University of Southern Queensland
Faculty of Engineering and Surveying

Comparison of Life Cycle Energy Consumption of Alternative Irrigation Systems

A dissertation submitted by

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Abstract

In the modern agricultural industry there are many different types of available irrigation systems to meet different needs and many are used inefficiently. The purpose following research project is to perform an in-depth and comprehensive comparison and examination on a range of different irrigation methods including; Border Check, Centre-Pivot and Sub-Surface Drip Systems. Based on past research and studies completed on the subject, this project has determined which is the most suitable and efficient irrigation method, in terms of life cycle energy use, and operational water use. The outcome is to determine, without reservation, which type of irrigation is overall the most energy efficient, cost effective and economical in terms of water consumption.

Keywords: Agriculture, irrigation, comparison, efficient.

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Limitations of Use

Professor R Smith
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Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in the dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Sunny Colin Jacobs

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Abbreviations

GJ: giga joule
MJ: mega joule
ML: mega litre
L: litre
yr: year
EE: embodied energy
GHG: greenhouse gas
CO_2: carbon dioxide
TAS: Tasmania
QLD: Queensland
VIC, Vic: Victoria
WA: Western Australia
SA: South Australia
NT: Northern Territory
ACT: Australian Capital Territory
NSW: New South Wales
ha: hectare
LEPA: Low Energy Precision Application
LESA: Low Elevation Spray Application
n/a: not available
DPI: department of primary industry
kg: kilogram
kWh: kilowatt hour
PVC: polyvinylchloride
USQ: University of Southern Queensland
kW: kilowatt
2WD: 2 wheel drive
m: metre
RRP: Regional Reference Price

1. Introduction

The environmental impact and sustainability of agricultural activities is increasingly becoming an issue of great national significance. Irrigation systems supply water to crops and pastures and therefore irrigation practices have a vital role in agriculture in Australia. The purpose of irrigation in agriculture is to supplement rainfall events during the growing seasons of crops or pastures to optimise the crop production or pasture growth.

Australia is on of the driest continents on earth, yet we are among the highest users of water per head in the world. On top of this Australia is the middle of one of its driest periods in its short history. For the seven month period from March 2006 to September 2006 there has been generally serious (rainfalls in the lowest 10% of historical totals, but not in the lowest 5%) to severe (rainfalls in the lowest 5% of historical totals) rainfall deficiencies covered most of the area south of a line from Exmouth (WA) to Eucla (WA) to Tarcoola (SA) to Mildura (Vic) to Albury (NSW) to Canberra (ACT) to Sale (Vic), as well as northern, central and eastern Tasmania (www.bom.gov.au). This is shown in figure 1. There have also been reports of record low rainfall (lowest since at least 1900 when the data analysed began) through Australia during the same time period. The low rainfall this year is also being compounded in the south-eastern area of the country as it comes following a series of consecutive dry years. Therefore it is of utmost importance that water is utilized both effectively and efficiently to manage the depleting supply during these drought years. Therefore, any method in which water resources can be optimized, particularly with regards to irrigation in the agricultural industry, need to be implemented in all states and territories of Australia.

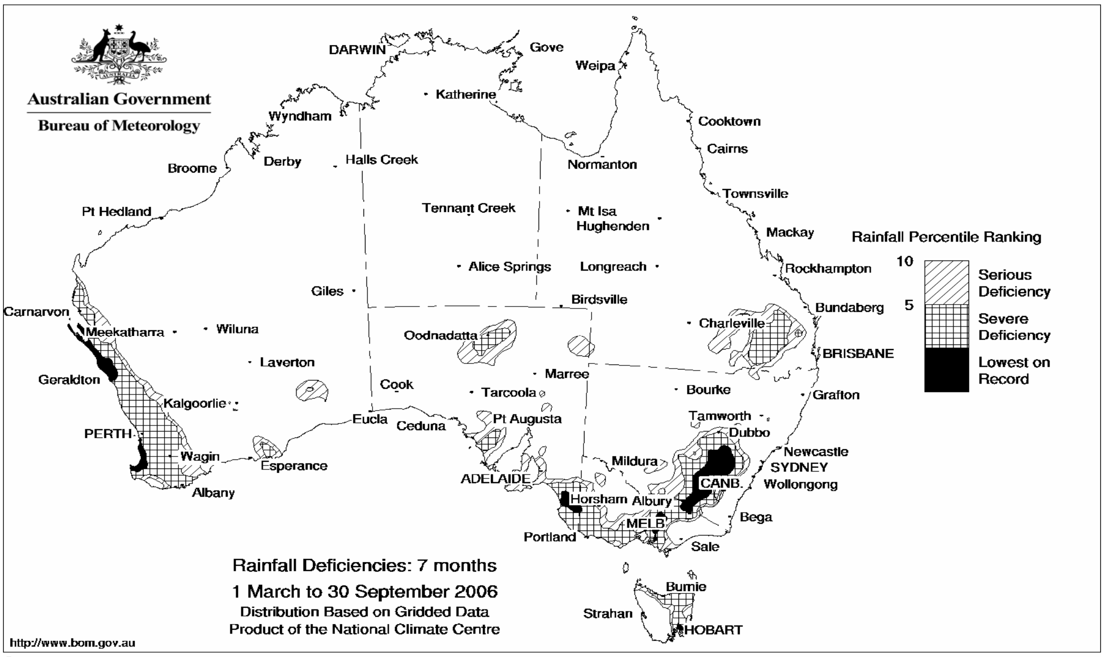


Figure 1: Rainfall Deficiencies from March 1st – September 30th 2006 in Australia.
Source: www.bom.gov.au.

1.1Project Aim

The overall aim of this research project will be to determine and compare the energy consumption and costs of alternative irrigation systems. This is to be achieved by way of in-depth life cycle analysis of the various systems. The irrigation technologies that are to be the predominant focus of this research project are; border check, centre pivot, and subsurface drip irrigation systems. The ultimate outcome of this research project will be to perform a comprehensive analysis and determine which system is the better option for farmers both economically and environmentally. Factors which will be used in the comparison include water use, energy use, and overall cost of each system.

1.2Specific Objectives of the Research Project

Specifically, the project aims are:

1. Conduct an in-depth and critical review of past research on the topic, with detailed consideration of two papers in particular previously completed by students at the University of Melbourne. The first one entitled *"Life Cycle Energy Analysis of Irrigation Systems"* by Manoj Jose Lukose completed in 2005, and the second being *"Life Cycle Energy Analysis of Irrigation Systems"* by Carlos Andres Amaya completed in 2000. This will be carried out to determine the accuracy of the past works and to identify any areas that are potentially incorrect and therefore will need to be reworked.

2. Undertake an analysis of the energy use and greenhouse gas (GHG) emissions of three of the main irrigation technologies (border-check, centre pivot, and subsurface drip) used in Australia. This will be completed so that a comparison can be made between the different irrigation technologies, with regards to, their energy use and GHG emissions.

3. Calculate the life cycle cost of each of the irrigation technologies, and determine any limitations of implementation for each of the three different types of irrigation systems that are being studied. This is being prepared so that a balance between water and energy consumption can be established.

4. Establish a sense of balance between water and energy consumption, so that the effect that widespread implementation of each of the three irrigation technologies would have on; the regional power network, energy demand, as well as required water supply, can be predicted.

