop - changed to single super and reduced MAP	More crops and prime lamb	No. Rotation system on cropping

Table 6.9 Response of Landholders to the Sudden Increase in Fertiliser Costs

When asked to predict the production response if phosphorus input was raised, the landholders replies were as expected, ie production would increase. Conversely landholders anticipated that production would eventually decline if the phosphorus application was lowered, the speed of it depending on the soil type. The DPI extension information on the effect of phosphorus on production had been disseminated widely to these groups of landholders. This will be discussed in more detail in Section 8.3.3. The response to knowing that the river levels of phosphorus were high was generally in terms of fencing out waterways to reduce the problem, although one landholder did suggest that he would review the placement of the fertiliser more carefully. The planned actions were based in the extension work undertaken by the DPI and CMA over the past decade.

The responses of landholders to the recommendations can be summarized as follows:

- Landholders recommended to raise the amount of phosphorus applied to crops could see the benefit of doing so but felt that they may be limited by their budget.
- Landholders recommended to raise the amount of phosphorus applied to their prime lamb pastures could see the benefit of doing so if the budget allowed. One producer however has native pastures which do not respond in the same way as improved pasture and he would not be increasing phosphorus levels.
- Landholders recommended to raise the amount of phosphorus applied to wool pastures could see the benefit of doing so if other nutrients were not limiting in the system and if their budgets allowed it.
- Landholders recommended to lower the amount of phosphorus applied to crops felt that while crop prices were good, they should continue to apply the same levels of phosphorus in order to maintain production levels, budgets permitting. As the information from Survey 1 reveals, many landholders had not calculated the financial benefit of fertiliser on a per kg basis and still held the belief that more fertiliser equals more production.

Table 6.9 summarises the responses to questions regarding rising costs of fertiliser. The rising cost of fertiliser, particularly MAP and DAP, encouraged some landholders to look at alternatives i.e. using single super in autumn followed up with reduced amounts of MAP or DAP at sowing time and using of guano instead of super. One crop producer indicated that they had already lowered P input as they were not getting production at predicted levels and considered there may be other limiting factors (such as declining rainfall or other nutrients). The landholder indicated that they would be examining the possibility of alternatives and undertaking more soil testing and strip tests for potassium and trace elements.

Landholders recommended to lower the amount of phosphorus applied to prime lamb pastures had similar responses. The rise in phosphorus prices in the past year has reduced the ability to apply high phosphorus amounts and has inspired some producers to seek alternatives. Landholders recommended to lower the amount of phosphorus applied to wool pastures indicated that they are seeking alternatives and may reduce the size of the wool enterprise until the commodity shows an increase in profitability.

Due to the large increase in the cost of fertiliser, landholders are looking more closely at their operations with several seeking alternative sources of phosphorus or adjusting management practices to try to minimise the impact. Landholders who are cropping are hoping that grain prices will be maintained at high levels so they can recover the additional input cost. Many were caught with forward sold grain during the drought year (2006) and made large financial losses so they are nervous of forward selling too much of their crop the following year as rain patterns continue to be difficult. Prime lamb prices are considered higher than during the first year of the project and several landholders have increased this enterprise in relation to wool sheep. A number of landholders have reduced their fertiliser input this year in the hope that the cost of fertiliser will return to a more normal level soon and they can continue applying fertiliser to replace nutrients which leave the farm in product. The landholders implied that they would assess the situation as the year progresses. Australian farmers, being price takers, are not able to pass costs on to the consumer and are therefore more likely to adjust their enterprise mix slightly, to take advantage of commodities that are performing better than others. Fertiliser is one of the last cost inputs to be reduced by high producing farmers as it is recognised that to maintain production, fertiliser is necessary to replace nutrients.

6.4.1 Survey 3: Discussion

The time between the initial survey and the final survey had been extended due to delays in the return of the calculations so it was decided to interview only 10 to 15 participants to gauge their response to the recommendations of fertiliser amounts, as calculated by the Game Theory model. The cost of fertiliser had increased considerably within this time and the drought had had a severe impact on the region and on people’s budgets. The delay may also have had an effect on the confidence of the participants in the information presented to them. Trust is a major factor in research and extension acceptance as described in Melland et al, (2005) and Petheram et al, (2000).

The reaction of landholders was cautious because the model had only been calculated with one parameter, the amount of P being varied. The landholders appreciated the economic sense in reducing phosphorus input based on cost to the environment but feel that over the long term there would be a reduction to soil P levels and ultimately a reduction in production. Their understanding of soil P levels and the need for maintenance amounts of phosphorus being applied annually to preserve productivity was reflected in the answers to the predicted production response over time, ie to raising or lowering phosphorus application amounts.

Haygarth and Jarvis (2002) have indicated that phosphorus input should not be taken in isolation when attempting to reduce nutrient pollution.

> The popular wisdom has been that reducing the inputs to a farm will reduce water problems…… In the practical sense, it is easy to understand why reducing fertilisers inputs is thought to be a more effective mitigation strategy than, for example, controlling irrigation water flow on to and over the soil. However while this may be appropriate for some issues (N for example) a concern is that in other instances, such source control wisdom may exist because it is convenient, rather than because of any objective scientific evaluation. A large source may not necessarily equate to a high impact, especially if issues of scale and connectivity are taken into consideration (Haygarth and Jarvis, 2002).

Questions were added regarding the response to the high increase in fertiliser costs in the past year, in order to gauge the response of landholders to an increase in costs as if a tax had been imposed on fertiliser costs. Cochard et al (2005) and Romstad (2003) discussed the use of input tax and ambient tax on regulating pollution and found that both are very effective at reducing pollution outputs. However, Romstad (2003) suggested that it does not show up in reduced NPS pollution immediately. The response of the landholders was in keeping with these findings, ie to reduce the amount of fertiliser (30% of landholders chose this), monitor more closely the amount and application of fertilisers (20%), monitor the enterprise mix for more efficient use of fertiliser inputs (50%) and to look at alternative sources of fertilisers (20%). The efficiency of the enterprise management will impact on the gross margins and the ultimate sustainability of the farming operation.

Chapter 7: Game Theory Model Design

7.1 Introduction

Game theory, which is used extensively in such diverse areas asnatural science, economics and social/political sciences, was developed early in the last century to provide models of how groups of human beings/organisations interact and make decisions in a risky competitive environment.

As described in Chapter 3, games are broadly divided into three classes:

- Non-cooperative: players are antagonistic. The main objective is to find the most favourable strategies which players can use to optimise one or more utility functions.
- Cooperative: players are able to form coalitions and utilities are transferable between the members. The main objective here is to understand how cooperation could lead to better distribution of benefits to all players.
- A mixed motive games (variable sum games): the players objectives are partly opposed and partly in agreement and the sum of the payoffs differs from strategy to strategy.

This research project can best be described by the prisoner's dilemma game, explained in Section 3.7, where the cooperative Pareto position is taken in a non-cooperative game. The problem will be considered from both the non-cooperative and cooperative perspective drawing a comparison from the different recommendations of phosphorus amounts calculated for the farmers to apply. Collaboration between the players can lead to greater payoffs for each agent.

The focus of the study is NPS pollution of waterways created from application of phosphorus in agricultural production. Xepapadeas (1999) and Cochard et al, (2005) suggested that the chief characteristic of NPS pollution is the inability of regulators to observe emissions by individual dischargers, leading to games where there is an asymmetric pattern of information. The regulators can only observe the ambient concentration of the pollutants without being able to detect the sources of these emissions with full certainty. The aggregate pollution will also affect the polluters themselves, directly or indirectly, so it is important that some measure of cooperation is achieved between the dischargers of the pollutant.

By using actual farmer data this research effectively enables the calculation of a cost benefit analysis of agricultural production for three different enterprises, when the economic cost to the environment is taken into account.

	Strategy 1 High Fert	Strategy 2 Mod Fert
Strategy 1 High Fert	$A, $A	$A, $B
Strategy 2 Mod Fert	$B, $A	$B, $B

Production Profit

	Strategy 1 High Fert	Strategy 2 Mod Fert
Strategy 1 High Fert	-$C, -$C	-$C, -$D
Strategy 2 Mod Fert	-$D, -$C	-$D, -$D

Cost to Environment

	Strategy 1 High Fert	Strategy 2 Mod Fert
Strategy 1 High Fert	a $A-C, $A-C	b $A-C, $B-D
Strategy 2 Mod Fert	c $B-D, $A-C	d $B-D, $B-D

Production and Cost to Environment

Figure 7.1 Schematic Representation of the Research Game Undertaken in the Hopkins Catchment

Figure 7.1 gives a schematic representation of the research game. Box *a* describes the Nash Equilibrium where each player maximises his own payoff but the effect on the environment is detrimental. Box *d* gives the cooperative Pareto Optimum which modifies the effect on the environment but still enables the player to make a profit. Boxes *b* and *c* give the Pareto positions where one player does the right thing by the environment but the other player maximises his profit with no regard for the environment (a freeloader situation).

The initial survey described fertiliser application data of several groups of farmers in the Hopkins catchment. The farmers were clustered according to production enterprise. Production costs and income were available through the SWFMP for several separate enterprises (wool, prime lamb, beef, canola, wheat and oats) although an average for the grain crops was chosen as there was no information on breakdown of crop enterprises for the individual farmers involved. Due to the low numbers of beef and dairy enterprises, they were not considered in this work.

7.2 Model Description Game Theory

Formulation of the Game Theory model was undertaken by Prof Panlop Zephongsekul, Dr Sergei Schreider and Matthew Fernandes from RMIT University. A full description of the model is given in Appendix 4. Effectively the model depicts a cost benefit analysis of a farming system (with single or multiple enterprises) including the parameters found to affect the impact of phosphorus on the environment.

The model was designed to explore the strategies of varying the 'amount' and the 'timing' of phosphorus application. Initially, three types of 'crops' were accounted for: prime lambs, wool sheep and cereal crops, though in the future other enterprises could be studied. Data was collected for dairy and beef in this catchment, however the data sets were very small and inadequate to represent the enterprises as a whole.

In Chapter 3 the current research was described by the 'prisoner's dilemma game' which in the taxonomy chart falls into the category of multi player, mixed motive (where both player's objectives are partly opposed and partly in agreement), no optimal equilibrium point (the Nash strategy is dominant at the one and only equilibrium point (NEP)) but this payoff is worse for both players than the alternative strategy (martyrdom).

Kelly (2003) has shown that a mixed motive multi-person games, with *n* players, is a game such that

- Each player P_i has a finite set of strategies S_i
- Each player P_i has a payoff utility function u
- Each player chooses a strategy S and receives a payoff u

In order to describe a game, the various sets of strategies $S_1 S_2 S_3 \ldots S_n$ need to be known, as do the pay-off functions $u_1 u_2 u_3 \ldots u_n$. Each player's payoff is a function of all *n* strategies and not just the player's own.

In the model currently developed, the system was defined initially as a 'static, multi player, non-cooperative game'. The cooperative Pareto Optimum was then considered. Appendix 4 contains details of this.

The Players:

In the Hopkins project, each farmer household is represented as a player. P_i

The Strategies:

The strategy set S_i ,*i*=1,2,…,*n*, available to each player is made up of tuples:

$$S_i = (\alpha_i^{1,}, \alpha_i^2, ...\alpha_i^R, t_i^1, t_i^2, ...t_i^R)$$

R is the number of the enterprises and

$\alpha_i^r =$ Amount of phosphorus used by P_i for crop *r* per unit of area

$t_i^r =$ Scheduling of the application of phosphorus by P_i for crop *r*

R = 1 = Wool *R* = 2 = Prime Lamb *R* = 3 = Cereal crop.

In the initial calculation of the model 'time scheduling' was not considered, therefore only the amount of phosphorus applied was calculated with resulting recommendations for optimisation according to Nash Equilibrium or Pareto Optimisations.

□

The Payoff Function

The payoff function will be measured by a *profit function* which has as its components the profit obtained from the farm production and the negative impact of environmental degradation calculated as an economic cost.

The payoff function accrued by player P_i if all players adopted the strategy profile

$$s_i = ((\alpha_1, t_1), (\alpha_2, t_2), ...(\alpha_n, t_n))$$

Can be expressed by

$$u_i(s) = \sum_{r=1}^{R} \left[p_r Q^r(t_i^r) A_i^r \left[\alpha_i^r q_i^r(\alpha_i^r, t_i^r) + \alpha_i^0 \right]^{\Upsilon} W_i^r(t_i^r)^{1-\Upsilon} - F A_i^r \alpha_i^r \right. \tag{1}$$

$$\left. - \sum_{j=1}^{N} \beta_{ij} E(t_j^r) A_j^r (\alpha_j^r (1 - q_j^r(\alpha_j^r, t_j^r)) - L) I(\alpha_j^r (1 - q_j^r(\alpha_j^r, t_j^r)) > L) \right]$$

Where 0≤ $\beta_{ij} \le 1$ are constants and *I(A)* refers to the indicator of the set *A*, i.e. *I(A)* = 1 if the event *A* has occurred, and equals to 0 otherwise.

For each strategy $((\alpha_i, t_i) \in S_i$ executed by P_i, let:

γ	= Cobb-Douglas constant
$q_i^r(\alpha_i^r, t_i^r)$	= proportion of phosphorus that is released into farmland devoted to crop *r*
$1 - q_i^r(\alpha_i^r, t_i^r)$	= proportion of phosphorus that flow into the river system as a consequence thereof
$E(t_i^r)$	= (negative) environmental impact manifested as cost per unit application of phosphorus

A_i^r	= total quantity of land devoted to crop r by P_i
$W_i^r(t_i^r)$	= amount of water available at time t_i^r
$Q^r(t_i^r)$	= quantity of crop r produced per unit area per unit phosphorus $^{\Upsilon}$ per unit of water $^{1-\Upsilon}$
p_r	= price (revenue) obtained per unit of crop r sold
α_i^0	= base quantity of phosphorus in soil of user I per unit area
F	= price per unit of phosphorus
β_{ij}	= environmental influence indirectly induced by P_i by P_j
L	= toxicity threshold level i.e. the amount of phosphorus in the river systems above which there will be a negative environmental impact

The Cobb-Douglas constant (γ) is a mathematical constant based on:

$$\text{Output } (\gamma) = K^{\Upsilon} \text{ x } L^{1-\Upsilon} \text{ x } A \qquad (2)$$

Where K equals Capital; L equals Labour and A equals the Total Factor Productivity $^{\Upsilon}$ and $^{1-\Upsilon}$ are output elasticity's.

Therefore it is an expression which describes the production output based on inputs and productivity.

In the model γ was valued at 0.115 calibrated on DPI figures for production of wool (kg/ha/100 mm rainfall), prime lamb (kg/ha/100 mm rainfall) and wheat/oats crop in (kg/ha/100 mm rainfall) (Schreider et al, 2008a). Figure 4.7 demonstrates the results of DPI research into gross margins of sheep production in relation to phosphorus application.

Optimal Strategies

Nash Equilibrium

The Hopkins project as outlined above is an example of a non-zero sum, *n*-person game. Therefore, the competitive optimal solutions, if they exist, can be expressed as Nash Equilibrium Profiles *(NEPs)*. A detailed description of this is provided in Appendix 4.

Pareto Optimum

The derivation of a Pareto optimum falls into the class of multi-objective decision problems where a vector valued function is optimised according to some vector optimisation criterion. A Pareto optimum is obtainable only if players enter into a binding cooperative agreement.

