AN INVESTMENT IN IRRIGATION BY DAIRY FARMERS
- THE PROBABILITY DISTRIBUTION OF
THE TIME TO PAYBACK

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Lorraine Joan Stachurski

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ABSTRACT

In recent years many dairy farmers, particularly in Northland, have expressed an interest in investing in irrigation. The main financial risk that dairy farmers face when considering such an investment arises from uncertainty about the stream of future returns to irrigation. This uncertainty primarily results from the variability of dryland pasture growth rates during the summer months. Obviously, the more prone an area is to drought or dry summer conditions the more profitable investment in irrigation is likely to be. Uncertainty as to the future values of the costs and returns associated with dairying is a second source of risk.

In this study a methodology has been developed to evaluate the economic benefits of an investment in irrigation which takes into account variation in climatic conditions during the summer, and which allows the effects of changes in other key variables to be assessed. Modelling techniques are used, in conjunction with historic meteorological data, to simulate pasture growth rates and derive the resultant farm gross margins, for both a dryland and an irrigated system, over a number of seasons. A Monte Carlo style simulation is then used to obtain the probability distribution of the time to payback.

The methodology was applied to a case dairy farm, based at Rukuhia in the Waikato, in order to illustrate the process. At current (1995/6) prices a $325,000 investment in irrigation at Rukuhia is estimated to take somewhere between three and ten years to repay its cost, with a 97% probability that payback will occur in the next four to seven seasons. Sensitivity analysis showed that, whilst interest rates, capital investment costs, and the manner in which the transition to an irrigated production system is achieved are important, the milksolids payout is the most significant factor in determining the likely time to payback.

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CHAPTER 1

INTRODUCTION

1.1 THE PROBLEM

Over recent years considerable interest has been expressed in the potential benefits of irrigation on dairy farms in New Zealand.

In autumn 1992 the Northland dairy company began fostering the local use of an irrigation system developed in Tasmania by Gerard Van Den Bosch. As reported by Bird (1993), more than 280 inquiries were received from farmers the following year, and this included expressions of interest from outside of the Northland region.

The potential benefits of investment by a dairy farmer in an irrigation system such as the Bosch Long Lateral System, in terms of the security of production over the summer months and the consequent reduction in stress on farmers, animals, and pasture, are obvious. The assessment of economic benefits, however, is not so straightforward. Obviously the more prone an area is to drought or dry summer conditions the more profitable investment in irrigation is likely to be.

A dairy farmer operating a non-irrigated system is subject to risk in that variations in summer pasture growth rates may have major implications on milksolids production and/or production costs, and hence the farm's gross margin. On the other hand, a dairy farmer with an irrigated system has "guaranteed" pasture growth and milksolids production for the season and in this context faces variation only in the costs of irrigating pasture in that season.

The relative profitability of investment in irrigation in a particular season therefore depends not only on economic factors, but also on the weather in that season. The more subject an area is to variable summer weather the more variable returns to irrigation will be.

Uncertainty about the future returns to irrigation, arising from variability in dryland pasture growth rates, is the main financial risk that farmers face when investment in irrigation is considered. Whether future returns to irrigation exceed the costs of the investment, and how long it will take to do so, depends on the climatic conditions that occur in future seasons and the relative profitability of milk production.

The problem farmers face is to quantify the economic benefits of investment in an irrigation system given a particular weather pattern, and hence returns to irrigation, during the summer months.

1.2 THE OBJECTIVES OF THE STUDY

The primary objective of this study is to develop a methodology which allows an evaluation of the economic benefits of investment in irrigation on a dairy farm by taking into account the risk associated with variation in climatic conditions during the summer.
To this end a systems approach is taken to obtain the probability distribution of the time to payback for investment in the irrigation system.

System components include:

- models of pasture growth that use meteorological data to predict pasture growth rates and irrigation requirements for different seasonal conditions

- a dairy farm model to estimate the gross margins associated with both an irrigated and a non-irrigated system for each set of pasture growth rates

- a simulation model which uses the above results to estimate the likely time period to payback the investment and the associated probabilities of occurrence for each of these scenarios.

The methodology is applied to a case study dairy farm, based at Rukuhia in the Waikato, in order to illustrate the process. The Waikato, while perhaps less subject to droughts than Northland, is an area that is also prone to extreme summer conditions (During et al. 1970). The dairy production system uses only grazed pasture and pasture conserved as silage. The assessment of the economic benefits of using purchased supplements as a regular management practice on non-irrigated pasture is seen as a separate issue. Similarly the evaluation of the potential benefits of the use of greenfeed crops or nitrogen fertiliser on either system is also considered beyond the scope of this study.

The probability distribution of the time to payback is initially derived under the assumption that prices remain constant at their current values. The relative profitability of investment in irrigation in a particular season, however, depends not only on the dryland pasture growth rates encountered, but also on the economic conditions that prevail in that season. Uncertainty as to the future values of the relevant costs and prices is a second source of risk when considering an investment in irrigation.

The second objective of the study is therefore to discover how variation in key economic variables might impact upon the probability distribution of the time to payback. The most relevant variables were considered to be the milksolids payout, the interest rate payable on rural loans, and the price of electricity. The effect of changes in these variables on the probability distribution of the time to payback for the case study farm are evaluated. The implications for differing capital costs for the investment in irrigation are also assessed.

Whilst the methodology is presented in the context of the case study farm, the framework developed in this study may be used to evaluate the economic benefits of investment in irrigation anywhere in New Zealand provided sufficient data exists.

This research is expected to be of benefit not only to dairy farmers in Northland and the Waikato, but also to have application to other dairying areas in New Zealand that are susceptible to dry summer conditions. These areas include parts of the Manawatu (Watters and Power 1994), Hawkes Bay (Watters 1995), and also the Wairarapa (Watters op cit.), where some traditional beef farmers are now considering the switch to dairying following the recent low beef prices (Journeaux 1996) and the relatively high returns currently available in the dairy industry.

CHAPTER 2

BACKGROUND

2.1 INTRODUCTION

This chapter provides background information on the irrigation system and outlines relevant research into irrigation of pasture in the Waikato.

The analysis is based on the Bosch Long Lateral Irrigation System around which current interest in the irrigation of dairy pastures is largely centred. Section 2.2 presents a brief description of this irrigation system based on information supplied by Bosch Irrigation (Bosch Irrigation Ltd. undated).

Limited irrigation research has been performed in Northland, and it is for this reason that the Rukuhia site was chosen for the case study. Irrigation trials on pasture in the Waikato first began over forty years ago and Section 2.3 describes some of the findings from this research. In particular, an eleven year trial at the Rukuhia Soil Research Station, the results of which provide the data for the pasture growth models developed in Chapter 4, is described in full.

2.2 THE BOSCH LONG LATERAL IRRIGATION SYSTEM

The Bosch Long Lateral Irrigation System in based on a series of sprinklers on a sled type stand which are attached to specially designed, lightweight, flexible, kink resistant polythene hoses. These hoses, or "laterals", are connected to permanent hydrants from a grid of underground mains and branch lines. The system makes use of water from dams or rivers, and is run each night to take advantage of the lower night rate electricity tariff and to minimise evaporation losses. Sprinklers are moved each day within a defined area of responsibility so that at the end of a six day cycle the entire area has been irrigated.

In comparison to other irrigation systems used on dairy farms, such as the handshift sprayline system or the travelling irrigator, both the labour requirement and running costs are lower, whilst capital costs are similar.
Another advantage claimed for the irrigation system is the more effective watering of pasture. This is achieved through the regular application of small amounts of water which ensures that soil moisture levels remain in the optimum range for pasture growth. Other irrigation systems tend to result in too much water being applied at once which not only increases the leaching of nutrients from the soil, but may also reduce pasture growth through lack of oxygen to the roots. Another possible problem with other irrigation systems is that plants are likely to have reached wilting point before the pasture is irrigated again and may also result in pasture growth being less than its potential. Bosch Irrigation recommend the installation of an evaporation pan

so that the farmer can monitor soil moisture levels and determine the water application rates required to maximise pasture growth.
Further details such as running costs, labour requirements, and the capital cost of installing this irrigation system are outlined in Chapters 5 and 6.

2.3 IRRIGATION RESEARCH IN THE WAIKATO

2.3.1 Irrigation and Pasture Growth

McAneney, Judd and Weeda (1982) report the findings of two separate irrigation trials. The first trial was conducted at the Rukuhia Soil Research Station between 1953 and 1964. Irrigated and non-irrigated pasture growth rates were measured on a perennial ryegrass/white clover pasture mix growing on Hamilton clay loam soil under rotational grazing by beef cattle.

Overhead sprinkler irrigation was used to return irrigated plots to field capacity whenever the estimated soil moisture deficit reached between 25 and 38 mm. The soil moisture loss was estimated as 90% of daily evaporation, as measured by the use of a sunken pan, less the daily rainfall. Pasture was irrigated between October and April in each season, however the above maximum allowable soil moisture deficit rule was not strictly adhered to at either end of this irrigation period, so that only small amounts and often no water was applied during the months of October and April.

Pasture production was measured using a pre-trimming frame technique (Weeda 1965) and herbage was cut when it reached cattle grazing height i.e. 15 to 20 cm, with a sickle-bar mower to a base height of 4 cm. The cutting interval varied from about three and a half weeks during the spring to around ten weeks in mid-winter. The botanical composition of the sward on the irrigated plots changed seasonally from typically around 70% to 80% ryegrass and 5% to 10% white clover in mid-winter, to 30% to 50% ryegrass and 30% to 50% white clover in mid-summer. Both irrigated and non-irrigated plots were given the same fertiliser treatment with 380 kilograms of superphosphate and 125 kilograms of potassium chloride being applied per hectare per year.

Responses to irrigation were measured in each season of the trial. The difference in dry matter yields between the irrigated and non-irrigated plots during the months of irrigation was substantial, with production on non-irrigated pasture being on average only 61% of that recorded on irrigated pastures.
The pasture growth rates and irrigation application levels recorded during this trial are used as input data for the estimation of the pasture production models in Chapter 4.

The second irrigation trial described by McAneney et al. (op cit.) was conducted between 1962 to 1967 on a Horotiu sandy loam soil at a site near the Hamilton airport some six kilometres south of the Rukuhia Soil Research Station. The conditions under which this experiment was conducted were similar to those of the first trial, however to combat grass grub, DDT was applied before the start of the trial and again in July 1966. In spite of this some insect damage was apparent on non-irrigated pastures in the early autumn of 1963.
Results in terms of pasture production were not dissimilar to those recorded in the first trial, with annual production on irrigated pasture averaging 17,890 kg DM/ha in the first trial and 17,800 kg DM/ha in the second. However in the second trial non-irrigated dry matter yields averaged 73% of the irrigated pasture production during the irrigation period. This higher value may be explained by the fact that the second site has a higher estimated available water capacity (Gradwell 1968). This tends to be confirmed by local experience which indicates that the pastures at the first

trial site are quicker to "brown-off" in the summer and take longer to recover from droughts than do pastures at the second site.

McAneney et al. (op cit.) used the results of the above trials to test the ability of a simple water balance-growth model to modify irrigated yields in order to predict dryland production. Their hypothesis was that the ratio of actual (dryland) to potential (irrigated) pasture dry matter yield is equal to the ratio of the actual to the maximum weather dependent evapotranspiration. They found that the regression equations for the two soil types were very similar and showed no significant departures from a one to one relationship consistent with the above hypothesis.

Baars and Coulter (1974) used the pasture yield data from the first Rukuhia trial to test a model which predicts monthly dryland pasture production from the number of "deficit days" in a given month. A "deficit day" occurs when the calculated available soil moisture plus daily rainfall is insufficient to meet that day's water need. They found that, in an average year with twenty-two deficit days, dryland pasture production is approximately 23% below that expected when soil moisture is not limited, and that winter and spring production is not influenced by soil moisture deficits that occur in the summer and autumn. They also found that the actual amount of water applied on average during the trial was about 1.9 times their calculated irrigation requirement and concluded that the trial results probably gave a more accurate indication of practical water needs.
The trial data was also used by Wright and Baars (1976) and Baars and Waller (1979) in studies which considered the effects of climate on pasture growth.

During et al. (1970) present a summary of the dryland pasture yields obtained in the first trial at Rukuhia which suggests that the four months -

January to April inclusive - are responsible for much of the large fluctuation in total annual pasture production that occurs in the Waikato. These months, and February in particular, are "high risk" relative to other months in terms of pasture production. The Waikato, however, is defined by During et al. (op cit.) as carrying only a medium risk of low production in summer when compared to some other areas of New Zealand.

The results of the research outlined above would therefore seem to indicate that irrigation has a major role to play in the Waikato, not only in terms of increased pasture growth, but, most particularly, in the reduction of the variation that occurs in dryland summer pasture production.

2.3.2 Dairy Cow Production on Irrigated Pasture

Bosch Irrigation state that increases in milksolids production on irrigated pasture are achieved not only through the extra dry matter produced but also from the improved quality of the feed (Bosch Irrigation Ltd. undated). According to Bosch, pasture quality values of over 12 MJ ME/kg DM have been consistently measured on irrigated pasture in Northland, and a value of 13 MJ ME/kg DM has been recently recorded (G. Van Den Bosch pers. comm.). These high pasture quality values are attributed to the greater persistence of clover in the sward and a leafier pasture occurring under irrigation than under dryland conditions.

Offering cows pasture of higher quality and consequently greater digestibility, should result in a higher per cow dry matter intake. Thus, individual cows grazed on irrigated pasture can achieve a greater metabolisable energy intake, and hence greater milksolids production, than cows grazed on non-irrigated pasture.

Between 1972/3 and 1974/5 an experiment, aimed at assessing the effects of irrigation on pasture and dairy cow production, was conducted at the Nutrition Centre of the Ruakura Animal Research Station in the Waikato. This experiment took the form of a series of farmlet-scale trials on pasture with a high soil fertility. Thirty-six sets of monozygous twins were divided into four herds, each of 18 cows, in such a way that there were six direct twin comparisons between any two herds. Two of the herds were grazed on non-irrigated farmlets at stocking rates of 4.1 and 4.9 cows per hectare, and the other two on irrigated pasture at stocking rates of 4.9 and 5.6 cows per hectare. In addition, a fifth farmlet was stocked at the rate of 5.6 cows per hectare on irrigated pasture with unrelated cows. These cows (merit cattle) were selected on the basis of high actual or potential milk yields. This was to provide a measure of the milk producing capacities of high yielding pastures when constraints on plant and animal performance were minimised.

On irrigated pasture the timing and extent of water applications were determined from the measured field capacity and from soil moisture changes associated with evaporation and/or rainfall. In general, sufficient water was applied to compensate for deficits of 20mm in early summer and of 12mm in mid-summer.

Preliminary findings after the first season of the trial were reported by Hutton (1974). Of particular interest is the comparison between the genetically comparable results for the non-irrigated and the irrigated farmlets with the identical stocking rate of 4.9 cows/ha. In this case 20% more pasture was produced on the irrigated farmlet which resulted in a 17% increase in milkfat production both per cow and per hectare when compared with the non-irrigated control. Increasing the stocking rate on irrigated pasture by a further 0.7 cows/ha reduced grass growth appreciably and resulted in a relatively small increase milkfat production per hectare, with the per cow milkfat production falling, when compared to the lower stocked irrigated farmlet. This effect was also observed on non-irrigated farmlets when the milkfat yields at a stocking rate of 4.9 cows/ha were compared to those at a stocking rate of 4.1 cows/ha. The merit cows when compared with twin cows at the same stocking rate on irrigated pasture produced approximately 12% more milkfat.

Changes in feed quality were measured by *in vitro* digestion of harvested samples of pasture herbage. Results indicated that over the summer-autumn period the apparent digestibility of feed was appreciably higher under irrigation, with the greatest difference being 75% versus 66% digestibility. Between farmlet differences in the average intake of digestible nutrients by cows were closely related to differences in their output of milkfat.

In a later paper Hutton (1978) presented results for the full three seasons of the trial. Summer droughts occurred in the Waikato in two of these three seasons. Dry conditions were experienced between December and March in both the 1972/3 and 1973/4 seasons, with the 1973/4 drought being the most severe. Between October and March the increased pasture growth due to irrigation was measured at 13%, 21%, and 11% in the successive seasons. The additional feed produced by irrigation at a stocking rate of 4.9 cows/ha in the two drought seasons raised cow intakes in the summer-autumn period by 20% and 46%, when compared to the similarly stocked non-irrigated farmlet, and by 6% and 10% in comparison with the lower stocked unit. Pasture quality, although similar during the July to December period at about 73% digestibility, was noticeably higher on irrigated pasture during the summer and autumn. The digestibility of pasture dry matter between January and June was around 67% on the non-irrigated farmlets in each season, while under irrigation pasture digestibility was 71% in the two drought years and 68% in the 1974/5 season. Thus, the cows on irrigated pasture ate more pasture of a higher quality than those on either of the non-irrigated farmlets.

At a stocking rate of 4.9 cows/ha the extra digestible nutrients produced by irrigation resulted in 47%, 81%, and 20% additional milkfat production between January and May in the 1972/3, 1973/4, and 1974/5 seasons. Annual milkfat production increased by 17%, 28%, and 13%, respectively. When compared to the non-irrigated farmlet with the lower stocking rate of 4.1 cows/ha, the milkfat produced per cow between January and May on the irrigated pasture was greater by 24%, 44%, and 4% in successive seasons, and by 10%, 7%, and 1% in terms of annual production. No results were presented for either of the irrigated farmlets with the higher stocking rate of 5.6 cows/ha. It is clear, however, that in each of the three seasons the total milkfat production per cow on irrigated pasture at a stocking rate of 4.9 cows/ha exceeded production on both the non-irrigated farmlets. In comparison to the non-irrigated farmlet with a stocking rate of 4.1 cows/ha, irrigation increased total milkfat production by 168, 128, and 107 kilograms per hectare.

Hutton (op cit.) concluded that similarities were evident in seasonal milkfat productions, mean liveweights, and condition scores, at the beginning and end of each season between irrigated and non-irrigated farmlets. Furthermore, the quantities of supplementary feed both conserved and fed were also similar, being on average 1.5 tonnes of high moisture silage or 14.5 bales of hay per cow. No replacement stock were carried and dry cows were wintered on their respective treatment farmlets. Although no mention of calving dates is made, it is assumed that these were also similar across the farmlets. Thus it seems that all farmlets in this trial were subject to similar management conditions. This, together with the use of genetically comparable stock, allowed measurement of the increase in milkfat production resulting from the utilisation of the extra digestible nutrients produced by irrigation, *ceteris paribus*.

This research indicates that increases in total milksolids production per hectare can be achieved on irrigated pasture in the Waikato. The increased production comes about through higher individual cow production levels, as well as through an increase in stocking rate made possible by irrigation.

2.2.3 Management of Dairy Farms Under Irrigation

As pointed out in Section 2.2.2 the Ruakura experiment appears to have been conducted using similar management strategies on the irrigated and non-irrigated treatment farmlets. It is possible, however, that changes in management may result in further increases in milkfat production and/or savings in the costs of production. Hutton (1978) made the point that irrigation is potentially most profitable on well managed properties where there is a high percentage utilisation of feed grown. A high utilisation of feed requires that the maximum amount of pasture should be eaten *in situ*. Brown (1975) in his discussion of the management of irrigated farms under high stocking rates stated that this is best achieved when stock policies generate a feed demand pattern that matches the irrigation modified pasture production curve. He went on to state that optimal management requires the use of feed budgets and that the degree of success achieved will depend on the individual farmer's ability to match feed demand with supply.

Bosch Irrigation suggest that optimal management of irrigated dairy farms involves calving later in the season i.e. the beginning of September, than is usual in the Waikato (Bosch Irrigation Ltd. undated). This policy has the twin objectives of, first, eliminating the feed deficit that tends to occur in early lactation before pasture growth rates accelerate in the spring, and, second, in maximising the *in situ* utilisation of spring and summer pasture. Surplus pasture is conserved as silage for feeding out in the winter months, rather than in early lactation and/or in the summer-autumn period, as is generally the case on non-irrigated farms. This strategy allows more cows to be wintered and hence enables the stocking rate to be increased.

Whilst no data for the Waikato was readily available, the above recommendation appears to provide a better match between the supply and demand of pasture under irrigation than does the current management practice on non-irrigated dairy farms. The issue of the optimal management of fully irrigated dairy farms is investigated and discussed in Chapter 5.

It should be noted that the pasture growth trials described in Section 2.3.1 were conducted under rotational grazing by beef cattle and that the rotation lengths were relatively long and the grazing pressure lenient i.e. to a height of 3 to 4 inches, compared to those applied on dairy farms. Weeda (1965) reported results from a separate trial, conducted at the second site between 1955 and 1960, which aimed to determine the effects of the frequency and severity of grazing by cattle on the yield of irrigated pasture. He found that grazing at 10 to 11 day intervals reduced dry matter yields markedly when compared to grazing at 21 day intervals, and that if severe grazing i.e. to a height of 1 to 2 inches, was carried out for an extended period then not only was the yield reduced but the botanical composition of the pasture was also adversely affected. The proportion of ryegrass was reduced and the percentage of white clover increased. Weeda noted that Freer (1960), working with dairy cows on irrigated pasture in Australia, also found that under a high stocking rate, which was considered to be similar to the frequent severe grazing treatment of the trial, the percentage of white clover increased, while a low stocking rate to some extent favoured the growth of ryegrass. Whether or not an increase in the proportion of white clover in the sward should be considered an adverse effect is perhaps a moot point, given the likely resultant increase in pasture quality as discussed in Section 2.3.2. The reductions in yield of dry matter on irrigated pasture that may result from short rotation lengths and/or severe grazing pressure are however of concern. These points need to be kept in mind when formulating a grazing management policy on irrigated pasture.

2.3.4 The Economic Returns from Irrigation

Hutton (1978) included cash surpluses for both the non-irrigated farmlet with a stocking rate of 4.1 cows/ha and for the irrigated farmlet stocked at 4.9 cows/ha described in Section 2.3.2. The cost and price data used in calculating the cash surplus in each season was derived from the N.Z. Dairy Board Cost of Production Survey for factory supply farms in South Auckland for that season.

The differences in the cash surplus between the irrigated and the non-irrigated farmlets in successive seasons were \$147, \$107, and \$52 per hectare. These corresponded to increases in milkfat production of 168, 128, and 107 kilograms of milkfat per hectare respectively. The cash surpluses for irrigated pasture did not include the costs of irrigation. These costs need to be deducted from the above figures to obtain the actual return to irrigation in each season. The above figures do however represent the levels beyond which investment in irrigation would have been unprofitable in each season.
As can be seen, considerable between season variation existed in the additional cash surplus generated by irrigation. Some of this variation can be explained by differing summer pasture growth rates as evidenced by the variation in the extra milkfat production due to irrigation. Clearly, however, seasonal changes in both milkfat prices and in the costs of production also contribute to the between season differences in returns from irrigation.

The above results, although based on costs and prices associated with dairy production in South Auckland, give an indication of the risk, in terms of economic returns, associated with investment in irrigation in the Waikato. The outcomes of only three seasons, two of which were among the worst droughts experienced in the Waikato, however, can hardly be expected to be representative of the set of possible outcomes.

By using historic data to estimate the return to irrigation for a large number of different seasons, this study attempts to derive a distribution of returns to irrigation that is representative of the true population of climatic conditions. This allows the risks associated with investment in irrigation to be quantified so that the profitability of such an investment can be more accurately assessed.

The only comparable research conducted in New Zealand, aimed at evaluating the financial benefits of irrigation, is that reported by the NZAEI (1985). In this study a series of simulation models were used to obtain the internal rates of return, over a twenty-five year period, associated with various investment options in irrigation of sheep farms on hill and high country. The research focused on the Hakatarmea Valley, situated on the east coast of the lower South Island. The basic objective of the study was "to develop a simulation model to enable a physical and economic evaluation of alternative farm scale irrigation systems in the hill and high country environment". Conclusions from the study state that while the simulation model did not fully satisfy the objective, due to various shortcomings in model structure and individual components, the progress made was encouraging. The study resulted in the development of a basic framework that accommodated the essential temporal and spatial features of hill country systems, which, with further work, could be used to develop improved predictions of the consequences of development options in the hill country environment.

It is expected that the methodology developed in this thesis will provide a similar basic framework for the economic evaluation of investment in irrigation in dairy systems.

CHAPTER 3

THE METHODOLOGY

3.1 INTRODUCTION

The time to payback is defined as the number of years taken for an investment in irrigation to generate sufficient returns to cover its capital cost and all subsequent interest payments. Clearly the time taken to payback will depend on the actual time pattern of the returns to irrigation obtained in the seasons following the installation of the irrigation system. As the future is unknown, the actual time to payback cannot be determined with certainty. Historical data, together with modelling techniques, can, however, be used to estimate the probabilities of occurrence associated with different payback periods i.e. the probability distribution of the time to payback.

The return to irrigation i.e. the extra profit gained from irrigation compared to a non-irrigated scenario, primarily depends on the pasture growth rates that occur during the months of irrigation. These pasture growth rates in turn depend on the climatic conditions encountered in a particular season. Thus, in order to obtain the probability distribution of the time to payback, it is necessary to first obtain the probability distribution of the returns to irrigation, which is ultimately determined by seasonal weather patterns.

The derivation of the probability distribution of the time to payback is therefore primarily based on recorded meteorological data. When a sufficiently large sample is available, these data are assumed to be representative of the weather patterns likely to occur in the future. In combination with various models, these data can be used to obtain expected pasture growth rates and hence the expected return to irrigation, as well as the probability of occurrence, for the different weather patterns.

As indicated above, considerable use needs to be made of models to estimate the probability distribution of the time to payback for investment in irrigation. In Section 3.2 the role of modelling in farm management is discussed. Section 3.3 provides an outline of the methodology and describes how the various models used in the analysis are linked. Finally, in Section 3.4, the linear programming (LP) model of a dairy production system, used to obtain gross margins upon which the economic returns to irrigation are estimated, is described.

3.2 THE USE OF MODELS IN FARM MANAGEMENT

Spedding (1979) defined a model as a "representation of the real thing, simplified for some purpose". The use of models throughout the history of farm management is well documented (Currie 1955; Jensen 1977; Nix 1979). From the budgeting techniques first developed in the 1920's and still widely used today, through the proliferation of mathematical programming models of the 1960's and early 1970's, to the more recent emphasis on simulation (Dent and Anderson 1971) and the development of decision support models (McCall et al. 1991) and expert systems (Jones 1989), modelling has become an important tool in farm management research and extension (McCall and Sheath 1993; McCall and Tither 1993; Bywater and Cacho 1994; McCall et al. 1994; Parker et al. 1994).