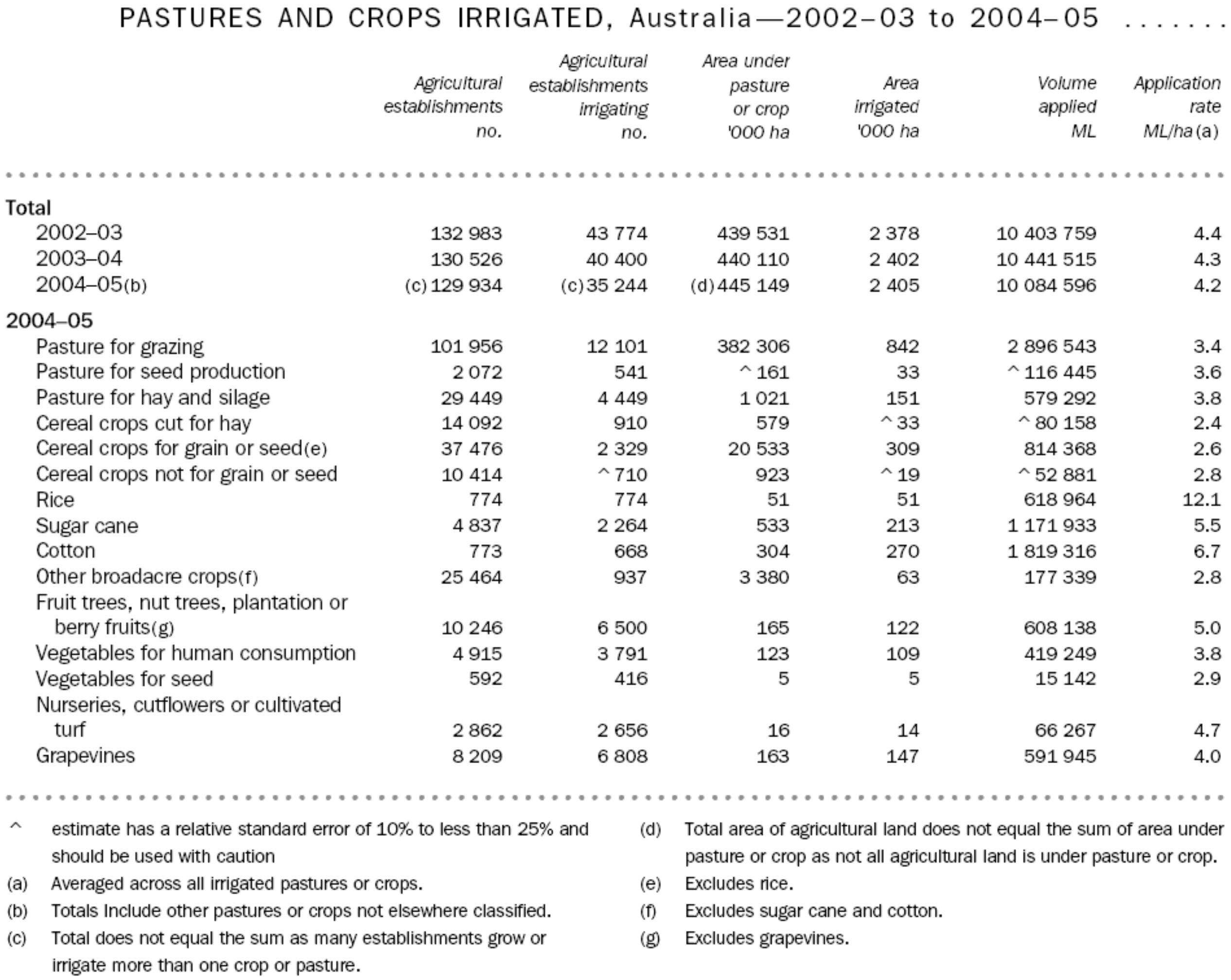
The definitive goal will be to evaluate each of these parameters and determine how each type of the examined irrigation systems will perform and compare with each other in the analysis. This will, in due course, lead to the final conclusion as to which form of irrigation system is in fact the most appropriate option for implementation, not only for farmers in the industry, but also for the environment and the economy.

1.3 Literature Review

The primary focus of past work done by Amaya (2000) and Lukose (2005), directly relating to the subject of total life cycle energy in irrigation is focused on irrigation in the north Victorian dairy industry.

1.3.1 Water Use in Irrigation

The predominant motive for irrigation is for pasture production for grazing as can be seen in table 1 (Terwin 2006). The irrigated pasture is predominately made up by the dairy industry which mainly uses border check irrigation to irrigate such pastures.



PASTURES AND CROPS IRRIGATED, Australia—2002–03 to 2004–05 ....

	Agricultural establishments no.	*Agricultural establishments irrigating* no.	*Area under pasture or crop* '000 ha	*Area irrigated* '000 ha	*Volume applied* ML	*Application rate* ML/ha (a)
Total						
2002–03	132 983	43 774	439 531	2 378	10 403 759	4.4
2003–04	130 526	40 400	440 110	2 402	10 441 515	4.3
2004–05(b)	(c) 129 934	(c) 35 244	(d) 445 149	2 405	10 084 596	4.2
2004–05						
Pasture for grazing	101 956	12 101	382 306	842	2 896 543	3.4
Pasture for seed production	2 072	541	^ 161	33	^ 116 445	3.6
Pasture for hay and silage	29 449	4 449	1 021	151	579 292	3.8
Cereal crops cut for hay	14 092	910	579	^ 33	^ 80 158	2.4
Cereal crops for grain or seed(e)	37 476	2 329	20 533	309	814 368	2.6
Cereal crops not for grain or seed	10 414	^ 710	923	^ 19	^ 52 881	2.8
Rice	774	774	51	51	618 964	12.1
Sugar cane	4 837	2 264	533	213	1 171 933	5.5
Cotton	773	668	304	270	1 819 316	6.7
Other broadacre crops(f)	25 464	937	3 380	63	177 339	2.8
Fruit trees, nut trees, plantation or berry fruits(g)	10 246	6 500	165	122	608 138	5.0
Vegetables for human consumption	4 915	3 791	123	109	419 249	3.8
Vegetables for seed	592	416	5	5	15 142	2.9
Nurseries, cutflowers or cultivated turf	2 862	2 656	16	14	66 267	4.7
Grapevines	8 209	6 808	163	147	591 945	4.0

^ estimate has a relative standard error of 10% to less than 25% and should be used with caution

(a) Averaged across all irrigated pastures or crops.

(b) Totals include other pastures or crops not elsewhere classified.

(c) Total does not equal the sum as many establishments grow or irrigate more than one crop or pasture.

(d) Total area of agricultural land does not equal the sum of area under pasture or crop as not all agricultural land is under pasture or crop.

(e) Excludes rice.

(f) Excludes sugar cane and cotton.

(g) Excludes grapevines.

Table 1: Pastures and Crops Irrigated in Australia, 2002-03 to 2004-05

Source: Terwin, 2006.

Lukose (2005) employed water use data that shows that both centre pivot and drip irrigation are 20% more water efficient then border check irrigation systems. Amaya (2000) used water use values for centre pivot and drip irrigation was 10% less then border check. However, upon review of current published works it is predicted that centre pivot is most likely less water efficient then drip irrigation systems, however, a value of 20% less then the border check irrigation would be acceptable for the purposes of comparison of the systems. Furthermore, border check irrigation can be less water efficient depending on the irrigation area and system setup.

1.3.2 Energy Use in Irrigation

Both Amaya (2000) and Lukose (2005) build on previous work completed on the subject when computing the energy use in irrigation systems. Past papers failed to consider all the energy consumed in the whole life cycle, which is an area that both Amaya (2000) and Lukose (2005) attempted to rectify.

Other then the previously mentioned works; there are further publications that have covered various areas of the energy consumed during the life of an irrigation system. A number these works, which have been produced on the energy consumption of a range of irrigation systems, not only come from areas around the world, but also from Australian sources.

Published in the mid 1970’s, two papers were found that produced studies on the on-farm energy use of range of irrigation systems (Batty et al 1975; Chen et al 1976). These two papers used theoretical studies to determine the energy inputs for a range of hypothetical irrigation system layouts. Batty et al (1975) included all the energy required in relation to the installation and operational stages of the different irrigation systems lives. The study conducted by Chen et al (1976) determined the energy used during installation and operation as well as the manufacturing and transportation component on the total energy consumption.

Shortly after the last two papers, two more papers where produced in Australia in the 1980’s (Croke 1980; Down et al. 1986). The study done by Croke (1980) focused primarily on, identifying the energy consumed in producing the infrastructure that is required to bring the water to the farm gate for use in a border check irrigation system. The actual energy that was consumed on the farm by the irrigation system was not determined. The study that was published following Croke (1980) was conducted by Down et al. (1986) and was more of a practical study. The purpose of this study was to calculate the total energy that was consumed by a border check irrigation system in which laser-graded earthworks where undertaken. In addition to this, installation and operational energy was determined for a range of surface and pressurized irrigation systems so that comparisons between the systems could be made. Around the same time as the study by Down et al. (1986) another analysis was completed in Israel by Stibbe (1986), in which a study was undertaken to determine the energy consumed during the manufacturing of the equipment required to build drip and sprinkler irrigation systems in the area.

Following these works, two projects were undertaken during the 1990’s in California by the Irrigation Training and Research Centre (1996). The purpose of the projects was to calculate the on-farm energy consumed by a sprinkler and row crop drip irrigation system. The study presented information on a wide range of areas which included; pumping energy, energy consumed during field operations, energy required for pipe installation, energy needed to manufacture the pipe, and the energy used to produce the fertilizers that are used to grow a crop. The study was quite comprehensive in regards to the areas that were covered however in did not include the energy that would be required to manufacture the pump or its accessories, and field equipment such as any tractors or implements that would be required for the irrigation system or crop. Furthermore, the Water District energy component that delivers water to the site was not included in the study.

1.3.3 Life Cycle Energy Analysis

The concept of life cycle energy analysis is described by both Amaya (2000) and Lukose (2005) as a method of analysis used by the environmental research community as the paramount way to analyse and compare alternative materials, components and services (Cole 1999). It is unfortunate that the large majority of such life cycle studies have been predominantly concerned with the construction of buildings and dwellings. There have however been studies such as the ones completed by Wells (2001), which was a study of the energy used on a dairy farm and Barber et al (2005), which was a study of the energy used arable and outdoor vegetable industry of New Zealand. Such studies were in reality a life cycle analysis of an entire farming system, a small part of which was irrigation.