7.2.1 Information Required for the Game Theory Model

Information required for calculating the 'Payoff Function' includes:

Production output and value

- Area under production
- Phosphorus kg/ha input for each 'crop'
- Amount of water available (rainfall)
- Base soil phosphorus
- % phosphorus absorbed by the crop
- Type of 'crop'
- Quantity of 'crop' produced
- Revenue per unit of crop
- Price of phosphorus
- % runoff

Cost factors

- Phosphorus kg/ha input
- Cost per unit of application of P
- Price of phosphorus
- Cost to the environment/unit of P
- % phosphorus not absorbed by the crop (runoff)
- Toxicity threshold of phosphorus in waterways

Other constants

- β Impact of external properties on the player's property and vice versa
- γ Cobb - Douglas constant

7.2.2 Parameters of Game Theory Model

The key requirement of the model developed is that all parameters included in the model should be measurable, thereby allowing appropriate data to be collected. Unfortunately, this requirement was not satisfied for all parameters and some of their values were estimated by trial and error or taken from external sources.

Some important parameters of the model were assigned to their numerical values based on the analysis of the literature review of research works implemented in the region, the value of the environmental impact constant (E), and outside the region (absorption constants q). Some of the parameters were immeasurable and were treated as free parameters of the model (for instance, the value of β and γ, characterising the spatial proximity of the players and the Cobb-Douglas constant respectively). These parameters were treated as values to be calibrated as discussed in Section 7.2 and Appendix 4.

The initial survey collected data in August/September 2006 with a second survey in June 2007. A group of dairy farmers was surveyed at the same time with a combination of the questions. Data was based on phosphorus application in 2006. The data collected from the survey and used in the game theory model included fertiliser amount (α), crop type (r), area (A_i^r), rainfall (W_i^r) and application timing (t).

Mapping data provided back-up data on soil type, rainfall, elevation and proximity of properties to each other. Toxicity threshold, *L,* was to be taken from the EPA target level for the region (0.325mg/L), but it was adjusted to zero because it was felt that any 'runoff' was considered undesirable due to the current poor state of the rivers.

The proportion of phosphorus that is released into farmland devoted to crop *r:* $q_i^r(\alpha_i^r, t_i^r)$ and the percentage runoff $(1 - q_i^r(\alpha_i^r, t_i^r))$ was initially calculated from previous research indicating expected phosphorus runoff from different soil and land use types and gave a value of q = 0.971(collaborated data in Schreider et al, (2008a). An alternative percentage runoff was calculated based on Read et al (1999). This gave a value of q = 0.985.

The cost to the environment $E(t_i^r)$ is calculated as the negative impact on economic production using figures obtained from Read et al, (1999). Schreider et al, (2008a) used the cost to the whole of the Glenelg Hopkins catchment divided by the phosphorus load in the regional catchment rivers to give a cost /kg, given as

$$E = \frac{\$1{,}820{,}807 \text{ per an}}{265{,}194 \text{ kg per an}} = \$6.87/kg \qquad (3)$$

The base quantity of phosphorus in the soil (α_i^0) has been initially set at zero.

The economic data for cost of inputs and outputs for production of the enterprises undertaken within the catchment were calculated from the data collected annually by the SWFMP, in the same financial year (See Section 4.3.2.1). The three crops initially calculated in the model are wool (r = 1), prime lamb (r = 2) and cereal cropping (r = 3). Prices used for these commodities were:

- p = \$7.78/kg wool;
- p = \$3.03/kg carcass weight prime lamb;
- p = \$0.16/kg grain.

The price of phosphorus, F = \$4.20/kg was also calculated from the SWFMP report based on an average annual cost of \$42/ha for fertiliser inputs and an average application rate of 10kg P/ha (Department of Primary Industries, 2006b).

The data collected from the farmers in this survey can be compared to the South West Farm Monitor Project data for verification, to determine the 'benefit to cost' for each enterprise without taking the environment into account, and to determine where in the commodity cycle each commodity lies. This will have some impact on theresults from the game theory calculations and may explain why the use of phosphorus on one particular enterprise is seen as more beneficial for this given year.

Chapter 8: Game Theory Model Results

8.1 Introduction

In this Chapter the results and interpretation of an initial calculation of the Game Theory model of phosphorus fertiliser use in the Hopkins River catchment are given. The model has been developed using actual data from the survey undertaken in 2006 and represents figures from only one year however, the modelling demonstrates that the cooperative Pareto Optimum values (i.e. those produced when players choose to cooperate in their strategy of P fertiliser application) produce a savings in comparison to the Nash Equilibrium *(NEP)* values, supporting the choice of this model.

Two sets of result data have been presented, one based on runoff expectations from past research data calculated on soil types ie adsorption of 0.971 implying runoff of 2.9 % and the other based on data from the Glenelg Hopkins catchments that Read et al. used in their report of 1999. This was calculated from the actual amount of phosphorus that was found in the river systems and the hectares in the catchment. This was equivalent to 1.5% runoff.

Table 8.1 gives the Nash and Pareto values for production profit and cost to the environment. The total revenues of the landholders are always larger in the case of the competitive Nash solutions than in the Pareto optimums. The model used is described in Chapter 7 and Appendix 4.

8.2 Game Theory Model Results

q=0.971

Nash Production	Pareto Production	Nash Environment	Pareto Environment
125541.48	125525.43	1170.45	1134.6
1096136.64	1096111.42	2844.71	2814.11
470463.99	470457.72	1727.21	1720.17
330437.28	330432.42	1658.85	1653.48
435370.28	435367.6	1665.66	1662.66
577271.65	557264.8	2332.92	2325.5
164504.09	164502.05	659.99	656.91
204191.05	204190.48	512.9	509.49
568686.93	568681.32	1811.37	1804.6
196094.92	196094.322	665.02	664.04
479241.54	479237.15	1797.7	1792.91
285232.05	285230.22	919.5	916.94
505174.54	505172.64	1662.63	1660.22
444043.84	440034.34	1932.94	1922.86
39176.78	39176.45	234.28	232.02
45555.15	45551.94	625.08	613.53
586762.37	586728.22	2817.95	2782.6
1118133.82	118119.28	911.67	885.17
99376.59	99362.29	906.7	880.07
113894.4	113879.85	888.24	862.12
404180.98	404119.49	1504.99	1450.42
130452.63	130441.86	1047.83	1025.26
986512.16	986464.17	2203.55	2150.67
374517.01	374479.5	1737.89	1692.97
170601.5	170577.82	1270.91	1226.27
242113.3	242086.93	1112.32	1078.18
165067.95	165043.25	1724.95	1660.92
165309.97	165294.34	1048.2	1014.49
503763.91	503722.71	1571.77	1512.62
83452.31	83442.66	1148.68	1116.26

q=0.985

Nash Production	Pareto Production	Nash Environment	Pareto Environment
125777.69	125773.23	701.83	690.71
1096687.01	1096675.18	2122.09	2109.21
470868.58	470866.2	1166.64	1164.01
330936.69	330935.2	962.99	961.32
435774.8	435773.81	1107.06	1105.97
577883.45	577881.05	1491.28	1488.69
164619.54	164618.69	461.28	460.1
204191.05	204190.48	469.03	467.51
569017.42	569014.92	1333.33	1330.47
196214.37	196214.06	487.64	487.24
479670.87	479669.22	1203.01	1201.23
285384.18	285383.34	690.58	689.5
505497.87	505497.05	1211.4	1210.41
440585.41	440582.28	1192.31	1188.96
39198.17	39198.01	165.03	164.24
45642.76	45641.86	343.9	340.5
587852.28	587842.61	1515.52	1505.41
118356.49	118352.45	505.04	497.27
99562.4	99558.44	502.22	494.42
114108.7	114104.66	492.54	484.88
404934.27	404917.25	886.38	869.25
130702.37	130699.37	611.42	604.2
987082.15	987061.18	1503.99	1483.85
374991.35	374979.42	1136.58	1120.54
170921.12	170914.56	736.66	723.06
242412.02	242403.59	632.23	622.17
165375.89	165369.06	1007.39	987.61
165543.54	165538.75	612.58	602.17
504208.11	504193.08	890.75	873.12
83610.06	83607.38	692.38	681.91

Table 8.1 Values of Production and Environmental Costs for Nash and Pareto Optimum

The ‘production’ outcome minus the ‘environmental cost’ outcome from the Nash Equilibrium equation gives the total (Nash) utility as shown in Table 8.2. Likewise, the production outcome minus the environmental cost outcome from the Pareto Optimum equation gives the total (Pareto) utility. Expressed in another way, the utility is the ‘payoff’ to the player for undertaking the strategy.

	q=0.971 Nash Utility	Pareto Utility	Pareto-Nash	1-β*ii*	*q=0.982* Nash Utility	Pareto Utility	Pareto-Nash
1	124371.03	124390.84	19.81	0.59	125075.86	125082.51	6.66
2	1093291	1093297.31	5.38	0.24	1094564.9	1094565.97	1.04
3	468736.78	468737.54	0.76	0.09	469701.94	469702.18	0.25
4	328778.42	328778.95	0.52	0.06	329973.7	329973.88	0.18
5	433704.61	443704.93	0.32	0.04	434667.74	434667.85	0.11
6	574938.73	574939.3	0.58	0.07	576392.17	576392.35	0.19
7	163844.1	163845.14	1.04	0.1	164158.25	164158.59	0.34
8	203678.15	203680.98	2.83	0.08	203722.03	203722.97	0.94
9	566875.56	566876.72	1.16	0.09	567684.09	567684.44	0.36
10	195429.9	195430.19	0.29	0.03	195726.73	195726.82	0.1
11	477443.84	477444.24	0.4	0.06	478467.86	478467.99	0.13
12	284312.54	284313.28	0.73	0.06	284693.6	284693.84	0.24
13	503511.92	503512.42	0.5	0.03	504286.47	504286.63	0.16
14	438110.9	438111.48	0.58	0.11	439393.1	439393.32	0.22
15	38942.5	38944.43	1.93	0.08	39033.13	39033.77	0.64
16	44930.07	44938.41	8.34	0.27	45298.86	45301.36	2.5
17	583944.43	583945.61	1.19	0.22	586336.76	586337.2	0.44
18	117222.15	117234.11	11.96	0.56	117851.45	117855.18	3.73
19	98469.89	98482.21	13.32	0.74	99060.18	99064.02	3.84
20	113006.16	113017.73	11.57	0.59	113616.16	113619.78	3.62
21	402675.99	402669.07	-6.92	0.88	404047.91	404048	0.09
22	129404.81	129416.61	11.8	0.32	130090.95	130095.16	4.21
23	984308.61	984313.5	4.89	0.56	985578.16	985577.33	-0.82
24	372779.12	372786.54	7.42	0.7	373854.76	373858.89	4.12
25	169330.6	169351.55	20.95	0.69	170184.47	170191.5	7.03
26	241000.98	241008.75	7.77	0.98	241779.79	241781.43	1.64
27	163342.99	163382.33	39.34	0.82	164368.51	164381.45	12.94
28	164261.76	164279.85	18.09	0.54	164930.96	164936.58	5.62
29	502192.14	502210.09	17.94	0.87	503317.36	503319.96	2.61
30	82303.63	82326.4	22.77	0.51	82917.68	82925.47	7.78

Table 8.2 Utilities for Nash and Pareto Optimums and their Differences

Table 8.2 displays the values of the utilities for players given that they adopt either the Nash Equilibrium or Pareto Optimum strategy. Twenty-nine out of 30utilities demonstrate that changing from competitive to cooperative strategies gives an increase in utility. The largest differences in players' utilities are seen when constants $1-\beta_{ii}$ are closer to 1, which means that farmers located closer to each other have a great influence on other farmers and vice versa, thus the cooperation strategy will be more pronounced. The increase in utilities is because of an increase in the environmental component of the objective function.

	Current Wool	Current Lamb	Current Crop	Nash Wool	Nash Lamb	Nash Crop	Pareto Wool	Pareto Lamb	Pareto Crop
1	17.05	17.05	0	12.15	13.88	0	11.79	13.46	0
2	13.9	13.9	13.9	11.05	12.62	14.44	10.91	12.46	14.38
3	9.1	0	21.9	10.17	0	13.36	10.13	0	13.34
4	10.5	10.5	21.9	10.95	12.5	14.4	10.91	12.46	14.25
5	0	15.3	18.1	0	12.48	14.4	0	12.46	14.38
6	13	0	31.28	10.95	0	13.37	10.91	0	14.38
7	11.37	11.37	27.37	10.18	11.62	15.53	10.13	11.56	14.38
8	0	0	13.14	0	0	13.36	0	0	13.34
9	15	0	20	10.17	0	14.39	10.13	0	15.51
10	5.16	5.16	11.81	10.93	12.48	14.4	10.91	12.46	13.34
11	17.91	17.91	17.91	10.95	12.5	13.36	10.91	12.46	14.38
12	0	19.45	19.45	0	11.6	14.3	0	11.56	14.38
13	14.76	14.76	30.27	10.93	12.48	14.41	10.91	12.46	13.34
14	13.25	13.25	19.06	10.98	12.53	13.36	10.91	12.46	14.38
15	4.55	4.55	10.9	10.17	0	13.29	10.13	0	14.38
16	15.11	15.11	0	12.84	14.65	0	12.66	14.45	0
17	7.76	0	0	12.81	0	0	12.66	0	0
18	0	18.96	0	0	14.88	0	0	14.45	0
19	13.96	13.96	0	13.16	15.02	0	12.66	14.45	0
20	18.2	18.2	0	13.05	14.9	0	12.66	14.45	0
21	10.7	10.7	0	12.34	14.09	0	11.79	13.46	0
22	13.65	0	0	11.98	0	0	11.79	0	0
23	0	18.2	21	0	13.85	15.67	0	13.46	15.51
24	13.65	13.65	27.38	12.22	13.95	15.71	11.79	13.46	15.51
25	10	0	0	12.21	0	0	11.79	0	0
26	9.1	9.1	21.8	12.41	14.16	15.79	11.79	13.46	15.51
27	16.22	16.22	0	12.3	14.05	0	11.79	13.46	0
28	7.55	7.55	20.01	12.12	13.84	15.66	11.79	13.46	15.51
29	0	70	7	0	14.08	15.76	0	13.46	15.51
30	11.85	0	0	12.1	0	0	11.79	0	0
Ave	12.22	16.53	19.69	11.63	13.43	14.47	11.40	13.13	14.51

Table 8.3 Nash Equilibrium and Pareto Optimum Solutions for Wool, Lamb and Cereal Crop in kg/ha γ = 0.115; (P retention) q = 0.971

The recommendations for P application amount/ha are given in Tables 8.3 and 8.4 with the original phosphorus application amounts for comparison. The estimated P retention rate is varied *(q)* according to (Olness et al, 1980) *q=0.971* or (Read et al, 1999) *q=0.985*.

Zero in Table 8.3 and 8.4 imply that the enterprise is not undertaken. Tables 8.3 and 8.4 indicate that the amount of phosphorus recommended to be applied is consistently larger if the landholder were to use the competitive strategy compared with the cooperative strategy for all types of land use in the Hopkins catchment.