The value of modelling is most apparent in situations where real life experimentation is impossible, costly - in terms of time and/or money, disruptive, or destructive (Wright 1971). For instance, to obtain real life values of the economic returns to irrigation for the case study farm, would require the use of 200 hectares of land over a trial period of 37 years. In addition, the costs of installing an irrigation system on 100 hectares of this land and the considerable amount of monitoring necessary, need to be taken into account. Finally, not only are the results of the experiment not available for a long period of time, but they are also site specific. In contrast, the use of modelling techniques allows an almost instantaneous analysis, and the methodology developed in this thesis may be applied to any dairying area in New Zealand, or even in other parts of the world, as long as the requisite data is available or can be modelled.

The major disadvantage of models is of course the many assumptions required in the simplification of the real life system. For instance, the analysis in this thesis whilst considering the consequences of variations in rainfall during the summer months, is generally based on average or expected values of a number of variables. In real life these values will obviously vary due to other factors that have not been taken into consideration.

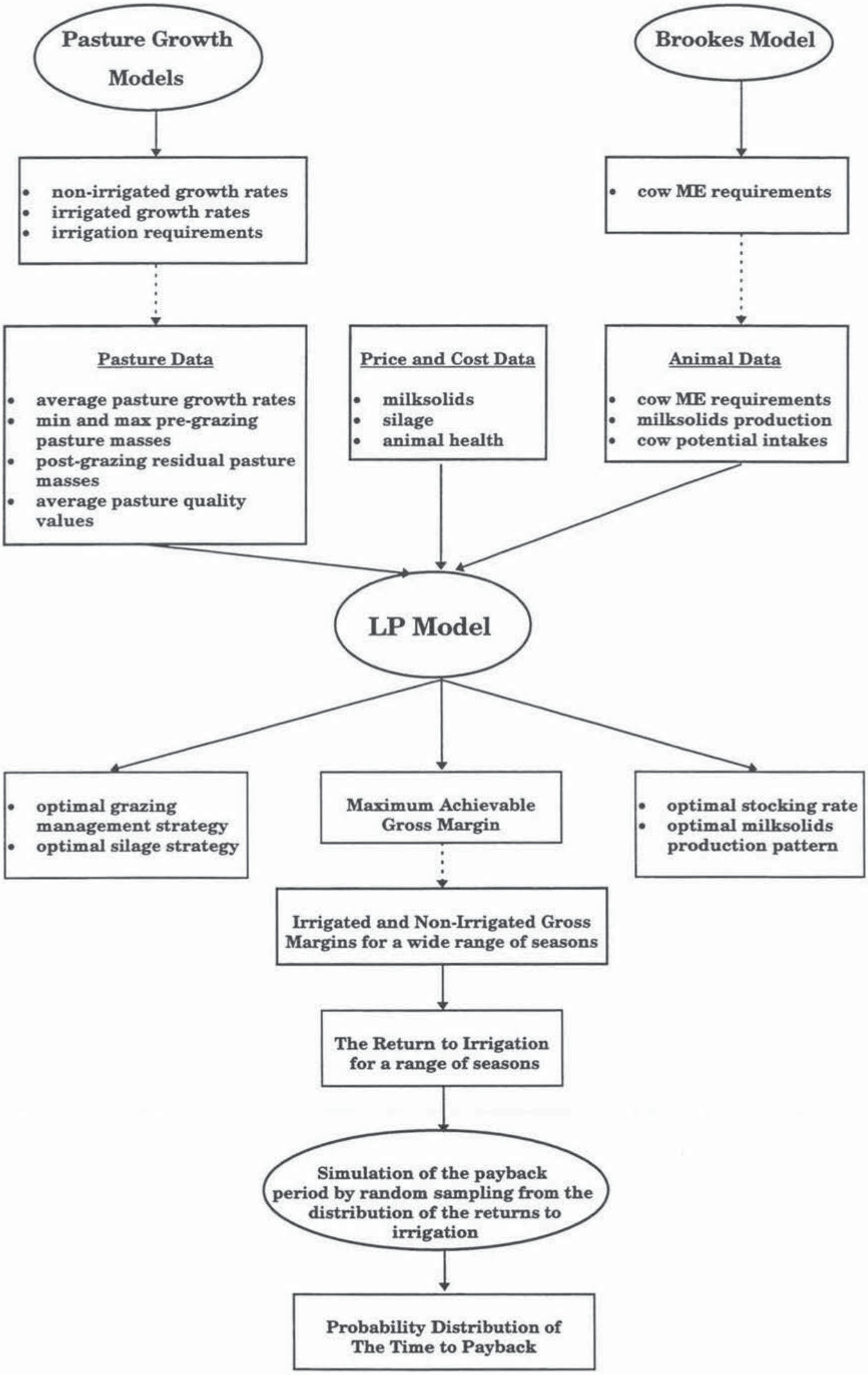
3.3 OVERVIEW OF THE METHODOLOGY

The process of decision making under risk in farm management was first addressed by Schultz (1939) nearly sixty years ago. The objective of this study is to quantify the risks associated with an investment decision in irrigation in the Waikato and to present the results in a format that is readily comprehensible by the decision makers, in this case dairy farmers.

This is to be achieved by using historic rainfall data in conjunction with modelling techniques to estimate the economic returns to irrigation at constant costs and milksolids prices in each season over a 38 year period. This time period encompasses the full range of seasonal variation in terms of summer pasture growth. These results will then be used to obtain the probability distribution of the time to payback for investment in irrigation, the chosen method of summarising the riskiness of investment in irrigation in terms of its economic return. The impacts of changes in costs and returns associated with dairy production under irrigation on the probability distribution of the time to payback are also explored.

Figure 3.1 (see over) presents a summary of the method and shows the linkages between the various models developed and/or used in the derivation of the probability distribution of the time to payback.
Initially models of pasture growth are developed to provide estimates of expected pasture growth rates for seasons that vary in terms of rainfall during the months of irrigation. In each season expected pasture growth rates are obtained for both irrigated and non-irrigated pastures, as well as an estimate of the amount of irrigation required to achieve these growth rates. Estimated values are obtained for the 37 seasons between 1946 and 1984. These models are based on the results of the first Rukuhia irrigation trial outlined in the previous chapter, and are fully described in Chapter 4.

Figure 3.1 Schematic Presentation of the Methodology used to Analyse Investment Decisions for Irrigation on Dairy Farms.



Expected pasture growth rates for a given season are then used as input data for a LP model of a dairy production system. The LP model is used to estimate gross margins for both an irrigated and a non-irrigated dairy system in that particular season. The variable costs of irrigation are based on the estimated irrigation requirement for that season. The exercise is repeated for each season so that irrigated and non-irrigated gross margins are obtained for each of the 37 seasons.

The LP model itself is described in Section 3.4 and the manner in which it is used to generate gross margins is discussed in Chapter 5. Other input data required by the LP model is also outlined in Section 3.4, as is the role of the "Brookes model" (Brookes et al. 1993) in determining cow energy intake requirements. The actual input data values used, and their derivation, are described in Chapter 5.

The difference between the estimated gross margins of the irrigated and the non-irrigated system in a particular season gives an estimate of the return to irrigation for that season. The distribution of the returns to irrigation over the entire 37 seasons thus derived forms the basis for the simulation of the probability distribution of the payback period. By randomly generating possible sequences of seasons the probability distribution of the time to payback is obtained. The actual estimation procedure is described in full in Chapter 6.

3.4 THE DAIRY LP MODEL

The dairy LP model is a version of the linear programming model of a dairy production system described by McCall et al. (1996). The objective of the LP model is to determine the pasture management strategy, stocking rate, and pattern of average cow production levels that maximise the gross margin of a seasonal dairy farm over a single year production cycle, given the resources available to the farmer in the short term. This model may however be used to find optimal strategies relating to other objectives such as the maximisation of milksolids production, or the least cost way to achieve a target level of milksolids production. In the model the gross margin of the farm is defined as the return from milksolids less the variable costs of production. Relevant costs are considered to be the costs of making and feeding silage, and an annual cost per cow to cover animal health and replacement costs.

Essentially the model can be divided into two components: the pasture production model, and animal production model, with the two being linked by feeding activities.

3.4.1 Pasture Production

The season is divided into 26 fortnightly periods, beginning on the first of July, thus allowing management decisions to be made every two weeks. For each period the following data is required: the average pasture growth rate and the average metabolisable energy (ME) content of pasture, or pasture quality, applicable in that period; and the maximum and the minimum permissible pre-grazing pasture masses as well as the post-grazing residual pasture mass required for pasture grazed in that period.

The farm is envisioned as one large paddock whereby the areas grazed and spelled in each period are separated by movable electric fences. All pasture grazed in a given period is assumed to be grazed to the same specified residual pasture mass. Grazed pasture is then spelled for as many periods as it takes for the minimum pre-grazing cover to be reached. All or part of the land may then be grazed or spelled for a further period until the maximum pre-grazing mass is reached, at which point all remaining pasture must be grazed. Thus the minimum and maximum number of periods pasture may be spelled for, following grazing in a given period, as well as the corresponding

pasture cover, can be calculated. In this way the entire set of feasible pasture transfer activities is generated through the use of a matrix generator.
Silage may also be conserved in a similar manner. The following data is required: the minimum and maximum pasture masses between which silage may be cut, the residual pasture mass after cutting, the cost per hectare of making silage, respiration and other field losses (%), the metabolisable energy content of silage, the cost per kilogram of feeding silage, and the periods in which silage may be harvested. Instead of being spelled, pasture is "shut up" for silage and harvested at pasture covers between the specified minimum and maximum pasture masses. It is assumed that silage is cut to the specified residual pasture mass at the beginning of the harvesting period, and that pasture regrows at 60% of the normal rate for the remainder of the period before being returned to the grazing system. The entire set of feasible silage conservation activities that correspond to the specified harvesting periods is also produced by the matrix generator.

In the context of the LP model the pasture transfer and silage conservation activities are all variables representing an area of land measured in hectares. Clearly in each period the sum of all variables using land in that period must be equal to the effective area of the farm, and similarly the sum of all "new" activities in each period must equal the total area of land grazed in the previous period. For each pasture transfer variable the quantity of pasture dry matter available in the grazing period is given by the post-grazing residual of the period in which the pasture was last grazed plus the sum of the pasture growth rates over the periods in which pasture is spelled, including the grazing period, less the post-grazing residual in the grazing period.

Equation 3.1 shows how the total amount of pasture dry matter available for grazing in a given period is converted into a pasture feeding activity.

Equation 3.1 Grazed Pasture Dry Matter Constraint for Period t.

$$\mathbf{PASTFED}_t - \sum_{n=0}^{\max n} (\mathbf{k}_{t-n,t})\,\mathbf{PASTXFER}_{t-n,t} \leq 0$$

where:

i. **PASTXFER**$_{t-n,t}$ is the area of pasture spelled from period **t-n** to be grazed in period **t** i.e. last grazed in period **t-(n+1)** and next grazed in period **t**;

ii. $\mathbf{k}_{t-n,t}$ is the quantity of dry matter available for grazing (kgDM/ha) on pasture that has been spelled for **n** periods; and

iii. **PASTFED**$_t$ is the total amount of dry matter fed to cows in period **t**.

Should a slack variable be associated with the above constraint in an optimal solution, then this is conceptualised as the amount of pasture that needs to be removed by topping after grazing in that period to ensure that maximum pasture covers are not exceeded and pasture quality maintained.

All pasture dry matter conserved as silage, less any field and respiration losses, is placed in a "stack" and may be fed to cows in any period. In a sense silage may be fed before being harvested. This is conceptualised as the feeding of silage cut in the previous season, with a corresponding amount of silage being carried forward from the current year to the next season.
Equation 3.2 illustrates how pasture dry matter conserved as silage is converted into silage feeding activities.

Equation 3.2 Silage Feeding Constraint.

$$\sum_{t=1}^{26} \mathbf{SILFED}_t - \sum_{s} \sum_{n=\min n}^{\max n} (\mathbf{k}_{s-n,s})\,\mathbf{SILCONSV}_{s-n,s} \leq 0$$

where:

i. **s** is a silage harvesting period;

ii. $\mathbf{SILCONSV}_{s-n,s}$ is the area of pasture shut up for silage in period **s-n** i.e. last grazed in period **s-(n+1)**, and cut for silage in period;

iii. $\mathbf{k}_{s-n,s}$ is the quantity of dry matter, less losses, that is conserved as silage (kgDM/ha) in period **s** from pasture that has been shut up for **n-1** periods; and

iv. $\mathbf{SILFED}_t$ is the total amount of dry matter fed to cows in period **t**.

When the LP model is optimised the set of basic pasture transfer and silage conservation activities represents an optimal grazing management strategy, which satisfies management requirements in terms of pre-grazing and post-grazing pasture masses; and the set of basic pasture and silage feeding activities in each period represents an optimal allocation of the feed available throughout the season. Average pasture covers over the season, calculated at the end of each fortnightly period, are also provided in the LP model output.

3.4.2 Animal Production

In order that the LP model can determine the optimum allocation of feed a number of "notional cows" are defined. These notional cows may vary in terms of their calving date, lactation length, milksolids production pattern, and/or liveweight changes throughout the season. Each notional cow corresponds to a given feeding regimen and resultant level of milksolids production.

Inputs required by the LP model for each notional cow are the metabolisable energy requirement in each two week period and the total milksolids production that results from this pattern of requirements over the season.

Maximum voluntary dry matter intakes for lactating cows in each period are also required.

Notional cows are developed in the following manner:

First, the calving date, the level of milk production in each two week period, and animal liveweights and condition scores at calving, and at the end of lactation, are specified for an individual cow. The Brookes (1993) model is then used to determine fortnightly ME requirements for this cow. The energy requirements in each period are based on published relationships (Agricultural Research Council, 1980), and are calculated as the sum of the requirements for maintenance, pregnancy, lactation, and liveweight gain. Dry cow requirements for liveweight gain are such as to ensure that any condition lost during lactation is regained prior to calving in the subsequent season. Finally, ME requirements in each two week period that correspond to an average per cow requirement for a herd with a specified calving pattern are calculated. Requirements in each period for the individual cow are weighted in accordance with the calving pattern. For example, if calving is spread over eight weeks with 20%, 40%, 30%, and 10% of the herd calving in each subsequent two week period, then the average requirement for the herd in the first period of calving is calculated as follows:

  0.2 x individual cow requirement in calving period (t)
+ 0.4 x individual cow requirement in the period (t-1) prior to calving
+ 0.3 x individual cow requirement two periods (t-2) prior to calving
+ 0.1 x individual cow requirement three periods (t-3) prior to calving

Calculated in this way the requirements of the notional cow are deemed to be representative of the average metabolisable energy requirements in each two week period, of a herd with an average milksolids production level corresponding to the individual cow's production level, and calving in the specified pattern.

As many notional cows as required may be developed in this manner and the associated ME requirements and total milksolids production for the season used as input for the LP model.

The LP model then determines how many, if any, cows should be run in each of the herds, as represented by the corresponding notional cow, so that the total metabolisable energy requirements in each period, or demand for feed, are both feasible, in terms of the available supply of feed, and optimal in that the gross margin of the farm is maximised.

In each period the total ME requirement of all cows on the farm must be met from the pasture and silage dry matter made available by the pasture production system. This is achieved by converting the pasture and silage feeding activities to their ME equivalents, and, after adjustment for utilisation losses, ensuring that the resultant supply of ME matches the demand in each period. This process is summarised in Equations 3.3 to 3.7. First, as lactating cows are subject to a maximum voluntary dry matter intake constraint in each period, it is necessary, when the notional cows vary in lactation length, to separate the pasture and silage feeding activities in each period into two components i.e.

Equation 3.3 Constraint to Divide Pasture Fed between Dry and Lactating Cows.

$$\mathbf{PASTFEDDRY_t + PASTFEDLACT_t - PASTFED_t = 0}$$

Equation 3.4 Constraint to Divide Silage Fed between Dry and Lactating Cows.

$$\mathbf{SILFEDDRY_t + SILFEDLACT_t - SILFED_t = 0}$$

where:

i. **$PASTFEDDRY_t$** and **$SILFEDDRY_t$** are the total amounts of pasture and silage dry matter respectively, fed to cows the are dry in period **t**; and
ii. **$PASTFEDLACT_t$** and **$SILFEDLACT_t$** are the total amounts of pasture and silage dry matter respectively, fed to lactating cows in period **t**.

Equation 3.5 shows how the total metabolisable energy requirements of lactating cows in a given period are met through the feeding of pasture and silage dry matter.

Equation 3.5 Match of ME Demand and Supply for Lactating Cows in Period t.

$$\mathbf{(MEp_t)(Up_t)\ PASTFEDLACT_t + (MEs)(Us_t)\ SILFEDLACT_t - \sum_{i}^{\text{no. of herds lactating in t}} (MEreq_{i,t})\ COWS_i = 0}$$

where:

i. **MEp_t** is pasture quality (MJME/kg DM) in period **t** and **MEs** is the metabolisable energy content of silage;
ii. **Up_t** and **Us_t** are the respective utilisation rates (%) for pasture (**p**) and silage (**s**) fed in period **t**;
iii. **$MEreq_{i,t}$** is the metabolisable energy requirement in period **t** of the **i^{th}** notional cow lactating in period **t**; and

iv. $\mathbf{COWS_i}$ is the number of cows in the herd described by the $\mathbf{i}^{th}$ notional cow.

Similarly, Equation 3.6 shows how the total metabolisable energy requirements of dry cows in a given period are met through the feeding of pasture and silage dry matter.

Equation 3.6 Match of ME Demand and Supply for Dry Cows in Period t.

$$(\mathrm{MEp}_t)(\mathrm{Up}_t)\ \mathrm{PASTFEDDRY}_t + (\mathrm{MEs})(\mathrm{Us}_t)\ \mathrm{SILFEDDRY}_t - \sum_{j}^{\text{no. of dry herds in t}} (\mathrm{MEreq}_{j,t})\ \mathrm{COWS}_j = 0$$

where, in this case, $\mathbf{MEreq_{j,t}}$ is the metabolisable energy requirement in period **t** of the $\mathbf{j}^{th}$ notional cow dry in period **t** and $\mathbf{COWS_j}$ is the number of cows in the herd described by the $\mathbf{j}^{th}$ notional cow.

Equation 3.7 limits the dry matter intake of lactating cows in a given period to a specified maximum level for that period.

Equation 3.7 Potential Intake Constraint for Cows Lactating in Period t.

$$\mathrm{PASTFEDLACT}_t + \mathrm{SILFEDLACT}_t - (\mathrm{MaxDM}_t) \sum_{i}^{\text{no. of herds lactating in t}} \mathrm{COWS}_i \leq 0$$

where $\mathbf{MaxDM_t}$ is the maximum voluntary dry matter intake per lactating cow in period t.

This constraint is primarily designed to ensure that Equation 3.5 does not result in an unrealistic amount of relatively low quality silage being fed to lactating cows. A one to one substitution rate between pasture and silage dry matter in each period is assumed in these constraints. In a similar manner, constraints for limiting the amount of silage fed per head in any period may be defined.

Finally, Equation 3.8 shows how the total amount of milksolids produced on the farm during the season is obtained.

Equation 3.8 Total Milksolids Production.

$$\mathbf{TOTALMS} - \sum_{m}^{\text{no. of herds}} (\mathbf{MS}_m)\,\mathbf{COWS}_m = 0$$

where:

i. $\mathbf{COWS}_m$ is the number of cows in the herd described by the $\mathbf{m}^{th}$ notional cow;

ii. $\mathbf{MS}_m$ is the total milksolids produced during the season by the $\mathbf{m}^{th}$ notional cow; and

iii. **TOTALMS** is the total amount of milksolids produced during the season on the farm.

Equations 3.5 to 3.8 essentially summarise the animal production model. In the context of the LP model the number of cows in each herd i.e. $\mathbf{COWS}_m$ (m=1 to the number of notional cows), and the total milksolids production are variables. When the LP model is optimised the optimal number of cows in each herd determines the stocking rate, calving date(s), lactation length(s), total milksolids production, and the pattern of milksolids production that maximise the gross margin of the farm.

3.4.3 Notes on the LP Model Input Data

i. Variations between periods in the post-grazing residuals reflect annual fluctuations in pasture height/mass relationships and the pasture accessibility requirements of cows in relation to stage of lactation. These together with the associated minimum pre-graze pasture covers need to be specified so as to ensure that the maximum voluntary pasture intake per cow in the model are achievable. In each period the maximum pre-graze mass reflects the pasture mass above which net pasture accumulation per day is no longer linear because of the negative impacts of senescence and decay. Maximum pre-grazing pasture masses also represent the bounds beyond which pasture digestibility declines due to the effects of increased leaf age and dead content of the pasture.

ii. As only one set of maximum intakes for lactating cows is specified, care needs to be taken when notional cows are defined that vary significantly in metabolisable energy requirements and/or potential intakes. If the ME requirements of one or more notional cows can be met with a dry matter intake which is less that the maximum intake in a given period, then Equation 3.7 may allow other notional cows dry matter intakes that are above the maximum for that period. As a first step, the ME requirements for each notional cow should be converted to pasture dry matter equivalents and checked for feasibility against the specified maximum intakes before being used as input.

3.4.4 Evaluation of the LP Model

McCall et al. (1996) reported the results of an evaluation of a more comprehensive version of the LP model, which included purchased supplements in the form of concentrated feed (grain) and silage, against data from nine grazing farmlet treatments in New Zealand and two in Pennsylvania. They found that this model could be used with confidence to develop optimal grazing systems both in the Northeast US and in New Zealand. The New Zealand data was based on the recorded performances of herds on two grazing system trials conducted at Ruakura. These trials were chosen because of the detailed input-output data available to describe the system. The first trial is described by Ahlborn and Bryant (1992) and the second by Penno et al. (1994 & 1996), although in both cases unpublished data was used for the model evaluation.

The first part of the evaluation procedure was to assess how well the feed supply and feed requirements of the model equated for the data sets. The major unknown from the farmlet trials was the pasture utilisation rate. On site pasture intakes were measured using pre- and post-grazing pasture disappearance techniques, however this ignores the loss of pasture due to trampling of dry matter as animals graze. The model was used to calculate the likely levels of utilisation on each farmlet based on matching feed requirements with feed supply. Feed supply data was directly available and the Brookes (1993) model was used to calculate the apparent average metabolisable energy demands from the recorded animal data. The model was constrained to the actual stocking rate, levels of supplementary feeding, and amount of silage harvested for each farmlet, and set up to minimise the total amount of pasture that was surplus to requirements. This resulted in estimated annual rates of pasture utilisation which ranged from 79% to 99% on the farmlets, with an average value of just over 86%. These results were consistent with an expected value in the order of 90% based on Sheath and Boom (unpublished), but were relatively high when compared to the range of "optimum" i.e. the best possible use of feed grown that can be achieved without compromising long term pasture production, pasture utilisation rates suggested by Smetham (1973), of 70% to 85%, for dairy cows.

The final stage of the evaluation was to use to model to obtain optimal, in terms of maximum milksolids production, solutions for each of the farmlets with pasture utilisation set at 90%. In this case the model was allowed to choose from a number of notional cows that varied in milksolids production patterns and lactation lengths, although the stocking rate was constrained to the recorded rate on each farmlet. The total amount of supplements fed was also constrained to the recorded levels however the model could choose when and how much to feed at any one time, as well as the time(s) and amount of silage conservation.

It was expected that the maximum achievable milksolids production predicted by the model would exceed the production levels actually recorded on the farmlets. The model, with perfect knowledge of pasture growth rates, is able to determine an optimal management strategy, whereas in reality, due to uncertainty about the future, sub-optimal decisions may have been made. On all but one farmlet the model predicted that either a similar or slightly higher milksolids production could have been achieved. The exception occurred on the farmlet that had an estimated pasture utilisation rate of 99%, and the discrepancy obviously resulted from the decision to use a utilisation rate of 90% in the model. In general the lactation lengths, average rotation lengths, and the amounts of silage conserved in the model solutions were similar to those recorded on the farmlets.

3.4.5 The LP Model and the Real System

In real life a farmer has a lot more flexibility with management decisions than is allowed in the LP model. For example, grazing decisions may be made daily rather than at two weekly intervals, and management requirements in terms of pre-grazing and post-grazing pasture masses need not be rigidly adhered to as is the case with the model. Thus the pasture transfer activities in the model represent only a small range of the options available to the farmer. Similarly, the set of notional cows, no matter how large, can only represent a subset of the different feeding regimes and milksolids production levels that could be achieved in practice. Optimal LP model output also generally assumes that all feed, less utilisation losses, that is offered to cows in a two week period is in fact eaten. In reality there may be any number of reasons why the prescribed intakes may not be achieved. For instance cows tend to spend less time grazing in wet weather. Finally, the LP model can only be used to provide optimal scenarios for the given input data. As future pasture growth rates are unknown, the ability of the model to accurately forecast the optimal management strategy for a forthcoming season is limited because there is a high probability that the derived values will differ to some extent from the actual values.

For this reason the model clearly cannot be used to provide an exact blueprint for the optimal management of a dairy farm. The results of Section 3.4.4 however indicate that the model can be used to predict production levels and management targets with an acceptable level of accuracy and which should more or less be achievable in practice for any particular distribution of pasture growth rates that may occur. Thus it is expected that the LP model will provide reasonable, though perhaps slightly optimistic, estimates of the gross margins that are achievable for given pasture growth rate data.

CHAPTER 4

THE PASTURE MODELS

4.1 INTRODUCTION

The objective of this chapter is to derive the pasture growth rates that can be expected to occur on both irrigated and non-irrigated pasture, and also the amount of irrigation required, in each of a wide range of seasons, in terms of weather patterns, on the Rukuhia case study farm.

The major conclusions from the Rukuhia irrigation trial (Section 2.3.1) were that irrigation resulted in increased pasture production and also significantly reduced the variation that occurs in pasture growth rates. The problem is to determine the optimal amount of irrigation to apply in a particular season, and also to determine the effects on dryland pasture production when soil moisture levels fall below the optimum range for growth.