Most of the information uncovered while reviewing the literature of the past work done in the area of energy use in irrigations systems, few conducted a full life cycle analyses of any irrigation systems with the exception of Amaya (2000) and Lukose (2005). Batty et al (1975) did not include the energy component that would be associated the manufacturing and maintenance stages of an irrigation systems life cycle. Chen et al. (1976) failed to include the energy that would be required to maintain and decommission the irrigation system. The studies conducted by both Down et al (1986) and Irrigation Training and Research Centre (1996), failed to include the energy that would be required in the manufacturing of any components or materials that would be required for the irrigation systems that were analysed.

The two previous studies performed by Amaya (2000) and Lukose (2005) both concluded that border check irrigation was the most appropriate option with minimal use of operational energy in comparison to the other irrigation systems. However, Amaya (2000) failed to include calculations of the energy required to pump the supply water to the border check irrigation system in the operational stage. However, these calculations were undertaken for operation of both the centre pivot and subsurface drip irrigation systems. Lukose (2005) corrected this by calculating the operational pumping energy using the same method as was used for the centre pivot and subsurface drip systems.

Amaya (2000) does not equate the sum of the four energies in the same units, i.e. operational energy was in GJ_{elec}, whereas the rest of the energy forms were in GJ_{oil}, which is the primary energy and therefore making the observations difficult to analyse (Lukose 2005). Attempts to rectify this inaccuracy were performed by Lukose (2005).

The following table provides a summary of the outcomes of the most relevant papers.

Comparison of the Total Energy that was Determined for the Different Irrigation Systems GJ/ha/year						
Irrigation Systems	**Batty, et al. (1975)**	**Chen, et al. (1976)**	**Down, et al. (1986)**	**Irrigation Training and Research Centre (1996)**	**Amaya (2000)**	**Lukose (2005)**
Border Check	2	1.12	1.8 – 7	n/a	1.76	8.01
Centre Pivot	11.1	21.4	6 – 14.9	47.6	11.85	15.26
Drip	8.9	6.8	21 – 67.4	46.1	5.97	15.68

Table 2: Comparison of the Total Energy that was Determined for the Different Irrigation Systems.

1.4 Methodology

This project aims to critically analyse past papers that have been published with regards to, the comparison of life cycle energy consumption of alternative irrigation systems. This will therefore determine whether there may be discrepancies in the previous published research, as well as to verify the methods that have been used.

After the initial study is carried out, new data will be used to revise past attempts. By utilizing different methods of analysis, it may be possible to use the previously researched data to assess if there is a need to perform further work. This will result in comparing the previously published studies to current research for this project, thereby, highlighting any discrepancies in data and altering such discrepancies to ensure the accuracy of the information published in this field.

There are a range of different areas that are of importance when conducting the life cycle energy analysis for the irrigation systems. These are as follows:

1. There is the initial embodied energy. This is the sum of all direct and indirect energy that is used in the manufacture, transport, and setting up of the system.

    - Direct energy is the energy that is used in the construction of the system. It consists of all the energy that is utilized in the transport and instillation stage of each component and its assembly (Amaya 2000).

    - Indirect energy is the material energy that is used in the production of any technology and includes transport energy. This energy consumption is related to the production of any components, external from any energy used in the transportation and construction of the system, as it requires the largest portion of the embodied energy (Amaya 2000).

2. Recurring embodied energy. This is the sum of all the energy that is required not only to maintain the various components that make up the irrigation system, but also the energy that is needed to replace and repair the components. This includes the transportation and construction energy that is required to carry out such activities (Amaya 2000).

3. Operational energy. This is the energy that is required to operate the irrigation system throughout its entire life span (Lukose 2005).

4. Decommissioning energy. This is the energy that is needed to dismantle and dispose of the irrigation system at the end of its life span. Additionally this includes any energy that is required to transport the decommissioned materials to either landfill or the appropriate recycling facilities (Amaya 2000).

The labour energy that is required throughout the life span of the irrigation system, in terms of its construction and maintenance, has to be calculated. Assessment of the recurring and decommissioning embodied energy will largely be reliant on information that is available from the irrigation systems manufacturer, as well as life cycles and replacement cycles of the materials and components used in the individual irrigation system. Any other data that is required will be obtained from people who have access to information such as operation energy.

Upon completion the total life cycle energy has been calculated for each irrigation system, the green house gas emissions that are associated with each system can be determined. This is due to the fact that the energy that is used in the system is produced from methods that emit greenhouse gases such as coal fired power stations.

1.5 Limitations

The construction of any water storages, such as dams, has not been included in the life cycle energy analysis. However, as border check has a comparatively greater water requirement than either centre pivot or subsurface drip in relation to irrigating the same crop, a larger storage volume capacity will be required. Consequently, this may result in an increase in the initial embodied energy required, in addition to an increased setup cost.

The predominant focus of this current analysis is regards to the past works completed by Amaya (2000) and Lukose (2005), has been on the sections of the life cycle analysis that make the greatest contribution to the total life cycle energy use. Example of this would the energy required to pump the irrigation water and the embodied energy component of the irrigation structure. The reasoning behind this is that errors in these areas would have a greater effect on the overall life cycle energy consumption of the irrigation systems.

The life cycle analysis focus is on the irrigation field and all the energy factors that would be required to irrigate the field in relation to the different system. An assumption has been made that getting that water to the field would be of a similar process no matter which irrigation technologies where used. This implies that the water is at the edge of the field being irrigated, and does not consider that supply water could originate from a dam, creek, river, bore, or possibly from a type of channel system that delivers the water to the farm.

The analysis has been limited to three irrigation methods which are border check, centre pivot, and subsurface drip irrigation systems. There are however other irrigation methods that could be used. These include furrow and lateral move irrigation systems.

The life cycle analysis does not include the energy component that would be incurred as a result of transportation of material components that would be required to set up and maintain each on the irrigation systems being analysed.

The size of the irrigated field is assumed to be 60 ha for all the irrigation methods so that a comparison between the three systems can be conducted with ease. For the centre pivot irrigation system, the irrigated area is assumed to be a circle that has an area of approximately 60 ha. The field shape is assumed to be of a square shape and the irrigated area of which equates to approximately 60 ha.

Irrigation pumps are generally run by either diesel or electric motors in most situations. The pumps are assumed to be run by an electric motor for the current analysis.

2. Background

2.1 The Issues

The current emphasis on society being more environmentally friendly is becoming an increasingly global issue. It is therefore imperative that everyone is required to become more environmentally conscientious. The agricultural industry is a significant area that is becoming the focus of such interests. One factor that is becoming a major issue is the greenhouse gas (GHG) production of agricultural activities which are directly related to the energy used in such activities. As agriculture makes up a large part of Australia’s economic, social, and environmental culture, it is therefore an area of great importance to Australia.

Another issue that is of great importance in Australia is water use. With the current water shortages in Australia it is becoming essential that the most efficient and effective water use practices are implemented, so that water usage can be optimized. For this reason appropriate studies need to be conducted to determine the practices that are most suitable for Australia and its agricultural industry.

2.2 Water Use in Australia

With Australia's growing population and increases in vicinities of irrigated land, the volume of water extracted for human expenditure has increased considerably over the past 15 years. The rate of extraction from some surface water and groundwater resources is close to or exceeds the sustainable yield of the water resource. The associated aquatic ecosystems are suffering from these effects of over-extraction and over-development. Water used for irrigational purposes in agricultural makes up about 75% of the total water used in Australia (www.deh.gov.au). Therefore any water savings that can be made will have a great effect on the total water supply within Australia.

2.3 Irrigation in Australia

Irrigation plays a major role in many agricultural practices throughout Australia as many farming regions do not receive consistent and adequate rainfall. Over the last quarter of a century the proportion of irrigated land in New South Wales and Queensland has almost doubled. A large proportion of which has occurred in the Murray-Darling Basin region, which makes up about 71% of the total area irrigated in Australia. The Amount of irrigated land has remained relatively unchanged in most other states and territories (www.deh.gov.au). A breakdown of the irrigation water use for a range of agricultural activities in 1996/97 is shown in Figure 2.

Currently the trend in irrigated agriculture is towards large-scale enterprises growing high-value horticulture, viticulture, cotton, rice and vegetables. The only manor that irrigated land will increase in the Murray-Darling Basin, in which a high level of

irrigation occurs, is if there are improvements in irrigation efficiency, or if there are increases in the development of groundwater resources. Currently the surface water use is capped at the 1993/94 levels of development (www.deh.gov.au).
Any great increases in irrigated land and water use is likely to occur in the relatively undeveloped northern drainage regions.