	Current Wool	Current Lamb	Current Crop	Nash Wool	Nash Lamb	Nash Crop	Pareto Wool	Pareto Lamb	Pareto crop
1	17.05	17.05	0	12.3	14.05	0	12.11	13.82	0
2	13.9	13.9	13.9	11.28	12.88	14.44	11.21	12.8	14.38
3	9.1	0	21.9	10.43	0	13.36	10.4	0	13.34
4	10.5	10.5	21.9	11.23	12.82	14.4	11.21	12.8	14.38
5	0	15.3	18.1	0	12.81	14.39	0	12.8	14.38
6	13	0	31.28	11.23	0	14.4	11.21	0	14.38
7	11.37	11.37	27.37a	10.43e	11.91f	13.37b	10.4	11.88	13.34c
8	0	0	13.14	0	0	15.53d	0	0	15.51
9	15	0	20	10.43	0	13.36	10.4	0	13.34
10	5.16	5.16	11.81	11.22	12.81	14.39	11.21	12.8	14.38
11	17.91	17.91	17.91	11.23	12.82	14.4	11.21	12.8	14.38
12	0	19.45	19.45	0	11.9	13.36	0	11.88	13.34
13	14.76	14.76	30.27	11.22	12.81	14.39	11.21	12.8	14.38
14	13.25	13.25	19.06	11.24	12.84	14.41	11.21	12.8	14.38
15	4.55	4.55	10.9	10.42	0	13.36	10.4	0	13.34
16	15.11	15.11	0	13.1	14.95	0	13	14.85	0
17	7.76	0	0	13.08	0	0	13	0	0
18	0	18.96	0	0	15.07	0	0	14.85	0
19	13.96	13.96	0	13.27	15.15	0	13	14.85	0
20	18.2	18.2	0	13.21	15.09	0	13	14.85	0
21	10.7	10.7	0	12.4	14.16	0	12.11	13.82	0
22	13.65	0	0	12.21	0	0	12.11	0	0
23	0	18.2	21	0	14.03	15.67	0	13.82	15.51
24	13.65	13.65	27.38	12.34	14.09	15.71	12.11	13.82	15.51
25	10	0	0	12.34	0	0	12.11	0	0
26	9.1	9.1	21.8	12.44	14.2	15.79	12.11	13.82	15.51
27	16.22	16.22	0	12.38	14.14	0	12.11	13.82	0
28	7.55	7.55	20.01	12.29	14.03	15.66	12.11	13.82	15.51
29	0	7	7	0	14.15	15.76	0	13.82	15.51
30	11.85	0	0	12.27	0	0	12.11	0	0
Ave	12.22	13.53	19.69	11.83	13.65	14.53	11.71	13.49	14.46

Table 8.4 Nash Equilibrium and Pareto Optimum Solutions for Wool, Lamb and Cereal Crop in kg/ha $\gamma = 0.115$, q = 0.985

In Table 8.4 the differences between *a* and *b* takes the gross margin for the commodity and cost to the environment into account. The differences between *b* and *c* are due to differences in competition versus cooperation modelling, and the differences between *b* and *d* are due to water input (rainfall). The difference between *e* and *f* recommendations, given that the current application was the same reflects the better gross margin of prime lamb compared with wool in this year (the gross margin for each commodity will vary with the economic cycles).

In the Tables, some recommendations go up and some go down. This is due to the impact of water inputs (rainfall), commodity and position of the farm in relation to other players. Many cooperative Pareto Optimal solutions are similar whilst Nash Equilibrium solutions are not because of the independence in the Pareto model of the constants γ and β.

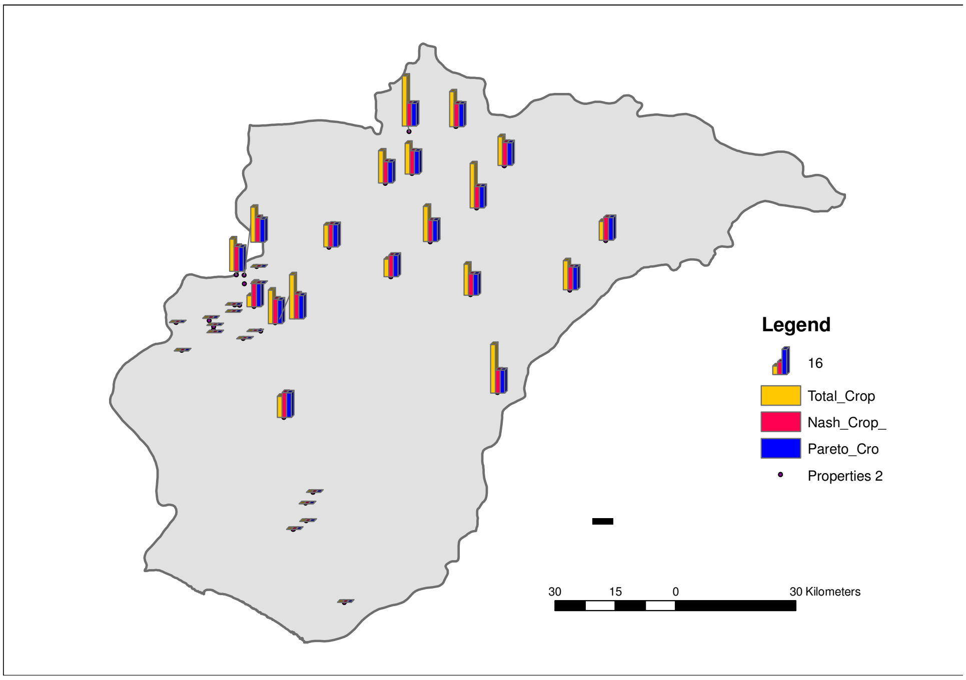


Figure 8.1: Comparative levels of P Recommendations for Crop Enterprise (current – yellow, Nash – red, Pareto – blue)

Figures 8.1 to 8.4 give a visual presentation of the information in Tables 8.3 and 8.4. In each figure the current fertiliser amount used is indicated with the Nash and Pareto recommendations beside it. It is possible for each farmer to observe quickly the need to reduce or increase the amount and by what proportion.

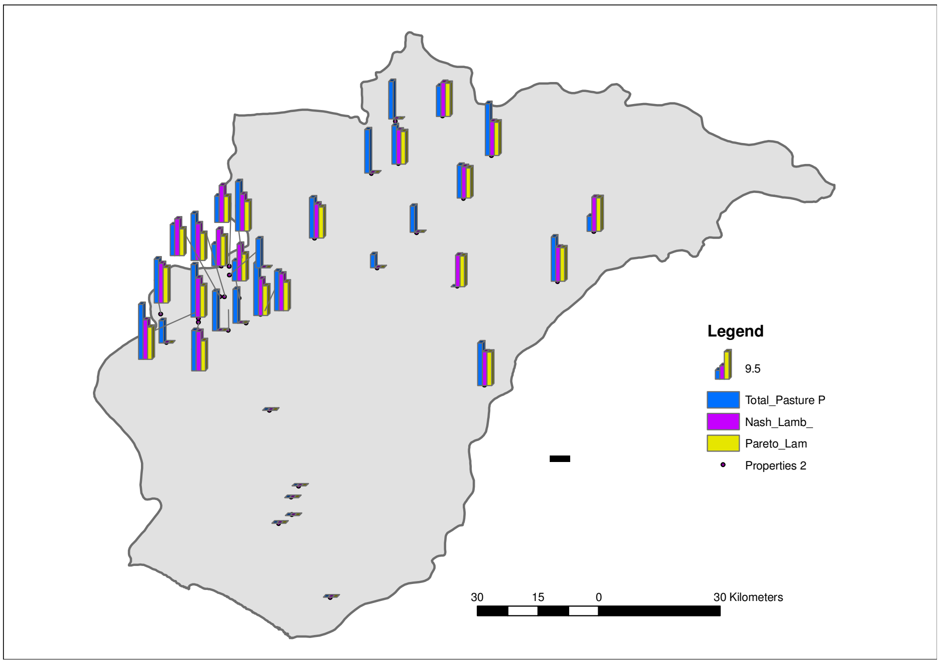


Figure 8.2. Comparative levels of P Recommendations for Prime Lamb Enterprise

(current – blue, Nash – pink, Pareto – yellow)

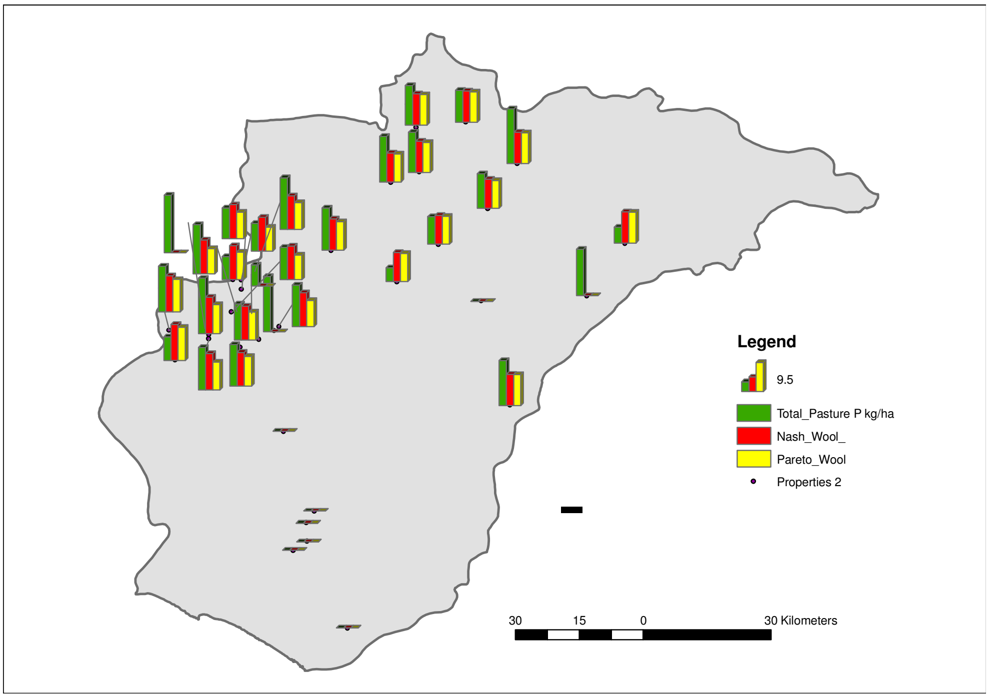


Figure 8.3 Comparative Levels of P Recommendations for Wool Enterprise:

(current - green, Nash - red, Pareto - yellow)

	Nash Wool	Nash PL	Nash Crop	Pareto Wool	Pareto PL	Pareto Crop
1	4.9	3.17	0	5.26	3.59	0
2	2.85	1.28	-0.54	2.99	1.44	-0.48
3	-1.07	0	8.54	-1.03	0	8.56
4	-0.45	-2	7.5	-0.41	-1.96	7.52
5	0	2.82	3.71	0	2.84	3.72
6	2.05	0	16.88	2.09	0	16.9
7	1.2	-0.25	14.01	1.25	-0.19	14.03
8	0	0	-2.39	0	0	-2.37
9	4.83	0	6.64	4.87	0	6.66
10	-5.77	-7.32	-2.46	-5.75	-7.3	-2.45
11	6.96	5.41	3.51	7	5.45	3.53
12	0	-11.6	6.09	0	-11.56	6.11
13	3.83	2.28	15.88	3.85	2.3	15.89
14	2.27	0.72	4.65	2.34	0.79	4.68
15	-5.62	0	-2.46	-5.58	0	-2.44
16	2.27	0.46	0	2.45	0.66	0
17	-5.05	0	-16.73	-4.9	0	-16.66
18	0	4.08	0	0	4.51	0
19	0.8	-1.06	0	1.3	-0.49	0
20	5.15	3.3	0	5.54	3.75	0
21	-1.64	-3.39	0	-1.09	-2.76	0
22	1.67	0	0	1.86	0	0
23	0	4.35	5.33	0	4.74	5.49
24	1.43	-0.3	11.67	1.86	0.19	11.87
25	-2.21	0	0	-1.79	0	0
26	-3.31	-5.06	6.01	-2.69	-4.36	6.29
27	3.92	2.17	0	4.43	2.76	0
28	-4.37	-6.09	4.35	-4.04	5.71	4.5
29	0	-7.08	-8.76	0	-6.46	-8.51
30	-0.25	0	0	0.06	0	0
Excess P (kg/30 farms)	2649	-1478	48073	4530	-101	48743
Sum of excess P			49244			53163

Table 8.5 Differences in Applied P, Nash and Pareto Solutions (kg/ha) $\gamma = 0.115$ q=0.971

While Tables 8.3 and 8.4 gave the recommended amounts of P for each individual landholder to apply per hectare, Tables 8.5 and 8.6 give the differences between the recommended application rates for Nash and Pareto solutions. Again the runoff value, *q,* is varied. This enabled the amount in kg/ha potentially saved and amount per farm when multiplied by the landholder's area to be calculated. We are then able to calculate the potential saving of P fertiliser used by the 30 farmers if they were to follow the cooperative Pareto strategy can then be calculated. Positive values indicate too much fertiliser and negative values indicate too little fertiliser.

	Nash Wool	Nash PL	Nash Crop	Pareto Wool	Pareto PL	Pareto Crop
1	4.75	3	0	4.94	3.23	0
2	2.62	1.02	-0.54	2.69	1.1	-0.48
3	-1.33	0	8.54	-1.3	0	8.56
4	-0.73	-2.32	7.5	-0.71	-2.3	7.52
5	0	2.49	3.71	0	2.5	3.72
6	1.77	0	16.88	1.79	0	16.9
7	0.94	-0.53	14.01	0.97	-0.5	14.03
8	0	0	-2.39	0	0	-2.37
9	4.57	0	6.64	4.6	0	6.66
10	-6.06	-7.65	-2.46	-6.05	-7.46	-2.45
11	6.68	5.09	3.51	6.7	5.11	3.53
12	0	11.9	6.09	0	-11.88	6.11
13	3.54	1.95	15.88	3.55	1.96	15.89
14	2.01	0.41	4.65	2.04	0.45	4.68
15	-5.87	0	-2.46	-5.85	0	-2.44
16	2.01	0.16	0	2.11	0.26	0
17	-5.32	0	-16.73	-5.24	0	-16.66
18	0	3.89	0	0	4.11	0
19	0.69	-1.19	0	0.96	-0.89	0
20	4.99	3.11	0	5.2	3.35	0
21	-1.7	-3.46	0	-1.41	-3.12	0
22	1.44	0	0	1.54	0	0
23	0	4.17	5.33	0	4.38	5.49
24	1.31	-0.44	11.67	1.54	-0.17	11.87
25	-2.34	0	0	-2.11	0	0
26	-3.34	-5.1	6.01	-3.01	-4.72	6.29
27	3.84	2.08	0	4.11	2.4	0
28	-4.54	-6.28	4.35	-4.36	-6.07	4.5
29	0	-7.15	-8.76	0	-6.82	-8.51
30	-0.42	0	0	-0.26	0	0
Excess P (kg)	813	-2442	48073	1820	-1705	48734
Sum excess P			46444			48849

Table 8.6 Differences in Applied P, Nash and Pareto Solutions (kg/ha) $\gamma = 0.115$ q = 0.985

Using Table 8.5, the model indicates that more fertiliser could have been spread on a third of all of the properties but according to the same basis too much was spread on the rest. The cumulative value for each enterprise group is given under each column and the overall calculation is an excess of 49,244 kg P if the competitive strategy (Nash) is followed or 53,163 kg P if the cooperative strategy (Pareto) is followed. The difference is a saving of 3,919 kg P. This means that the advantage of cooperation would save approximately 4 tons of P or 35.27 tons of superphosphate for the 30 properties, an average of 1.175tons/property. Across1540 properties this would equate to 1809.5 tons of superphosphate at a value of $844,200 (using the cost of superphosphate from the model). While this is only a small amount per property, it demonstrates that utilizing the model would achieve a significant reduction in phosphate costs.