Pasture growth rate and irrigation data from the first Rukuhia irrigation trial (W. Weeda pers. comm.) are presented and evaluated. These data are then used to develop models that predict irrigation requirements and dryland pasture growth rates from seasonal rainfall data during the months of irrigation. The aim is to obtain reasonable estimates of the growth rates and irrigation requirements that can be expected to occur in a particular season, rather than to develop a detailed model of the pasture growth and soil moisture relationship.

Monthly rainfall data measured at the Rukuhia Meteorological Station immediately adjacent to the irrigation trial site were available from 1946 to 1984 (NIWA unpublished data). It was felt that these 38 seasons should constitute a large enough sample to be representative of the weather patterns likely to occur in this region. Thus the results obtained in this chapter should provide a reasonable basis for the estimation of the distribution of the returns to irrigation for the case study farm.

4.2 IRRIGATED PASTURE

The method of irrigation employed during the Rukuhia trial, which involved using overhead sprinkler irrigation to return irrigated pasture to field capacity before the soil moisture deficit became critical, is similar to that advocated by Bosch Irrigation. It is expected therefore that similar pasture growth rates could be achieved by the use of the Bosch Long Lateral Irrigation System in the recommended manner.

4.2.1 Pasture Growth Rates

McAneney et al. (1982) assert that pasture growth is maximised and achieves its full potential under the irrigation regime described in Section

2.3.1. This seems a reasonable assumption as the irrigation regime is designed to ensure that soil moisture levels remain in the optimum range for growth during the months of irrigation i.e. October to April inclusive.

It is expected that, while some seasonal variation may occur due to changes in other climatic conditions, the maximum pasture growth rate achievable in any given month during the irrigation period is likely to be relatively constant, although the potential for growth will vary between months.

Table 4.1 shows the mean monthly growth rates and the corresponding coefficients of variation for irrigated pasture obtained over the eleven years of the Rukuhia trial.

Table 4.1 Average Pasture Growth Rates for Irrigated Pasture.

Month	Average Pasture Growth Rate (kgDM/ha/day)	Coefficient of Variation (%)
Jun	15.6	25.5
Jul	15.6	27.7
Aug	25.2	23.5
Sep	57.5	21.9
Oct	80.4	16.3
Nov	72.8	12.2
Dec	78.2	13.4
Jan	73.7	8.1
Feb	62.0	9.0
Mar	49.6	14.9
Apr	37.0	16.6
May	21.3	22.9

Source: W. C. Weeda (pers. comm.).

As can be seen from Table 4.1, some between-season variation occurs in irrigated pasture growth rates. The magnitudes of the coefficients of variation, however, indicate that these deviations are relatively small, particularly in the months of irrigation. Thus our expectation that the maximum pasture growth rate achievable in any given month of the irrigation period is practically invariant between seasons seems to be confirmed.

The pasture growth rates of Table 4.1 are therefore accepted as being reasonable estimates of the pasture growth rates that can be achieved in any season at Rukuhia under an optimal irrigation regime, such as that provided by the Bosch long lateral system.

4.2.2 Optimal Water Requirements

Given that the maximum pasture growth rate achievable in any given month of the irrigation period is more or less constant between seasons, it seems possible that the amount of water required by pasture in a particular month to achieve this growth rate may also be relatively constant between seasons. Table 4.2 (see over) shows the total amount of water i.e. rainfall plus irrigation, applied on average in each month of irrigation during the last ten years of the Rukuhia irrigation trial (irrigation data was not available for the first season of the trial), and also the associated coefficients of variation.

The general trend was for the average monthly water application to increase with day-length to a maximum in December and then decrease through to March. The coefficients of variation, however, are generally higher than was the case for pasture growth rates (Table 4.1). There are two likely explanations for this. First, seasonal variation in other climatic factors, particularly temperature and wind run, can be expected to have a more significant effect on the amount of water required to maximise pasture growth than on the actual potential for growth from optimally watered pasture. Second, differences between seasons in the timing and magnitude of individual periods of rainfall in a given month may also result in variations in the amount of irrigation required even though the total monthly rainfall may be the same between years.

Table 4.2 Average Water Applications on Irrigated Pasture.

Month	Average Water Application (mm/ha/month)	Coefficient of Variation (%)
Oct	91.6	15.7
Nov	107.3	32.2
Dec	172.2	28.2
Jan	154.0	18.9
Feb	134.6	29.1
Mar	127.3	30.0
Apr	141.4	45.6

Sources: W. C. Weeda (pers. comm.) & NIWA (unpublished data).

Notes to Table 4.2:

i. as pointed out in Section 2.3.1 pasture was not always optimally irrigated in October and April therefore the above values are based only on the years where pasture was irrigated in those months; and
ii. the 1958 February value was omitted due to an extremely high recorded total rainfall of 317.8 mm.

Notwithstanding the above comments, the coefficients of variation for October to March are still acceptably low enough to conclude that the average water applications in Table 4.2 provide reasonable estimates of the optimal water requirement i.e. the amount of water required in each month to achieve the pasture growth rates of Table 4.1, in each of these months.

Unfortunately, the relatively high coefficient of variation, together with the against the trend increase in the average amount of water applied, means that a similar conclusion cannot be drawn for April.

It is probable that the values shown in Table 4.2 are over-predictions of the optimal water requirements. Infrequent periods of heavy rain may have led to a high total monthly rainfall, yet resulted in dry spells and hence in irrigation water being applied. This was clearly the case in February 1958 where approximately 56 mm of irrigation was applied despite total rainfall for the month being over twice the average amount of water applied in February during the other seasons of the Rukuhia trial. On the other hand, it is possible that a heavy "drenching" at the end of a month may have resulted in a water application value for the next month which was less than that which would normally be required.

4.2.3 Irrigation Requirements

The amount of irrigation required in a given month between October and March is estimated as the shortfall between the total monthly rainfall and the optimal water requirement for that month (Table 4.2). Using this method monthly irrigation requirements were estimated for each of the seasons of the Rukuhia irrigation trial and summed to predict the total amount of irrigation required between October and March in each season. Table 4.3 (see over) shows the actual amount of irrigation applied between October and March and the predicted irrigation requirement in each of the seasons of the Rukuhia trial. With the notable exception of the 1958/9 season, it can be seen from Table 4.3 that the predicted irrigation totals either overestimate or are close to the actual amounts of irrigation applied. As far as the 1958/9 season is concerned, the rainfall totals from November through to January were relatively high when compared to other seasons of the Rukuhia trial, yet significant amounts of irrigation were applied in each of these months. A possible explanation is that longish dry spells, punctuated by isolated periods of heavy rain, may have occurred in these months.

Table 4.3 Actual and Predicted Irrigation Applications (mm/ha).

Season	Actual Irrigation Applied*	Predicted Irrigation Requirement	Difference
1954/5	436.9	418.4	18.5
1955/6	304.8	399.0	-94.2
1956/7	284.5	275.5	9.0
1957/8	304.8	319.8	-15.0
1958/9	271.8	168.9	102.9
1959/60	190.5	272.8	-82.3
1960/1	309.9	408.0	-98.1
1961/2	287.0	293.0	-6.0
1962/3	292.1	296.3	-4.2
1963/4	307.3	309.4	-2.1

**Source: W. C. Weeda (pers. comm.).*

The objective in obtaining irrigation requirements is to be able to predict the variable cost of irrigating pasture in a particular season. As it seems preferable to generally overestimate rather than underestimate the costs of irrigation, the method of estimating the total amount of irrigation required over the season, outlined earlier in this section, is considered acceptable for our purposes.

Estimates of the monthly irrigation requirements between October and March, and also the total irrigation requirement for each of the seasons between 1946/7 and 1983/4 are presented in Table AI.1 in Appendix I. An extra 30 mm of irrigation is included in the total irrigation requirement for the season, this being approximately the amount applied during those seasons of the Rukuhia trial when pasture was irrigated in April.

4.3 NON-IRRIGATED PASTURE

Table 4.4 shows the mean monthly growth rates and the corresponding coefficients of variation for non-irrigated pasture obtained over the eleven years of the Rukuhia trial.

Table 4.4 Average Pasture Growth Rates for Non-Irrigated Pasture.

Month	Average Pasture Growth Rate (kgDM/ha/day)	Coefficient of Variation (%)
Jun	18.3	12.9
Jul	16.5	23.6
Aug	24.8	24.2
Sep	55.5	22.2
Oct	73.2	22.6
Nov	63.7	27.5
Dec	55.0	29.7
Jan	28.7	49.4
Feb	16.3	98.6
Mar	31.8	65.6
Apr	31.5	44.4
May	25.0	24.2

Source: W. C. Weeda (pers. comm.).

For the months outside the irrigation period i.e. May to September, it can be seen that the average daily growth rates and the associated coefficients of variation are similar to those for irrigated pasture (Table 4.1). Pasture growth rates between October and April, however, are all lower than those for irrigated pasture, with the greatest differences occurring in January and February. On the other hand, the coefficients of variation in these months are all significantly higher than those for irrigated pasture, with major variations in pasture growth rates occurring in the months January to April, and most particularly in February.

In order to explain the variations in pasture growth between October and April on non-irrigated pasture, in terms of rainfall and the optimal water requirements derived in the previous section, the following model is proposed:

Equation 4.1 The Non-Irrigated Pasture Growth Model.

$$\mathbf{Gr_t/Gr_t^* = k_0 + k_1(R_{t-1} - W_{t-1})/W_{t-1} + k_2(R_t - W_t)/W_t}$$

where:

$\mathbf{t}$ is a month in the irrigation period;

$\mathbf{Gr_t}$ is the non-irrigated growth rate in month $\mathbf{t}$ (kgDM/ha/month);

$\mathbf{Gr_t^*}$ is the potential or irrigated growth rate in month $\mathbf{t}$;

$\mathbf{R_t}$ is total rainfall in month $\mathbf{t}$ (mm);

$\mathbf{W_t}$ is the optimal water requirement in month $\mathbf{t}$ (mm); and

$\mathbf{k_0}$, $\mathbf{k_1}$, $\mathbf{k_2}$ are constants.

That is, the ratio of actual growth to potential growth depends on the water deficit, expressed as a percentage, in both the previous and the current month. We would expect k_0 to be equal to one i.e. actual growth to equal potential growth in the absence any moisture stress. We would also anticipate that k_1+k_2 would be greater than or equal to one i.e. negative or zero growth rates may occur in prolonged dry periods.

The data from the Rukuhia irrigation trial were used to estimate the above model for each month individually using OLS regression. The regression statistics indicated a lack of fit in the months of October, November, December, and April. Accordingly, the model was rejected for these months and the average monthly pasture growth rates of Table 4.4 were taken to be the best estimates of expected pasture growth rates between April and December on non-irrigated pasture.

Table 4.4 indicates that pasture growth rates between October and December exhibit significantly less variation than occurs later in the irrigation period. The lack of fit in April is not surprising given the results of Section 4.2.2, however the relatively high coefficient of variation is of concern.

Good fits were found in February and March, and a moderate fit in January. Data for these three months was pooled and the model estimated after omitting three "outliers": two values where reasonably high rainfall in the month had resulted in low pasture growth - perhaps the bulk of the rain occurred toward the end of the month and rainfall in the previous month toward the beginning, so that a long dry period occurred - and the previously mentioned 1958 February value. This generated the results presented in Table 4.5.

Table 4.5 The Regression Statistics - Fit of the Rukuhia Dryland Pasture Growth Data (January to March) to Equation 4.1.

Coefficient	Value	Standard Error	t-statistic
k_0	0.9891	0.0553	17.8874
k_1	0.5021	0.0609	8.2405
k_2	0.6423	0.0799	8.0436

with $\mathbf{R^2}$ **= 0.83** and **Adjusted** $\mathbf{R^2}$ **= 0.82.**

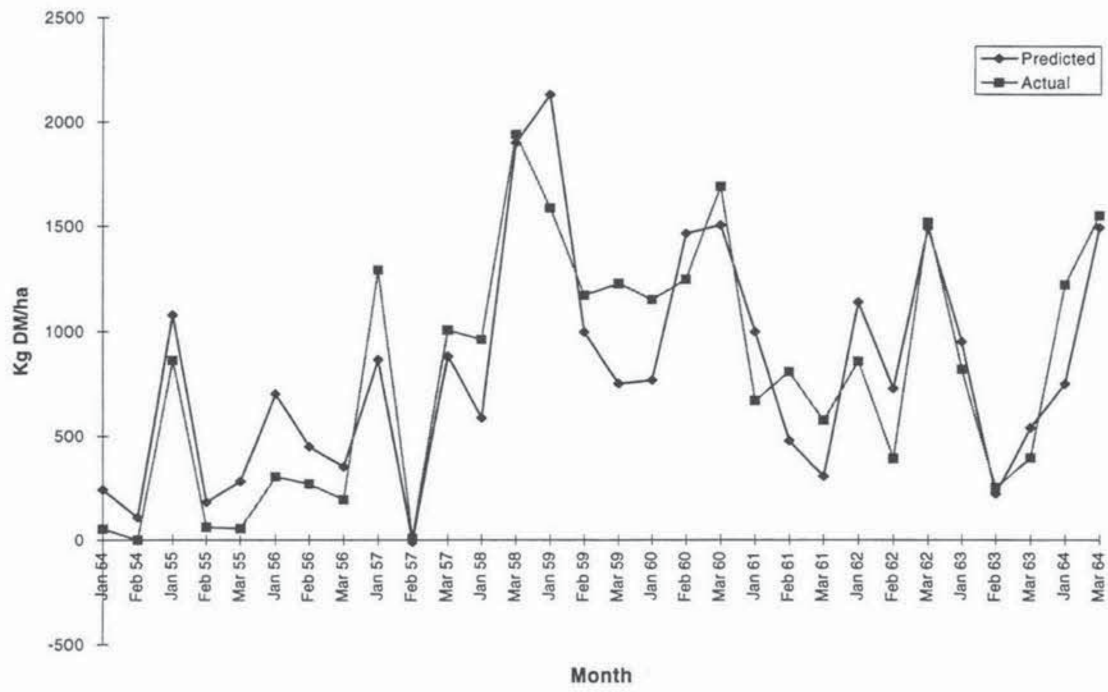
The postulated model explains 82% of the variation in pasture growth rates on non-irrigated pasture between January and March. All coefficients are significant at the one percent level (27 degrees of freedom) and the hypothesis that $k_0 = 1$, with a t-statistic of 0.1979, cannot be rejected. Whilst a test statistic was not derived, k_1+k_2 is greater than one as expected.

The pasture growth rates predicted by the model were regressed on the actual growth rates for each month individually. The t-statistics obtained indicated the hypothesis of a one to one relationship could not be rejected in any of the months. R^2 values were as follows: Jan-0.44, Feb-0.82, and Mar-0.90. The relative lack of fit in January may perhaps be explained by the fact that rainfall in December exhibits less variation than occurs in the later summer months, and that, during the years of the trial, January rainfall did not vary between extremes to the extent that it did in February and March. Also, as discussed by Baars and Waller (1979), variations in soil temperature have a significant effect on pasture production during January and February. This effect is independent but secondary to that of soil moisture.

Figure 4.1 (see over) shows the actual and predicted monthly growth rates for each year of the trial ("outliers" are omitted).

A general trend to either consistently overestimate or underestimate pasture growth in a given season is shown in Figure 4.1. This may in part be due to the lagged nature of the model but may also be explained by seasonal variation in other climatic factors that affect the rate of pasture growth, for instance above average or below average temperatures.

Figure 4.1 Actual and Predicted Pasture Growth Rates at Rukuhia for the Summer Months Between 1954 and 1964.



This model is used to estimate expected growth rates on non-irrigated pasture during January to March for each of the seasons between 1953/4 to 1963/4, with the exception of the 1957/8 season which is omitted here and from all future analysis due to its extreme February rainfall value. The predicted values of the pasture growth rates between January and March in these seasons are presented in Table AI.2 in Appendix I. The total amount of pasture dry matter grown during this period is also shown in Table AI.2. The effects of the summer droughts mentioned by Hutton (1978) which occurred in the Waikato during the 1972/3 (least severe), 1973/4 (most severe), and the 1977/8 seasons can clearly be seen.

Table 4.6 shows the actual mean monthly growth rates and associated coefficients of variation over the eleven years of the Rukuhia irrigation trial and the values obtained by using the model predictions over the 37 seasons.

Table 4.6 Actual and Predicted Average Pasture Growth Rates (kgDM/ha/day).

	Average Growth Rate		Coefficient of Variation(%)	
Month	Actual	Predicted	Actual	Predicted
Jan	28.7	33.5	49.4	48.5
Feb	16.3	26.8	98.6	70.6
Mar	31.8	26.4	65.6	68.1

As can be seen the coefficients of variation associated with the actual and predicted mean monthly growth rates are very similar for January and March. The actual and predicted mean growth rates in these two months are not dissimilar with the predicted value being slightly higher than the measured value in January and the reverse situation occurring in March. In February however the predicted mean monthly growth rate is significantly greater than that actually recorded in the Rukuhia trial and the coefficient of variation significantly lower. This would tend to imply that during the 11 years of the Rukuhia trial pasture growth rates in February were generally lower, and displayed more variation relative to the mean, than those that could be expected to occur on average. It is more probable, however, that, by failing to take into account the previously discussed negative impact that the high soil temperatures likely to occur during February will have on pasture production (Baars and Waller 1979), the model predictions in this month overestimate the true values. The results predicted by the model must clearly be interpreted with caution.

4.4 CONCLUSIONS

In this chapter the procedure by which estimates of the pasture growth rates on both non-irrigated pasture and on optimally irrigated pasture were obtained has been described. The irrigation requirements that might be expected to apply at Rukuhia in each of the 37 seasons under consideration were also derived.

To summarise:

- monthly pasture growth rates on optimally irrigated pasture are assumed not to vary between seasons and are predicted by the mean monthly growth rates recorded on irrigated pasture at the Rukuhia irrigation trial (Table 4.1)

- the optimal amount of irrigation required in each month is the amount by which total rainfall during the month falls short of the estimated optimal water requirement for that month (Table 4.2). Predicted irrigation requirements for each of the 37 seasons are presented in Table AI.1 in Appendix I

- monthly pasture growth rates on non-irrigated pasture between April and December are assumed not to vary between seasons and are predicted by the mean monthly growth rates recorded during the Rukuhia irrigation trial (Table 4.4)

- dryland pasture production between January and March is assumed to vary as a direct result of variation in the amount and distribution of rainfall during these months. The model described in Section 4.3 is used to estimate pasture growth rates that could be expected to occur during these months in each season based on the rainfall patterns that actually occurred. Predicted monthly pasture growth rates on non-irrigated pasture during this period are presented for each of the 37 seasons in Table AI.2 in Appendix I.

Obviously the actual outcome in a particular season will vary depending on climatic conditions, other than the pattern of rainfall during the irrigation period, actually encountered in that season. The predicted values described above should however provide a reasonable indication of the likely outcome in each of the 37 seasons, which are assumed to be representative of the long-term range of weather patterns likely to be encountered in the Rukuhia region. The objective of predicting long-term pasture production under both irrigation and dryland conditions has therefore been achieved. These results are used in the next chapter to obtain the gross margins likely to be associated with both an irrigated and a non-irrigated dairy production system in each of these37 seasons.

CHAPTER 5

THE DAIRY FARM MODELS

5.1 INTRODUCTION

The aim of this chapter is to obtain annual estimates of the gross margins achievable on both a dryland and a fully irrigated dairy production system at Rukuhia over 37 years using the pasture growth data described in the previous chapter. Gross margins are estimated at current i.e. 1995/6 prices, and are to be obtained for a case study dairy farm of 100 hectares, although the results may also all be interpreted on a per hectare basis. A two stage process is used to obtain the gross margins for the case study farm.

In the first stage the dairy LP model, described in Section 3.3, is used to obtain the optimal "base strategy" for both types of production system. The base strategy relates to the farmer's annual planning horizon and determines the stocking rate, target production levels, and the management plan for the coming season. It is assumed that the base strategy is implemented at the start of each season and proceeds according to plan through the winter and spring.

For an optimally irrigated system it is assumed that there is no variation in the final outcome i.e. pasture production is "constant" between seasons and hence the management plan and the milksolids production target are always realised. The only variable factor is the amount of irrigation required in each season. In this case the second stage merely involves adjusting the gross margin associated with the base strategy in each of the 37 seasons to reflect the annual cost of irrigating pasture in that season.

On dryland pasture, however, deviations in pasture growth rates from anticipated levels between January and March will have a major impact on the production levels that can be achieved, and the management plan for the rest of the season will also need revision. In this case the LP model is used to obtain the optimal outcome in each of the 37 seasons based on the predicted monthly growth rates listed in Table AI.2.

The difference between the dryland and the irrigated gross margin in a particular season measures the return to irrigation in that season. The gross margins obtained in this chapter are used to estimate the return to irrigation in each of the 37 seasons and hence to obtain the distribution of returns to irrigation that are likely to be achieved in the Waikato.

5.2 LP MODEL INPUT DATA

5.2.1 Returns and Costs

The gross margin is defined as the return from milksolids less the variable costs of production in a given season. The New Zealand Dairy Board initially forecast a final payout of between \$3.40 and \$3.50 per kilogram of milksolids for the 1995/6 season. This was later revised upwards to a payout of \$3.55 to \$3.60, thus a milksolids price of \$3.55 per kilogram was chosen for the model runs. A final payout of \$4.00 per kilogram has subsequently been announced, but this does not materially affect the outcome, except that the gross margins obviously increase.

Production costs for the Waikato are based on the values used by McCall et al. (1996). The cost of harvesting silage was set at \$240 per hectare, the cost of feeding out silage at 2c per kilogram, and animal health and replacement costs at \$180 per cow (D. McCall pers. comm.).

5.2.2 Pasture Data

Fortnightly pasture growth rates are calculated from the monthly estimates derived in the previous chapter. Pasture quality values for dryland pasture are based on the data of Moller et al. (1996) and are presented in Table AII.1 in Appendix II. These values represent the average quality of pre-grazing pasture on New Zealand dairy farms measured over a three year survey. It is assumed that on irrigated pasture the ME content of pasture does not deteriorate during the irrigation period, and that pasture quality remains constant at 11.3 MJME/kg DM from October to May. This assumption is perhaps conservative given the Northland results reported by Bosch Irrigation (Section 2.3.2).

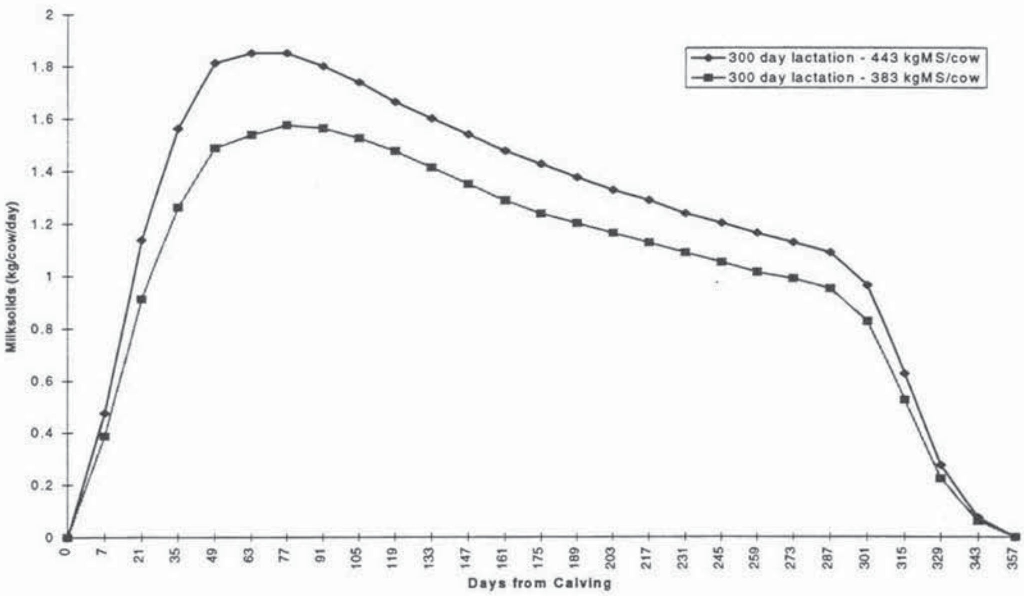
Maximum and minimum pre-grazing pasture mass values and post-grazing residuals are based on those used by McCall et al. (op cit.) and were derived from decision rules developed to guide grazing systems at Ruakura. These values are also presented in Table AII.1.

Silage is cut to a residual of 2000 kg DM/ha from a pre-cutting pasture mass of between 3500 and 5000 kg DM/ha. Field and stack losses are set at 20% of the total dry matter harvested - a rate of loss that should be achievable if sufficient attention is paid to detail in the field and at the stack (Holmes et al. 1994). Silage may be harvested between September and December on non-irrigated pasture, and as late mid-February on irrigated pasture. Irrigation is expected to result in a leafier pasture with less stem, and consequently a higher ME content, relative to dryland pasture (Section 2.3.2). Thus there seems to be no reason why good quality silage may not be made from irrigated pasture during January and February. All silage is assumed to have a ME content of 9.0 MJ/kg DM. This value is perhaps conservative when compared to an estimated range of 9.3 to 9.6 MJ/kg DM for pasture silage made in New Zealand during the 1994/95 season (Howse et al. 1996).

5.2.3 Cow Data

The notional cows used in the LP model runs are based on those described by McCall et al. (op cit.). Two herds of Friesian cows which correspond to average cow production levels of 382 and 443 kg milksolids respectively, over an individual 300 day lactation length, are considered. The same calving pattern is assumed for both herds. This is based on Ruakura data, with 29%, 38%, 22%, and 11% of the herd calving in successive two week periods from the start of calving. Figure 5.1 (see over) shows the average amount of milksolids produced per cow in each two week interval from the start of calving for each herd based on this calving spread.

Figure 5.1 Simulated Herd Average Milksolids Production Pattern for Two Levels of per cow Production.