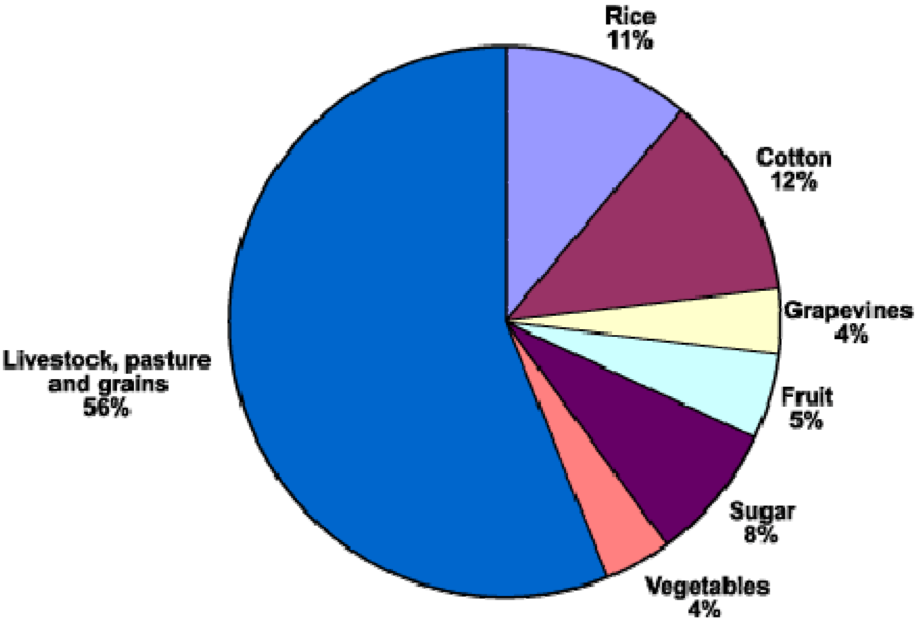


Figure 2: Total Annual Irrigation Water Use 1996/97 by Crop Type
Source: www.deh.gov.au.

2.4 Irrigation Methods

There is a variety of irrigation methods used in the Australian agricultural industry. Table 3 highlights the main types of systems used in Australia. It shows that surface irrigation systems, such as, border check and furrow irrigation are the most widely used irrigation systems overall throughout Australia. The pressurized spray irrigation methods, which include centre pivot, lateral move, and solid set systems, are the secondary most used system overall in Australia. Drip and micro spray systems are among the least used irrigation methods. These types of systems include subsurface drip irrigation. Border check, centre pivot and subsurface drip irrigation systems are the focus of this project.

IRRIGATION METHODS USED - Percentage Reported of Total Irrigated Area - Year Ending June 2000									
IRRIGATION METHOD	NSW %	VIC %	QLD %	SA %	WA %	TAS %	NT %	ACT %	Australia %
Spray method (excluding micro spray)	11	12	37	44	23	86	26	58	22
Drip or micro spray	3	5	8	33	38	6	68	42	8
Furrow or flood	85	82	54	21	35	8	—	—	70
Other	1	—	1	1	4	—	5	—	1
Total of Irrigation Methods Reported	100	100	100	100	100	100	100	100	100

Table 3: Irrigation Practices within Australia.

Source: Terwin 2001**.**

2.4.1 Border Check Irrigation

Border check irrigation systems are the most predominantly used irrigation method in Australia. It is a method of flood irrigation set up on gently sloping land. Its layout requires both surface grading and smoothing of the land into rectangular irrigation bays. These bays can either be gravity fed down sloping land or are terraced across it, whilst being separated either by parallel checkbanks, or borders. At the base end of the irrigated field there are run off drains that are slightly graded to remove excess run off water (Amaya 2000). Refer to Figure 3.

Water is introduced into the system via a supply channel which is located at the top end of the irrigated field. The water flows onto the designated area for irrigation through either pipe outlets or concrete bay outlets, utilizing sliding doors. The water then flows down the sloping field between checkbanks or borders. The supply water is then cut off when it reaches the required distance down the field, or, after a predefined time period to minimize runoff. This water then infiltrates into the soil as it progresses down the field. The slope of the field and the drains are such that they minimize the period that waterlogging may occur from either irrigation or rainfall, therefore, reducing any damage that the crop may experience from waterlogging (Amaya 2000). Refer to Figure 3.

The predominant purpose of the drainage system involved in Border check irrigation is that excess irrigation water can be reused, therefore, improving irrigation efficiency and reducing the instances of waterlogging (Amaya 2000).

Border Check irrigation systems are predominantly used to irrigate pastures, lucerne and fodder crops. However, this system can also be used to irrigate grain and oilseed crops, as well as orchards and vineyards, even though furrow irrigation is normally used for such crops (Amaya 2000).

The limitations of Border Check irrigation are:-

- The topography of the field must be smooth with suitable soil that has enough depth for levelling purposes. Sandy soils are not suitable for this type of irrigation.
- The field for this form of irrigation needs to have a slope of at least 1: 1500 no steeper than 1: 750. Any field outside of these parameters will slow down irrigation and the field will be prone to waterlogging thereby inhibiting the growth of the crop.
- Border Check irrigation the not suitable for undulating land which requires large volumes of soil to be moved increasing expenditure related to the set up of the irrigation system
- The amount of available water must be sufficient enough to irrigate the size of field practically.

- It is difficult to provide a light irrigation of less than two inches efficiently to the field

For further summary of the advantages and disadvantages of Border Check irrigation, refer to table 4.

Figure 3: Border Check Irrigation.
Source: Amaya 2000

2.4.2 Centre Pivot Irrigation

Centre Pivot irrigation is a method of self-propelled pressurized irrigation. Refer to figure 4. This system constitutes of a number of spans which vary are from 30 -50 meters in length and around 3 meters in height, that are connected and rotate about a central fixed point or pivot point. Refer to figure 4. Water is supplied to this system through the pivot point. Each span is propelled by a small electric or hydraulic motor. The speed of which each span travels in determined by the controls on the individual spans tower and which increases as it is moved away from the fixed central point. For a typical 400 meter long system the rotation or speed can vary from 12 -120 per revolution. The rate of water supply to the system is depended on the pump rate and the design of the system. However, the water application rate increases along the pivot spans as it digresses outwards from the centre. Due to the spans rotating in a circular motion around the central pivot, irrigation is formed in a circular motion; therefore, the corners of a square field can often be left un-irrigated (Bert et al 2000; Amaya 2000).

Centre pivot systems are suitable to irrigate most crops and have been developed to irrigate vineyards and dwarf orchards. However, due to the overall pivot structure, the irrigated field has to be free of obstacles such as trees, power lines, and buildings so that the structure can freely move over the field. Total pivot spans can be from 100 to 800 meters, the typical total pivot span length is however, around 400 meters (Bert 2000).

Water can be applied to the field using a range of sprinkler and nozzle types that operate under a wide variety of pressures. The industry is however tending to move more towards the use of drop tubes with and Low Energy Precision Application (LEPA) or Low Elevation Spray Application (LESA) sprinklers. LEPA sprinkler system apply the irrigation water close to or on the soil surface via drop tubes that are connected to the irrigation water pipe on one and have a low pressure nozzle on the other. LESA are similar to LEPA, however, LESA uses sprayers that are closer to the grounds surface (Bert et al 2000).

Limitations of centre pivot irrigation are:-

- Requires more pumping energy than border check irrigation.
- Requires better water filtration than border check irrigation.
- Sprinkler methods that apply water to the leaves of the plants are unsuitable for irrigating with salty water.
- Irrigated area needs to be free of obstacles.
- Set up costs can be high.

For a Summary of the advantages and disadvantages of centre pivot irrigation refer to Table 4.

Figure 4: Centre Pivot Irrigation System
Source: Foley 2001.

2.4.3 Sub-Surface Drip Irrigation

Subsurface drip irrigation is a pressurized micro irrigation method. Refer to Figure 5. It is a permanently buried irrigation method that is often used to irrigate high profit row crops. Subsurface drip irrigation has a high degree of automation. Sub-surface drip systems have a dripper tube, which containers drip emitters that are spaced along the dripper tube and can be purchased in a range of emitter spacing. The dripper tube is typically buried 20-40cm below the grounds surface. The dripper tubing's are spaced up to 2 meters apart to ensure adequate supply of water to crops. The overall life of the dripper tube ranges from 6-10 years at which point the system has to be completely replaced. Due to the size of the drip emitters, the irrigation water requires high levels of filtration to prolong the life of the system (Bert et al 2000).

Irrigation via subsurface drip is of high water efficiency of up to 94%. Such efficiency is easily obtainable. This system can also be utilized to apply fertilizers directly to the crop roots. This method of irrigation is suitable for the vast majority of soil types and topography circumstances as it can be used to irrigate a wide variety of crops, however, its implementation is usually limited by the set up costs in relation to crop value (Bert et al 2000).