The greatest saving would be to the farms with cropping enterprises. In this year the prime lamb pastures could have had more P applied. There appears to be no correlation between too little or too much fertiliser applied and the size of the property or the proportion of the enterprise. Table 8.6 tells a similar story albeit with slightly smaller numbers due to a predicted smaller runoff percentage.

Figures 8.4 (a) to (f) give a visual representation of the difference tables for Pareto and Nash solutions for each of the three enterprises. The larger the dot, the greater the variation from the recommended amount, the dark dots (negative) indicate under-fertiliser use and the pale dots (positive) indicate over-use of fertiliser. The amounts are measured in kg/ha.

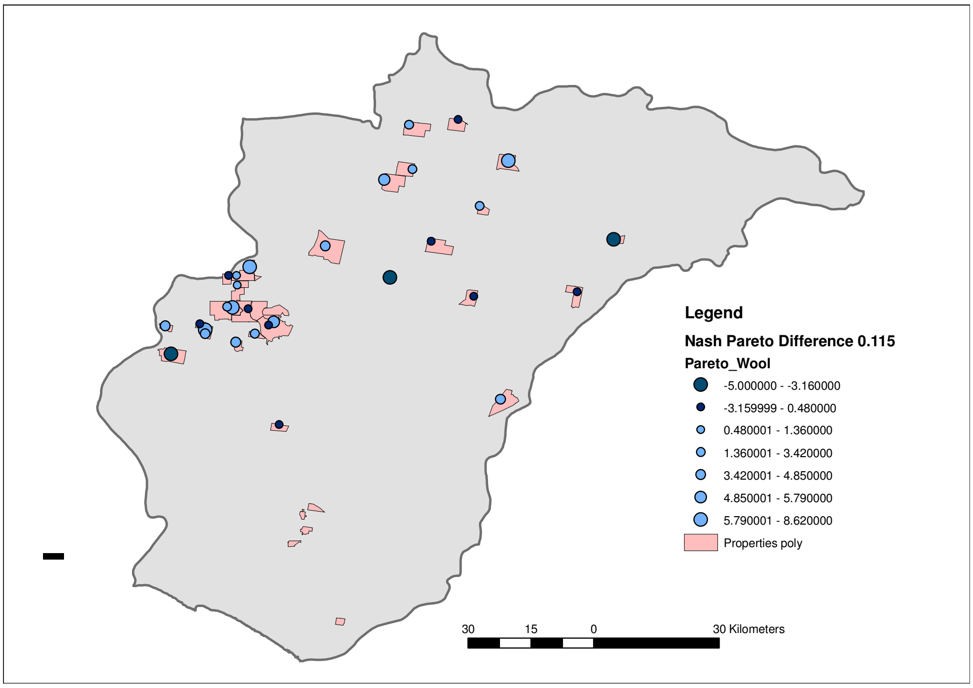


Figure 8.4(a) Pareto Difference for Wool Enterprises (kg/ha)

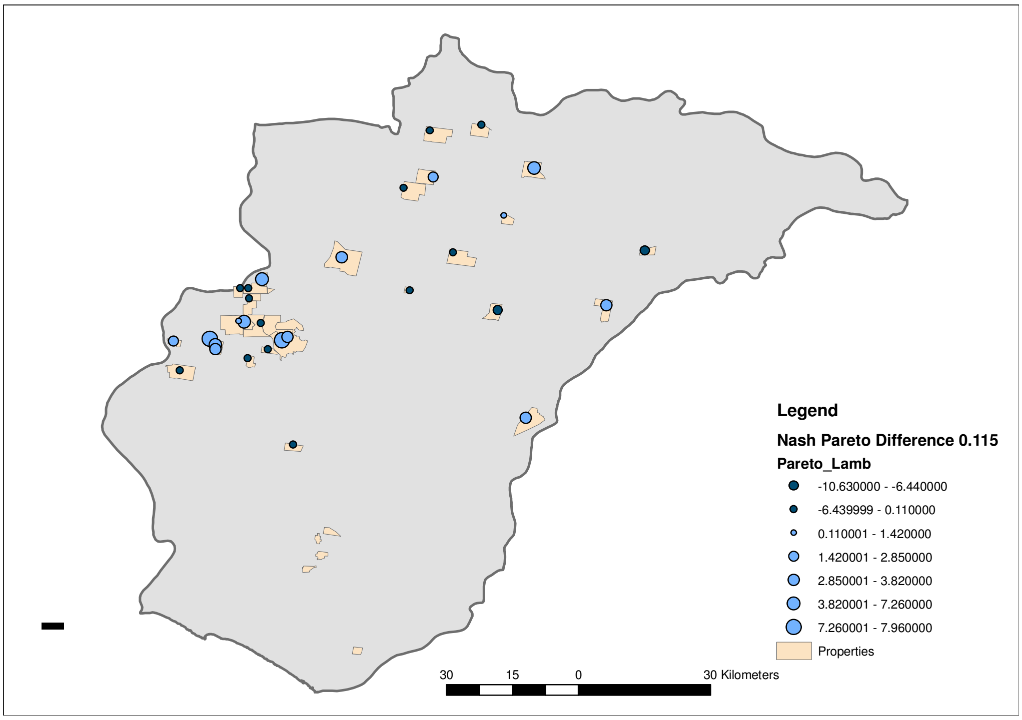


Figure 8.4(b) Pareto Difference for Prime Lamb Enterprises (kg/ha)

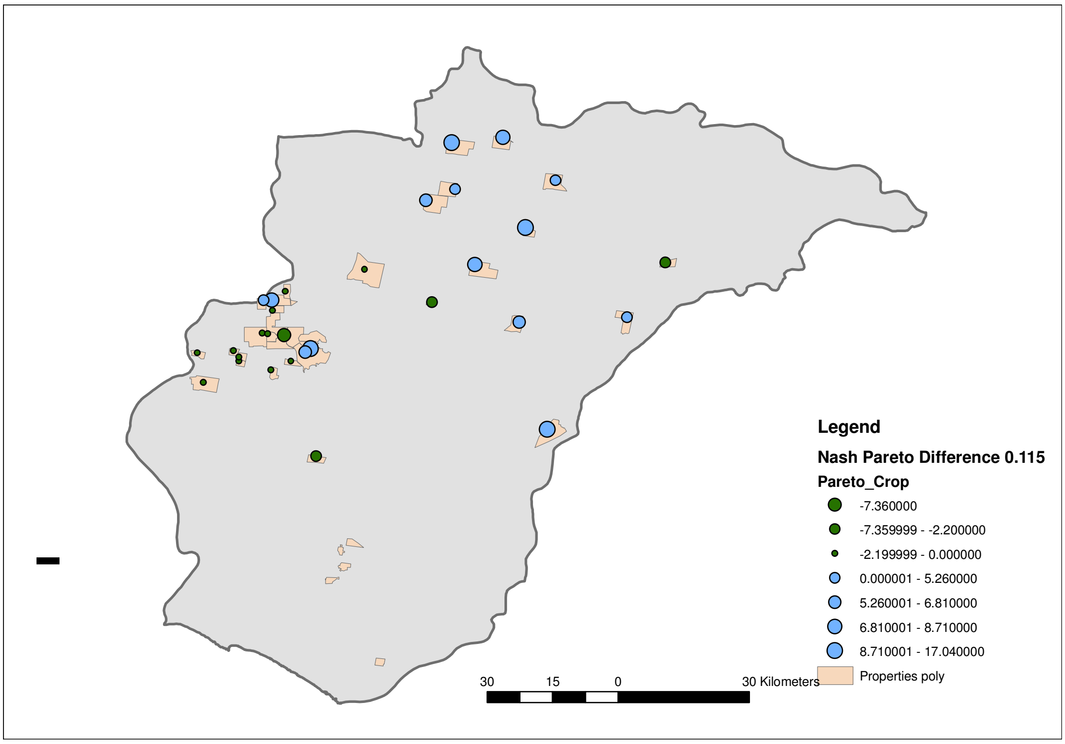


Figure 8.4(c) Pareto Difference for Crop Enterprises (kg/ha)

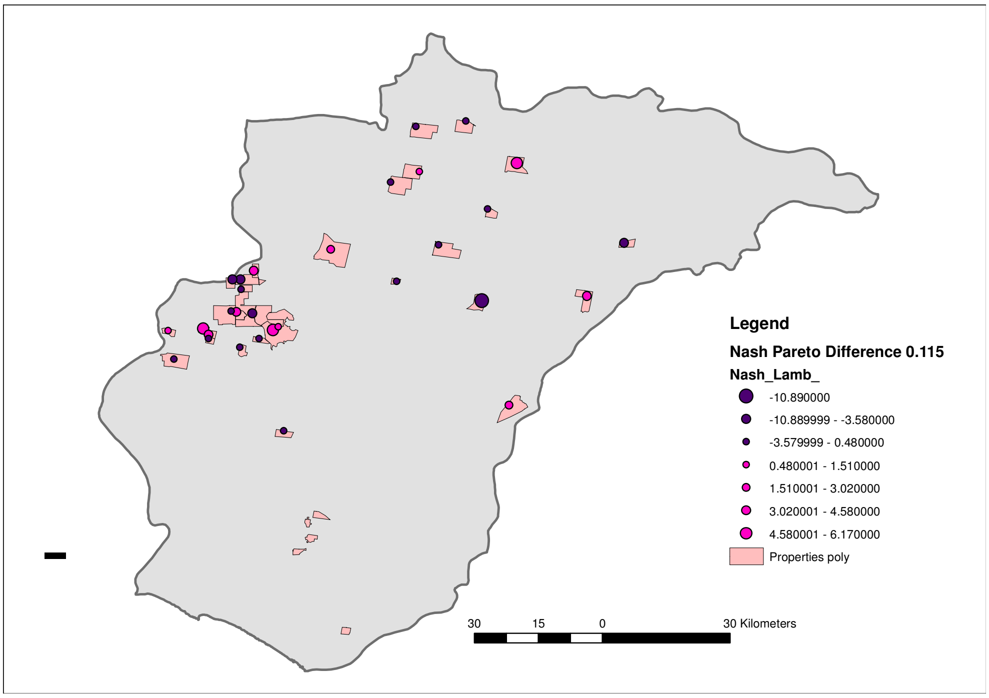


Figure 8.4(d) Nash Difference for Prime Lamb Enterprises (kg/ha)

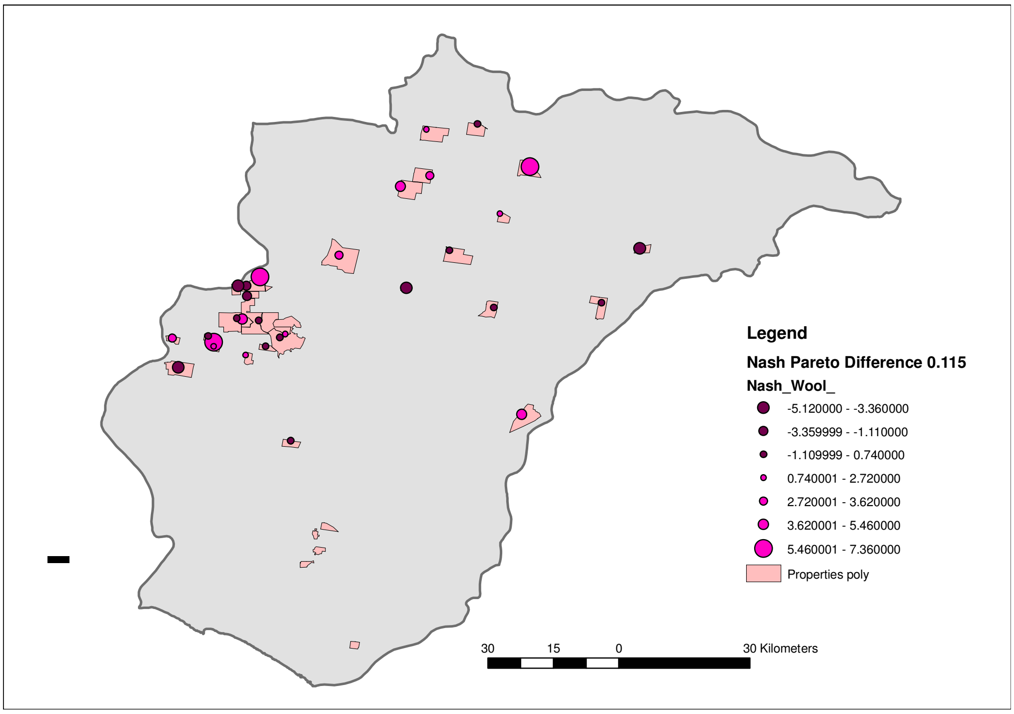


Figure 8.4(e) Nash Difference for Wool Enterprises (kg/ha)

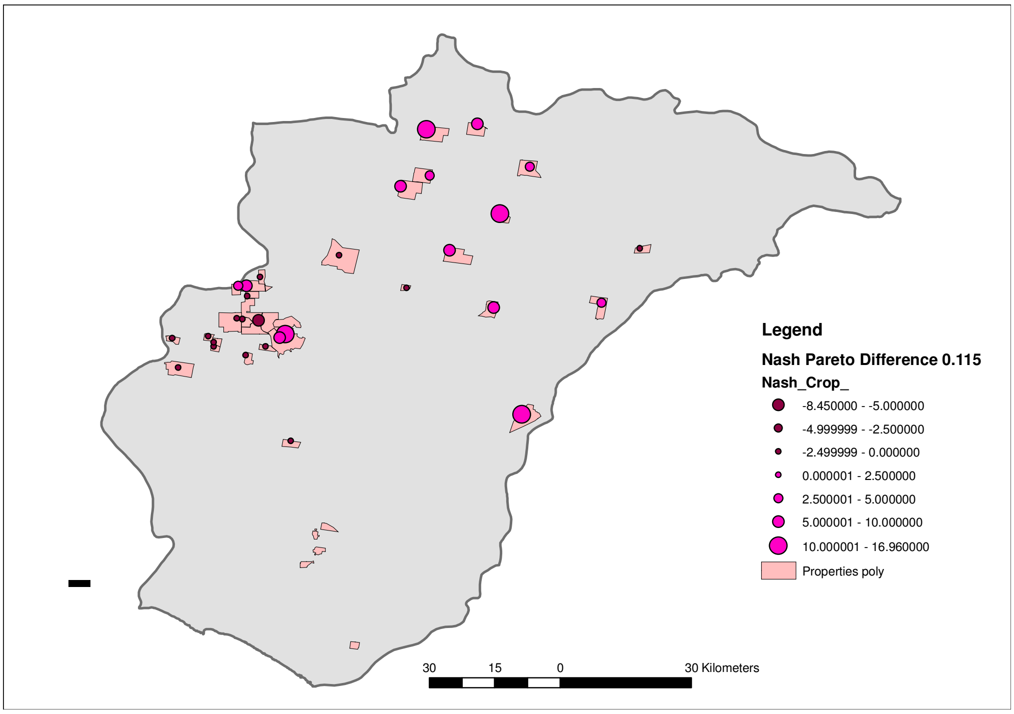


Figure 8.4(f) Nash Difference for Crop Enterprises (kg/ha)

8.2.1 Sensitivity Analysis

Sensitivity analysis is carried out to determine how changes in the model parameters will affect the modelling and how sensitive the solution will be to these changes, ie how great the change will be. The analysis in this case generally shows only slight change in sensitivity in the solutions when there is change to the model parameter, with the exception of the Cobb-Douglas constant γ, which displays a much greater percentage change to the consequence than the increase in the parameter.