Average herd requirements for each fortnightly period were derived using the individual cow requirement data produced by the Brookes (1993) model as described in Section 3.4.2. Calving begins on the 15^{th} of July and cow liveweights at a post-calving condition score of 5 were assumed to be 450 kg and 500 kg for the low and high production herds respectively. The average daily ME requirement in each two week period for each herd is shown in Figure 5.2 (see over). In a similar manner, ME requirements for notional cows corresponding to reductions in lactation length to 180, 210, 240, and 270 days for both herd types were derived, with cows being dried off in accordance with the calving pattern. These herds have the same average energy requirements as the parent herd up to the start of drying off at which point the dry cows are fed to maintenance levels. Milksolids production is adjusted to correspond to the relevant lactation length and production level for each herd. Figure 5.3 illustrates a comparison between the average milksolids production pattern for the lower producing herd for individual cow lactation lengths of 300 and 270 days.

Figure 5.2 Herd Average Metabolisable Energy Requirements for Two Levels of per cow Milksolids Production.

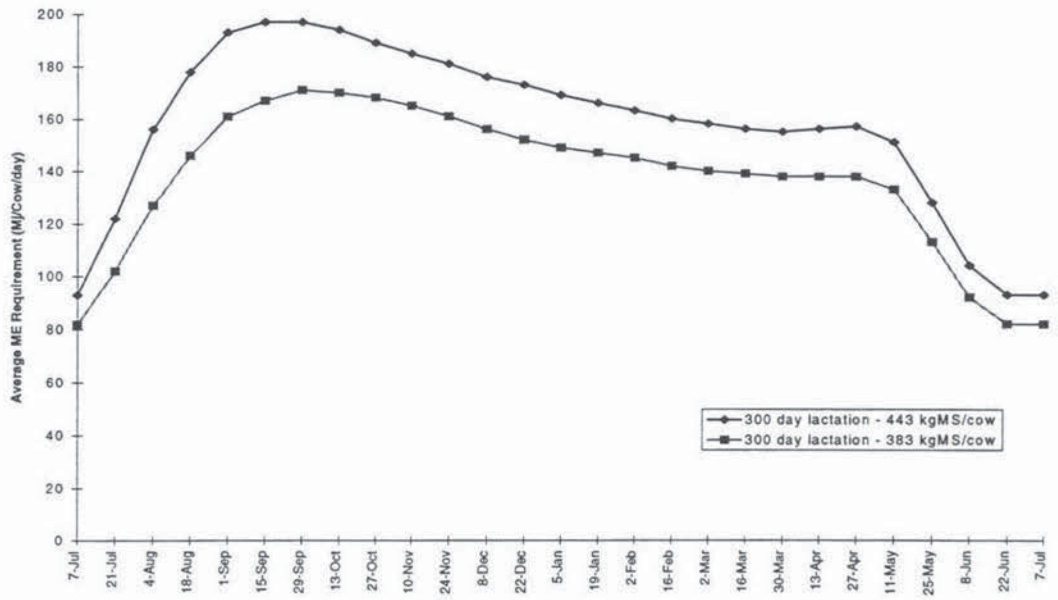


Figure 5.3 Milksolids Production for 270 & 300 Day Lactations for the Lower Producing Herd.

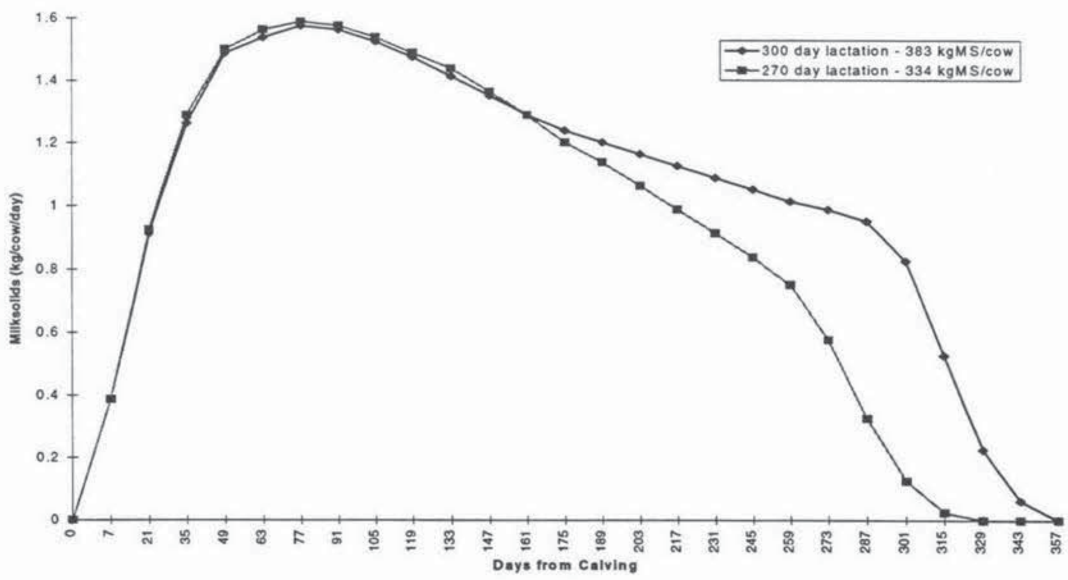


Table 5.1 (see over) presents a summary of the annual milksolids production and ME requirements for the ten notional cows defined in this way.

Table 5.1 Herd Production Data and Energy Requirements for High and Low Milksolids Production per cow and Different Lactation Lengths.

Cows	High Production Herd		Low Production Herd	
Lactation Length (days)	Milksolids (kg/cow/year)	ME Requirement (MJ/cow/year)	Milksolids (kg/cow/year)	ME Requirement (MJ/cow/year)
300	443	58100	382	50736
270	385	53606	334	47166
240	364	51800	315	45304
210	336	50176	292	43918
180	300	47488	261	41510

Up to 20% of the total number of cows on the farm may be culled in each season. Thus herds corresponding to cows culled before the next season are also defined for each herd type and lactation length. Individual cows are culled at the end of their lactation and in accordance with the calving distribution. As cows are culled their energy requirements are set to zero until replacement stock arrive. Replacement heifers are assumed to be raised off the farm and are returned, and included in the cull herd requirements, four weeks prior to calving. Table 5.2 summarises the ten cull herds.

Table 5.2 Cull Herd Data for Alternative per cow Production and Lactation Length Scenarios.

Culls	High Production Herd		Low Production Herd	
Lactation Length (days)	Milksolids (kg/cow/year)	ME Requirement (MJ/cow/year)	Milksolids (kg/cow/year)	ME Requirement (MJ/cow/year)
300	443	55286	382	48244
270	385	50064	334	44002
240	364	46158	315	40446
210	336	42168	292	37016
180	300	37422	261	32858

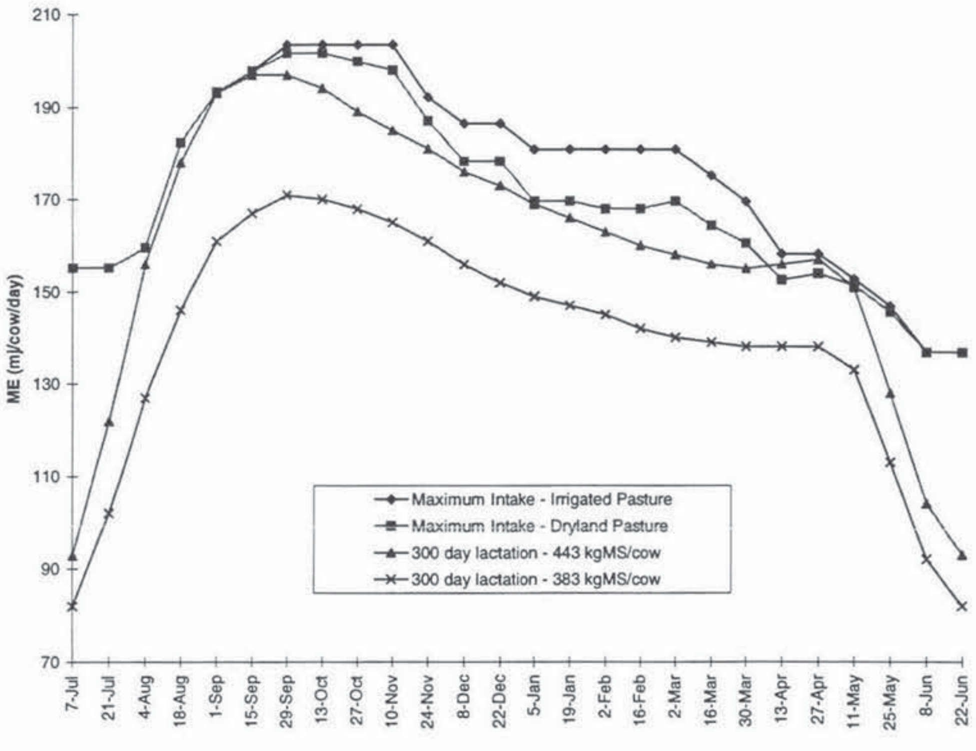
In this way a total of 20 herds are defined for a calving start date of the 15th of July. In addition, another 20 herds corresponding to a later start to calving, the 29th of July, were defined. The calving pattern and milksolids production patterns are as previously described, however calving, drying off, and culling all occur two weeks later in the season. These herds have the same lactation lengths, annual milksolids productions, and annual ME requirements as the herds described in Tables 5.1 and 5.2. The patterns of average herd ME requirements are the same, however the timing of the demands is different i.e. two weeks later in the season.

Thus a total of 40 herds, comprising two production levels by two calving dates by five lactation lengths with cows to be retained or culled, were available for the dairy LP model runs.

Maximum per cow daily pasture dry matter intakes in each period were based on the levels used by McCall et al. (op cit.), which in turn were based on Larcombe (1989) and the model of McCall et al. (1986). Maximum dry matter intakes (kg DM/cow/day) are presented in Table AII.1 of Appendix II. Figure 5.4 (see over) shows the maximum intakes in terms of the ME available on both irrigated and dryland pasture. The ME requirements for both the high and low producing herds calving at the earlier date of July 15th and on a 300 day lactation are also shown.

Note that the energy requirements of the higher producing herd on a 300 day lactation cannot be met by dryland pasture during April. There is also a very limited capacity to substitute silage, which has a lower ME content, for pasture during the summer months - a time when silage is most likely to be fed on a dryland system. For these reasons only the lower producing herd is considered for the non-irrigated dairy production system.

Figure 5.4 Maximum Intakes and Metabolisable Energy Requirements per cow for High and Low Level Producing Herds Grazed on Irrigated and Non-Irrigated Pasture.



Finally, silage feeding was limited to no more than 6 kilograms of dry matter per cow per day, and utilisation rates were set at 90% for pasture (Section 3.4.4) and 95% for silage (Holmes et al. op cit.).

5.3 THE BASE STRATEGIES

The base strategy is the farmer's plan for the coming season and is based on the pasture growth rates that are expected to occur during the season.

The base strategy sets the stocking rate and pasture cover at the start of the season, defines the production targets for the season, and provides a management plan to achieve these targets. This management plan determines the grazing management strategy, the amount and timing of silage harvesting, and when silage is to be fed during the season.

The dairy LP model is used to determine the optimal base strategies for both a dryland and a fully irrigated dairy production system. A one year cycle is assumed so that initial and final pasture covers are constrained to be the same. These strategies are optimal in that the expected gross margin for the coming season is maximised. It is possible that, given the farmer does not know with certainty the costs and returns that will apply in the coming season, the maximisation of milksolids production may be a more likely objective for a farmer operating a low input dairy production system such as the one under consideration. The implications of this motivation will be investigated.

5.3.1 Irrigated Pasture

The pasture growth rates that can be expected to occur on optimally irrigated pasture were derived in the previous chapter (Table 4.1). The dairy LP model was used to obtain the strategy that maximises the gross margin for a fully irrigated system based on these growth rates and the data described in Section 5.2. In this case all forty herds of notional cows were included. The optimal solution is summarised in Table 5.3 (see over).

A single herd which begins calving at the later date of the 29th of July is chosen. The herd is comprised of 308 of the higher producing cows, with 80% of these cows averaging 443 kilograms of milksolids per cow over a 300 day lactation, and the remaining 20% being culled after a 240 day lactation to produce an average of 364 kilograms of milksolids per cow.

Table 5.3 The Base Strategy for Irrigated Pasture (100 hectares).

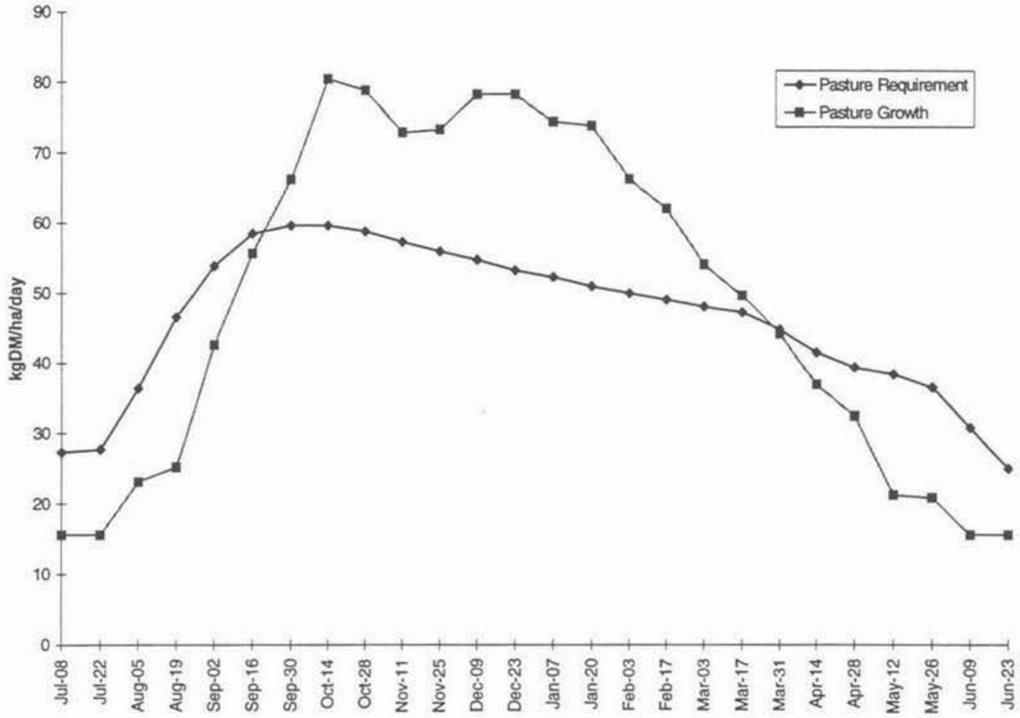
Gross Margin ($)	391206
Pasture Cover at 1st of July (kgDM/ha)	1998
Pasture Cover at Start of Calving (kgDM/ha)	2062
Area Cut for Silage (ha)	72.87
Silage Fed to Cows (kgDM)	138745
Pasture Fed to Cows (kgDM)	1568012
Milksolids produced (kg)	131517
Number of Cows	308

The difference between this solution and that which maximises milksolids production for these pasture growth rates is negligible. The LP model can be used to show that a mere 0.09 kilograms more milksolids per hectare could be produced per year at the expense of a very slight reduction in the gross margin.

Figure 5.5 (see over) illustrates the optimal match between average pasture growth and the optimal feed requirements, expressed in kilograms of pasture dry matter per hectare per day and including an allowance for utilisation losses, over the season. Values are plotted at the mid-points of each fortnightly period.

As can be seen from Figure 5.5 there is a pasture surplus during the months of irrigation and a deficit during the winter months. A later calving date reduces the demand for feed in late July and August and minimises the pasture deficit at this time. Later calving does however mean that a pasture deficit arises during late lactation. This deficit is minimised by the culling of 20% of the herd after a 240 day lactation.

Figure 5.5 Optimal Demand and Supply of Irrigated Pasture Dry Matter.

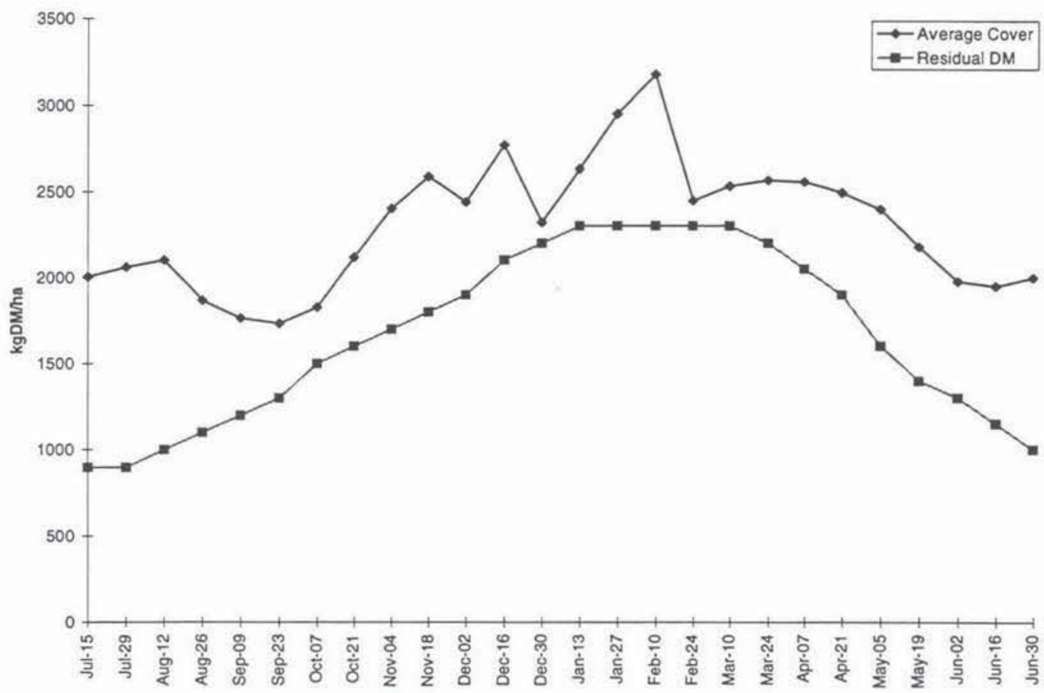


The optimal grazing management strategy for the irrigated system involves the transfer of pasture dry matter, in the form of late summer/autumn saved pasture and silage, from the summer surplus period to the winter deficit period. Figure 5.6 (see over) summarises the grazing management strategy in terms of the average pasture covers at the end of each fortnightly period and the corresponding post-grazing residual pasture masses.

Silage is cut as follows: 1.15 hectares on the 4th of November, 12.34 hectares on the 18th of November, 24.35 hectares on the 16th of December, and 35 hectares on the 10th of February, and is fed out in each period from May to September, with the dry cows being fed the maximum silage allowance of 6 kg/head through June and July. This allows average pasture cover to build up slightly in order to meet the increased intake requirements in early lactation.

The transfer of autumn saved pasture to the winter is indicated by the rising average pasture cover during late February and March and the subsequent decline in cover from April onwards.

Figure 5.6 Average Covers and Post-Grazing Residuals on Irrigated Pasture.



It can be seen that feed is at its "tightest" in terms of herd demand in late September/early October when, ignoring the silage cutting period, average pasture cover is closest to the required residual pasture mass.

5.3.2 Non-Irrigated Pasture

The pasture growth rates expected to occur on non-irrigated pasture between April and December were summarised previously in Table 4.4. In effect, the growth rates that the farmer anticipates will occur between January and March, the months of major variations in pasture growth on a dryland system, are assumed to be the mean values of the growth rates that are predicted to occur in each of the thirty-seven seasons (Table AI.2).

The strategy that maximises the expected gross margin for the non-irrigated system was obtained using these growth rates. For the reasons discussed in Section 5.2.3, only the lower producing herds were considered for the non-irrigated pasture system. The non-irrigated base strategy is summarised in Table 5.4.

Table 5.4 The Base Strategy for Non-Irrigated Pasture (100 hectares).

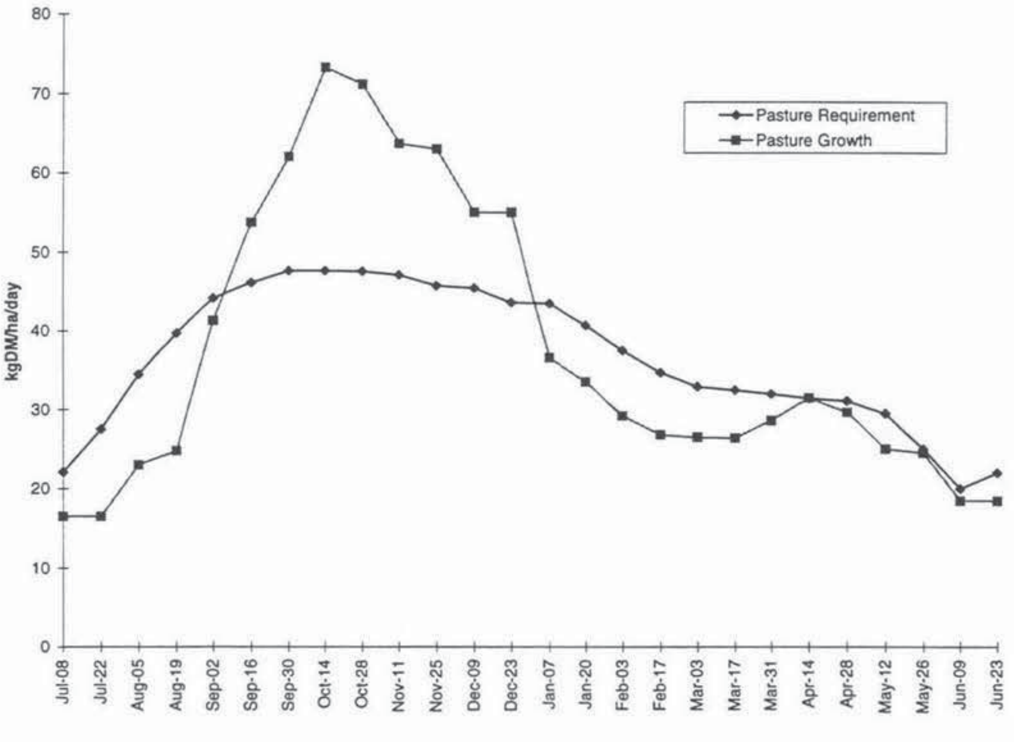
Gross Margin ($)	296278
Pasture Cover at 1st of July (kgDM/ha)	2314
Pasture Cover at Start of Calving (kgDM/ha)	2235
Area Cut for Silage (ha)	28.51
Silage Fed to Cows (kg DM)	51067
Pasture Fed to Cows (kg DM)	1285480
Milksolids produced (kg)	99819
Number of Cows	279

In this case a single herd of 279 cows is optimal. Calving begins on the earlier date of the 15th of July and 80% of the herd complete a 300 day lactation with an average production of 382 kilograms of milksolids per cow. The remaining 20% of the cows are culled after a 180 day lactation and produce an average of 261 kilograms of milksolids per cow. The total production level of 998 kilograms of milksolids per hectare is in fact the maximum that can be achieved by the LP model for these pasture growth rates.

The optimal match between feed requirements and pasture growth is shown in Figure 5.7 (see over). A pasture surplus occurs between the months of

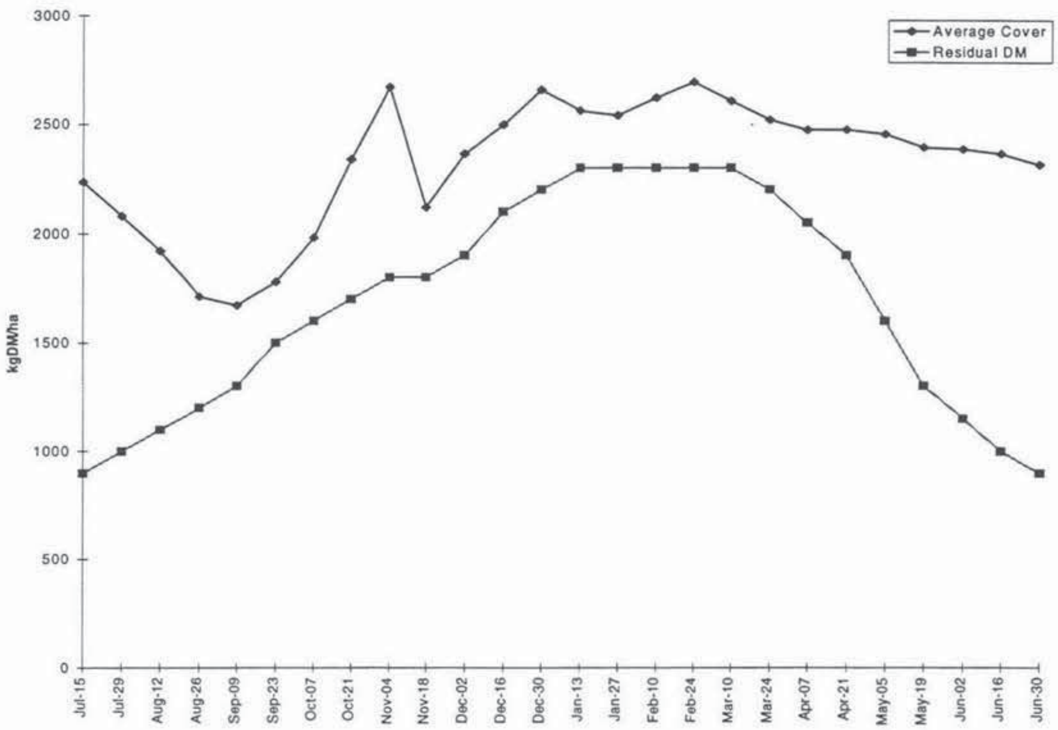
September and December inclusive, with pasture growth not exceeding pasture requirements at any other time of the year. Two major deficits occur, one in late summer/early autumn and one during the winter in early lactation. The summer deficit is minimised by culling 20% of the herd as soon as possible i.e. after a 180 day lactation.

Figure 5.7 Optimal Demand and Supply of Non-Irrigated Pasture Dry Matter.



The optimal grazing management strategy on non-irrigated pasture involves the transfer of pasture dry matter, in the form of silage and saved pasture, from the surplus period into the late summer/autumn deficit period, with autumn saved pasture being used to combat the winter deficit. This results in the average pasture cover and post-grazing residuals summarised in Figure 5.8.

Figure 5.8 Average Covers and Post-Grazing Residuals on Non-Irrigated Pasture.



All silage is cut on the 4th of November and is primarily fed out during February with a relatively small amount being fed in the latter half of January. As a consequence of average pasture cover builds up and this allows more autumn saved pasture to be transferred to the winter. In the case of the non-irrigated system feed supply is most limited in September and January.