Limitations of subsurface drip irrigation include:-

- Requires high level of water filtration
- High pumping energy costs
- High set up costs
- Requires extensive maintenance
- Requires a reliable and constant source of water

For a summary of advantages and disadvantages of subsurface drip irrigation refer to table 4.

Figure 5: Subsurface Drip Irrigation System.
Source: www.pcca.com.

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2.5 Comparison of the Irrigation Systems

Some comparisons of the three irrigation system are provided in following tables.

Table 4: Advantages and Disadvantage of the Irrigation Systems.

Differences in the Irrigation systems		
Irrigation system	Advantages	Disadvantages
Border Check	-- Low operating cost. -- Can cover large areas rapidly. -- Long run lengths.	-- High labour cost -- Unsuitable on sandy soils -- Paddocks must be levelled -- Unsuitable on steeper terrain -- Very high flow rates required.
Centre Pivot	-- Low labour requirements -- Can be used in undulating paddocks -- Easy to automate -- Good running costs -- Good rotation time -- Good uniformity.	-- No trees can be present -- High Initial capital costs -- Limits method of ground preparation -- Energy consumption high -- Paddocks must be round or square.
Subsurface Drip	-- Erosion, run-off, excessive leaching of nutrients, seepage, and large surface drain flows are avoided -- High degree of water application control -- Better access to crop -- Good uniformity. -- Easy to automate	-- Requires uninterrupted supply of water -- May require an alternative system for germination -- Requires constant flushing to avoid bacteria and debris in the lines -- Requires water filtration -- Energy consumption

Source: Austin 1998; Rural Water Commission of Victoria 1988

Comparison of Irrigation Systems			
Criteria	**Border Check**	**Centre Pivot**	**Subsurface Drip**
Application efficiency	50 – 75%	75 – 90%	70 – 94%
Frequency of Irrigation	Low	Low	High
Soil evaporation losses	High	Low	Minimal
Use of pesticides	High	Low	Low

Table 5: Comparison of Border Check, Centre Pivot and Subsurface Drip Irrigation Systems.
Source: Amaya 2000; Bert et al 2000.

Water Use of Irrigation Systems	
Irrigation System	**Water Use (ML/ha/year)**
Border Check	10
Centre Pivot	8
Subsurface Drip	8

Table 6: Water Used of Irrigation Systems
Source: Foley 2006; Lukose 2005.

When selecting the most suitable irrigation system there a range of factors that needs to be considered. Such considerations are summarised in the tables 4, 5, and 6. Quite simply put some irrigation systems will not be suited to curtain situations. For example border check irrigation systems will not suit areas that are not relatively flat.

3. Life Cycle Analysis

3.1 Initial Embodied Energy

The initial embodied energy is essentially all the energy that is required to setup any of the irrigation systems. This includes all the direct and indirect energy components that are associated with; any land forming operations required for the layout, any manufacturing components required to build the irrigation system structure, and any energy that is required in the installation process of the structure and operating system (Amaya 2000). The initial embodied energy component constitutes a substantial portion of the total life cycle energy for all the irrigation systems.

3.1.1 Border Check

The initial embodied energy of a border check irrigation system includes a range of processes. These include (Down et al, 1986):

- Land Forming
  - Clearing fences, trees etc.
  - Preparatory cultivation
  - Land form: elevating scraper
  - Formation of channel pads
  - Formation of check-banks
  - Grading
  - Formation of channels
  - Cultivation
  - Sowing of pasture/crop
  - Application of fertilizers
- Structure
  - Concrete bay outlets
  - Operating System
- Installation
  - Water control structure
  - Seed
  - Fertilizers

A summary of these values is shown in table 7. For specific details of all the values for the initial embodied energy associated with a border check irrigation system, refer to Appendix B.

Summary of the Initial Embodied Energy of a Border Check Irrigation System	
Process	**GJ / ha / year**
Land Forming	1.816
Structure	0.021
Instillation	0.475
Total	**2.312**

Table 7: Border Check – Initial Embodied Energy – Summary.

3.1.2 Centre Pivot

The initial embodied energy of a centre pivot irrigation system includes a range of processes. These include (Amaya 2000):

- Land forming
    - Clearing fences, trees etc.
    - Formation of drains
    - Cultivation
    - Sowing of pasture/crop
    - Application of fertilizers
- Structure
    - Centre pivot structure
    - Water mains
    - Operating system
- Installation
    - Overall structure, including pump
    - Seed
    - Fertilizers

The land forming operations for a centre pivot irrigation system that are not directly related to water application are considered to be the same as for a border check irrigation system. The formation of drains is assumed to be 30% of the grading of the border check system Amaya (2000).

A summary of the initial embodied energy for a centre pivot irrigation system is shown in table 8. For specific details of all the values for the initial embodied energy associated with a centre pivot irrigation system, refer to Appendix B.

Summary of the Initial Embodied Energy of a Centre Pivot Irrigation System	
Process	**GJ / ha / year**
Land Forming	0.534
Structure	0.996
Instillation	0.455
Total	**1.985**

Table 8: Centre Pivot – Initial Embodied Energy – Summary.

3.1.3 Subsurface Drip

The initial embodied energy of a subsurface irrigation system includes a range of processes. These include:

- Land forming
    - Clearing fences, trees etc.
    - Formation of drains
    - Cultivation
    - Sowing of pasture/crop
    - Application of fertilizers
- Structure
    - Drip tube, fittings, mains, filters etc
    - Operating system
- Installation
    - Overall structure, including pump and water mains
    - Seed
    - Fertilizers

The land forming operations for a centre pivot irrigation system that are not directly related to water application are considered to be the same as for a border check irrigation system. The formation of drains is assumed to be 30% of the grading of the border check system Amaya (2000).

A summary of the initial embodied energy for a centre pivot irrigation system is shown in table 9. For specific details of all the values for the initial embodied energy associated with a subsurface drip irrigation system, refer to Appendix B.

Summary of the Initial Embodied Energy of a Subsurface Drip Irrigation System	
Process	**GJ / ha / year**
Land Forming	0.534
Structure	4.856
Instillation	0.575
Total	**5.964**

Table 9: Subsurface Drip – Initial Embodied Energy – Summary.

3.2 Recurring Embodied Energy

The recurring embodied energy component of the total energy used in a systems life cycle is primarily any energy required to keep the system operational (Amaya 2000). This includes all the energy that is required to maintain, repair, and replacement of any of the components and materials that would result from general operations during a systems life cycle.

3.2.1 Border Check

For border check irrigation the recurring embodied is an important component as such systems require relatively high levels of continued maintenance to ensure that the systems will operate effectively. A number of typical maintenance processes include (Amaya, 2000):

- Repairs to channel banks
- Channel desilting
- Repairs of leaks
- Mechanical and manual removal of weeds
- Fence repairs
- Repairs to structures
- Repairs to beaching
- Maintenance of meter outlets
- Grading and repair or access tracks

For an in-depth description of any of the recurring embodied components of border check irrigation systems, refer to the Rural Water Commission of Victoria (1988).

Re-grading should occur every 7 years at the very least and therefore would be approximately 2.5% of the initial embodied energy over the whole life cycle alone. As a result the recurring embodied energy is assumed to be 5% of the initial embodied energy to account for all factors. The recurring embodied energy is presented in table 13.

3.2.2 Centre Pivot

The energy that would be required to maintain a centre pivot irrigation system includes the replacement of worn sprinkler heads and nozzles, and the labour required to check the sections of the irrigation machine, and complete such tasks as move fences etc.

The cost of the maintenance of a centre pivot irrigation system was stated to be 4% by DPI (2004) and 5% by Bert et al (2000) of the initial capital cost of the system per year was stated. The figure stated by Bert et al (2000), is based on equipment lives and includes maintenance of the pipes and mainlines. As a result the recurring embodied energy of a centre pivot irrigation system is assumed to be 5% of the initial embodied energy of the system. This value is shown in table 13.

3.2.3 Subsurface Drip

The recurring embodied energy of a subsurface drip system can vary greatly depending on how the system is designed. Unforeseen obstacles frequently arise in newly installed drip systems puzzling even veteran system designers and farmers. These obstacles range from sand of unusual densities that are not removed by the filters to insects that bore through the drip tube. Troubleshooting these unforeseen obstacles are quite often time consuming and expensive, however, can usually be resolved with time (Bert et al, 2000).

Recurring embodied energy under standard condition includes the energy that would be used by the labour to carefully check and maintain the system, predominantly the filters and pumps on a daily basis. Additionally, replacement of damaged or worn fittings and repairing leaks are included in the recurring embodied energy component of a subsurface drip system (Bert et al, 2000).

Amaya (2000) stated a value of approximately 1.5% of the initial capital cost of the system per year is generally required to maintain the system. This figure includes the cost to maintain and service the pumps and water treatment facilities. As a result a value of 1.5% of the initial embodied energy is assumed as the recurring embodied energy for a subsurface drip system. This value is shown in table 13.