- A 25% increase and decrease in γ resulted in a 46.0% increase and a 33.4% decrease respectively in the average difference in solutions.
- A 25% increase and decrease in the environmental constant *E* resulted in a 23.1% increase and a 23.9% decrease respectively in the average difference.
- A 25% increase and decrease in the 'crop' price vector *p* resulted in a 29.8% increase and a 27.8% decrease respectively in the average difference.
- A 25% increase and decrease in the factor β gave a 27% increase and a 26% decrease respectively in the average difference.

The sensitivity analysis is demonstrated in Figure 8.5. The difference in Nash and Pareto equilibrium solutions is linear with respect to percentage change in the parameters tested in the vicinities analyzed (+/- 50%) with the exception of γ.

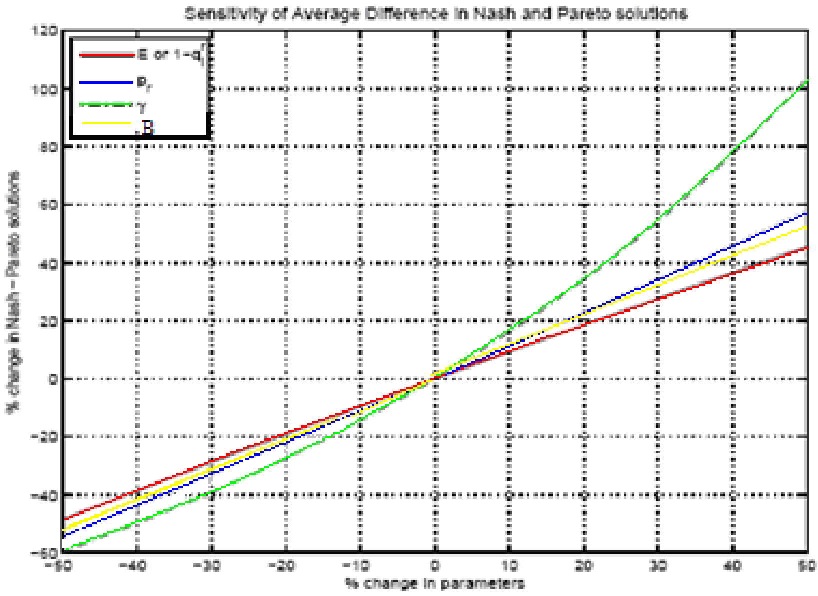


Figure 8.5 Sensitivity Analysis of the Average Difference in Nash and Pareto Equilibrium Solutions

In Section 7.2, a description was given of the calculation of the factor γ. This was based on the DPI research undertaken into gross margins for sheep enterprises in relation to phosphorus input. As γ is dependent on a production factor itself it is reasonable to assume that a doubling of the cost of an input will have a significant effect on the gross margin considering that the producers estimated that fertiliser is >10% of their input costs. For this reason it was decided to undertake an analysis of changes to average application solutions versus fertiliser costs for the three enterprises. Figure 8.6 presents the results of this analysis and while not linear they would indicate a solution that almost halves the amount of fertiliser recommended by the model if the price doubles. This supports the graph in Figure 4.7, ie that gross margin and fertiliser use is closely related.

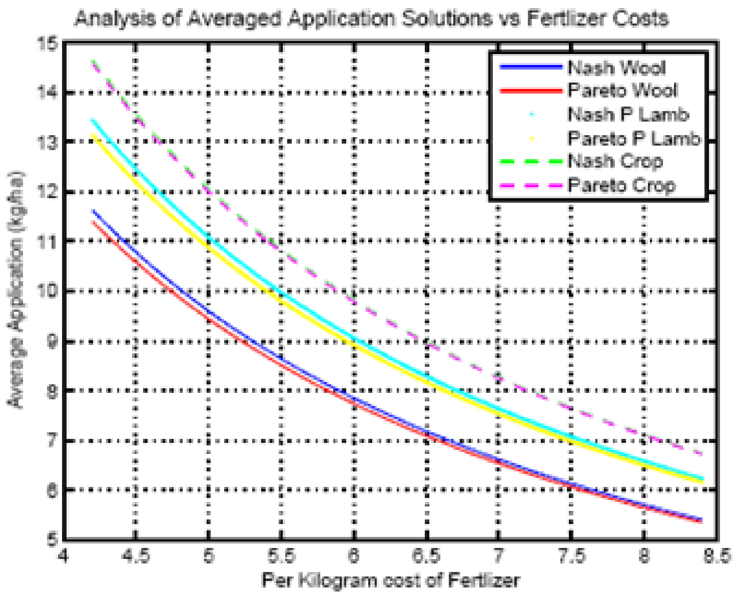


Figure 8.6 Sensitivity of Nash and Pareto Equilibrium Solutions Subject to Fertiliser Costs

The doubling of superphosphate and MAP prices did occur in 2008, with DAP tripling (DAP went from US $400-450 to $1200) (Troth J, 2008). The answers given to the third survey indicate that some landholders do respond to such increase by cutting fertiliser inputs, in this case by a third rather than a half. These landholders are hoping that it will only be temporary and they will assess what happens with the commodity markets in the coming year.

8.3 Discussion

8.3.1 Justification of the Selected Approach

A range of optimum techniques, especially linear programming, are used in environmental economics for the calculation of objective functions. There is an assumption of revenue maximization (or cost minimization) as the motivation for all agents to participate in the business. Environmental parameters can also be incorporated in these objective functions after being expressed in some monetary equivalent (Schreider et al., 2008b).

Game Theory Modelling suits solving natural resource problems which have an economic impact beyond the agent's own property.

> Since the problems of natural resource use are situations in which externalities cross frontiers so that the impacts of the externality are not confined to the agent of origin, one agent's choice depends on the choice of the others. From this perspective it is impossible not to think in terms of game theory to model natural resource conflicts, even if one avoids the phrase itself (Pham Do, 2003).

The objective of revenue maximization places the players (in this case the farmers) in a competitive situation as described in a non-cooperative game. When there are more than two parties involved in the negotiation, similar to the research project, it is possible that a variety of coalitions could form and these may do so under the guidance of scenarios represented by the game theory models. In this situation most landholders will also be potentially impacted upon by the nutrient pollution. They also share the same environmental concerns reguarding water quality and loss of biodiversity, so the reasons for collaboration are relatively strong.

Generally, in modelling natural resource predicaments the cooperative Pareto optimum is adopted from a non-cooperative game rather than initially modelling from a cooperative game perspective because the element of ‘externality’ exists with the problem, ie the pollution affects not only the agent but also outsiders. This is the outcome that maximises the sum of the individual player’s net benefits, internalising the adverse effects of its strategy on its own welfare and on the welfare of all other agents in the system (Pham Do, 2003). The difference between the cooperative and non-cooperative outcomes is the gain to be had from collaborating.

Such a game was used to model the NPS phosphorus pollution in the Hopkins catchment. The players' optimal strategies in case of competition are given by the set of *NEPs* as described in Appendix 4. The cooperative Pareto optimum is then calculated to characterise collaboration between the agents.

Game Theory has been used both for analyzing environmental problems and for modelling possible situations and solutions. It provides parties on opposite sides of the negotiating table with the benefit of models which will potentially give the best case scenario, with an outcome beneficial to all parties.

8.3.2 Use of GIS in Mapping Natural Resource Issues and Modelling

Geographic Information Systems (GIS) were used to assist the research undertaken and have provided a visual presentation of results, which has been of assistance when explaining the Game Theory model to the farmers. Data, modelling and scenarios are often easier for people to understand in a short time frame when presented as visual data. GIS consist of a computer mapping program with layers that can be switched on or off to enable variation in expression. The layers carry a database of features attributable to the area shown on the map, generally regarding location and topography, but layers can also offer spatial analysis of these objects (Tsihrintzis et al., 1997). Information can be added to separate layers about the features within a map and overlaid on the original metadata for analysis. In this way, modelling of scenarios can be presented and a temporal picture built up.

In the past two decades appropriate techniques, computational resources, and data of suitable quality have become widely available, so that the gap between the desirable and feasible in environmental modelling keeps decreasing. At the same time GIS, with their power to integrate diverse databases, undoubtedly have played a key role in this development and have become a core technology of environmental research (Alizadeh Shabani et al, 2006). GIS have contributed to research in many environmental problem areas: water resource management, nutrient pollution, loss of natural resources, forestry management, land use changes and modelling soil erosion risk.

GIS are also used to create models which show the physical impact of management on the environment. This is somewhat different to the economic modelling undertaken during this research where a visual expression of the change in management has been shown, rather than the impact on the ecosystem. In this study data obtained from the GIS meta-databases was used to create maps and to provide a visual presentation of the current phosphorus management situation in the catchment in relation to levels of phosphorus application and the use of contractors. The differences between the Game Theory models of Nash Equilibrium and the cooperative Pareto Optima have been presented to support the tabulated data.

8.3.3 Limitations of the Model

8.3.3.1 Potential Bias Problems Associated with Using Groups

One possible dilemma associated with using established groups rather than doing a mass mailout of surveys to individual landholders, is that the data is skewed to the ‘more progressive’ farmers. Study of the adoption of new production practices uptake by Trompf, (2000) has shown that farmers who participate in groups have a greater uptake of ideas and technology. This means that the farmers participating in the research may not represent the whole farmer population. This is a common problem faced by researchers, facilitators and extension staff that needs to be acknowledged.

The farmers in the South Eckland dairy discussion group chose not to participate and at the meeting there was an air of defensiveness and suspicion. This group is outside the local region in which the researcher is known and the farmers indicated concern that the topic may lead to targeting of the group for over-use of fertilisers and resultant nutrient run-off, hence a nil return of surveys was not unexpected, as indicated by observation of the need to build trust for acceptance of Decision Support Tools (Melland et al, 2005). The second group of dairy farmers was approached through the EBMP project facilitator, whom they knew well and 50% responded to the survey. The fact that the landholders were undertaking a program such as EBMP indicates an interest in environmental issues and introduces a bias. As there were only five dairy participants, the calculations were not pursued.

8.3.3.2 Limitations of the input data

The lack of data regarding accurate dates of fertiliser application, due to the realities of flexible management required on a farm meant that the model did not incorporate a time parameter. The important factor is the time of application of P fertiliser in relation to the likelihood of rainfall within four days (the half life of P fertiliser). This would vary for each property and for each year (ie it is relatively random and unpredictable).

The report by Read et al (1999) provides an economic assessment of the ‘potential’ impact of algae outbreaks in the catchment. It is not based on actual figures of past costs, because these are not known. In addition, it only presents part of ‘the story’ and the calculation of the true cost would include cost to the environment through loss of biodiversity and cost of restoring habitat, hence the true figure of *E* (negative environmental impact) maybe double or more of that used. Read et al (1999) state ‘This represents an under-estimate of the total economic impacts of nutrient management’ and they advise that further research needs to be done in this area. The sensitivity analysis indicates that the environmental cost, *E*, figure resulted in linear change showing a 23.1% change in the Nash minus Pareto solutions for a 25% increase in cost to the environment, thus indicating that the impact is linear.

In this initial model the proximity factor, β, was calculated on distance between landholders properties, however a more accurate figure would need to be based on proximity, elevation, slope and water flow direction. Because, proximity does not indicate impact of one property on another, particularly as the region is recognised for its wetlands and water may stay on the one property. Similarly, the total average rainfall was used as the parameter for available water. In a more detailed calculation of the game theory model rainfall, rainfall intensity and duration, and timing of rainfall with respect to timing of application should be included. The soil base P level (α_i^0) was taken as zero in this first calculation. For greater accuracy a figure of 2 to 4 mg P/kg should be used in future calculations (Nash, 2007).

In the research project production data from the South West Farm Monitor Project was used, however as described earlier the landholders may have been above average in production techniques and their actual gross margins may be higher than those calculated. A comparison of data to the SWFMP is described in Section 8.3.3. Haygarth and Jarvis (2002) point out there is a danger in taking fertiliser amount as the single physical parameter for change in an agricultural production system to correct environmental pollution because production will ultimately suffer. Section 8.3.4 will expand on this. Finally, the Game Theory model brings the calculations down to common denominator of an economic computation of impact on the players and the environment. As such, it runs the risk of unsubstantiated calculations of costs and being taken out of context. The model was calculated using one year of data only and has not yet been verified by further testing.

8.3.4 Comparison with the South West Farm Monitor Project

Section 6.2.4 provided a comparison of the amounts of P applied to the enterprises in the project and the difference to the results obtained by the SWMFP. The wool, lamb and cropping producers in this project applied 138%, 131.4% and 124.2% respectively more than the producers in the SWMFP. This put them well above the average for farmers in the south west and the production output figures that were used do not reflect this. Greater accuracy would be possible if the farmer's actual individual production figures were used in the model.

The data from the SWFMP has been collected for 36 years and therefore it can be used to determine where in the commodity cycle each commodity lies. This will have some impact on theresults from the Game Theory calculations and may explain why the use of phosphorus on particular enterprise in any one year is seen as more beneficial. According to the South West Farm Monitor report of 2006 the commodities of wool, prime lamb and beef were all down in value:

- Real $ gross margin for wool decreased by 56% compared with the 36-year average
- Real $ gross margin for prime lambs decreased by 28% compared with the 36-year average
- Real $ gross margin for beef decreased by 6% compared with the 36-year average (Department of Primary Industries, 2006b)
- David McInnes, a farmer participant, stated that cropping was also down further than prime lambs in that year but did not give a proportion. (Personal communication)

Since most commodities were at the low end of their economic cycles, some more than others, and the absence of accurate rate figures for comparison with cropping data, accurate recommendations can not be made.

The sensitivity graph of the price received for the commodity gave a linear change in the solutions (refer to Figure 8.6) so it is to be expected that if prices for commodities rise there will be a rise in gross margin. For example, wool gross margin was down 56%, this will affect

p^r which due to the linear sensitivity in an average year would be 59.6% higher. Prime lamb was down by 28% therefore in an average year the p^r may be 35% higher. This highlights the importance of verifying the results over several years rather than just one. There is an absence of figures for comparing cropping gross margins over the past 36 years therefore, an average year can not be accurately determined. Unfortunately there is often a mismatch with a rise in costs earlier than the rise in price received for the commodities. The choice of financial period from which the production figures are taken needs to reflect the inputs and outputs which impact on each other so the growing year (February to January) could be used rather than the financial year (July to June).

It has however been established that the model works and that the cooperative Pareto optimum provides greater savings to most parties than the Nash equilibrium.