5.3.3 Discussion

In this section the optimal stocking rates and target production levels for both an irrigated and a non-irrigated system were derived based on anticipated pasture growth rates for the season. These base strategies not only maximise the expected gross margins at current prices but also essentially maximise milksolids production on each system, within the constraints of the LP model, which is perhaps the more likely farmer objective.

Currently top producers on dryland pasture in the Waikato are those members of the "600 Club" i.e. farmers producing more than 600 kilograms of milkfat, or 1044 kilograms of milksolids, per hectare (D McCall pers. comm.). Our expected production level of 998 kilograms of milksolids per hectare falls a little short of this. This is likely to be, at least in part, due to the limitations and restrictions imposed on the system by the LP model. On the other hand, an expected production of 1315 kilograms of milksolids per hectare for the irrigated system is significantly higher than the best production levels presently achieved on dryland pasture.

Clearly if the LP model were allowed more options in terms of calving date, production patterns, and lactation lengths more strategies that result in higher returns and/or milksolids production might be identified. The base strategies obtained in this section, however, do not seem unreasonable relative to current levels of dairy farm performance in the Waikato.

On non-irrigated pasture optimal management involves the conservation of silage in late spring for feeding out during the summer months which is in line with current management practices. On irrigated pasture an increased stocking rate and a higher individual milksolids production per cow is achieved through later calving and the feeding of supplements during the winter. In this case the optimal management strategy conforms to that suggested by Bosch Irrigation for the management of an irrigated dairy system (Section 2.2.3).

It is likely however, due to the conservative view taken with regard to the quality of irrigated pasture (Section 5.2.2), that the summer surplus that occurs on irrigated pasture is underestimated. If this is true then, while the topping of irrigated pasture may become necessary, more of the surplus could perhaps be conserved as silage and as saved pasture to meet the winter deficit thus allowing a higher stocking rate and a greater annual milksolids production. It is also possible that by calving at least part of the herd even later, more pasture may be able to be consumed *in situ* and the need to cut silage minimised. Later calving would, however, increase the demand for feed in the autumn unless a shorter lactation length is associated with these cows.

There is therefore considerable scope for further research with the model into the optimal management of irrigated pasture.

5.4 GROSS MARGINS FOR THE 1946/7 TO 1983/4 SEASONS

5.4.1 Irrigated Pasture

The base strategy gross margin shown in Table 5.3 does not reflect any of the costs associated with irrigating pasture in a given season. These costs include the electricity costs of pumping water, maintenance costs of the irrigation system, and the cost of the extra fertiliser required on the more intensive irrigated dairy production system (Department of Agriculture NSW 1977).

The Bosch Long Lateral Irrigation System is designed to deliver 3.5 mm of water per hour to one sixth of the farm area. The electricity requirement is around 160 kilowatts per hour of pumping, thus at an off-peak rate of 5c per unit it will cost approximately $48 to apply 3.5 mm to the entire farm over the six day irrigation cycle. An average cost of $50 per 3.5 mm application over the whole farm was chosen as in particularly dry periods it may be necessary to irrigate during the day, which incurs a higher tariff, as well as at night. Estimated pumping costs in each of the 37 seasons, based on the irrigation requirements derived in the previous chapter (Table AI.1), are presented in Table AII.2 in Appendix II.

The irrigation system requires minimal maintenance, with the above ground lateral hoses having an expected lifespan of ten years and the sprinklers an expected lifespan of seven years. As neither of these components are expensive to replace, an allowance of $10 per hectare per year should provide sufficient funds to cover any maintenance costs.

Although the application of additional nitrogen and fertiliser containing zinc may be considered, high rates of superphosphate are more commonly applied to irrigated pastures in Australia (Department of Agriculture NSW op cit.). The extra superphosphate input required on irrigated pasture for the case study farm was therefore calculated in the following manner. First, phosphorus maintenance requirements for both irrigated and non-irrigated systems were estimated using the procedure described by Cornforth and Sinclair (MAF 1984). Table 5.5 shows the values assumed for pasture utilisation rates, animal loss factors, and soil loss factors, as well as the number of stock units per hectare, derived from the base strategy solution, for each system.

Table 5.5 Maintenance Phosphorus Requirements for Irrigated and Non-Irrigated Systems.

	Non-Irrigated System	Irrigated System
Pasture Utilisation Rate	0.9	0.9
Animal Loss Factor	0.9	0.9
Soil Loss Factor	0.4	0.4
Stock Units per hectare	15	20
Phosphorus Requirement (kg/ha)	26	46

The non-irrigated system has a phosphorus requirement of 26 kilograms per hectare while the more intensive irrigated system requires 46 kilograms of phosphorus per hectare. Thus an extra 20 kilograms per hectare is required on irrigated pasture. Second, one kilogram of superphosphate provides approximately 0.09 kilograms of phosphorus, thus the application of an extra 250 kilograms of superphosphate per hectare should be sufficient to supply the additional phosphorus required on irrigated pasture.

The *Financial Budget Manual* (Lincoln University 1995) gives a cost of between \$167 and \$180 per tonne of bulk superphosphate, depending on the source, and a ground spreading cost of \$33.23 per tonne for an application rate of 250 kilograms per hectare in the Waikato. Bagged fertiliser incurs an additional charge of up to \$40 per tonne, hence it can be expected that a tonne of superphosphate will cost at most \$253.23 to buy and spread.
An additional 25 tonnes of superphosphate will be required on the 100 hectare case study farm when pasture is irrigated, thus the maximum cost of the extra fertiliser required on the irrigated system is estimated at \$6331.

Gross margins for each of the 37 seasons are estimated by subtracting the pumping, maintenance, and additional fertiliser costs from the irrigated base strategy gross margin of \$391206. Results are summarised in Table AII.2 in Appendix II.

It should be noted that there are also labour costs involved in irrigating pasture. Sprinklers need to be moved at least once a day during the irrigation cycle, a process which takes between two and three hours a day. Perhaps the major factor that needs to be taken into account is not the time spent moving sprinklers - there is now no need to feed silage during the summer thus there is a trade-off as far as summer labour is concerned - but rather the requirement to feed out silage through the winter on an irrigated system. The opportunity cost of a farmer's, or his workers', time will of course depend on the individual farmer. Whether the returns, in terms of both cash and security, are worth the amount of time and effort required on an irrigated system is a decision that can only be made by the farmer in relation to his or her expectations in terms of the farm gross margin and the labour input necessary to achieve this.

5.4.2 Non-Irrigated Pasture

On the non-irrigated system deviations from the expected, or base strategy, gross margin occur as a result of the major variations in pasture growth that are experienced on dryland pasture between January and March. In this case the LP model is used to estimate the maximum gross margin that can be achieved in each of the thirty-seven seasons. It is assumed that the base strategy is implemented in each season and proceeds according to plan until deviations from anticipated pasture growth rates begin to occur in January. In each season pasture growth rates between April and December are the same as those used to obtain the base strategy (Table 4.4), however, the predicted values of Table AI.3 for that particular season are used to determine the pasture growth rates between January and March. The LP model is constrained so that initial and final pasture covers, the stocking rate, and the amount and times of silage harvesting, are the same as in the base strategy.

All ten notional cows corresponding to the lower producing herd calving at earlier date are included so that, while the same number of cows as in the base strategy must be calved and milked through to mid-January in each season, the LP model is allowed to choose the lactation length(s) and the times when cows are culled in each particular season. All or part of the herd may be dried off, and up to a total of 20% of the herd culled, at 30 day intervals once a 180 day lactation has been completed as described in Section 5.2.3.

Harvested silage may be fed out at any time and any silage that is surplus to requirements may be stockpiled.

In some seasons, most particularly when low pasture growth rates are encountered in January, the use of purchased supplements may be required in order to obtain a feasible LP model solution. Concentrate feed, which is assumed to have an metabolisable energy content of 12 MJ/kgDM, and bought-in silage are made available only in those seasons where the feeding of purchased supplements is necessary to allow the herd to complete a 180 day lactation. Where purchased supplements in the form of silage and concentrates are required these are costed at 30c and 45c per kilogram respectively to buy and feed (D. McCall pers. comm.). Any silage that is stockpiled is imputed a value of 28c.

When necessary, pasture may be topped after grazing to the level of the required residual pasture mass so that maximum pre-grazing pasture masses are not exceeded and pasture quality is maintained. Topping costs are not included in the gross margins.

The dairy LP model was used to obtain the strategy that maximises the gross margin under the conditions described above in each of the thirty-seven seasons. Results for the non-irrigated production system are summarised in Table AII.3 in Appendix II.

5.4.3 Summary of Results

The gross margins derived in this section, associated with both an irrigated and a non-irrigated dairy production system for each of the 37 seasons between 1946 and 1984, are presented in Table 5.6 (see over).

Table 5.6 Irrigated and Non-Irrigated Gross Margins Between 1946 and 1984.

Season	Irrigated Gross Margin	Non-Irrigated Gross Margin	Return to Irrigation
1946/7	378825	263489	115336
1947/8	377834	270625	107209
1948/9	378928	225696	153232
1949/50	378224	278020	100204
1950/1	378232	265114	113118
1951/2	378975	277833	101142
1952/3	380117	306302	73815
1953/4	378041	186195	191846
1954/5	377469	238275	139194
1955/6	377747	233072	144675
1956/7	379511	218132	161379
1958/9	381034	317126	63908
1959/60	379549	320712	58837
1960/1	377618	260124	117494
1961/2	379261	314073	65188
1962/3	379214	245669	133545
1963/4	379027	309331	69696
1964/5	380885	323807	57078
1965/6	380714	326058	54656
1966/7	381074	324008	57066
1967/8	377621	241610	136011
1968/9	380291	315631	64660
1969/70	377759	202779	174980
1970/1	378424	298749	79675
1971/2	379521	264534	114987
1972/3	377684	205857	171827
1973/4	377365	184975	192390
1974/5	379347	309449	69898
1975/6	379498	310721	68777
1976/7	378669	286378	92291
1977/8	377769	199615	178154
1978/9	379992	311795	68197
1979/80	381688	325684	56004
1980/1	378365	265519	112846
1981/2	379237	296278	82959
1982/3	377227	230671	146556
1983/4	379484	307967	71517
Mean	378979	271942	107036
Coefficient of Variation (%)	0.31	16.21	40.34

Table 5.7 (see over) shows, for both systems, the total amount of pasture dry matter produced, the net dry matter input, the total amount of milksolids produced, and the efficiency with which available dry matter is converted into milksolids, in each of the 37 seasons. The net amount of dry matter available in each season on dryland pasture is calculated by adding any supplementary dry matter provided through buying in silage or concentrate feed, or by subtracting any surplus silage dry matter, as shown in Table AII.3, from the annual amount of dry matter produced from pasture in each season.

Table 5.7 shows that a more efficient rate of conversion of available dry matter into milksolids can be achieved under irrigation than on non-irrigated pasture in all of the 37 seasons. Conversion rates on the non-irrigated system are closest to the irrigated rate when pasture growth rates during the irrigation period do not significantly diverge from their mean values (Table AI.2), and the base strategy management plan is more or less realised. The lower conversion rates on non-irrigated pasture clearly occur as a result of the "wastage" of pasture, through topping, in the LP model solutions. There are two reasons for this. First, once the base strategy has been implemented, the LP model has a limited capacity to take advantage of above average pasture growth rates in the irrigation period. The only options are to allow the cull herd a longer lactation and/or reserve silage. Second, if below average pasture growth occurs during the irrigation period, then at least a proportion of the herd will be dried off as soon as the feed situation becomes "tight". This also means that there is once again very little capacity to utilise pasture grown later in the season. This effect is particularly noticeable in those seasons where low pasture growth rates are encountered in January (Table AI.2).

Table 5.7 Production Statistics for the Two Systems Across 37 Seasons.

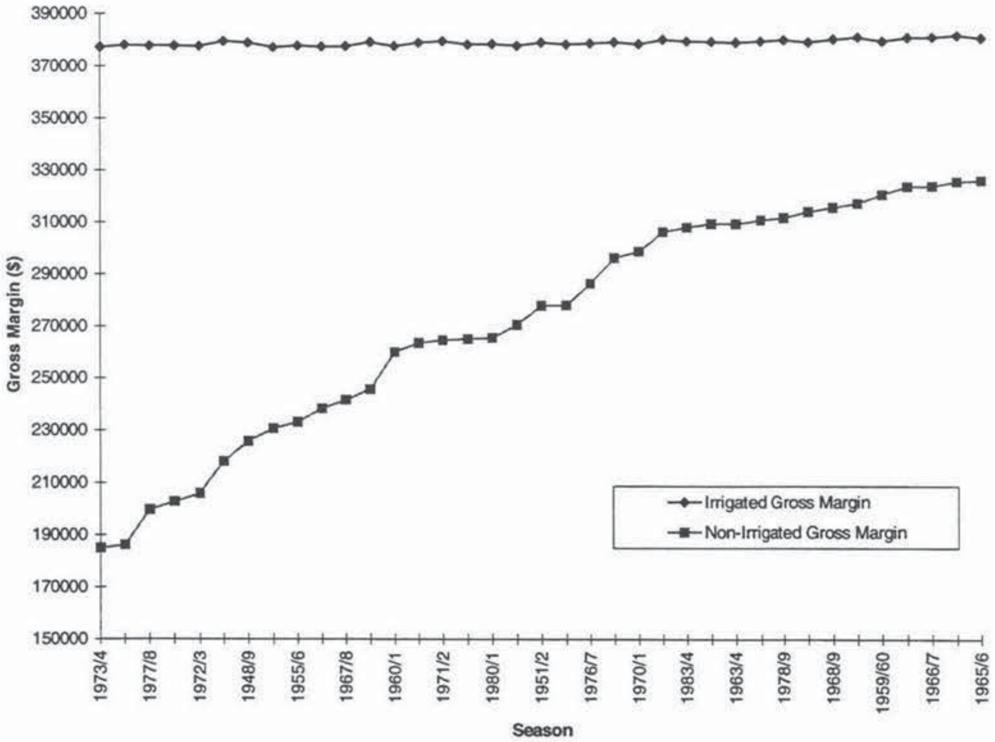
Non-Irrigated System	Annual DM Production (kg/ha)	Net Annual DM Input (kg/ha)	Milksolids Production (kg/ha)	Conversion Efficiency (%) (kg MS per kg DM (net))
1946/7	12898	12898	906	7.02
1947/8	13045	13045	926	7.10
1948/9	12981	12981	799	6.16
1949/50	13205	13205	947	7.17
1950/1	12916	12916	910	7.05
1951/2	13199	13199	946	7.17
1952/3	14052	14052	1026	7.30
1953/4	12838	13303	728	5.47
1954/5	12571	12571	835	6.64
1955/6	12534	12534	820	6.54
1956/7	12764	12764	778	6.10
1958/9	14920	14707	1039	7.06
1959/60	14773	14441	1039	7.19
1960/1	12814	12814	896	6.99
1961/2	14389	14278	1039	7.28
1962/3	12733	12733	856	6.72
1963/4	14213	14213	1035	7.28
1964/5	16078	15642	1039	6.64
1965/6	15660	15149	1039	6.86
1966/7	16234	15792	1039	6.58
1967/8	12593	12593	844	6.70
1968/9	14503	14340	1039	7.25
1969/70	12475	12495	728	5.83
1970/1	13737	13737	1005	7.32
1971/2	14053	14053	909	6.47
1972/3	12200	12200	743	6.09
1973/4	11915	12374	728	5.88
1974/5	14679	14679	1035	7.05
1975/6	14284	14284	1039	7.27
1976/7	13402	13402	970	7.24
1977/8	12092	12121	728	6.01
1978/9	15044	15009	1039	6.92
1979/80	15530	15032	1039	6.91
1980/1	12937	12937	912	7.05
1981/2	13637	13637	998	7.32
1982/3	12492	12492	813	6.51
1983/4	14134	14134	1031	7.29
Mean	13636	13588	925	6.80
Coefficient of Variation (%)	8.5	7.5	12.2	7.3
Irrigated System	17814	17814	1315	7.38

5.4.4 Discussion

In this section estimates of the gross margins achievable on both a dryland and a fully irrigated dairy production system were derived for 37 seasons that vary in terms of rainfall during the irrigation period. On irrigated pasture variations in the pattern of rainfall during the irrigation period result in different irrigation requirements in each season, whilst on non-irrigated pasture variations in rainfall lead to variations in pasture growth.

Figure 5.9 presents a comparison of the gross margins achievable in each season for both types of system (Table 5.6). Values are presented in order of increasing non-irrigated gross margins.

Figure 5.9 Irrigated and Non-Irrigated Gross Margins in Order of Increasing Value Across 37 Different Seasons.



As can be seen in Figure 5.9 the gross margins associated with the non-irrigated system exhibit considerably more variation than do those for the irrigated system. Whilst the coefficient of variation associated with the gross margins for the dryland system is quite low at 16% (Table 5.6), a coefficient of variation of just 0.3% for the irrigated system (Table 5.6) indicates an almost total lack of risk as far as achieving the expected result is concerned. Figure 5.9 also indicates that significant returns to irrigation may be achieved even in seasons where dryland pasture growth rates are well above average and minimal irrigation is required.

There are however several points that should be noted with regard the results obtained in this section. First, as discussed in Section 5.3.3, it is more than probable that, by considering more options in terms of calving date and lactation patterns, the base strategy for both types of production system may be improved upon. Second, as the dairy LP model has perfect knowledge of future pasture growth rates in each season the gross margins obtained for non-irrigated pasture relate to the best possible outcome. In practice the farmer has no knowledge of future growth rates and may make a sub-optimal decision. For instance, if low pasture growth is encountered in January and it is known that this will continue through February and March, then the LP model will choose to dry cows off as soon as possible and reserve silage to be fed out as it is needed later in the season. Conversely, if it is known that pasture growth will increase, then the optimal decision will be to feed the silage in January and milk the cows through. A dairy farmer can only guess as to which will be the best strategy.

However, the advantage of "perfect knowledge" in the LP model is likely to be more than outweighed by the restrictions imposed on the model. In reality, not only may decisions may be made daily rather than fortnightly, but more importantly the farmer has more flexibility in the pattern of milksolids production than is allowed the LP model. For instance, if lower than expected pasture growth rates are encountered then cows may be dried off at any time rather than only at thirty day intervals. The farmer might also choose to continue milking but reduce individual cow milksolids production levels by restricting intake. Thus, in practice, the farmer is likely to be in a better position to take advantage of improved pasture growth rates later in the season. Similarly, when above average pasture growth occurs the extra dry matter produced can be more fully utilised in the real system. As far as the LP model is concerned the only options are to delay culling and stockpile silage, and, after these measures have been implemented, any surplus pasture dry matter is assumed to be topped and is lost from the system. In practice this "wasted" dry matter may be used to increase individual cow intake and hence milksolids production, with a resultant increase in the efficiency with which available dry matter is converted into milksolids (Table 5.7). It follows then, as in the case of the base strategies, that the LP model predictions could be improved by the inclusion of more options in terms of the possible lactation patterns. For the above reasons the values of Table AII.3 are likely to underestimate both the amount of milksolids and the gross margins achievable in practice on dryland pasture in each of the 37 seasons.

As far as the irrigated system is concerned, the results of Section 4.2 indicate that the amount of irrigation required in each season is likely to have been overestimated, and, for this reason, the corresponding gross margins underestimated. Pumping costs, however, are a relatively insignificant component of the gross margins associated with this system. In this case improved estimates of the gross margins achievable will primarily result from further investigation into the optimal management of irrigated dairy production systems.

Finally, variations in climatic factors other than rainfall during the irrigation period, and in the factors that influence pasture growth at other times of the year, will clearly have an impact on the gross margins of both systems. It is expected that any such variation in climatic conditions will cause the gross margins for both systems to move in the same direction, though these changes are unlikely to be of the same magnitude.

5.5 CONCLUSIONS

Under the assumption that the farmer sets up the farm in accordance with the relevant base situation, gross margins for both an irrigated and a non-irrigated dairy production system have been derived for 37 seasons that differ in terms of the pattern of rainfall occurring during the irrigation period.

It is the difference between the two gross margins, or the return to irrigation, in each season that is of interest in the determination of the payback period. Thus, whilst variations can be expected to occur, the values of Table 5.6 provide a basis for the estimation, in the next chapter, of the probability distribution of the time to payback.

CHAPTER 6

THE TIME TO PAYBACK

6.1 INTRODUCTION

The objective of this chapter is to derive the probability distribution of the time to payback for an investment in irrigation on the dairy farm described in Chapter 5. The payback period is defined as the number of years required for the investment to generate sufficient returns to cover the initial capital costs and all subsequent interest payments. That is, the time to payback is the year in which the net present value of the investment first becomes positive. It is assumed that the investment in irrigation is fully financed by borrowing at the market rate of interest.

Other criteria that might have been used to assess the profitability of investment in irrigation include the expected net present value (NPV) and the internal rate of return (IRR). One problem with these approaches, as pointed out by Anderson, Dillon, and Hardaker (1977), is that the time pattern of cash flows is not adequately taken into account. A farmer is unlikely to be indifferent between a project that initially has high returns which then diminish, and a project that takes some years to furnish positive returns which then increase. On the other hand, as noted by Rae (1994), the payback period completely ignores the future profitability of the investment after the payback period and thus does not indicate the true profitability of the project. Neither criticism is considered relevant to the analysis as the return to irrigation in any particular year is assumed to depend only on the vagaries of nature in terms of rainfall. Thus, the time pattern of the returns to irrigation, whether within or beyond the payback period, is assumed to be randomly determined.

There were two main reasons why the payback period, rather than the expected net present value or the internal rate of return, was chosen for the appraisal of investment in irrigation. First, the life of the Bosch Long Lateral Irrigation System is not known with any certainty. The underground componentry of the system, which was developed some twenty five years ago, has a minimum rated lifespan of 50 years. Whilst probability distributions of the expected NPV or the IRR over the minimum expected life of the irrigation system could be obtained, it seems likely that the results obtained may underestimate the true profitability of the investment. It also seems likely that the irrigation system will outlast the farmer's career on the farm, thus there may be some difficulty in interpreting the results as far as the individual farmer is concerned. The time to payback, however, is a concept which may be readily understood and interpreted, and, as such, is considered likely to be of more relevance to a dairy farmer considering investment in irrigation. Second, as a discrete variable the time to payback lends itself readily to the analysis, which involves obtaining frequency distributions .

6.2 DATA FOR THE ESTIMATION OF THE TIME TO PAYBACK

Initially, a probability distribution is estimated under the assumption that costs and returns remain constant at their current levels. A typical capital investment cost for the Rukuhia region is also assumed for the initial analysis. The relevant variables and assumed values are outlined in the ensuing sections.

6.2.1 Capital Costs of the Irrigation System

Bosch Irrigation estimate the capital cost of installing their long lateral system at between \$2,700 and \$3,800 per hectare, depending on the size and terrain of the farm, and the distance from the water source. For the purposes of this study a capital cost of \$3,000 per hectare was considered appropriate. On top of this, the cost of running power to the pump site, as well as the cost of obtaining resource consent, must also be considered. The cost of installing a power supply is estimated at approximately \$20 per metre, whilst a resource consent typically costs around \$2,000. An allowance of \$25,000 was made to cover these costs, giving a total capital cost of \$325,000 for the installation of the irrigation system on the 100 hectare farm.

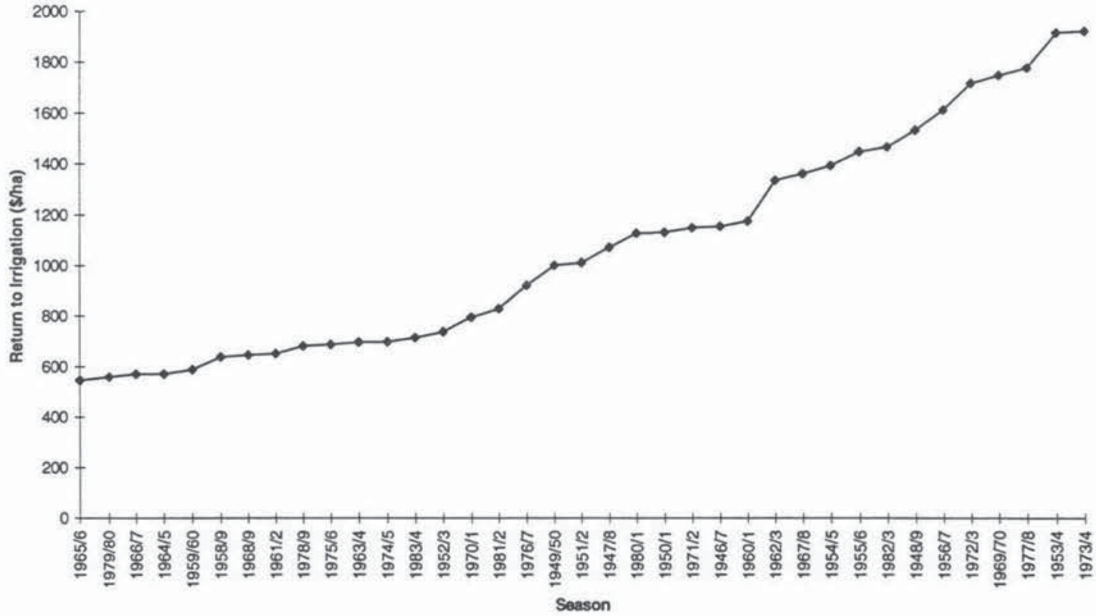
It is possible that other capital expenditure may be necessary in the move to an irrigated system. For example, an increase in milking shed capacity or the provision of a loafing pad for feeding silage in the winter may be required. Also if a water source such as the Waikato river is not readily available it may be necessary to construct dams. Costs such as these are not included in the analysis.

6.2.2 The Returns to Irrigation

The return to irrigation in a given season is defined as the difference between the gross margins that could be achieved on an irrigated and a non-irrigated production system in that season. The gross margins obtained in the previous chapter are used to estimate the return to irrigation that may be expected to occur in each of the 37 seasons between 1946 and 1983, excluding the 1957/8 season (Table 5.6). Note that the values presented are all measured at current prices i.e. a milksolids payout of $3.55 per kilogram of milksolids and with variable production costs as outlined in Chapter 5.