3.3 Operational Energy

The operational energy component of the total life cycle energy requirement consists primarily of the energy used in the pumping of the water and operation of the irrigation systems (Amaya 2000). Operational energy is one of the highest components of the life cycle energy consumption throughout the life cycle along with the initial embodied energy of all the irrigation systems (Amaya 2000).

3.3.1 Border Check

The operation energy of a border check irrigation system includes a range of processes. The main procedures include controlling the applied water, control of weeds in the channels, and pumping of the tail water (Amaya 2000). Pumping of the application water is also a process that is included.

All bar the pumping of application water has been determined from Down et al (1986). Pumping of the application water has been included as there is energy consumption associated with this process in a large number of systems. Including, circumstances when water is supplied to the systems via channels.

The energy that is required to control the weeds is entirely related to human labour (Down et al, 1986). The energy was determined to be less then 1 MJ/ha/year and so assumed to be negligible. Some of the processes, such as controlling weeds, have both direct and indirect energy inputs. In the case of weed control it would include the weedicide that was used and its application (Amaya, 2000).

The values obtained can be seen in table 10 For more details of how the values where derived can be found in appendix B.

Operational Energy - Border Check	
Operation	**EE/Area/Year GJ/ha/year**
Application of weedicides	negligible
Weedicides	0.06
Pumping of supply water	1.1772
Pumping of tail water	0.92
Total	**2.1572**

Table 10: Border Check – Operational Energy.

3.3.2 Centre Pivot

The operational energy components related to factors such as, labour and weed control, are assumed to be similar to border check irrigation. The energy required to operate the system, which includes, the energy required to operate the centre pivot structure as well as the energy required to pump the irrigation water can be found in table 11. For more information on the results refer to appendix B.

Operational Energy - Centre Pivot	
Operation	**EE/Area/Year GJ/ha/year**
Application of weedicides	negligible
Weedicides	0.06
Centre pivot structure operation	0.198
Pumping of supply water	3.662
Total	**3.920**

Table 11: Centre Pivot – Operational Energy.

3.3.3 Subsurface Drip

The operational energy component related to factors such as labour and weed control is assumed to be similar to border check irrigation. The energy required to operate the system which includes the pumping of the irrigation water can be found in table 12. For more information on the results refer to appendix B.

Operational Energy - Subsurface Drip	
Operation	**EE/Area/Year GJ/ha/year**
Application of weedicides	negligible
Weedicides	0.06
Pumping of supply water	3.662
Total	**3.722**

Table 12: Subsurface Drip – Operational Energy.

3.4 Decommissioning Energy

The decommissioning energy component on the total life cycle energy is composed of the energy required to dismantle and recycle the irrigation systems at the end of the systems life cycle (Amaya 2000).

3.4.1 Border Check

The decommissioning energy that is required at the end of the life cycle, or when changing to another system such as a pressurized system, of a border check irrigation system is minimal. In addition, none of the system can be recycled. As a result the decommissioned energy is assumed to be 1% of the initial embodied energy (Amaya, 2000). This value is shown in table 13.

3.4.2 Centre Pivot

Due to uncertainty surrounding what is required to be done with the centre pivot system at the end of its life cycle a few assumptions have been made. The first assumption made is that 25% of the structure can be recycled at a recycling facility, or reused in another system. This process would require the irrigation system to be dismantled, and the components that can be recycled or reused be sorted and cleaned. Other components will simply be disposed of. It is then assumed that the energy consumed during dismantling, cleaning, transporting, and disposing of the irrigation system, the decommissioning energy, be 8% of the initial embodied energy of the centre pivot irrigation system (Amaya, 2000). The value is shown in table 13.

3.4.3 Subsurface Drip

In relation to uncertainty surrounding what is required to be done with the subsurface drip system at the end of its life cycle; a few assumptions have been made. The first assumption being made is that 80% of the structure can be recycled at a recycling facility, or reused in another system This process would require the irrigation system to be dismantled, and the components that can be recycled or reused be sorted and cleaned. Other components will simply be disposed of. It is then assumed that the energy consumed during dismantling, cleaning, transporting, and disposing of the irrigation system, the decommissioning energy, be 12% of the initial embodied energy of the subsurface drip irrigation system (Amaya, 2000). The value is shown in table 13.

3.5 Areas of Previous Publications That Have Been Reworked

The following highlights the areas of the current energy life cycle analysis that have been reworked from the publications works of Amaya (2000) and Lukose (2005).

3.5.1 Border Check

Initial embodied energy;

Land forming operations:

- The average of these operations was used, as it was considered that the average from Down et al (1986) would be a more accurate representation of the embodied energy associated with such operations. With the exception of where Down et al (1986) stated that a certain value should be assumed for some operations. Mutually, both of the past publications obtained their values from the study conducted by Down et al (1986) utilising one of the farms that was closest to 60 ha.
- Re-grading of the field is required at the very least every 7 years (Foley 2006). Past work stated that re-grading occurred every 10 years.

Structure:

- The concrete in situ (EE of 0.002 GJ/kg (www.boralgreen.shares.green.net.au)) that has been reinforced with reinforcing steel (EE of 8.9 MJ/kg (Briad 1997)) is assumed to be the material that is used to make the concrete bay outlets. The reinforcing steel is assumed to be 1% the weight of the concrete. Amaya (2000) used concrete with an EE of 0.0017 GJ/kg. Lukose (2005) used 30 MPa concrete with an EE of 5.5 GJ/m^3.
- A pump has been added to the structure component that was not included in either of the past works.

Instillation:

- The fertiliser component was determined from and average of values from Down et al. (1986). Both of the previous publications utilised a different value.

Recurring embodied energy;

The recurring embodied energy has been increased to 5% of the initial embodied energy as grading occurs more often (every 7 years (Foley 2006) instead of every 10 years). Mutually, both of the past works assumed it to be 3% of the initial embodied energy.

Operational energy;

- A pump has been used with a pumping assumed efficiency of 75% that adds 9 metres (Foley 2006) of head to 600 ML of supply water. Amaya (2000) did not include any water supply pumping energy. Lukose (2005) used a pump efficiency of 95%. To calculate the energy required to pump the water, a different equation was used than the one employed by Lukose (2005) as well.
- The weedicide component is the average of the values determined by Down et al. (1986). The value used by both of the works was the minium value.

3.5.2 Centre Pivot

Initial embodied energy;

Land forming operations:

- The changes made with regards to this area, have been made as a result of grading occurring every 7 years instead of every 10 years, as was done by Lukose (2005) and Amaya (2000).

Structure:

- A typical centre pivot structure was determined to be made of galvanized steel (Brown 2006), with each span weighing 2372 kg and of a length of 48.77 m. The number of spans required for the total structure was therefore calculated to be 9. Galvanized steel was found to have an embodied energy coefficient of 34.8 MJ/kg (www.vuw.ac.nz). Both of the past works stated that 12 spans made of stainless steel would be required for the system and they would weigh 3000kg each. Both Amaya (2000) and Lukose (2005) used an EE for steel of 0.096 GJ/kg and 85 GJ/t respectively.
- Neither of the past works considered the concrete that is needed to support the pivot centre, as has be done in this project.
- Neither of the past works included the PVC water mains that would be required for the system, as has been done in this project.

- 9 electric motors are required in this project as apposed to the 12 that where required in both of the past works.

Instillation:
- A component of 2% of the embodied energy has been assumed to install the PVC mains. Both of the past works did not have this component as they did not include a PVC main in their centre pivot irrigation system.
- The fertiliser component was determined from an average of values from Down et al. (1986). Both of the previous publications used a different value.

Recurring embodied energy;

As the maintenance costs per year was found to be 4% to 5% (DPI 2004; Bert et al 2000) of the initial setup costs, the recurring embodied energy is assumed to be 5% of the initial embodied energy. Both of the past work used a value of 2.5% of the initial embodied energy as there was stated to be an average cost of maintenance of 2.5%.

Operational energy;

- A pump was been used with a pumping assumed efficiency of 75% that adds 35 meters (Foley 2006) of head to 480 ML of supply water. A different equation has been utilised, in this paper, to calculate the pumping energy required to pump the water, than was used in both of the past works. Amaya (2000) used a pump efficiency of 75% that added 55 metres of head to 432 ML of water. Lukose (2005) used a pump efficiency of 75% that added 30 meters of head to 120 ML of water.
- 9 electric motors are required to power the movement of the centre pivot structure around the field in this project as apposed to the 12 that where required in both of the past works.
- The weedicide component is the average of the values determined by Down et al. (1986). The value used by both of the works was the minium value.

3.5.3 Subsurface Drip

Initial embodied energy;

Land forming operations:
- The lone variation in this section occurs as a result of grading occurring every 7 years instead of every 10 years, as was done by Lukose (2005) and Amaya (2000).