8.3.5 Implications of Recommended P Application Levels on Production

Haygarth and Jarvis (2002) discussed the problems that arise if the amount of fertiliser is taken as the only parameter to be adjusted when Modelling changes to fertiliser application within a production system for the benefit of reducing environmental pollution. Following is an example of the expected changes that would occur on one of the properties. As recorded earlier, the DPI has produced tables of the expected changes to soil P levels according to annual phosphorus fertiliser application. These are given in Tables 4.4 and 4.5 for different soil types and shown in Figure 8.7 for a basalt soil. The tables are used to calculate the maintenance phosphorus input required to keep the soil P levels stable. For example, if the soil P level is currently 15mg P/kg then the amount required to maintain this level is 20kg P/ha. It is therefore possible to calculate the reduction in soil P that would occur with a reduction in application amount. Using Table 4.3 which gives the predicted kg P/dse for maximum profit, it is possible then to calculate the predicted stocking rate that a reduction in amount of P applied/ha would affect.

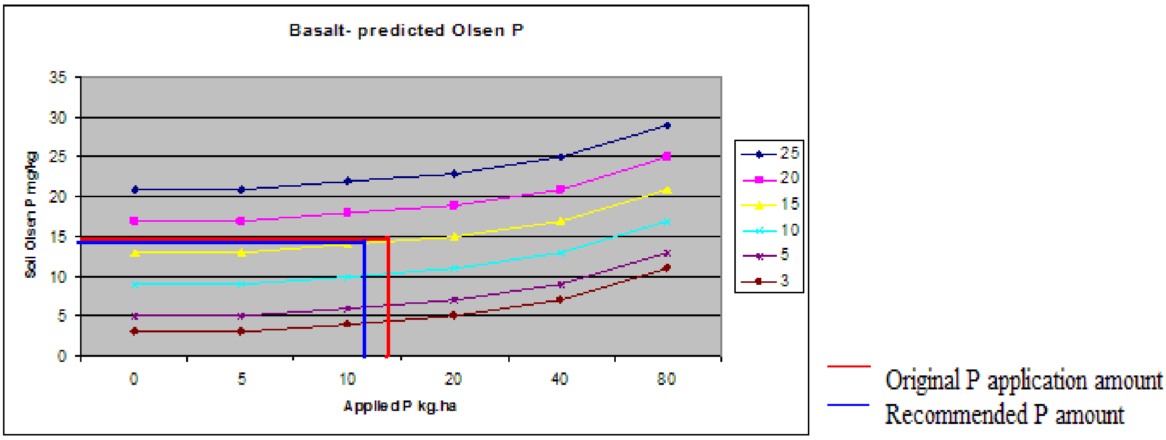


Figure 8.7 Basalt Soils Predicted Olsen P for Given Amounts of Applied P Showing Affect on Soil P mg/kg for Applied P kg/ha

An example of this would be:

PLAYER 22   320 Ha   Wool Producer   Current application: 13.65kg P/ha

Production calculated from Nash Equilibrium	$130,702.37
Production calculated from Pareto Optimum	$130,699.37
Cost to environment calculated from Nash Equilibrium	$611.42
Cost to environment calculated from Pareto Optimum	$604.20

Nash Utility $130,090.95   (Nash Production minus Nash Environment)

Pareto Utility $130,095.16   (Pareto Production minus Pareto Environment)

Pareto minus Nash Utility $ 4.21 (Savings accrued to the farmer by cooperating compared with Nash)

The recommended fertiliser application from the Nash Equilibrium Modelling would be 12.21 kg P /ha (a saving of 1.44kg P /ha)
The recommended fertiliser application from the Pareto Optimum Modelling would be 12.11 kg P/ha (a saving of 1.54kg P/ha). This equates to 19.25 kg superphosphate/ha at $0.42/kg = $8.09/ha compared with current application.

Using the graph in Figure 8.7, a reduction from 13.65 kg P/ha to 12.11 kg/ha would give a predicted annual reduction in soil P of -0.2 to -1.0 mg/kg/an for a basalt soil type.

The impact on wool production based on DPI Figures for production forecasts:

At the current application rate of 13.65 kg P/ha

- Current potential stocking for the property with a 600ml rainfall, improved pasture and medium soil loss factor would be 15.51 dse/ha

At an application rate of 12.21 kg/ha (as recommended by the Game Theory equation)

- Predicted stocking rate (0.88kgP/DSE) will equal 13.875 dse/ha
- 15.51-13.875 = 1.635 d.s.e/ha difference approximately 1 sheep/ha
- Wool cut/head=5.0 to 7.5 kg (this depends on the size and wool cut of the sheep)
- Predicted reduction in wool cut approximately 5.0 to 7.5 kg/ha
- 5.0 to 7.5kg @ $ 7.78/kg = potential reduction in income of $38.90 to $58.35/ha in the following year, dependent on the commodity cycle.

Taking the sensitivity results for the price of P, estimating the amount that should be applied from the model when the price of P input doubles, thus halving the amount of P applied to 6.06kg P/ha, and then running a production estimation similar to above, it may be concluded that production would spiral down unless prices received for the commodities rises, or the size of farms needs to be much larger to run the same amount of animals (therefore altering the costs and the gross margins).

> At the farm level on a cash-crop farm, anything that improves the efficiency of nutrient utilisation and thus minimises losses should increase the economic returns to the farm. Thus there is a strong incentive for good nutrient management consistent with water quality protection. On an animal production farm, neither crop production nor fertiliser use is directly connected to the output of such farms. Farm performance depends on the animal husbandry skills of the farmer… (Beegle et al, 2002).

The game theory model recommendations do not take into account decisions made by certain farmers as to the type of pasture being fertilised (native or introduced). The farmer that is retaining native pasture to graze stock on is doing so for reasons other than maximising production (such as minimising inputs, retaining native grasses for drought or conservation reasons or a desire to grow very fine wool in a traditional manner). This puts him outside the Game Theory model, which previously stated

> Assumes two or more rational players, the basic assumption of the 'game' is that each has an understanding of the expected rational behaviour of the other and will act accordingly in pursuit of their own goal.

Rational behaviour in this case implies 'maximising profit'.

8.3.6 Benefit of the Research Outcomes

This research has demonstrated that optimal solutions from a Game Theory model can be used to recommend fertiliser amounts for application on mixed enterprise properties within a region, based on the economics of production which includes a cost to the environment. If farmers are willing to take up cooperative Pareto strategies, then there would be an overall reduction in fertiliser use within the catchment and in the long run a reduction in nutrient pollution of the catchment waterways.

The overall model calculations gave an excess of 49,244 kg P if the competitive strategy (Nash) is followed or 53,163 kg P if the cooperative strategy (Pareto) is followed. The difference is a saving of 3,919 kg P or 35.27 tons of superphosphate for the 30 properties (an average of 1.175 tons/property). Over the estimated 1540 properties which occur in the Hopkins catchment this equates to 1809.5 tons of superphosphate at a value of approximately $844,200 (applyingthe cost of superphosphate used in the model). While this is only a small amount per property, it demonstrates that the model would achieve a significant reduction in phosphate costs.

Cropping enterprise farms in particular could benefit from the use of the model as the calculations suggest that there is greater overuse of fertiliser on cropping than on other enterprises. Based on the data from 2006, the economic calculations suggest that the production income does not justify the fertiliser amounts being applied. Unfortunately, the farmers incur the cost before reaping the income and as they are price takers it is not possible for them to know in advance the cost benefit of the phosphorus input.

The fact that one of the research team was resident in the region was important in obtaining data for the Game Theory model and in building trust in the initial contact between researchers and landholders. The suggestion by Lund and Palmer (1997) for a shared vision model could arise by development of further collaboration. The use of Game Theory to identify optimal outcomes for participants is a useful tool in the process of planning and goal setting in a region interested in improving environmental end results. It would also be possible to transfer this model for use in other catchment regions where similar enterprises are undertaken. Furthermore, the model could be trialled on dairy, beef and horticultural properties.

Chapter 9: Conclusion

9.1 Conclusion

Waterways are amongst Australia's most valuable assets. Without good quality water we would not be able to undertake the agricultural, economic and cultural activities that the community requires for healthy living. Healthy waterways with high biodiversity can only exist when nutrients are kept in a balance. When excessive amounts of nutrients enter the waterways, weed plants take over and algal blooms can occur, leading to a reduction in habitat and available oxygen for aquatic life, odours and possibly toxins that are dangerous to animals and humans. This has an impact on the whole catchment to the estuary and out into the sea.

In this project the use of phosphorus fertilisers by farmers with mixed grazing and cropping enterprises within a catchment was examined. The information was applied using in Game Theory modelling to determine and recommend the optimal amounts of fertilisers that each individual landholder should use according to a strategy of cooperation between landholders.

9.1.1 Conclusions from the Survey Data

The survey indicated that the farmers in the project were well aware of the DPI recommendations regarding amounts of P fertiliser for given soils, rainfall regions and stock levels. These farmers aimd to achieve soil P levels within the DPI recommended range, to give them optimum chance of achieving maximum production output. However, one-third of the farmers in the groups were using below the DPI recommended rates of fertiliser use.

The timing of fertiliser application by the landholder is dependent on budget, climate and the availability of the contractor, with only slight variation from year to year. Split applications of phosphorus are one option to minimise the risk of application within four days of heavy rain which is the danger period for runoff.

The landholders' knowledge of the condition of the major waterways was limited, however their understanding of the causes of nutrient pollution was sound and they had a positive attitude to minimising runoff. Fifty percent of the nutrient runoff impacts on their own properties so it is in their own interests to fence off water points and control fertiliser application as part of a strategy to improve water quality while also benefiting their crops or pasture. Over 80% of these landholders are using soil testing regularly to aid in their fertiliser management decisions.

The CMA and DPI programs fund fencing and the revegetation of river and creek banks. These two organisations also support the EBMP and DairySAT programs which raise awareness of nutrient runoff and management on farms. The dairy industry's Codes of Practice also provides information to improve dairy effluent management, and the use of soil and tissue testing. Extension services could also be expanded to educate landholders on the state of the rivers.

Using a straight economic analysis to demonstrate savings to each farmer (equivalent to $1.1/ha) is not likely to persuade them to reduce fertiliser use. Economic figures only tell part of the story as there may be specific reasons that a farmer is currently using a low rate of fertiliser, for example, pastures are native species and require low soil P levels. Alternatively a farmer may currently be using a high rate of fertiliser because the landholder is catching up after a period of low fertiliser use.

Aside from whether the landholder will adjust their applicatipon rates if there is increased knowledge, the current increase in fertiliser costs will impact on the amount of fertiliser being used. High costs will encourage the exploration of alternative sources, improved management techniques and consequently more efficient use of fertilisers.

9.1.2 Conclusions from the Game Theory Model

This research has demonstrated that game theory can be used to calculate optimal recommendations for an input (such as the amount of fertiliser) to a farm business ahentaking into account not only the income and costs to the landholderbut also an estimated cost to the environment. If the cooperative Pareto strategies are agreed to, then an overall reduction in recommended fertiliser rates could be demonstrated for the 30 farms, in comparison to either the Nash Equilibrium recommendations, or the current use of fertiliser on the farms. In the long term, the choice of the cooperative Pareto strategy would lead to a reduction in base soil P levels and potentially the NPS nutrient pollution in the streams of the region, although a direct reduction would be hard to measure particularly in the short term. A cooperative strategy could be implemented through the system of farmer community groups that already exists. These groups are influential in the region and supported thisproject from the initial stages of its implementation.

Two types of animal enterprises and a cropping enterprise, on single or mixed enterprise farms, were part of the study and the model could be transferred to other regions with similar structures of business. The overall model calculations gave an excess of 49,244 kg P if the competitive strategy (Nash) is followed or 53,163 kg P if the cooperative strategy (Pareto) is followed. The difference is a saving of 3,919 kg P or 35.27 tons of superphosphate for the 30 properties (an average of 1.175tons/property). If the q is taken as 0.985 then the corresponding figures are 2405kg P over the 30 properties or 21.6 tons of superphosphate (average of 0.72 tons P/ property). Across1540 properties this would equate to 1,109 - 1,809.5 tons of superphosphate at a value of $517,810 - $844,200. However, as this is an initial trial, further studies incorporating data from several years (to account for cycles in the commodities) and the use of more accurately reckoned parameters or factors need to be done before recommendations and comparisons are made between enterprises.

In the final year of the project the price of phosphorus fertiliser rose by over 100% motivating farmers to examine closely the amount of phosphorus they were applying and what strategies were available to increase its efficiency of use. While prices for commodities had also risen during the period, due to drought, low world food stores and competition for producing crops to meet energy demands, there was no reason to indicate that prices they would remain high, hence creating a great deal of uncertainty. The increase in fertiliser prices effectively worked like a tax applied to the input cost and instigated changes in management practice on the farms.

9.2 Future Directions

9.2.1 Future Directions for this Study

As discussed in Chapter 8, there were limitations to the model that was formulated. Further research could modify the model to reduce or remove these limitations. The most pressing issue is the need to verify the results with replication using data over several years, if possible with production data from farmers' own systems. To achieve this, the model would need to be accessible for afarmer to input his own data to preserve the privacy of his figures.

It is also suggested that a better estimation of the environmental cost parameter (E) could be undertaken. Some research has been done in the Murray Darling catchment on the costs of a BGA outbreak but more research needs to be done on the costs to a smaller, more intensively farmed catchment.

The proximity factor, β, should be re-calculated with placement of the property in relation to the direction of water flow and elevation. The soil basis level (α_i^0) could to be adjusted to 2 - 4 mg/l however, as Nash, (2007) explained this is above the EPA toxicity target used in the model and the use of zero may be preferable. This would give greater accuracy to these factors. Lastly, the model could be calculated with a timing parameter, which reflects the application of fertiliser on grazing properties in relation to rainfall.

It was envisaged that a decision support tool maybe designed to help farmers choose the level and timing of application of phosphate fertiliser on farms, which reflected not only the economic impacts on production but also incorporated the economic impact of the cost to the environment. As discussed above, the tool could then be trialled with actual production data from individual farmers. This is an area for further development.

9.2.2 Future uses of Game Theory in Natural Resource Management

From an agricultural scientist's perspective, the current areas of 'conflict' at the agriculture/ natural resource managment interface, which have an economic component, and where it is possible for Game Theory modelling to be used are:

- competition of land use for 'energy crops' and 'food crops'
- competition of land use for 'carbon' and food production
- competition between the use of water for people, agriculture and the environment
- nutrient pollution of the waterways specifically the management of Nitrogen on farms.

The changing global climate has had a large impact on the world food stores with rising costs of food in developing countries becoming critical for the poor. At the same time, the energy crisis has driven up the cost of fuel thus making the growing of crops for fuel an attractive option for farmers who have felt the price cost squeeze reducing their family incomes. The conflicting dilemma for countries, regions and farmers is 'how much of their land should they put into energy crops and how much into food crops'. The logical answer for farmers is to chase the maximum profit but from the nation's perspective it is important to continue to grow food for its citizens at a 'reasonable' price and sustainably (environmentally, economically and socially). Game Theory Modelling could be directed at this problem to assist in the evaluation of the potential balance and negotiation in policy making.

Climate change and the signing of the Kyoto protocol by Australia recently has brought the need for producing and protecting carbon stores on farms to the forefront of farmer's minds as they face the prospect of being subject to accusations and taxes for producing greenhouse gasses as a result of their food or material production. A side issue of the carbon storage is the preservation and replanting of the indigenous vegetation and preserving biodiversity on farms. Similarly, there will be conflict over the use of land for carbon production versus food production. A balance needs to be found which enables farms to continue to produce food at a cost suitable for the population but balancing the greenhouse gas emissions produced through animal and crop production..