Figure 6.1 shows the estimated returns to irrigation per hectare, presented in order of increasing returns, over these seasons.

Figure 6.1 The Expected Returns to Irrigation per Hectare in Order of Increasing Value Across 37 Different Seasons.



The return to irrigation over the 37 seasons has a mean value of $107,036 on the 100 hectare farm, and varies between $54,655 in 1973/4 and $192,390 in the 1965/6 season. The associated coefficient of variation of 40% indicates that considerable between season differences occur in the return to irrigation at the Rukuhia case study site.

6.2.3 The Discount Rate

It is assumed that the investment in irrigation is financed entirely by borrowing, therefore the relevant discount rate, in the calculation of the time to payback, is the market rate of interest for rural loans. Should the farmer be in the fortunate position of having the available cash, then the returns to irrigation should be discounted at the highest risk-free interest rate that can be obtained by lending the funds. This rate of return will almost certainly be less than the cost of borrowing.

The National Bank, as one of the largest rural lending institutions in New Zealand, was selected as the indicator of market interest rates. The rural lending rates currently offered by the National Bank i.e. as at the 26th of April 1996, are 10.5% for a fixed term of up to three years, or 10.7% at floating rates. The fixed rate of 10.5% was chosen as the discount rate for the initial analysis.

6.3 PROBABILITY DISTRIBUTION OF THE TIME TO PAYBACK

It is assumed that the seasons between 1946/7 and 1983/4 comprise a random sample of the population of possible seasons, in terms of rainfall during the irrigation period, and that each season has an equal probability of occurrence. It is also assumed that the first return to irrigation occurs at the end of the season in which the irrigation system, installed in year 0, is first used i.e. in year 1. A Monte-Carlo style simulation approach is then used to generate random sequences of seasons and the time to payback is calculated for each sequence in the following manner. For the sequence of randomly generated numbers: $\mathbf{r}_1$, $\mathbf{r}_2$, ..., the time to payback is given by the smallest value of **t** that satisfies:

Equation 6.1 The Time to Payback for an Investment in Irrigation.

$$-\mathbf{CAPCOST} + \sum_{t} \mathbf{RETIRR}[\mathbf{r}_t] / (1 + \mathbf{i})^t > 0$$

where:

i. **CAPCOST** is the capital investment cost of the irrigation system;

ii. $\mathbf{r}_t$ is a randomly generated number between 1 and 37;

iii. $\mathbf{RETIRR}[\mathbf{r}_t]$ is the estimated return to irrigation in the $\mathbf{r}_t^{th}$ season of the 37 possible seasons; and

iv. **i** is the interest rate payable on rural loans.

When a sufficiently large number of sequences of seasons are simulated, the frequency distribution of the time to payback values obtained from the simulation is assumed to provide a reasonable approximation to the probability distribution the payback period.

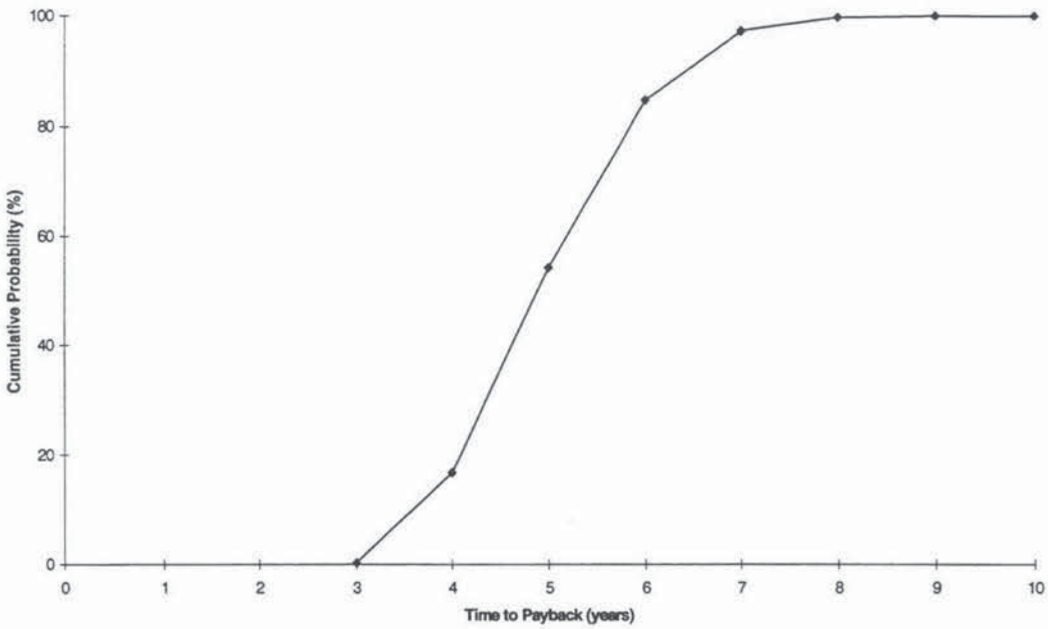
Using the values described in Section 6.2 (i.e. capital costs of $325,000, a milksolids payout of $3.55, and an interest rate of 10.5%), a simulation involving the random generation of 10,000 possible sequences of seasons was performed. Initially, 100 random numbers were generated and each of these was then used as the seed, or starting point, for the generation of random numbers for a 100 sequences of seasons. Results are tabulated in Table 6.1 and presented graphically in Figure 6.2 (see over).

As can be seen the time to payback varies between three and ten years, with a 97% chance that the investment in irrigation will repay its costs sometime in the next four to seven years. There is nearly an 85% probability that the time to payback will be no more than six years.

Table 6.1 Results of the Simulation of the Time to Payback.

Time to Payback (years)	Frequency	Probability (%)	Cumulative Probability (%)
3	29	0.29	0.29
4	1644	16.44	16.73
5	3757	37.57	54.30
6	3054	30.54	84.84
7	1244	12.44	97.28
8	243	2.43	99.71
9	28	0.28	99.99
10	1	0.01	100.00
Total	10000	100.00	

Figure 6.2 The Probability Distribution of the Time to Payback.



Whilst these results are very encouraging as regards the profitability of investment in irrigation, it needs to be remembered that they are based a constant return for milksolids of $3.55 per kilogram. In the next section the impact of variations in the price of milksolids on the probability distribution of the time to payback is investigated. Variations in the capital investment cost and in the interest rate are also considered. Furthermore, the cost of the labour requirement involved in irrigating pasture is not included in this analysis. Obviously the time to payback will increase when labour costs are taken into account, though, as mentioned in the previous chapter, the value a farmer places on his or her time will depend on their individual circumstances.

6.4 SENSITIVITY ANALYSIS

It would have been preferable to have been able to include variations in milksolids prices and interest rates when calculating the time to payback. Historical data however are unlikely to provide a reliable guide to the future values, and the associated probability of occurrence, of these variables.

The deregulation of the economy has resulted in New Zealand becoming much more vulnerable to conditions prevailing in the wider global economy. For instance, milksolids payouts depend not only on the prices received in world markets but also on New Zealand's exchange rate. Following the floating of the New Zealand dollar in March 1985, the exchange rate responds to changes in interest rates, both in New Zealand and abroad. Domestic interest rates, under the Reserve Bank Act of 1991, in turn respond to changes in inflationary pressures, and finally, as New Zealand is a net importer of manufactured goods, changes in the rates of inflation experienced by its major trading partners in the industrialised world will have an impact on the New Zealand inflation rate. Thus, it can be seen that milksolids prices and interest rates depend significantly on global events as well as the economic and political conditions prevailing internally. Unfortunately for New Zealand dairy farmers the linkage between interest rates and the exchange rate, through capital flows, means that high interest rates tend to be associated with low milksolids payouts and vice versa. For these reasons historical milksolids prices and interest rates are used only to establish a likely range of values for these variables.

6.4.1 Milksolids Price

Table 6.2 shows the average milksolids payout made by N.Z. Dairy Companies to their farm suppliers in each season from 1984/5 onwards.

Table 6.2 Average Milksolids Payouts (Nominal) from 1984/5 to 1994/5.

Season	Milksolids Price (cents per kg)
1984/85	233.94
1985/86	229.27
1986/87	202.26
1987/88	232.04
1988/89	325.36
1989/90	359.70
1990/91	241.98
1991/92	334.45
1992/93	365.83
1993/94	331.72
1994/95	339.85

Source: New Zealand Dairy Board.

It can be seen that, although there are significant fluctuations, the average milksolids payout has been between $2.00 and $4.00 per kilogram. Accordingly, the simulation of the previous section was repeated for differing milksolids prices in this range. To do this the return to irrigation for each of the 37 seasons was re-calculated using the relevant milksolids price. It was assumed that the farmer would continue to set up the farm in accordance with the optimal base strategies obtained in Chapter 5, regardless of the milksolids price[1]. Thus milksolids production levels in each season are assumed to be unchanged and changes in the gross margins of both systems arise only as a result of the change in the milksolids price.

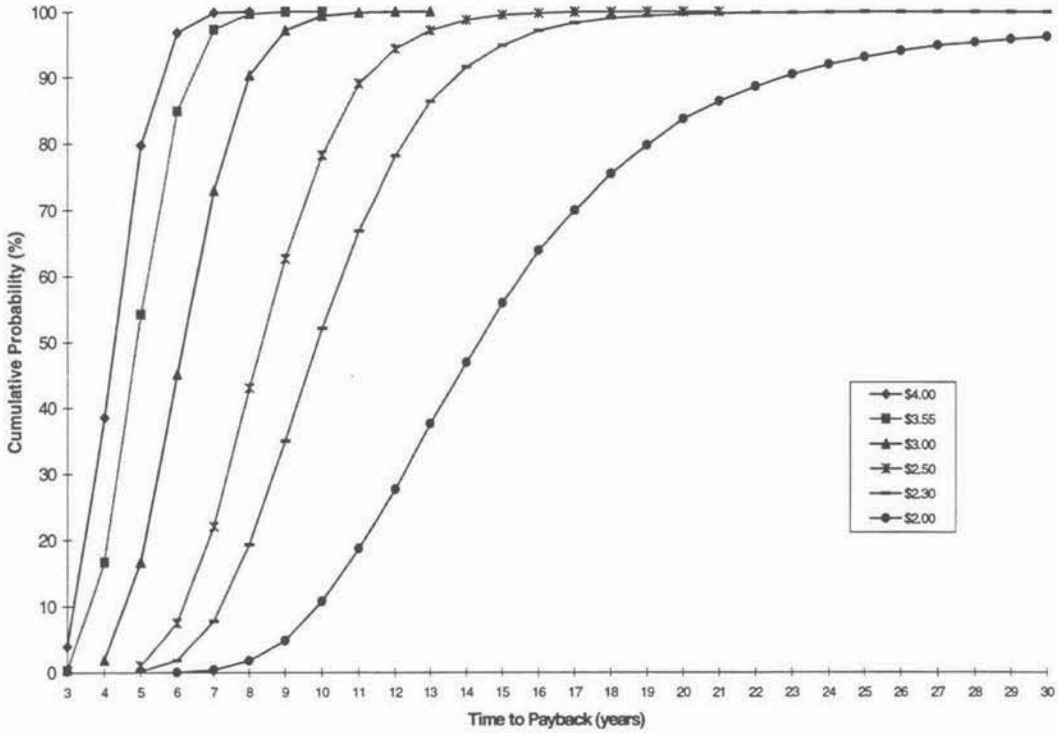
The returns to irrigation in each season, calculated in this manner, at the differing milksolids prices of \$4.00, \$3.00, \$2.50, \$2.30, and \$2.00 are presented in Table AIII.1 in Appendix III.

Using these values the probability distribution of the time to payback was obtained for each of the above milksolids prices, assuming capital costs of \$325,000 and an interest rate of 10.5% as previously (Figure 6.3 - see over, and Table AIII.2 - Appendix III).

It can be seen from Figure 6.3 that variations in the milksolids payout have a significant impact on the expected time to payback. This is not surprising as the payment received for milksolids is the major determinant of the gross margin of a dairy farm. Clearly the lower the milksolids payout is the longer the expected time to payback. If milksolids prices range between \$2.30 and \$4.00 per kilogram then there is more than a 99% probability of payback occurring within 20 years, given a constant interest rate of 10.5% and an initial capital investment of \$325,000. However, at a milksolids price of \$2.00 per kilogram, the chances of payback within 20 years are only 83%, and in fact there is a 1.3% probability that payback will not be achieved within the minimum expected life of the irrigation system i.e. 50 years.

[1] If milksolids prices below \$2.50 are expected to persist in the long term then, at the current variable production costs, the base situation for the non-irrigated system is no longer optimal. It would pay the farmer to reduce the stocking rate, milk all cows through to a 300 day lactation, and harvest and feed more silage to achieve this. Total milksolids production is reduced in this case but the savings in animal health and breeding costs resulting from the lower stocking rate more than offset the loss in milksolids revenue and increased silage costs.

Figure 6.3 Probability Distributions of the Time to Payback for Varying Milksolids Prices.



6.4.2 Interest Rates

Table 6.3 (see over) shows movements in the Rural Bank floating interest rates from March 1988, when any "concessional" element remaining in the terms and conditions of mortgages registered by the Rural Bank ceased and loans became fully "commercial", to September 1993, when the Rural Bank was fully taken over by the National Bank. The rates shown in Table 6.3 between September 1993 and December 1995 are the National Bank floating term lending rates in the rural market.

Leaving aside the high interest rates at the beginning of the period, which almost certainly still reflected the uncertainty involved in the deregulation of the financial sector, it can be seen that rural lending rates over the last five years have been between 8% and 15%.

Table 6.3 Variation in Rural Lending Rates Between March 1988 and December 1995.

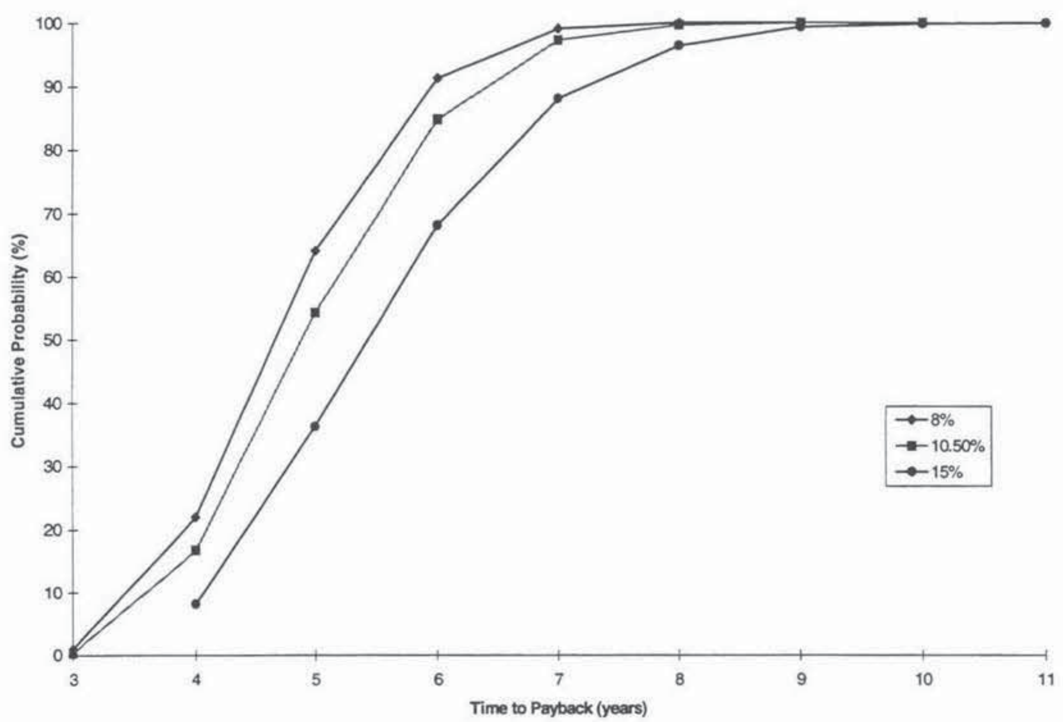
Effective From:	Floating Term Lending Rate (percent/annum)
3/7/88	19.00
9/9/88	17.50
11/23/88	16.50
3/6/89	16.00
4/6/89	15.75
8/3/89	15.50
8/25/89	14.90
5/24/90	14.50
2/11/81	13.95
4/23/91	13.25
5/29/91	12.75
8/6/91	12.25
9/30/91	11.75
2/12/92	10.90
5/4/92	10.65
7/15/92	10.40
10/23/92	9.80
7/21/93	9.30
9/21/93	8.75
2/25/94	8.25
9/9/94	8.95
12/9/94	9.70
2/10/95	11.20
12/29/95	10.70

Source: The National Bank of New Zealand Limited, RURAL BANKING.

Accordingly, the probability distributions of the time to payback were obtained for discount rates of both 8% and 15%, assuming a milksolids payout of $3.55 per kilogram and a capital investment cost of $325,000.

The cumulative probability distributions of the time to payback for interest rates of 8%, 10.5%, and 15% are shown below in Figure 6.4 and are tabulated in Table AIII.3 in Appendix III.

Figure 6.4 Probability Distributions of the Time to Payback for Varying Interest Rates.

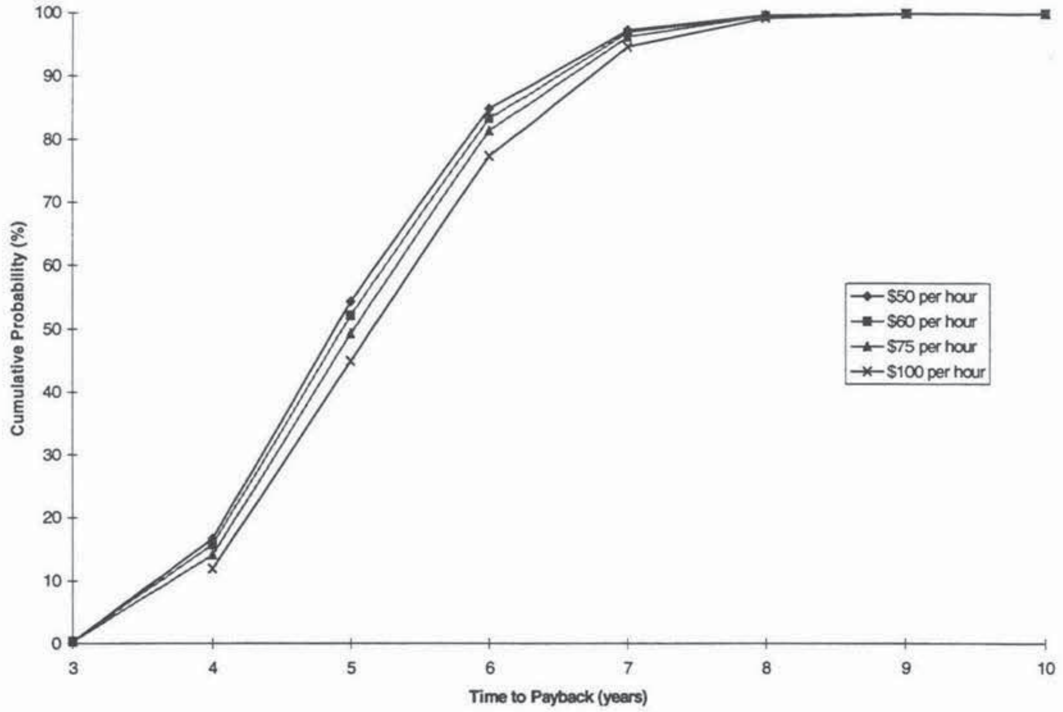


Whilst obviously higher interest rates are associated with an increased expected time to payback, the impact of variations in interest rates on the time to payback is relatively insignificant when compared to the effect of variations in the price of milksolids. For a capital investment cost of $325,000 there is a 99% probability that payback will occur within nine seasons regardless of the actual level of the interest rate (so long as it does not rise above 15%), under the assumption of a constant milksolids payout of $3.55 per kilogram. It is expected that as the milksolids payout decreases then variations in interest rates will become relatively more significant.

6.4.3 Electricity Costs

The price of electricity is unlikely to fall in the foreseeable future. Accordingly, the probability distributions of the time to payback corresponding to increases in pumping costs of 20%, 50% and 100% were obtained, assuming a milksolids payout of $3.55 per kilogram, an interest rate of 10.5%, and a capital investment cost of $325,000. Results are summarised in Figure 6.5 and Table AIII.4.

Figure 6.5 Probability Distributions of the Time to Payback for Varying Pumping Costs.

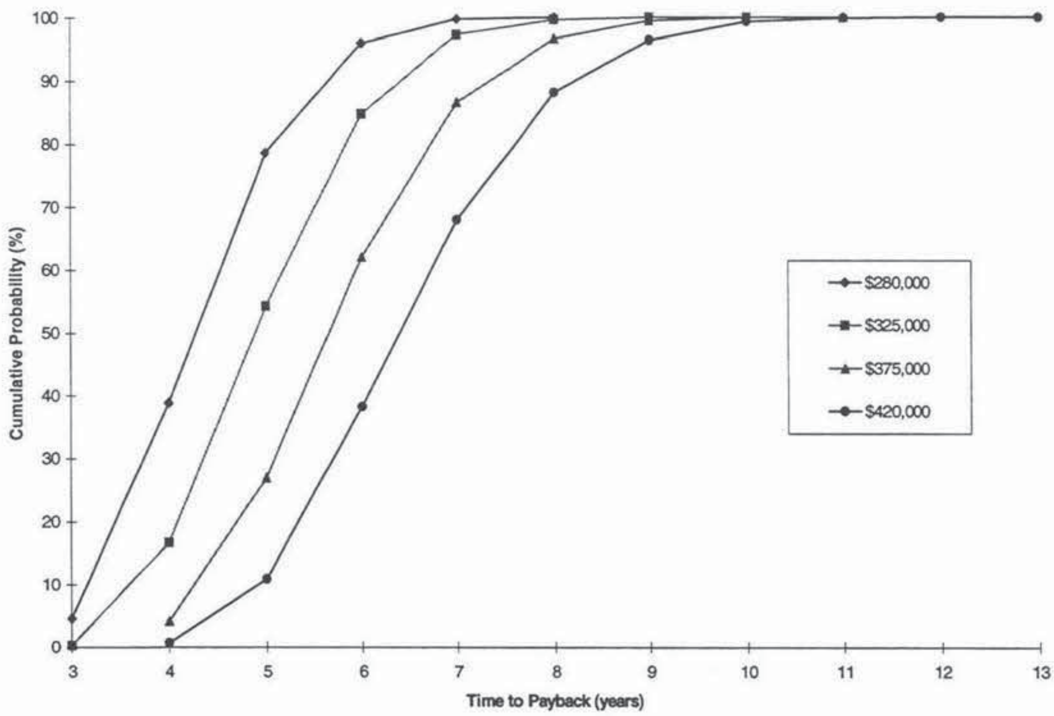


As can be seen in Figure 6.5, increases in the price of electricity had minimal impact on the time to payback. Even if pumping costs were to double there is still a 95% probability that payback will occur within four to seven years. Increased electricity charges are therefore one of the least concerns of a farmer contemplating an investment in irrigation.

6.4.4 Capital Investment Cost

The cost of installing the Bosch long lateral system varies between $2,700 to $3,800 per hectare (Section 6.2.1). Allowing a further $10,000 to $40,000 to cover resource consent and power supply, the capital cost of an investment in irrigation on the case study farm is assumed to range from $280,000 to $420,000. Probability distributions of the time to payback were therefore derived for capital investment costs of $280,000, $375,000, and $420,000 (assuming a milksolids payout of $3.55 per kilogram and an interest rate of 10.5%). Results are shown in Figure 6.6 and summarised in Table AIII.5.

Figure 6.6 Probability Distributions of the Time to Payback for Varying Capital Investment Costs.



The effect of differing capital investment costs on the probability distribution of the time to payback is relatively insignificant, as was the case for interest charged on capital, when compared to that of changes to the milksolids payout. In this case there is a 99% probability that payback will occur within ten seasons regardless of the capital cost of the investment, assuming that the milksolids payout and rural lending rates remain at current (1995/6) levels. The capital investment cost is expected to have a more significant impact when lower milksolids prices and/or higher interest rates are considered.

6.4.5 Upper and Lower Bounds for the Probability Distribution of the Time to Payback

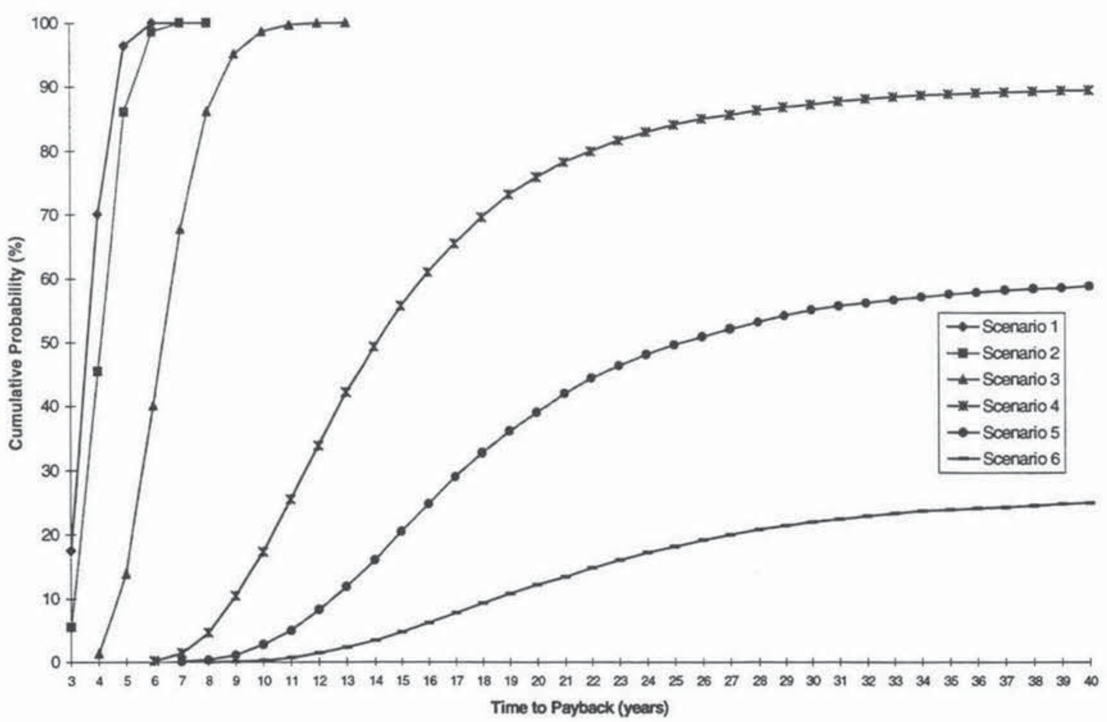
In Sections 6.4.1 to 6.4.4 the effect of a change in a single determinant of the time to payback *ceteris paribus* was investigated. In this section upper and lower bounds for the likely time taken to payback for an investment in irrigation are derived by considering different combinations of milksolids payouts, interest rates, and capital costs. Increases in the price of electricity were not considered due to their negligible impact on the time to payback (Section 6.4.3). Probability distributions of the time to payback were obtained for the scenarios described in Table 6.4.