Structure:
- It was determine that 20000 kg of polyethylene (www.t-tape.com; S Raine et al, 2000) would be required to setup a subsurface drip irrigation system. EE of polyethylene was found to be 95.4 MJ/kg (www.vuw.ac.nz). Amaya (2000) also determined that 20000 kg of low-density polyethylene would be required for the

system. However, the EE for low-density polyethylene was not found, therefore, the EE of plastic, which is 0.095 GJ/kg, was used. Lukose (2006) also determined that 20000 kg of low-density polyethylene would be required for the system. However, the EE for low-density polyethylene was not found, therefore, the EE of general plastic, which was 162 GJ/t, was used.

- Neither of the past works included the PVC water mains that would be required for the system, as has been done in this project.

Installation:

- A component of 2% of the embodied energy has been assumed to install the PVC mains. Both of the past works did not have this component as they did not include a PVC main in their centre pivot irrigation system.
- The fertiliser component was determined from and average of values from Down et al. (1986). Both of the previous publications utilised a different value.

Operational energy;

- A pump has been used with a pumping assumed efficiency of 75% that adds 35 meters (Foley 2006) of head to 480 ML of supply water. A different equation has been utilised in this paper to calculate the pumping energy required to pump the water than was utilised by both of the past works. Amaya (2000) used a pump efficiency of 75% that added 28 metres of head to 432 ML of water. Lukose (2005) used a pump efficiency of 75% that added 30 meters of head to 72 ML of water.
- The weedicide component is the average of the values determined by Down et al. (1986). The value used by both of the works was the minium value.

3.6 Comparison of Total Energy Consumption

The following figures and tables show that the total life cycle associated with the different irrigation systems for not only the current study but also for the previous studies completed by Amaya (2000) and Lukose (2005). As can be seen in the current study the total life cycle energy for the border check system is about 75% of the total energy of the centre pivot system and about 45% of the total energy in the subsurface drip system.

Life Cycle Energy Analysis of Irrigation Systems			
	GJ/ha/yr		
Life Cycle Analysis Stage	Border Check	Centre Pivot	Subsurface Drip
Initial Embodied Energy	2.312	1.985	5.964
Recurring Embodied Energy	0.116	0.099	0.089
Operational Energy	2.157	3.920	3.722
Decommissioning Energy	0.023	0.159	0.716
Total	**4.608**	**6.163**	**10.492**

Table 13: Current Analysis – Summary.

Life Cycle Energy Analysis of Irrigation Systems			
	GJ/ha/yr		
Life Cycle Analysis Stage	Border Check	Centre Pivot	Drip
Initial Embodied Energy	1.479	4.952	2.511
Recurring Embodied Energy	0.044	0.124	0.038
Operational Energy	0.220	6.377	3.120
Decommissioning Energy	0.015	0.396	0.301
Total	**1.758**	**11.848**	**5.970**

Table 14 : Amaya (2000) – Life Cycle Analysis – Summary

Life Cycle Energy Analysis of Irrigation Systems			
	GJ/ha/yr		
Life Cycle Analysis Stage	Border Check	Centre Pivot	Subsurface Drip
Initial Embodied Energy	1.484	4.424	5.471
Recurring Embodied Energy	0.045	0.111	0.082
Operational Energy	6.469	10.376	9.469
Decommissioning Energy	0.015	0.354	0.657
Total	**8.012**	**15.264**	**15.679**

Table 15: Lukose (2005) – Life Cycle Analysis – Summary

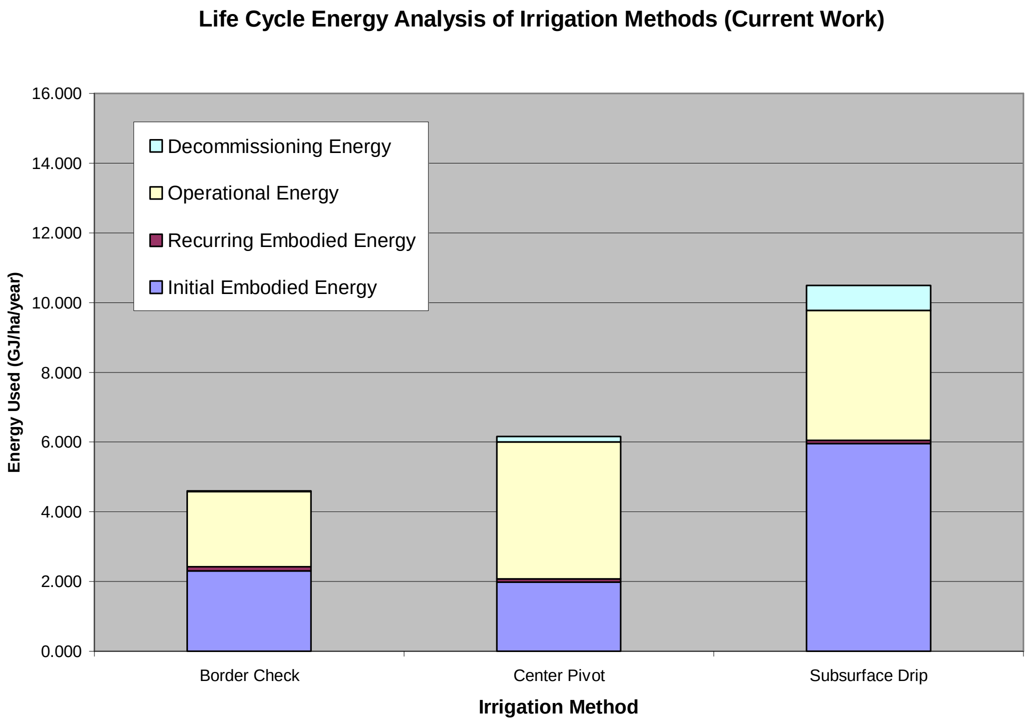

Figure 6: Current Analysis – Summary

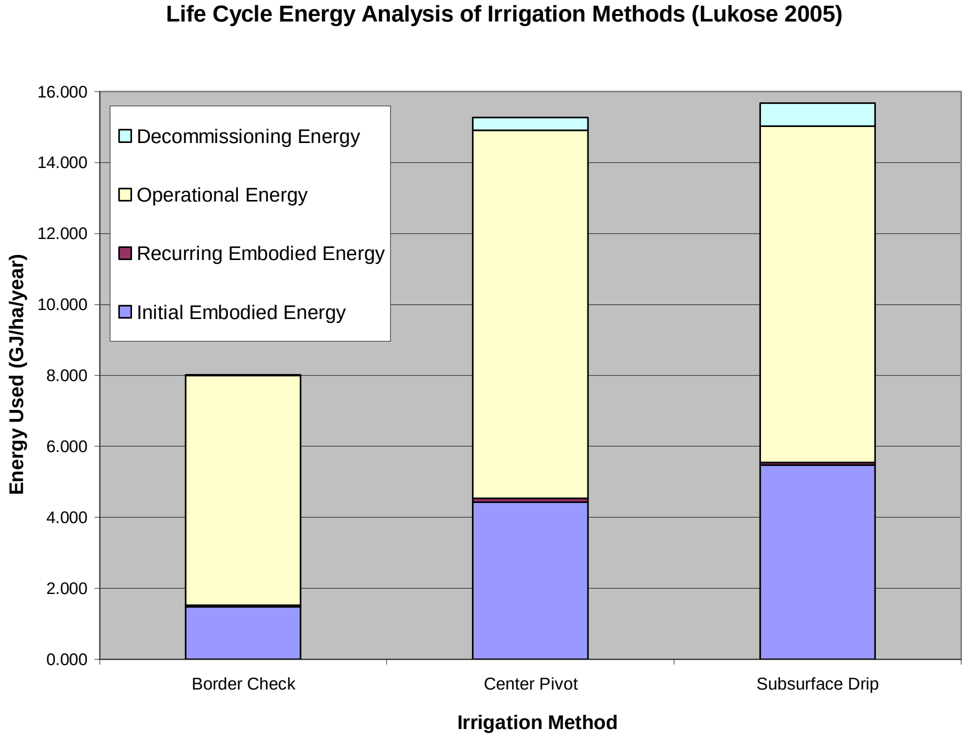

Figure 7: Lukose 2005 – Life Cycle Analysis – Summary.