Water sharing arrangements have been, and will continue to be an area for the use of Game Theory Modelling as will shared food resources. This has been discussed in the literature research. The overuse of nutrients other than phosphorus, such as nitrogen, which lead to pollution of waterways, could also be explored using a similar method to the model developed in this project.

In conclusion Game Theory can be used to model multiple scenarios and enable calculation of equitable sharing arrangements for agricultural production and societal needs. Negotiation between different agents would benefit from the insights gained from the simulation and effective coalitions could be formed to enable sustainable and cost effective solutions to be developed.

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Appendices

Appendix 1

Survey 1 Questions

Name:

Address:

Phone No: Fax No:

CFA Map Ref:

Farm Type:

a)	Grazing Wool	%
b)	Grazing Prime Lambs	%
c)	Grazing Beef	%
d)	Cropping conventional	%
e)	Raised bed cropping	%
f)	Controlled traffic cropping	%
g)	Forage crops	%
h)	Dairy	%

Farm Size:

Soil Types:

Average annual rainfall:

Pasture Types:

Native	%
Introduced	%

Annual	%
Perennial	%

Do you have wetlands, creeks or rivers on your property?

Fertiliser Application Questions

1) What type of fertilisers do you use on your farm?
2) Specify what they are used on:
a) grain crops
b) pasture
c) hay crops
d) other
3) How often do you use fertilisers? Please specify for each type.
4) Do you normally use fertilisers during a particular season? Please discuss if needed.
5) What amount of fertiliser do you use?
6) Do you decide the amount according to family tradition, as advised by an agronomist or as recommended by the Department of Primary Industry.
7) How does your fertiliser use vary year to year?
8) Are you planning to change the type of fertiliser that you currently use? Please specify.
9) Do you use a contractor to spread the fertiliser or do the spreading yourself?
10) Do you use granular fertilisers, liquid fertiliser or foliar sprays?
11) Do you follow the recommendations of the ‘Codes of practice’ for the fertiliser industry?
12) Do you use soil tests or tissue tests to determine how much fertiliser to spread on pastures or crops? Please specify.
13) If a heavy rain occurs right after fertilizing the farm, do you re-apply fertilisers?
14) What margin would you put on the benefit you get by applying fertiliser? E.g. for each $ spent on fertiliser you gain $3 in income.
15) What is the cost of fertiliser expressed as a percentage of your annual farm costs? Eg If your annual farm costs are $100,000 and the fertiliser costs $15,000, equates to 15% of the overall costs.

Nutrient Pollution Questions

16) What is your understanding of nutrient pollution of waterways?
17) How does this affect you and your region?
18) Are you concerned with the long term effect of nutrient pollution on the wider catchment?
19) What monetary value do you place on the benefits of a healthy catchment?

20) Do you recognise that there is a problem of nutrient pollution associated with agricultural activities? What activities? – please specify.

21) What % of your waterways and wetlands have been fenced and revegetated to at least 10m from the edge of the water?

22) Is it possible for you to contribute to solving the problem of excess nutrient pollution in waterways?

23) What frustrates you most in discussions of environmental issues and agriculture? Why?

Appendix 2

Survey 2 Questions

Name:

Questions clarifying answers from first survey and seeking additional information

1) What is your soil P target?
2) What percentage of your production areas are at or near this target?

From Questions 5 and 12

The amount you indicated that you applied was………kg/ha

3) Does this reflect where you are aiming for in soil P target?
4) Was the amount indicative of what was applied over the whole farm?
5) Was it specific to certain paddocks with the aim of raising soil P?
   If so
6) What percentage of the farm was this?
7) Please indicate below in which month/s you apply Phosphorus fertiliser. C-Crop & P- Pasture

Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*

From Question 21

You indicated that you have fenced------------ % of your waterways and wetlands

8) At what distance from the waterway are the fences?
9) Have you observed an improvement in water quality?
10) What are the local attitudes on fencing waterways and wetlands?
11) Would you allow me to map this on a GIS for the purposes of the project?
12) Do you use land class fencing to manage low lying areas of your farm?
13) Are you an active member of a Landcare group?

Appendix 3

Survey 3 Response to Game Theory Calculations for Phosphorus Fertiliser Application

Name:

The result of the calculations suggests that a) if you were taking only the ‘cost of production’ and the ‘cost to the environment’ into account you should raise/lower the amount of Phosphorus applied from ___________ to ___________.

The result of the calculations suggests that if you were taking a community wide cooperative approach to P fertiliser application, you should raise/lower the amount of phosphorus applied from ___________ to ___________.

1) How do you respond to this suggestion?
2) Knowing that there is a problem with rising Phosphorus levels in the Hopkins River, does this alter your decision making with regard to Phosphorus fertiliser application? How?
3) If you raised/ lowered the amount of P (kg/ha) what do you predict would be the production response in 3-5 years?

Impact of fertiliser cost increases on short term fertiliser application decision making.

4) What impact has the doubling in cost of fertiliser had on your decision making this year?
5) Has this altered the timing of fertiliser application?
6) Has this altered the amount of fertiliser applied?
7) Has this altered the mix of enterprises that you are planning to produce?
8) If you grow grain crops:
   Has this altered the mix of crops that you are planning this year? How?

Appendix 4

Game Theory Formulation to Phosphorus Pollution of Waterways

In this section a static, non-cooperative game model of phosphorus pollution in the Hopkins catchment region is formally presented, which will be referred to as the *Hopkins project*. As a preliminary remark, a *strategic form non-cooperative game* Γ is defined as the system represented by

$$\Gamma = (N, (S_i)_{i \in N}, (u_i)_{i \in N})$$

where $N = \{1, 2, \ldots, n\}$ represents the set of players, S_i is the set of *pure strategies* available to Player i and $u_i(s)$ is a function defined on the Cartesian product set

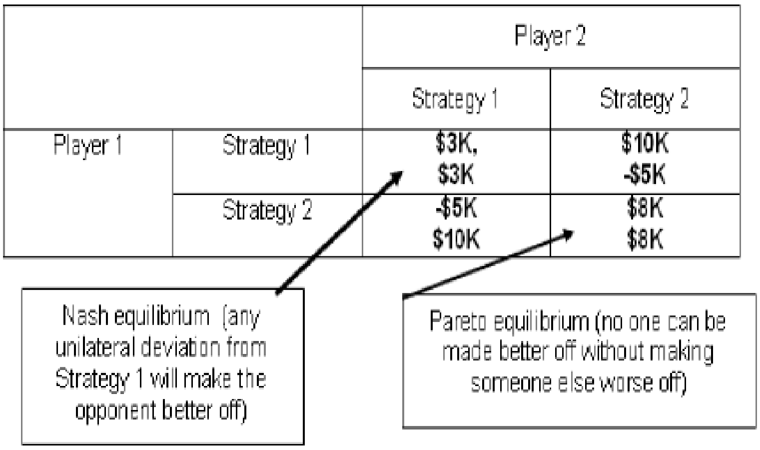

Figure 32: Prisoners' Dilemma in economics: illustration of Nash and Pareto Equilibrium. The objective function is the expected outcome accrued to each player.

$S = \prod_{i \in N} S_i$ which represents the payoff or *utility* to Player i when a combination of strategies, or *profile*, $s \in S$ is selected by the players. If chance is involved in a game, i.e. a lottery is played, then the payoff is an *expected value*, as commonly defined in probability theory.

4.5.1 The Players

In the Hopkins project, each farmer household is represented as a player. The number of players, n, should not be too large. Otherwise, the analysis would be intractable. We will denote Player i by P_i.

4.5.2 The Strategies

The strategy set S_i, $i = 1, 2, \ldots, n$, available to each player, consists of tuples

$$s_i = (\alpha_i, t_i) = (\alpha_i^1, \alpha_i^2, \ldots, \alpha_i^R, t_i^1, t_i^2, \ldots, t_i^R)$$

where R is the number of crops fertilized using phosphorus and

$$\begin{aligned} \alpha_i^r &= \text{the amount of phosphorus used by } P_i \text{ for crop } r \text{ per unit area} \\ t_i^r &= \text{the scheduling of the application of phosphorus by } P_i \text{ for crop } r, \\ &\quad \forall\ r = 1, 2, \ldots, R. \end{aligned}$$

That is, each member of S_i consists of the amount and time of application of phosphorus to crop r planted by the farmers, $r = 1, 2, \ldots, R$. It is allowed for the α_i^r to vary continuously within the interval $A_r = [A_{r1}, A_{r2}]$, i.e., irrespective of the player, there is a minimum quantity A_{r1} and a maximum quantity A_{r2} of phosphorus that can be applied to crop r. Similarly, the time of application, t_i^r, also takes values in an interval $T_r = (t_{r1}, t_{r2}]$ where t_{r1} is the minimum time and t_{r2} the maximum time of application. Note that it is sometimes more realistic for T_r to be a finite set, e.g. $T_r = \{1, 2, \ldots, 12\}$ when phosphorus is applied once - a -month; however, an interval for mathematical convenience and tractability has been chosen.

Thus, $s_i \in S_i = \prod_{r=1}^{R} A_r \times \prod_{r=1}^{R} T_r$ for any i and $s = (s_1, s_2, \ldots, s_n) \in S = \prod_{i \in N} S_i$ represents a profile adopted by all players. In the sequel, we also use the notation $s_{-i} = (s_1, s_2, \ldots, s_{i-1}, s_{i+1}, \ldots, s_n)$ to represent a profile adopted by all players *except* P_i.

4.5.3 The Pay-off Function

This will be measured by a *profit function* which has as its components the price obtained for the farm produce and the negative impact of environmental degradation. Before displaying the payoff function the following terms are defined:
For each strategy $(\alpha_i, t_i) \in S_i$ executed by P_i, let

γ = Cobb-Douglas constant

$q_i^r(\alpha_i^r, t_i^r)$ = proportion of phosphorus that is released into farmland devoted to crop r;

$1 - q_i^r(\alpha_i^r, t_i^r)$ = proportion of phosphorus that flow into the effluent river systems as a consequence thereof;

$E(t_i^r)$ = (negative) environmental impact manifested as cost per unit application of phosphorus;

A_i^r = total quantity of land devoted to crop r by P_i;

$W_i^r(t_i^r)$ = amount of water available at time t_i^r;

$Q^r(t_i^r)$ = quantity of crop r produced per unit area per unit phosphorus$^\gamma$ per unit of water$^{1-\gamma}$;

p_r = price (revenue) obtained per unit of crop r sold;

α_i^0 = base quantity of phosphorus in soil of user i per unit area;

F = price per unit of phosphorus fertiliser ;

β_{ij} = environmental influence indirectly induced on P_i by P_j

and L = toxicity threshold level, i.e. the amount of phosphorus in the effluent river systems above which there will be a negative environmental impact.

The payoff function accrued by Player i if all players adopted the profile

$$s = ((\alpha_1, t_1), (\alpha_2, t_2), \ldots (\alpha_n, t_n))$$

can be expressed as

$$u_i(s) = \sum_{r=1}^{R} \Bigg[p_r Q^r(t_i^r) A_i^r \left[\alpha_i^r q_i^r(\alpha_i^r, t_i^r) + \alpha_i^0\right]^\gamma W_i^r(t_i^r)^{1-\gamma} - F A_i^r \alpha_i^r$$
$$- \sum_{j=1}^{N} \beta_{ij} E(t_j^r) A_j^r (\alpha_j^r(1 - q_j^r(\alpha_j^r, t_j^r)) - L) I(\alpha_j^r(1 - q_j^r(\alpha_j^r, t_j^r)) > L) \Bigg] \quad (1)$$

where $0 \leq \beta_{ij} \leq 1$ are constants and $I(A)$ refers to the indicator of the set A, i.e. $I(A) = 1$ if event A has occurred, and equals to 0 otherwise.

The rationale for (1) is as follows: not all phosphorus that were used are released into farmland, a proportion of this flowed into the effluent river systems, producing a negative environmental impact if the total amount released exceeded a toxicity threshold level. The term in β_{ii} represents Player i's own impact with constants $\beta_{ii} = 1 \; \forall \, i \in \{1, 2, \ldots, N\}$. Fixed proportions β_{ij} $i \neq j$, of this environmental influence are indirectly induced by other players on $P_i's$ domain and add a further negative impact on $P_i's$ payoff. Note that the functions $E(.)$ and $Q^r(.)$ depend only on the time of application t_i^r and not on α_i^r. This assumption is not unreasonable since these quantities, expressed as amounts per unit application, should be independent of the total amount of phosphorus being applied.

4.5.4 Optimal Strategies

Nash Equilibrium The Hopkins project as outlined above is an example of a non-zero sum, n-person game. Therefore, the competitive optimal solutions, if they exist, can be expressed as *Nash Equilibrium Profiles (NEPs).* A profile

$$s^* = (s_1^*, s_2^*, \ldots, s_n^*) \in S$$

is a NEP if it satisfies the following property:

$$u_i(s_i^*, s_{-i}^*) \geq u_i(s_i, s_{-i}^*), \;\; \forall s_i \in S_i \;\text{ and }\; \forall i \in N. \quad (2)$$

Thus, a NEP is stable for all players since any unilateral deviation from equilibrium by a player, given that all other players adhere to their best strategies, will result in a possible decrease of its revenue. We note that the Nash equilibrium point in Figure 32 satisfies (2).

If the various functions forming $u_i(.), i = 1, 2, \ldots, n$, render them *concave* with respect to the variables α_i^r and t_i^r, and, in addition, the optimum occurs in the interior of S, then the NEP of the game is the solution of the following systems of equations involving first-order partial derivatives:

$$\begin{aligned} \left.\frac{\partial u_i}{\partial \alpha_i^r}\right|_{s^*} &= 0 \\ \left.\frac{\partial u_i}{\partial t_i^r}\right|_{s^*} &= 0 \\ r &= 1, 2, \ldots, R; i = 1, 2, \ldots, n. \end{aligned} \quad (3)$$

Pareto Equilibrium The derivation of a Pareto equilibrium falls into the class of multiobjective decision problems where a vector- valued function,

$$\mathrm{f}(\mathrm{x}) = (f_1(\mathrm{x}), f_2(\mathrm{x}), \ldots, f_n(\mathrm{x})),\ \mathrm{f} : A \to R^n, A \subset R^k,$$

is optimized according to some vector optimization criterion. For a detailed discussion of multiobjective decision problems, the reader is referred to a comprehensive discussion in Chankong and Haimes (1983).

A point x^* is a *Pareto optimum* if there exist no other feasible x such that $f_j(\mathrm{x}) \geq f_j(\mathrm{x}^*)\ \ \forall j$ with at least one j such that $f_j(\mathrm{x}) > f_j(\mathrm{x}^*)$.