Table 6.4 Differing Scenarios for an Investment in Irrigation.

Scenario	Milksolids Payout ($/kg)	Interest Rate (%)	Capital Cost ($)
1	4.00	8.0	280,000
2	4.00	8.0	325,000
3	3.00	11.5	325,000
4	2.30	15.0	325,000
5	2.30	15.0	375,000
6	2.30	15.0	420,000

Scenarios 2, 3, and 4 all relate to the typical capital investment cost of $325,000. Middle of the range values for the milksolids payout and the rural lending rate are assumed in Scenario 3, whilst Scenarios 2 and 4 correspond to the "best" and "worst" likely situations, in terms of these variables, respectively. Thus, in a sense, the time to payback probabilities associated with Scenario 3 can be thought of as the "expected" probabilities of occurrence, and those associated with Scenarios 2 and 4 as providing upper and lower limits, for the given level of capital investment. The remaining scenarios (1, 5, & 6) show how these limits vary for differing levels of capital costs. Scenario 1 relates to the best possible outcome for the minimum likely capital cost of $280,000 for an investment in irrigation, and Scenarios 5 and 6 to the worst possible outcomes for the higher capital cost levels of $375,000 and $420,000, respectively. The cumulative probability distributions of the time to payback for each of these scenarios are shown below in Figure 6.7 and are summarised in Table AIII.7, Appendix III.

Figure 6.7 Probability Distributions of the Time to Payback for Different Milksolids Payout, Interest Rate, and Capital Cost Scenarios for an Investment in Irrigation.



As can be seen from Figure 6.7, for a capital investment of $325,000 the "expected" probability that payback will occur within 11 seasons is over 99% (Scenario 3). The actual probability, however, when variation in milksolids prices and interest rates during this period is taken into account, lies somewhere between 25% (Scenario 4) and 100% (Scenario 2). Similarly, the probability that payback will be achieved within the 50 year minimum lifespan of the irrigation system is between 90% and 100%. Whilst New Zealand's position in relation to the changing global economy makes the estimation of the probabilities of occurrence of various milksolids payout/interest rate combinations virtually impossible (Section 6.1), the chances of adversely extreme values of both variables occurring continuously over a 50 year period must be very small. Thus the chance that a $325,000 capital investment in an irrigation system at Rukuhia is not repaid during the next 50 years will be very close to zero. Obviously, by considering more combinations of milksolids prices and interest rates which incorporate the farmer's expectations of the likely ranges of values for these variables in the near future, confidence intervals describing the minimum and maximum expected time to payback could be established.

When increased capital investment costs are considered, Figure 6.7 indicates that the chance of payback not occurring within 50 seasons increases significantly. While "best-case" scenarios were not obtained, it can be seen that the minimum probability that that an investment in irrigation is repaid during the lifespan of the system falls from 90% to 60% for a required capital investment of $375,000, and further falls to only 25% when an investment of $420,000 is required. In contrast, when the minimum required capital investment of $280,000 is considered, the effect on the "best-case" outcome is minimal with an approximately 99% chance of payback occurring within 6 years for both Scenarios 1 and 2. These results clearly confirm the previously stated expectations that as both capital costs and interest rates rise, and milksolids prices fall, a change in any one of these determinants of the payback period will have an increasingly significant impact on the probability distribution of the time to payback.

6.5 THE TRANSITION TO AN IRRIGATED SYSTEM

In the preceding analyses, the transition from a dryland dairy production system to an optimally managed irrigated system was assumed to occur instantaneously and without cost. In practice it is unlikely that a herd with an average production of 358 kilograms of milksolids per cow can, through the extra digestible nutrients made available through irrigation, be suddenly transformed in the first season into a herd capable of producing 427 kilograms of milksolids per cow, not to mention the increase in stocking rate required. In this section alternative methods of achieving the transition to an irrigated system, and the consequent effect on the probability distribution of the time to payback, are investigated.

Two purely hypothetical scenarios are considered. First, the farmer immediately increases the stocking rate and upgrades the herd so that optimal production targets can be met in the following season. It is assumed that a total cost of, say, $50,000 will be sufficient to cover the required transactions so that the transition is achieved instantaneously, but at the expense of an increase in the initial capital outlay. In this case the relevant probability distribution of the time to payback, calculated at current prices, is that corresponding to a capital investment of $375,000 (see Section 6.4.4). Second, the farmer may decide to gradually increase both the stocking rate and the herd per cow performance over a number of seasons. Assume, for instance, that the transition to an optimally managed irrigated system is finally achieved in the fourth season of irrigation, and that the milksolids production levels and gross margins, excluding the variable costs of irrigation, achievable in this case are as shown in Table 6.5.

Table 6.5 Base Strategy Milksolids Production Levels and Gross Margins for an Irrigated System with a Three Year Transition Period.

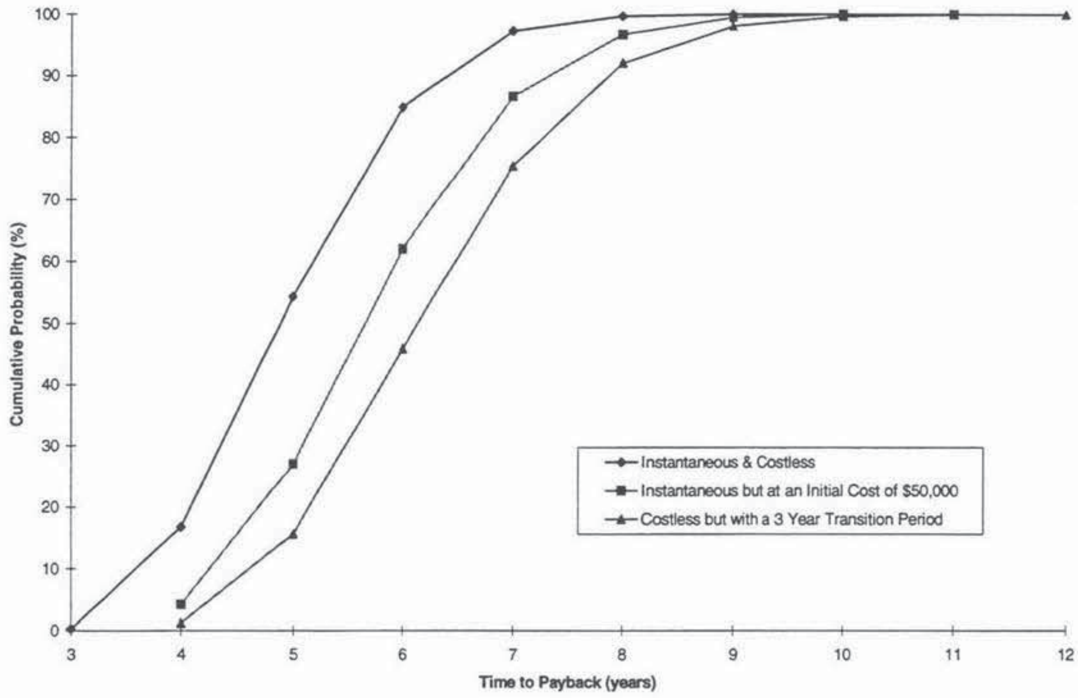
Season:- following an Investment in Irrigation	Total Milksolids Produced (kg)	Irrigated Base Strategy Gross Margin ($)
1	116649	338426
2	123044	361128
3	128603	380862
4 onwards	131517	391206

The probability distribution of the time to payback is obtained by randomly sampling, in each season of irrigation, from the relevant set of gross margins obtained by adjusting the base strategy gross margin for the variable costs of irrigation in the 37 seasons. The cumulative probability distribution of the time to payback, calculated at current prices and assuming a capital investment of $325,000, for this three year transition period is summarised in Table AIII.8 in Appendix III.

Figure 6.8 (see over) shows the probability distributions of the time to payback associated with different transition pathways to an optimally managed irrigated system.

Figure 6.8 indicates that if the transition to an optimally irrigated system cannot be achieved instantaneously and costlessly, then the probability that payback occurs between four and seven years decreases from 97% to 87% (assuming an instant transition cost of $50,000). If the option for a costless but extended transition over three years, as described above, is implemented then the probability of payback occurring between four and seven years falls even further to 75%. Thus, it seems that the best option for a farmer investing in irrigation may be to make the immediate move to an optimal system.

Figure 6.8 Probability Distributions of the Time to Payback for Different Methods of Achieving the Transition to an Irrigated System.



The above results, however, are based on speculative estimates of both the cost of an instantaneous transition, and the gross margins associated with an extended transition. The actual cost of achieving an instantaneous transition will depend on dairy cattle sale prices and on the percentage of the herd to be replaced. Similarly, the gross margins achievable during an extended transition period will depend on the herd average milksolids production response to irrigation, as well as the management policy employed, in each subsequent season of irrigation, and on how the required increase in stocking rate is achieved. The manner in which the transition to an optimal irrigated dairy production system might be best achieved is clearly an area for further research.

6.6 CONCLUSIONS

In this chapter the procedure by which the probability distribution of the time to payback for an investment in irrigation was derived for the Rukuhia case study farm has been described. The probability distributions of the time to payback, for different investment scenarios, indicate that, whilst the required capital cost of the investment and the interest rate payable on rural loans are significant in determining the time to payback, the milksolids payout is the single most important determinant of the likely time taken to payback an investment in irrigation.

CHAPTER 7

CONCLUSIONS

7.1 INTRODUCTION

In this chapter the methodology developed to study irrigation investment decisions is evaluated relative to the stated objectives of the study, and in terms of the strengths and weaknesses of the analysis. Areas toward which further research should be focused are identified, and the main conclusions from the Rukuhia case study are presented with recommendations for future research.

7.2 THE OBJECTIVES OF THE STUDY

"The primary objective of this study is to develop a methodology which allows an evaluation of the economic benefits of investment in irrigation on a dairy farm by taking into account the risk associated with variation in climatic conditions during the summer" (Section 1.2).

This objective was achieved in three stages:

- the models of pasture growth developed in Chapter 4 provided a satisfactory basis for the prediction of pasture growth rates and irrigation requirements for 37 seasons that differed in terms of summer rainfall.

- the use of the dairy LP model in conjunction with the pasture growth data enabled the gross margins achievable on both an irrigated and a non-irrigated dairy production system to be estimated for each of the 37 seasons (Chapter 5).

- these data were then used in the simulation procedure described in Chapter 6 to derive the probability distribution of the time taken to payback an investment in irrigation.

The probability distribution of the time to payback thus derived (summarised in Table 6.1 and Figure 6.2) clearly reflected the risk associated with variation in climatic conditions, and the consequent effects on pasture growth rates, during the summer. Thus the primary objective for the research was satisfactorily achieved.

The second objective of the study was "to discover how variation in key economic variables might impact upon the probability distribution of the time to payback" (Section 1.2). This objective was achieved in Section 6.4 by deriving probability distributions of the time to payback for different combinations of milksolids prices, interest rates, electricity costs, and capital investment costs.

Overall, the methodology developed was appropriate for the type of problem investigated and the data available. A basic framework for the economic evaluation of an investment in irrigation on a dairy production system has been developed which can now be applied in other dairying contexts.

7.3 STRENGTHS AND WEAKNESSES OF THE METHODOLOGY

The methodology is based on a series of models, thus the strengths and weaknesses of the methodology primarily result from advantages and disadvantages of the use of models rather than real-life experimentation (Section 3.2).

7.3.1 Strengths

Apart from the benefits of models when compared to the costs of real-life experiments, in terms of time, resources, and money; the major strengths of the optimisation modelling approach are seen as the "portability" and "flexibility" that it allows.

7.3.1.1 Portability

Obviously the pasture growth models developed in this thesis are relevant only to the Rukuhia region, however similar models could be developed for other dairying areas where irrigation data is available. Alternatively, simulation models of pasture growth e.g. GROW (Butler et al. 1990), might be able to be used, in conjunction with historic meteorological data, to provide the requisite data. Similarly LP model inputs can be readily modified. Pasture quality values and grazing management objectives and constraints can be defined, and the Brookes (1993) model used to generate "notional" cows that are typical of the milksolids production patterns, for the relevant area.

Thus, the methodology could be adapted to obtain estimates of the likely time to payback for an investment in irrigation in any dairying region of New Zealand.

7.3.1.2 Flexibility

First, the methodology is flexible in that varying degrees of "sophistication" in the model sub-components are possible. For instance, the work of Baars and Waller (1979) indicates that soil temperature has an effect, independent to that of soil moisture, on pasture production. Clearly, this effect could be incorporated, through regression analysis, into the models of pasture growth developed in Chapter 4. Similarly, as discussed in Section 5.4.4, estimates of the returns to irrigation could be improved by defining more notional cows in the LP model. Thus the level of complexity in the modelling analysis can easily be adjusted.

Second, extended versions of the LP model (McCall et al. 1996) may be used to obtain management strategies that include the use of greenfeed crops, purchased supplements, and/or the application of nitrogen fertiliser as options to combat summer pasture deficits on dryland pasture. In this respect the methodology can be used to evaluate the relative advantage of an investment in irrigation as an alternative to, or in conjunction with, a "higher-input" dairy production system.

Third, the methodology can be tailored to suit the circumstances of an individual farm and farmer. Farmers in the same geographical region may well have different motivations, attitudes and beliefs. For instance, the optimal base strategies obtained for the case study farm were based on the average pasture growth rates expected to occur during the period of irrigation. Particular farmers, however, make have differing attitudes toward risk. A "risk-averse" farmer is likely to choose a lower stocking rate and aim to minimise any losses in production that result from adverse summer conditions. On the other hand, a farmer with a more optimistic outlook may choose a higher stocking rate so that s/he is in a position to reap the benefits of above average summer pasture growth. The LP model may be used to obtain base strategies that reflect a farmer's preferences in this respect. Also, as previously mentioned, LP model input can readily be modified so that differing management targets and requirements can be included. Similarly, options that represent farmer's preferred management responses to variation in dryland pasture growth rates during the months of irrigation can be incorporated. Finally, the analysis can be based on the farmer's own expectations about the likely future values of the milksolids payout and the relevant rate of interest. Thus the methodology can be implemented in a manner that is consistent with achieving a high level of farmer participation.

Fourth, the methodology can easily be adapted to other costs and returns not considered in the case study analysis. For example, pasture "topping" costs, and perhaps, depending on the circumstances, the effects of a tax on water use, the explicit labour costs of say a waged worker, the cost of any additional capital investment required over and above the installation of the irrigation system, any tax deductions that may result from an investment in irrigation, and/or payment incentives for shoulder milk production, could all be incorporated if they were relevant to a particular system.

Finally, as demonstrated in Section 6.4, the methodology allows the effect of different prices and costs, on the probability distribution of the time to payback, to be assessed. Whilst only the variables deemed to be most relevant in determining the time to payback were investigated in the case study, the methodology can be used to evaluate the impact of changes in the cost of any of the factors of production.

7.3.2 Weaknesses

The major weakness of the methodology is its dependence on the assumptions made to simplify the real system to a level that can be modelled. The limitations of the LP model and the use of average, or expected, values have been discussed elsewhere in this thesis (Sections 3.4.5 and 5.4.4). Two other points should however also be noted. First, the assumption that the farm is in a *status quo*, or equilibrium, situation, so that the same base strategy is implemented every season, is likely to be unrealistic. In general, most farmers will be in the process of further developing their farm, perhaps through pasture renewal or fertiliser treatments, and will have medium to long term goals aimed at increasing productive capacity. Second, no matter how large the sample of representative seasons, the future is unknown, and, as a consequence, there will always be a degree of uncertainty about the reliability of predictions. Studying a significant time period, such as the 37 years for the Rukuhia case study, helps to mitigate this problem.

In conclusion, the flexibility permitted in model design means that more complex representations of the components of the real-life system can be developed (Section 7.3.1.2), and consequently the likely accuracy of the simulation of the time to payback can be increased. There is, however, a trade-off between the gains from improved estimates and the costs involved, in terms of the time and money, in achieving them.

7.3 FURTHER WORK

Two major areas were identified for further research. First, the optimal management of an irrigated dairy production system, and second, the manner in which the transition from a dryland system to an optimally managed irrigated system may best be achieved. The dairy LP model, in tandem with the Brookes (1993) model, may be used to investigate alternative options and provide some insights in these areas. Data may also soon be forthcoming from the recent Northland irrigation experience.

Currently, considerable research is aimed the use of nitrogen fertiliser and concentrate supplements to increase output (McCallum et al 1994; Penno et al 1996). Similarly, greenfeed crops have become increasingly popular as a means providing high quality feed during the summer in many dairying regions of New Zealand (Daniels 1995). The methodology should therefore be evaluated in the context of such "higher-input" dairy production systems.

Finally, the methodology needs to be applied and evaluated under different climatic conditions, especially in the Northland region.

7.4 MAIN CONCLUSIONS AND RECOMENDATIONS

The results obtained from the Rukuhia case study are encouraging. At current (1995/6) prices a $325,000 investment in irrigation at Rukuhia is estimated to take somewhere between three and ten years to repay its cost, with a 97% probability that payback will occur in the next four to seven seasons (Section 6.3). The analyses of Sections 6.4 and 6.5 indicate that, whilst interest rates, capital investment costs, and the manner in which the transition to an irrigated production system is achieved are important, the milksolids payout is the most significant factor in determining the likely time to payback.

Recent changes in the international dairy scene mean that the market for New Zealand dairy products is growing. This is expected to result in increasing returns to New Zealand dairy farmers, both in total dollars and in the milksolids payout (Marshall 1995). Whilst the actual gains from the market will depend on the exchange rates that prevail in the future, the outlook for New Zealand's dairy industry is positive and conditions seem ideal to take full advantage of the economic benefits of an investment in irrigation.

Finally, New Zealand's natural competitive advantage is in pasture (Hurley 1995), and it is therefore recommended that a farmer considering the move to a higher-input/higher-output dairy production system should at least investigate the benefits of irrigation as a possible alternative.

APPENDIX I

APPENDIX TO CHAPTER 4 :

"THE PASTURE MODELS"

AI.1 IRRIGATION REQUIREMENTS BETWEEN 1946 AND 1984

Table AI.1 shows the predicted monthly irrigation requirement (mm/ha/month) from October to March and the total amount of irrigation required for each of the seasons between 1946/7 and 1983/4.

Table AI.1 Predicted Irrigation Requirements.

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
1946/7	0.0	11.8	70.3	86.2	103.6	51.6	30.0	353.5
1947/8	0.0	63.6	107.4	82.9	68.3	70.7	30.0	422.9
1948/9	0.0	0.0	117.1	108.5	66.3	24.4	30.0	346.3
1949/50	9.3	34.9	94.7	108.0	20.6	98.1	30.0	395.6
1950/1	0.0	0.0	123.4	51.1	85.6	104.9	30.0	395.0
1951/2	0.0	0.0	73.9	89.7	50.0	99.4	30.0	343.0
1952/3	0.0	0.0	63.5	18.4	96.0	55.2	30.0	263.1
1953/4	6.5	26.5	107.9	136.2	101.3	0.0	30.0	408.4
1954/5	56.8	49.1	0.0	127.3	98.3	86.9	30.0	448.4
1955/6	0.0	38.7	83.8	105.0	81.3	90.2	30.0	429.0
1956/7	0.0	0.6	25.9	128.1	120.9	0.0	30.0	305.5
1957/8	0.0	31.1	89.4	113.1	0.0	86.2	30.0	349.8
1958/9	14.9	0.0	0.0	38.9	60.4	54.7	30.0	198.9
1959/60	0.0	63.1	100.6	86.2	0.0	22.9	30.0	302.8
1960/1	38.3	38.2	64.5	87.2	90.1	89.7	30.0	438.0
1961/2	0.0	68.4	87.1	56.7	80.8	0.0	30.0	323.0
1962/3	0.0	0.0	23.4	121.0	97.8	54.1	30.0	326.3
1963/4	60.1	30.8	95.2	91.8	31.5	0.0	30.0	339.4
1964/5	0.0	49.1	50.0	28.8	0.0	51.4	30.0	209.3
1965/6	41.3	4.4	69.8	14.0	0.0	61.8	30.0	221.3
1966/7	29.9	0.0	41.1	95.1	0.0	0.0	30.0	196.1
1967/8	73.1	0.0	36.1	108.5	91.2	98.9	30.0	437.8
1968/9	0.0	30.8	15.5	45.8	36.3	92.5	30.0	250.9
1969/70	40.0	57.0	27.2	137.2	115.8	20.9	30.0	428.1
1970/1	0.0	58.3	124.4	83.0	5.6	80.3	30.0	381.6
1971/2	0.0	0.0	88.2	97.0	89.6	0.0	30.0	304.8
1972/3	0.0	30.3	69.2	95.0	128.6	80.3	30.0	433.4
1973/4	11.6	0.0	121.2	145.0	72.6	75.3	30.0	455.7
1974/5	8.6	80.3	44.2	0.0	113.6	40.3	30.0	317.0
1975/6	0.0	27.3	101.2	14.0	50.6	83.3	30.0	306.4
1976/7	0.0	29.3	80.2	23.0	107.6	94.3	30.0	364.4
1977/8	0.0	23.3	37.2	121.0	107.6	108.3	30.0	427.4
1978/9	36.6	0.0	69.2	136.0	0.0	0.0	30.0	271.8
1979/80	0.0	0.0	42.2	0.0	62.6	18.3	30.0	153.1
1980/1	44.6	0.0	72.2	95.0	87.6	56.3	30.0	385.7
1981/2	25.6	24.3	80.2	97.0	67.6	0.0	30.0	324.7
1982/3	0.0	69.3	99.2	78.0	115.6	73.3	30.0	465.4
1983/4	0.0	41.3	111.2	50.0	49.6	25.3	30.0	307.4
Mean	13.1	25.8	71.3	81.6	67.2	53.9	30.0	342.9
Coefficient of Variation(%)	158.2	97.3	48.5	50.9	60.4	69.1	0.0	23.8

AI.2 DRYLAND SUMMER PASTURE GROWTH RATES (1946 TO 1984)

Table AI.2 shows predicted pasture growth rates (kgDM/ha/day) on non-irrigated pasture for January, February, and March in each of the seasons between 1946/7 and 1983/4, with the exception of the 1957/8 season. The total amount of pasture dry matter grown per hectare over this three month period is also shown.

Table AI.2 Predicted Growth Rates on Non-Irrigated Pasture.

Season	Jan	Feb	Mar	Total DM
1946/7	31.3	13.3	17.0	1869.7
1947/8	24.3	24.4	18.7	2016.2
1948/9	14.4	19.8	30.7	1952.5
1949/50	19.3	33.4	20.7	2175.2
1950/1	30.6	25.7	7.0	1885.2
1951/2	29.4	28.4	14.9	2168.5
1952/3	53.6	29.2	17.5	3021.7
1953/4	7.8	3.8	47.0	1805.2
1954/5	34.7	6.5	9.1	1539.8
1955/6	22.6	16.0	11.4	1502.0
1956/7	27.9	-0.4	28.4	1734.1
1958/9	69.0	35.8	24.2	3891.6
1959/60	24.8	52.4	48.6	3742.6
1960/1	32.2	17.0	9.9	1781.1
1961/2	36.7	26.0	48.2	3359.9
1962/3	30.6	7.9	17.2	1703.0
1963/4	24.2	33.4	48.3	3182.7
1964/5	53.3	70.7	45.7	5048.6
1965/6	53.6	64.6	37.4	4629.8
1966/7	34.8	65.0	74.4	5205.2
1967/8	31.8	12.4	7.4	1562.4
1968/9	55.5	41.3	19.2	3472.1
1969/70	24.9	-0.7	22.4	1446.7
1970/1	20.6	42.9	27.9	2704.7
1971/2	24.1	15.2	59.6	3020.3
1972/3	28.8	4.1	5.2	1168.8
1973/4	2.3	10.5	16.8	886.1
1974/5	70.5	32.4	17.9	3647.6
1975/6	46.8	43.5	18.8	3251.6
1976/7	48.6	24.8	5.5	2371.5
1977/8	27.7	5.0	2.0	1060.7
1978/9	16.2	54.1	64.4	4013.4
1979/80	69.9	46.9	32.9	4500.0
1980/1	28.2	16.2	18.7	1907.5
1981/2	25.8	21.7	38.7	2607.1
1982/3	27.6	11.4	9.3	1463.1
1983/4	33.6	36.5	33.5	3102.1
Mean	33.5	26.8	26.4	2605.4
Coefficient of Variation(%)	48.5	70.6	68.1	44.4

APPENDIX II

APPENDIX TO CHAPTER 5 :

"THE DAIRY FARM MODELS"

AII.1 DAIRY PRODUCTION LP MODEL INPUT DATA

Table AII.1 shows the average ME value of both dryland and irrigated pasture, the post-grazing residual, the minimum and maximum pre-grazing pasture cover constraints, and the maximum cow intake assumed to apply in each fortnightly period of the year.

Table AII.1 Fortnightly Data for the LP Model.