In the context of our model therefore, a strategy profile s^* defines a Pareto Optimum if there exists no profile s such that

$$u_i(s) \geq u_i(s^*) \quad \forall i \in N$$

with at least one $i \in N$ such that

$$u_i(s) > u_i(s^*).$$

A Pareto optimum is obtainable only if players enter into a binding cooperative agreement. The Pareto optimum point in Figure 32 satisfies (7). One method of obtaining a Pareto optimum is to solve the *weighting problem* which is defined as follows:

For some set of weights $\mathrm{w} = (w_1, w_2, \ldots, w_n) \in R^n$ such that $w_j \geq 0, \forall j$ and $\sum_{j=1}^{n} w_j = 1$, find x^* such that

$$\mathrm{w.f}(\mathrm{x}^*) \;=\; \max_{\mathrm{x} \in A} \mathrm{w.f}(\mathrm{x}) \quad (4)$$

where the symbol x.y refers to the scalar product between vectors x and y. The following sufficient conditions for the existence of the Pareto optimum point x^* are given in Chankong and Haimes (1983) (cf. Theorem 4.6):

x^* is a Pareto optimum point of a multiobjective decision problem if one of the following two conditions hold:

(i) there exists a set of weights $w = (w_1, w_2, \ldots, w_n) \in R^n$ such that $w_j > 0, \forall j$ and $\sum_{j=1}^{n} w_j = 1$, such that x^* solves the *weighting problem*;

(ii) x^* is the unique solution of the *weighting problem.*

Thus, in our model, using the first condition above, Pareto optimum solutions can be obtained by maximizing the following weighted sum of the players' payoff functions:

$$Z(s) = \sum_{i=1}^{n} w_i \, u_i(s) \tag{5}$$

provided a set of weights $w = (w_1, w_2, \ldots, w_n)$ can be found satisfying $w_i > 0, \forall i$ and $\sum_{i=1}^{n} w_i = 1$. Therefore, sufficient first order conditions for the Pareto optimum solutions are given by

$$\begin{aligned} \left.\frac{\partial Z}{\partial \alpha_i^r}\right|_{s^*} &= 0 \\ \left.\frac{\partial Z}{\partial t_i^r}\right|_{s^*} &= 0 \\ & r = 1, 2, \ldots, R; i = 1, 2, \ldots, n. \end{aligned} \tag{6}$$

This project is particularly concerned with the special cooperative Pareto Equilibrium mentioned above. Intuitively this equilibrium maximizes the sum of utilities.

Strong Nash Equilibrium A closely related equilibrium concept to the NEP and Pareto equilibrium, introduced by Aumann (1959), is the concept of a *Strong Nash Equilibrium* (SNE). This generalizes the NEP concept in the sense that instead of just looking at the negative effect to the individual deviating, one now considers group of individuals,i.e. a *coalition*, deviating from adopting the optimum strategy, given that the remaining players adhere to theirs. For any $K \subseteq N$, let us first define

$$S_K = \prod_{i \in K} S_i \quad \text{and} \quad S_{-K} = \prod_{i \ni K} S_i$$

and use the notation $s_K \in S_K$ and $s_{-K} \in S_{-K}$. A profile s^* is a SNE if there exists no coalition $K \subseteq N$ such that

$$u_i(s_K, s_{-K}^*) \;\; \geq \;\; u_i(s^*) \quad \forall i \in K$$

with at least one $i \in K$ such that

$$u_i(s_K, s^*_{-K}) \;\; > \;\; u_i(s^*). \tag{7}$$

Thus, no group of individuals would deviate from adopting SNE since each individual in that group would do no better, and, some would do worse, if those not in the group adhere to their SNE.

We should note here that by letting $K = \{i\}$ and $K = N$ in (7) respectively, it follows that SNE is also a NEP and a Pareto optimum point. Out intention for introducing SNE is only to show that it generalizes both NEP and Pareto optimality, and we will therefore not consider SNE further in this report.

4.6 Application of the Model

For this project, a special survey of farmers in the Hopkins River catchment region was conducted. This allows us to learn about attitude of landowners to phosphorus application and to collect information about timing and quantity of phosphorus application in this region. Detailed description of this survey is beyond the scope of the present report and is described in a separate work (Schlapp and Schreider, 2007).

Results from this survey can be used in applications of the model. In a first run of the model the time component of the strategy was not considered and thus the strategy set is $s_i = (\alpha_i^1, \alpha_i^2, \ldots, \alpha_i^R)$. So the variables to be determined are the α_i^r, phosphorus application by player i on crop r over the season. As a consequence,

$$\begin{aligned} E(t_i^r) &= E \\ Q^r(t_i^r) &= Q^r \\ W_i^r(t_i^r) &= W_i^r \end{aligned}$$

become exogenous parameters. Furthermore for simplicity sake the α_i^r dependence from the absorption constant $q_i^r(\alpha_i^r, t_i^r)$ is removed. That is $q_i^r(\alpha_i^r, t_i^r) = q_i^r$ is an exogenous parameter. Then (1) becomes,

$$u_i(\alpha_i^r) = \sum_{r=1}^{R} \Bigg[p_r Q^r A_i^r [\alpha_i^r q_i^r + \alpha_i^0]^\gamma (W_i^r)^{1-\gamma} - F A_i^r \alpha_i^r \\ - \sum_{j=1}^{N} \beta_{ij} E A_j^r (\alpha_j^r (1 - q_j^r) - L) I(\alpha_j^r (1 - q_j^r) > L) \Bigg] \tag{8}$$

and (5) becomes

$$Z(s) = \sum_{i=1}^{N}\sum_{r=1}^{R}\left[w_i p_r Q^r A_i^r[\alpha_i^r q_i^r + \alpha_i^0]^\gamma (W_i^r)^{1-\gamma} - w_i F A_i^r \alpha_i^r \right.$$
$$\left. - \sum_{j=1}^{N} w_j \beta_{ji} E A_i^r(\alpha_i^r(1-q_i^r) - L) I(\alpha_i^r(1-q_i^r) > L)\right]. \quad (9)$$

In order to find the Nash Equilibrium the following must be solved,

$$\frac{\partial u_i}{\partial \alpha_i^r} = 0 \qquad r = 1, 2, \dots, R; i = 1, 2, \dots, N.$$

That is, solve $R \times N$ equations for the $R \times N$ variables α_i^r. The solutions yielded are

$$\alpha_i^r = \frac{W_i^r\left[\frac{F+E(1-q_i^r)I(\alpha_i^r(1-q_i^r)>L)}{\gamma p_r Q^r q_i^r}\right]^{1/\gamma-1} - \alpha_i^0}{q_i^r}. \quad (10)$$

With regards to second order conditions,

$$\frac{\partial^2 u_i}{\partial \alpha_i^{r\,2}} < 0 \;\; \forall\; r = 1, 2, \dots, R$$

Indeed,

$$\begin{aligned}\frac{\partial^2 u_i}{\partial \alpha_i^{r\,2}} &= \gamma(\gamma-1) q_i^{r\,2} p_r Q^r A_i^r[\alpha_i^r q_i^r + \alpha_i^0]^{\gamma-2}(W_i^r)^{1-\gamma} - E A_i^r(1-q_i^r)\delta\left\{\frac{L}{EA_i^r(1-q_i^r)}\right\} \\ &< 0,\end{aligned}$$

given a non-negative solution for α_i^r, $r = 1, 2, \dots, R$, is obtained and $0 < \gamma < 1$.

In order to find the Pareto Equilibrium the following must be solved,

$$\frac{\partial Z}{\partial \alpha_i^r} = 0 \qquad r = 1, 2, \dots, R; i = 1, 2, \dots, N.$$

That is, solve $R \times N$ equations for the $R \times N$ variables α_i^r. The solutions yielded are

$$\alpha_i^r = \frac{W_i^r\left[\frac{w_i F + \sum_{j=1}^{N} w_j \beta_{ji} E(1-q_i^r) I(\alpha_i^r(1-q_i^r)>L)}{w_i \gamma p_r Q^r q_i^r}\right]^{1/\gamma-1} - \alpha_i^0}{q_i^r}. \quad (11)$$

With regards to second order conditions the Hessian matrix for Z must be analsyed. Indeed it can be seen that

$$\frac{\partial^2 Z}{\partial \alpha_{i_1}^{r_1} \partial \alpha_{i_2}^{r_2}} \neq 0 \Leftrightarrow i_1 = i_2 \text{ and } r_1 = r_2.$$

This implies that all non-diagonal entries of the Hessian are zero, thus the determinant of the Hessian can be calculated as the product of diagonal entries. A typical diagonal entry is,

$$\begin{aligned}\frac{\partial^2 Z}{\partial {\alpha_i^r}^2} &= \gamma(\gamma-1){q_i^r}^2 p_r Q^r A_i^r[\alpha_i^r q_i^r + \alpha_i^0]^{\gamma-2}(W_i^r)^{1-\gamma} - \sum_{j=1}^{N} w_j \beta_{ji} E A_i^r (1-q_i^r)\delta\left\{\frac{L}{EA_i^r(1-q_i^r)}\right\} \\ &< 0,\end{aligned}$$

given a non-negative solution for α_i^r, is obtained and $0 < \gamma < 1$. Therefore,

$$|H_n| < 0 \text{ for odd } n \text{ and } |H_n| > 0 \text{ for even } n \text{ , } n \in \{1, 2, \ldots, R \times N\}$$

where H_n represents the Hessian matrix with any $n - R \times N$ rows and columns removed. This is sufficient to conclude Z attains a maximum at the above solutions for α_i^r.

4.6.1 Estimation of Parameters

Blue-green algae blooms due to increased phosphorus in the water is selected as the most significant environmental impact in the region. The environmental impact constant E is the cost per unit of phosphorus above threshold L in the effluent rivers systems. Read et al. (1999) estimated that the expected annual impacts of toxic blue-green algae blooms would be $\$1,820,807$ per year for the combined Glenelg and Hopkins Catchments. Of this, $\$963,927$ is directly attributable to farm dams (domestic and stock water supplies) throughout the basins highlighting just how directly phosphorus use can negatively impact farmers. Phosphorus loads in the combined Catchments are estimated to be $265,194$ kg per year. Thus a justifiable estimate for E is,

$$E = \frac{\$1,820,807 \text{ p.a.}}{265,194 \text{ kg p.a.}} = \$6.87/\text{kg}.$$

With regards to the threshold level L, Schlapp and Schreider (2007) shows phosphorus levels in the waterways of the region to be above 0.118 mg/L (eutrophication level) for increasing periods of the year. Holmes (2002) displays EPA guidelines for phosphorus levels to be 0.030 mg/L. Read et al. (1999) estimates pasture runoff contributes $15 - 20\%$ of total phosphorus to surface waters of Glenelg-Hopkins region. Thus current levels of phosphorus in waterways are unacceptably high already even with the effects of farming removed (Nash, 2007). For this reason we set the safe threshold level,

$$L = 0.$$

Within the Glenelg-Hopkins region we consider three main types of farming enterprize; wool, prime lamb and regular cropping (wheat, oats and canola). Thus we define,

$$\begin{aligned} r = 1 &\Leftrightarrow \text{wool} \\ r = 2 &\Leftrightarrow \text{prime lamb} \\ r = 3 &\Leftrightarrow \text{regular cropping} \end{aligned}$$

Wool, prime lamb and regular cropping prices are obtained from average prices listed in DPI (2006). For regular cropping the average was taken from wheat and oats prices.

$$\begin{aligned} p_1 &= \$7.78/\text{kg} \\ p_2 &= \$3.03/\text{kg CW (carcass weight)} \\ p_3 &= \$0.16/\text{kg} \end{aligned}$$

The water constants W_i^r will depend on the location of the player i and the type of crop r. Within the region of the survey, annual precipitation can be separated into four separate categories as can be seen in Schlapp and Schreider (2007). These ranges are,

$$[562 - 600), [600 - 650), [650 - 700), [700 - 750) \text{ mm p.a.}$$

For crops $r = 1, 2$ the water constants for each player i will be the yearly rainfall based on location. However due to regular cropping only taking place usually from mid-April through to mid-December (Saul et al., 1999) the water constants will be just be the average rainfall over this period for $r = 3$.

In determining the absorption constant q_i^r readers are referred to Murray et al. (2004) in which numerous studies regarding phosphorus runoff are discussed. Dougherty (2004) also shows results for phosphorus runoff under different rainfall simulations and times since fertilizer application. Both papers indicate that phosphorus runoff is proportional to the amount of fertilizer applied. The proportion of runoff depends more on the quantity and intensity of rainfall since application of fertilizer. In a study by Sharpley et al. (1983) total fertilizer phosphorus lost ranged from $3.8 - 11.5\%$ in New Zealand clay type soils. Sharpley et al. (1976) show 6.1% and 5.7% of applied phosphorus in grazed and ungrazed pastures respectively is lost via surface runoff. Thus taking 6.1% as runoff rate a reasonable estimate for absorption constants,

$$q_i^1 = q_i^2 = 93.9\% \qquad i = 1, 2, \ldots, N.$$

Zhang et al. (2003), China, show $0.4 - 1.2\%$ runoff of applied phosphorus in paddy soil under wheat. Withers et al. (2001), UK, show 0.7% runoff of applied phosphorus in cultivated seed beds. Thus taking 1.2% as runoff rate a reasonable estimate for absorption constant q_i^3,

$$q_i^3 = 98.8\% \qquad i = 1, 2, \ldots, N.$$

The constant α_i^0 represents the base phosphorus levels in soil for user i. Since the clay type soils of the region naturally have very low phosphorus levels and an inability to retain phosphorus well, an initial estimate is,

$$\alpha_i^0 = 0$$

The price of phosphorus, F, is calculated from results in DPI (2006). An average of \$42/ha was spent on fertilizers with an average of 10kg/ha phosphorus applied. Thus a reasonable estimate for the price of fertilizer is,

$$F = \$4.20/\text{kg}$$

DPI (2006) Wool production results show an average of 6.2kg/ha/100mm of rainfall. This is effectively $\frac{620}{100^{1-\gamma}}$kg/ha/100mm$^{1-\gamma}$. Furthermore, an average of 10 kg of phosphorus was used to produce this quantity, so a reasonable estimate for Q^1 is,

$$Q^1 = \frac{620}{10^\gamma \times 100^{1-\gamma}} \text{kg Wool/ha/100mm}^{1-\gamma}/\text{kg P}^\gamma$$

In a similar fashion Q^2 and Q^3 are obtained as

$$\begin{aligned} Q^2 &= \frac{1790}{10^\gamma \times 100^{1-\gamma}} \text{kg CW Prime Lamb/ha/100mm}^{1-\gamma}/\text{kg P}^\gamma \\ Q^3 &= \frac{13.45 \times 100^{1-\gamma}}{10^\gamma} \text{kg Crop/ha/100mm}^{1-\gamma}/\text{kg P}^\gamma \end{aligned}$$

where 13.45 is the average of Wheat and Oats figures.

With regards to the constants β_{ij}, these are of the form

$$\beta_{ij} = \frac{k}{x_{ij}^2}$$

where x_{ij} is distance from Player i to Player j, $i \neq j$. The constant $k = 1$ and the smallest unit of distance is 1.

An infinite number of Pareto equilibria exist though the particular cooperative Pareto equilibrium sought here is that with weights

$$w_i = \frac{1}{N} \qquad i = 1, 2, \ldots, N.$$

Intuitively this is the Pareto equilibrium that maximizes the sum of utilities.

The areas A_i^r are provided from the survey.

After calibration of the model the value of the Cobb-Douglas production constant γ is

$$\gamma = 0.115.$$

The calibration process of the parameter γ was based on the assumption that all farmers in the region act reasonably well in sense of fertilizer applications and follow the recommendations of the Department of Primary Industries, Victoria, which assign the threshold of phosphorus application within the interval of between 13 to 18 kg/ha.