Two Weekly Period	Start Date	ME Content of Dryland Pasture (Mj/kgDM)	ME Content of Irrigated Pasture (Mj/kgDM)	Post-Grazing Residual DM (kgDM/ha)	Maximun Pre-Grazing Pasture Cover (kgDM/ha)	Minimum Pre-Grazing Pasture Cover (kgDM/ha)	Maximum DM Intake (kg/cow/day)
1	1-Jul	11.5	11.5	900	3600	2600	13.5
2	15-Jul	11.5	11.5	1000	3600	2600	13.5
3	29-Jul	11.4	11.4	1100	3600	2400	14.0
4	12-Aug	11.4	11.4	1200	3600	2400	16.0
5	26-Aug	11.3	11.3	1300	3600	2200	17.1
6	9-Sep	11.3	11.3	1500	3300	2000	17.5
7	23-Sep	11.2	11.3	1600	3000	2400	18.0
8	7-Oct	11.2	11.3	1700	3000	2500	18.0
9	21-Oct	11.1	11.3	1800	3000	2500	18.0
10	4-Nov	11.0	11.3	1800	3000	2500	18.0
11	18-Nov	11.0	11.3	1900	3000	2500	17.0
12	2-Dec	10.8	11.3	2100	3300	2500	16.5
13	16-Dec	10.8	11.3	2200	3600	2300	16.5
14	30-Dec	10.6	11.3	2300	3800	2300	16.0
15	13-Jan	10.6	11.3	2300	4000	2300	16.0
16	27-Jan	10.5	11.3	2300	4000	2300	16.0
17	10-Feb	10.5	11.3	2300	4000	2300	16.0
18	24-Feb	10.6	11.3	2300	4000	2300	16.0
19	10-Mar	10.6	11.3	2200	4000	2300	15.5
20	24-Mar	10.7	11.3	2050	3800	2300	15.0
21	7-Apr	10.9	11.3	1900	3600	2000	14.0
22	21-Apr	11.0	11.3	1600	3600	2000	14.0
23	5-May	11.2	11.3	1300	3600	2000	13.5
24	19-May	11.2	11.3	1150	3600	2000	13.0
25	2-Jun	11.4	11.4	1000	3600	2000	12.0
26	16-Jun	11.4	11.4	900	3600	2000	12.0

AII.2 GROSS MARGINS FOR THE IRRIGATED SYSTEM

Table AII.2 shows the estimated pumping, maintenance, and extra fertiliser costs associated with irrigating pasture on the case study farm in the 37 seasons. Gross margins for each season are calculated by subtracting the sum of these costs from the base strategy gross margin of $391206.

Table AII.2 Cost Data and Gross Margins for Irrigated Pasture Across 37 Seasons ($).

Season	Pumping Cost	Maintainence Cost	Fertiliser Cost	Total Cost	Gross Margin
1946/7	5050	1000	6331	12381	378825
1947/8	6041	1000	6331	13372	377834
1948/9	4947	1000	6331	12278	378928
1949/50	5651	1000	6331	12982	378224
1950/1	5643	1000	6331	12974	378232
1951/2	4900	1000	6331	12231	378975
1952/3	3759	1000	6331	11089	380117
1953/4	5834	1000	6331	13165	378041
1954/5	6406	1000	6331	13736	377469
1955/6	6129	1000	6331	13459	377747
1956/7	4364	1000	6331	11695	379511
1958/9	2841	1000	6331	10172	381034
1959/60	4326	1000	6331	11656	379549
1960/1	6257	1000	6331	13588	377618
1961/2	4614	1000	6331	11945	379261
1962/3	4661	1000	6331	11992	379214
1963/4	4849	1000	6331	12179	379027
1964/5	2990	1000	6331	10321	380885
1965/6	3161	1000	6331	10492	380714
1966/7	2801	1000	6331	10132	381074
1967/8	6254	1000	6331	13585	377621
1968/9	3584	1000	6331	10915	380291
1969/70	6116	1000	6331	13446	377759
1970/1	5451	1000	6331	12782	378424
1971/2	4354	1000	6331	11685	379521
1972/3	6191	1000	6331	13522	377684
1973/4	6510	1000	6331	13841	377365
1974/5	4529	1000	6331	11859	379347
1975/6	4377	1000	6331	11708	379498
1976/7	5206	1000	6331	12536	378669
1977/8	6106	1000	6331	13436	377769
1978/9	3883	1000	6331	11214	379992
1979/80	2187	1000	6331	9518	381688
1980/1	5510	1000	6331	12841	378365
1981/2	4639	1000	6331	11969	379237
1982/3	6649	1000	6331	13979	377227
1983/4	4391	1000	6331	11722	379484
Mean	4896	1000	6331	12227	378979
Coefficient of Variation (%)	24.15	0	0	9.67	0.31

AII.3 GROSS MARGINS FOR THE NON-IRRIGATED SYSTEM

Table AII.3 shows the estimated milksolids production levels (kg) and gross margins ($) achievable on the non-irrigated case study farm in the 37 seasons. Also included for the relevant seasons are the total amounts (kg) of bought-in supplements (silage at 30c/kgDM and concentrated feed at 45c/kgDM) or the amount of harvested silage which was not required (valued at 28c/kgDM).

Table AII.3 Milksolids Production and Gross Margins for Non-Irrigated Pasture Across 37 Seasons.

Season	Milksolids	Silage Bought	Concentrates	Surplus Silage	Gross Margin
1946/7	90583				263489
1947/8	92593				270625
1948/9	79937				225696
1949/50	94676				278020
1950/1	91041				265114
1951/2	94623				277833
1952/3	102643				306302
1953/4	72814	39266	7154		186195
1954/5	83480				238275
1955/6	82015				233072
1956/7	77806				218132
1958/9	103893			21294	317126
1959/60	103893			33244	320712
1960/1	89635				260124
1961/2	103893			11116	314073
1962/3	85563				245669
1963/4	103496				309331
1964/5	103893			43562	323807
1965/6	103893			51067	326058
1966/7	103893			44231	324008
1967/8	84420				241610
1968/9	103893			16308	315631
1969/70	72814	2013			202779
1970/1	100515				298749
1971/2	90877				264534
1972/3	74349				205857
1973/4	72814	30684	15206		184975
1974/5	103529				309449
1975/6	103888				310721
1976/7	97031				286378
1977/8	72814	2838			199615
1978/9	103893			3524	311795
1979/80	103893			49819	325684
1980/1	91155				265519
1981/2	99819				296278
1982/3	81338				230671
1983/4	103112				307967
Mean	92552				271942
Coefficient of Variation (%)	12.22				16.21

APPENDIX III

APPENDIX TO CHAPTER 6 :

"THE TIME TO PAYBACK"

AIII.1 VARIATION IN THE MILKSOLIDS PAYOUT

Table AIII.1 shows the returns to irrigation for 37 seasons calculated at different milksolids payouts, based on the milksolids production levels of Table 5.7. Table AIII.2 (see over) shows the resultant cumulative probability distribution of the time taken to payback an investment in irrigation for each milksolids price (assuming an interest rate of 10.5% and a capital investment cost of $325,000).

Table AIII.1 The Returns to Irrigation at Various Milksolids Prices ($/kg) Across 37 Seasons.

Season	$2.00	$2.30	$2.50	$3.00	$3.55	$4.00
1946/7	51889	64169	72356	92823	115336	133756
1947/8	46877	58554	66339	85801	107209	124725
1948/9	73284	88758	99073	124863	153232	176443
1949/50	43101	54153	61521	79942	100204	116782
1950/1	50381	62523	70619	90857	113118	131333
1951/2	43958	55026	62404	80851	101142	117744
1952/3	29060	37722	43497	57934	73815	86807
1953/4	100856	118467	130208	159559	191846	218262
1954/5	64738	79149	88756	112775	139194	160811
1955/6	67947	82797	92698	117449	144675	166950
1956/7	78128	94241	104983	131838	161379	185549
1958/9	21090	29377	34902	48714	63908	76338
1959/60	16020	24308	29833	43645	58837	71269
1960/1	52578	65142	73518	94459	117494	136341
1961/2	22370	30658	36182	49994	65188	77618
1962/3	62317	76103	85293	108270	133545	154223
1963/4	26264	34670	40274	54284	69696	82305
1964/5	14261	22548	28073	41885	57078	69509
1965/6	11838	20125	25650	39462	54656	67086
1966/7	14249	22536	28061	41873	57066	69497
1967/8	63011	77140	86559	110108	136011	157204
1968/9	21843	30130	35655	49467	64660	77091
1969/70	83991	101602	113343	142694	174980	201397
1970/1	31623	40923	47123	62624	79675	93625
1971/2	51996	64188	72316	92636	114987	133275
1972/3	83216	100367	111800	140384	171827	197553
1973/4	101401	119012	130752	160104	192390	218806
1974/5	26517	34913	40511	54505	69898	82492
1975/6	25952	34241	39766	53581	68777	81209
1976/7	38838	49184	56081	73324	92291	107810
1977/8	87166	104776	116517	145868	178154	204571
1978/9	25380	33667	39192	53004	68197	80628
1979/80	13187	21474	26999	40811	56004	68435
1980/1	50285	62394	70466	90647	112846	131009
1981/2	33828	43337	49676	65525	82959	97222
1982/3	68779	83833	93869	118958	146556	169136
1983/4	27490	36011	41692	55894	71517	84299
Mean	46641	58330	66123	85606	107036	124571
Coefficient of Variation (%)	55.34	49.99	47.48	43.22	40.34	38.73

Table AIII.2 The Cumulative Probability Distributions of the Time to Payback for Different Milksolids Prices ($/kg).

Time to Payback (years)	$2.00	$2.30	$2.50	$3.00	$3.55	$4.00
3					0.29	4.01
4				1.92	16.73	38.59
5		0.17	1.06	16.66	54.30	79.74
6	0.07	1.83	7.50	45.07	84.84	96.80
7	0.36	7.76	22.06	72.91	97.28	99.88
8	1.78	19.32	43.05	90.23	99.71	100.00
9	4.81	35.05	62.65	97.13	99.99	
10	10.79	52.13	78.23	99.35	100.00	
11	18.68	66.79	89.03	99.90		
12	27.65	78.13	94.37	99.98		
13	37.64	86.29	97.15	100.00		
14	46.92	91.55	98.72			
15	55.89	94.89	99.49			
16	63.82	97.10	99.77			
17	69.94	98.32	99.93			
18	75.45	98.96	99.96			
19	79.75	99.39	99.97			
20	83.69	99.62	99.99			
21	86.36	99.72	100.00			
22	88.57	99.85				
23	90.44	99.90				
24	91.95	99.96				
25	93.10	99.97				
26	94.03	99.98				
27	94.85	99.98				
28	95.38	99.99				
29	95.86	99.99				
30	96.29	99.99				
31	96.67	99.99				
32	96.97	99.99				
33	97.22	99.99				
34	97.43	99.99				
35	97.57	100.00				
36	97.76					
37	97.86					
38	98.02					
39	98.15					
40	98.25					
41	98.32					
42	98.39					
43	98.51					
44	98.59					
45	98.63					
46	98.65					
47	98.67					
48	98.68					
49	98.71					
50+	100.00					

AIII.2 VARIATION IN INTEREST RATES

Table AIII.3 shows the cumulative probability distributions of the time taken to payback an investment in irrigation for three different rural lending rates (assuming a milksolids payout of $3.55 and a capital investment cost of $325,000).

Table AIII.3 The Cumulative Probability Distributions of the Time to Payback for Different Interest Rates.

Time to PayBack (years)	8%	10.50%	15%
3	0.99	0.29	
4	21.96	16.73	8.18
5	64.11	54.30	36.31
6	91.28	84.84	68.10
7	99.11	97.28	88.09
8	99.97	99.71	96.41
9	100.00	99.99	99.39
10		100.00	99.89
11			100.00

AIII.3 VARIATION IN ELECTRICITY COSTS

Table AIII.4 (see over) shows the effect of increases in the price of electricity, and presents the cumulative probability distributions of the time taken to payback an investment in irrigation for four different hourly pumping costs (assuming a milksolids payout of $3.55, an interest rate of 10.5%, and a capital investment cost of $325,000).

Table AIII.4 The Cumulative Probability Distributions of the Time to Payback for Different Pumping Costs.

Time to Payback (years)	$50 per hour	$60 per hour	$75 per hour	$100 per hour
3	0.29	0.32	0.30	
4	16.73	15.81	14.15	11.95
5	54.30	52.17	49.29	44.92
6	84.84	83.32	81.39	77.35
7	97.28	96.88	96.20	94.60
8	99.71	99.64	99.58	99.23
9	99.99	99.98	99.97	99.91
10	100.00	100.00	100.00	100.00

AIII.4 VARIATION IN THE CAPITAL INVESTMENT COST

Table AIII.5 shows the cumulative probability distributions of the time taken to payback an investment in irrigation for differing levels of the required capital investment cost (assuming a milksolids payout of $3.55 and an interest rate of 10.5%).

Table AIII.5 The Cumulative Probability Distributions of the Time to Payback for Different Capital Investment Costs.

Time to Payback (years)	$280,000	$325,000	$375,000	$420,000
3	4.61	0.29		
4	38.83	16.73	4.19	0.70
5	78.63	54.30	27.00	10.90
6	95.97	84.84	62.01	38.31
7	99.74	97.28	86.65	67.97
8	100.00	99.71	96.66	88.23
9		99.99	99.51	96.39
10		100.00	99.99	99.33
11			100.00	99.90
12				99.98
13				100.00

AIII.5 DIFFERENT COMBINATIONS OF MILKSOLIDS PAYOUT, INTEREST RATE, AND CAPITAL INVESTMENT COST

Table AIII.6 repeats, for convenience, the different combinations of milksolids payout, interest rate, and capital investment costs considered in Section 6.4.5. Table AIII.7 (see over) shows the cumulative probability distribution of the time taken to payback an investment in irrigation for each of these differing investment scenarios.

Table AIII.6 The Different Combinations of Milksolids Payout, Interest Rate and Capital Investment Cost.

Scenario	1	2	3	4	5	6
Milksolids Payout ($/kg)	4.00	4.00	3.00	2.30	2.30	2.30
Interest Rate (%)	8.0	8.0	11.5	11.5	15.0	15.0
Capital Cost ($)	280,000	325,000	325,000	325,000	375,000	420,000

Table AIII.7 The Cumulative Probability Distributions of the Time to Payback for Different Combinations of Milksolids Payout, Interest Rate and Capital Investment Cost.

Time to Payback (years)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
3	17.56	5.53				
4	70.12	45.50	1.39			
5	96.39	86.14	13.88			
6	99.98	98.64	40.10	0.18		
7	100.00	99.99	67.74	1.37	0.07	
8		100.00	86.16	4.64	0.33	0.01
9			95.14	10.41	1.06	0.08
10			98.62	17.32	2.77	0.26
11			99.70	25.47	5.00	0.71
12			99.94	33.81	8.28	1.47
13			100.00	42.15	11.88	2.31
14				49.33	16.04	3.38
15				55.77	20.52	4.75
16				60.99	24.77	6.21
17				65.46	28.97	7.76
18				69.56	32.70	9.28
19				73.18	36.10	10.79
20				75.91	39.03	12.19
21				78.24	41.97	13.39
22				79.94	44.36	14.76
23				81.61	46.35	16.02
24				82.93	48.08	17.16
25				84.07	49.61	18.10
26				85.04	50.91	19.11
27				85.61	52.08	19.98
28				86.33	53.18	20.76
29				86.83	54.15	21.36
30				87.21	55.04	21.90
31				87.66	55.70	22.33
32				88.09	56.10	22.83
33				88.39	56.61	23.21
34				88.63	57.07	23.58
35				88.84	57.50	23.78
36				89.00	57.81	24.06
37				89.16	58.14	24.20
38				89.26	58.39	24.45
39				89.42	58.54	24.69
40				89.48	58.75	24.86
41				89.61	58.91	24.97
42				89.67	58.99	25.05
43				89.76	59.06	25.17
44				89.79	59.14	25.36
45				89.80	59.22	25.44
46				89.86	59.29	25.50
47				89.90	59.32	25.56
48				89.91	59.40	25.63
49				89.94	59.47	25.68
50+				100.00	100.00	100.00

AIII.6 DIFFERENT TRANSITION PATHWAYS TO AN IRRIGATED SYSTEM

Table AIII.8 shows the cumulative probability distributions of the time taken to payback an investment in irrigation for the different transition pathways to an optimally managed irrigated dairy production system discussed in Section 6.5 (assuming a milksolids payout of $3.55, an interest rate of 10.5%, and a capital investment cost of $325,000).

Table AIII.8 The Cumulative Probability Distributions of the Time to Payback for Different Methods of Achieving the Transition to an Irrigated System.

Time to Payback (years)	Instantaneous & Costless	Instantaneous, but at an Initial Cost of $50,000	Costless, but with a 3 Year Transition Period
3	0.29		
4	16.73	4.19	1.23
5	54.30	27.00	15.62
6	84.84	62.01	45.75
7	97.28	86.65	75.40
8	99.71	96.66	92.05
9	99.99	99.51	98.09
10	100.00	99.99	99.65
11		100.00	99.97
12			100.00

BIBLIOGRAPHY

A

Agricultural Research Council. 1980. *The nutrient requirements of ruminant livestock*. Farnham Royal, Commonwealth Agricultural Bureaux.

Ahlborn, G. and Bryant, A. M. 1992. *Production, economic performance and optimum stocking rates of Holstein-Friesian and Jersey cows*. Proceedings of the New Zealand Society of Animal Production **52**: 7-9.

Anderson, J. R.; Dillon, J. L.; Hardaker, J. B. 1977. *Agricultural Decision Analysis*. Iowa State University Press.

B

Baars, J. A. and Coulter, J. D. 1974. *Soil moisture and its influence on pasture production in the Waikato*. Proceedings of the New Zealand Grassland Association **35**: 197-203.

Baars, J. A. and Waller, J. E. 1979. *Effects of temperature on pasture production*. Proceedings Agronomy Society of New Zealand **9**: 101-104.

Bird, P. 1993. *Irrigation as an option for Northland*. Dairy Exporter, May 1993: 37-39.

Bosch Irrigation Ltd. Undated. *Long Lateral Irrigation System* - Advertising Material. Bosch Irrigation Limited, P.O. Box 1420, Whangarei, New Zealand.

Brookes, I. M.; Morris, S. T.; Parker, W. J. 1993. *Computer spreadsheets for predicting feed requirements and feed budgeting*. Proceedings of the New Zealand Grassland Association **55**: 209-210.

Brown, G. R. L. 1975. *Management of irrigation farms under high stocking*. Proceedings of the New Zealand Grasslands Association **36**: 45-53.

Butler, B. M.; Matthew, C.; Heerdegen, R. G. 1990. *The greenhouse effect - what consequences for seasonality of pasture production*. Weather and Climate **10**: 55-60.

Bywater, A. C. and Cacho, O. J. 1994. *Use of simulation models in research*. Proceedings of the New Zealand Society of Animal Production **54**: 403-412.

C

Currie, J. R. 1955. *A review of fifty years' farm management research*. Journal of Agricultural Economics **11**: 350-360.

D

Daniels, N. 1995. *Summer Forage Crop Survey*. Dairyfarming Annual **47**: 32-39.

Dent, J. B. and Anderson, J. R. 1971. *Systems Analysis in Agricultural Management*. John Wiley & Sons Australasia Pty. Ltd.

Department of Agriculture New South Wales. 1977. *Animal production from irrigated pastures and forage crops in New South Wales*. Technical Bulletin **15**.

During, C.; Mitchell, K. J.; Lancaster, R. J. 1970. In (Ed. A. G. Campbell) *New Zealand Beef Production, Processing and Marketing*: 236-238. New Zealand Institute of Agricultural Science.

F

Freer, M. 1960. *The utilisation of irrigated pastures by dairy cows. II. The effect of stocking rate*. Journal of Agricultural Science (Cambridge) **54**: 243-256.

G

Gradwell, M. W. 1968. *The moisture-holding properties of Waikato soils and methods of their determination*. New Zealand Journal of Agricultural Research **11**: 631-654.

H

Holmes, C. W.; Brookes, I. M.; Ritchie, W. R. 1994. *The potential and cost of pasture silage as a supplement for dairy cattle.* Dairyfarming Annual **46**: 158-166.

Howse, S. W.; Isherwood, P.; Miller, D. B.; Wells, J. L.; Riddick, C. M.; Thomson, N. A.; Clark, D. A. 1996. *Pasture silage in New Zealand - targets and current practice*. Proceedings of the New Zealand Grassland Association **57**: 157-160.

Hurley, C. 1995. *Higher milk prices higher profits or higher costs? Lessons for New Zealand from developments in the Irish dairy industry*. Dairyfarming Annual **47**: 84-90.

Hutton, J. B. 1974. *The effect of irrigation on forage yield, dairy cow production, and intake under intensive grazing conditions in New Zealand*. Proceedings of the 19th Dairy Congress. New Delhi. 1E: 73-74.

Hutton, J. B. 1978. *Dairy cattle management, irrigation potential in South Auckland*. Proceedings of the Ruakura Farmer's Conference. AgLink, **30** RFC: FPP 167.

J

Jensen, H. R. 1977. *Farm management and production economics, 1946-70*. In (Ed. L.R. Martin) *A Survey of Agricultural Economics Literature*. Volume 1: *Traditional Fields of Agricultural Economics, 1940s to 1970s*: 3-89. Minneapolis, University of Minnesota Press.

Jones, P. 1989. *Agricultural applications of expert systems concepts.* Agricultural Systems **31**: 3-18.

Journeaux, P. R. 1996. *Long term outlook - should I stay in beef cattle?* Proceedings of the Central Districts Sheep and Beef Cattle Farmers Conference **5**: 9-14.

L

Larcombe, M. T. 1989. *The effects of manipulating reproduction on the productivity and profitability of dairy herds which graze pasture*. Unpublished PhD Thesis. University of Melbourne.

Lincoln University. 1995. (Ed. J. R. Oliver and E. S. Burtt) *Financial Budget Manual 1995*. Lincoln University, Canterbury, New Zealand.

M

MAF. 1984. *Fertiliser Recommendations for Pastures and Crops in New Zealand*. (Comp. I. S. Cornforth & A. G. Sinclair). Second revised edition. New Zealand Ministry of Agriculture and Fisheries.

Marshall, K. R. 1995. *What is the potential size of the dairy industry? Markets.* Dairyfarming Annual **47**: 73-75.

McAneney, K. J.; Judd, M. J.; Weeda, W. C. 1982. *Loss in monthly pasture production resulting from dryland conditions in the Waikato*. New Zealand Journal of Agricultural Research **25**: 151-156.

McCall, D. G.; Townsley, R. J.; Bircham, J. S.; Sheath, G. W. 1986. *The interdependence of animal intake, pre and post grazing pasture mass and stocking density*. Proceedings of the New Zealand Grassland Association **47**: 255-262.

McCall, D. G.; Marshall, P. R.; Johns, K. L. 1991. *An introduction to STOCKPOL: A decision support model for livestock farmers*. Proceedings of the International Conference on Decision Support Systems for Resource Management, Texas A & M University: 27-30.

McCall, D. G. and Sheath, G. W. 1993. *Development of intensive grasslands systems - from science to practice*. In (Ed. M.J. Baker) *Grasslands For Our World*: 468-476. SIR Publishing, Wellington, New Zealand.

McCall, D. G. and Tither, P. M. 1993. *Use of the Stockpol computer decision-support program in commercial consultancy*. Proceedings of the New Zealand Grassland Association **55**: 207-208.

McCall, D. G.; Sheath, G. W.; Pleasants A. B. 1994. *The role of systems research in animal science*. Proceedings of the New Zealand Society of Animal Production **54**: 417-421.

McCall, D. G.; Clark, D. A.; Stachurski, L. J.; Penno, J. W.; Bryant, A. M.; Ridler, B. J. 1996. *Contrasting feed-flow and economic characteristics of optimised dairy grazing systems in Northeast USA and New Zealand. I. Description and evaluation of a model*. Journal of Dairy Science (submitted).

McCallum, D.; Thomson, N.; Clough, J. 1994. *Meal feeding at high stocking rates at Waimate West demonstration farm*. Dairyfarming Annual **46**: 50-54.

Moller, S. N.; Parker, W. J.; Edwards, N. J. 1996. *Within-year variation in pasture quality has implications for dairy cow nutrition*. Proceedings of the New Zealand Grassland Association **57**: 173-177.

N

Nix, J. S. 1979. *Farm management: The state of the art (or science)*. Journal of Agricultural Economics **30**: 277-291.

NZAEI 1985. *A model of hill and high country pastoral systems for evaluation of irrigation investment*. New Zealand Agricultural Engineering Institute, Project Report Number **40**.

P

Parker, W. J.; Gray, D. I.; Lockhart, J. C.; Townsley, R. J. 1994. *Farm management research in New Zealand and its contribution to animal production*. Proceedings of the New Zealand Society of Animal Production **54**: 357-362.

Penno, J. W.; McDonald, K. A.; Bryant, A. M. 1994. *1.75t Milksolids per hectare - year 1*. Proceedings of the Ruakura Farmers Conference **46**: 75-79.

Penno, J. W.; Bryant, A. M.; McDonald, K. A. 1996. *Effect of nitrogen fertiliser and supplements on pasture production and milksolids yield from dairy farm systems*. Proceedings of the New Zealand Society of Animal Production **56**: 236-238.

R

Rae, A. N. 1994. *Agricultural Management Economics. Activity Analysis and Decision Making*. CAB International.

S

Schultz, T. W. 1939. *Theory of the firm and farm management research*. Journal of Farm Economics **21**: 570-586.

Sheath, G. W. and Boom, R. C. Unpublished.

Smetham, M. L. 1973. *Grazing Management*. In (Ed. R. H. M. Langer) *Pastures and Pasture Plants*. A. H. & A. W. Reed Ltd.

Spedding, C. R. W. 1979. *An Introduction to Agricultural Systems*. Applied Science Publishers Ltd. London.

W

Watters, A. F. 1995. *Dairying in the Tararua district - area and farm statistics*. Dairyfarming Annual **47**: 1-5.

Watters, A. F. and Power, M. 1994. *Managing a growing milk supply*. Dairyfarming Annual **46**: 5-12.

Weeda, W. C. 1965. *The effects of frequency and severity of grazing by cattle on the yield of irrigated pasture*. New Zealand Journal of Agricultural Research **8**: 1060-1069.

Wright, A. 1971. *Farming systems, models and simulation*. In (Ed. J.B. Dent & J.R. Anderson) *Systems Analysis in Agricultural Management*: 17-33. John Wiley & Sons Australasia Pty. Ltd.

Wright, A. and Baars, J. A. 1976. *A simulation model of a grazing system with particular reference to soil-plant-climate relationships*. Symposium of Meteorology and Food Production: 183-196. Wellington, New Zealand Meteorological Service.