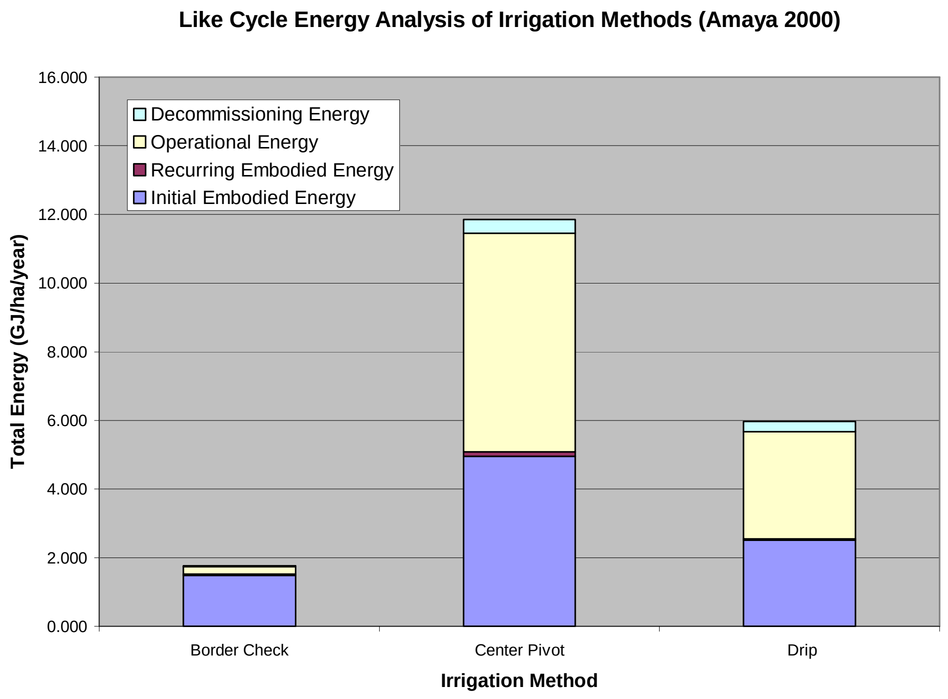

Figure 8: Amaya 2000 – Life Cycle Analysis – Summary.

A somewhat different outcome was obtained for the analysis's undertaken by Amaya (2000) and Lukose (2005). The total life cycle energy associated with the border check irrigation system, as was determined by Amaya (2000), is 33% and 15% of the total life cycle energy of drip and centre pivot irrigation systems respectively. The total life cycle energy associated with the border check irrigation system, as was determined by Lukose (2005), is approximately 50% of the total life cycle energy for both subsurface drip and centre pivot irrigation systems.

The main reason for the differences between the past work and the current study is predominately due to the changes in the operational energy and embodied energy associated with the production of the materials and components that are required to setup the system.

4. Economic and Environmental Analysis

4.1 Setup Costs

The setup cost of an irrigation system is one of the predominant factors for farmers when deciding which irrigation system to implement. Typical setup cost coupled with expected life span is summarised in table 16.

Irrigation System Setup Cost		
Irrigation System	Approximate Setup Cost $/ha	Life Expectancy Years
Border Check	$1800-$2500	10-20
Centre Pivot	$2500-$4000	15-25
Subsurface Drip	$4,500	7-10

Table 16: Irrigation Systems Typical Setup Costs and Life Expectancy

Source: Douglass 2000; Foley 2001; Bert 2000; Amaya 2000; DPI 2004.

As can be seen in table 16 border check is the cheapest system to install followed by centre pivot and then subsurface drip. Also an important point to highlight is the fact that subsurface drip is the most costly to install yet also has the lowest life expectancy of any of the irrigation systems being analysed.

4.2 Operational Energy Cost

The main operational cost that would be incurred to operate any of irrigation systems is the cost of the electricity that is required to operate the irrigation system. For both the border check and subsurface drip irrigation system this component consists solely of the energy required to pump the water in each of the systems. Centre pivot includes an additional component other then the pumping of the irrigation system. This additional component is a result of the motors that are required to propel the system around the irrigated field.

The value of electricity not only varies with the time of day, from peak to off-peak rates, but also with days, weeks, months, and years. Location of the irrigation field also affects the cost of electricity. An example of this can be seen in table 26 and 27 of appendix C. The result of this is that it becomes quite difficult to predict with a great deal of accuracy the electricity cost associated with the operation of the irrigation methods. An estimate of the potential costs of the electricity required has been derived so that a comparison can be made. There should however be a stable relationship between the costs associated with the electricity required for each of the irrigation systems. This is due to the fact that the electricity requirement will remain relatively constant for each of the irrigation systems. Table 17 shows the possible cost to operate the systems in different areas around Australia. For the details as to how the values were calculated refer to appendix C.

Electricity Cost to Operate Irrigation Systems $/ha/year						
Irrigation Method	NSW	QLD	SA	SNOWY	TAS	VIC
Border Check	19.31	13.93	16.63	14.22	21.44	15.00
Centre Pivot	40.14	30.31	40.40	33.40	60.58	34.98
Subsurface Drip	38.08	28.76	38.33	31.69	57.48	33.19

Table 17: Electricity Cost to Operate Irrigation Systems in a Range of Locations

From table 17 it can be easily seen that the electricity operational cost is approximately 50% cheaper then either one of the other two irrigation systems in most cases, expect for Tasmania were it was about one third the cost. Centre pivot and subsurface drip systems have almost the same electricity cost with centre pivot being slightly higher. This would be as a result of the extra electricity required in the centre pivot irrigation system caused by the motors that propel the system around the irrigation field.

4.3 Water Cost

The price of irrigation water is also a fluctuating variable. To illustrate this point, from the website www.watermove.com.au, water values from $100 and $600 per ML were found. To highlight the effect that water price can have on the cost, table 18 below shows the extremities of the potential cost for the irrigation water if its cost is set at either $100 or $600 per ML for the different irrigation systems.

Example of Potential Water Cost Associated with Each Irrigation Method			
Irrigation Method	Water Requirement ML/ha/year	Total Cost of Water at $100/ML/year	Total Cost of Water at $600/ML/year
Border Check	10	$1,000	$6,000
Centre Pivot	8	$800	$4,800
Subsurface Drip	8	$800	$4,800

Table 18: Possible Water Costs.

Table 18 demonstrates the importance of the cost of water even though the border check system is only uses 20% more water then either of the other systems. If the price of water was at around $600 per ML the border check system would incur an additional cost of $72000 in a year greater then either of the other irrigation methods in a 60 ha irrigated field.

4.4 Greenhouse Gas Production

As there is an increasing emphasis on the environmental impact on almost every process, the greenhouse gas (GHG) that would be produced as a direct result of irrigating has been considered. The predominate producer of greenhouse gases is the electricity that is required to operate the irrigation system i.e. pumping of the irrigation water. In Australia the main source of electricity is from thermal power plants, coal and gas powered power stations (www.worldpress.org; www.iaea.org).

Greenhouse Gas (CO$_2$) Produce During The Production Of Required Electricity For The Irrigation Methods kg/year								
Irrigation Method	NSW, ACT	VIC	QLD	SA	WA	TAS	NT	Australia Average
Border Check	18992	28783	20405	21759	20248	39	14833	20621
Centre Pivot	62274	94376	66906	71345	66391	129	48635	67613
Subsurface Drip	59087	89546	63482	67693	62993	122	46146	64153

Table 19: GHG Produced While Powering Irrigation Systems.

Table 19 shows the amount of GHG that would be produced as a consequence of providing electricity to the different irrigation system in different states around Australia. The reason for the low value for Tasmania is due to the fact that much of their electricity is produced from hydro powered power plants (www.development.tas.gov.au). As the table shows the GHG produced during the production of the electricity for each border check system is about 33% of that produced by either the centre pivot system or the subsurface drip system. More information of the GHG calculations can be found in appendix C.

5. Discussion, Conclusions, and Recommendations

5.1 Discussion of Results

In terms of total life cycle energy consumption of each of the irrigations systems investigated, the total energy per year related to border check, centre pivot, and subsurface drip irrigation system was determined to be 4.6, 6.2, and 10.5 GJ/ha/year respectively. These results where found to be somewhat different to the ones determined in the past project undertaken by Amaya (2000) and Lukose (2005). The differences in the results obtained where largely due to changes made in the calculations of the operational energy requirement as well as the embodied energy of the materials and components that are required to setup the different irrigation systems.

The economic analysis established that a border check irrigation system was the cheapest irrigation system to install, followed by centre pivot and finally subsurface drip. Another point to add is that not only is a subsurface drip irrigation systems the most costly in terms of installation cost, but in also has the lowest life expectancy, which was around half the expected life of both the border check and subsurface drip systems.

Major operational costs for all the irrigation systems was not only from purchasing the electricity to operate the systems but also the cost of the irrigation water itself. The analysis showed that even though border check irrigation had the lowest electricity costs and was about half the amount of the other systems, it did have the highest water cost. This is as result of the fact that border check irrigation systems require more water due to its lower water use efficiencies in comparison to centre pivot and subsurface drip irrigation systems.

The greenhouse gases (GHG) produced as a result of producing the energy required to power the irrigation system produced an outcome that was not unexpected. Border check irrigation has the lowest greenhouse gas production related to it. Centre pivot and subsurface drip irrigation systems produced approximately three times the amount of GHG through power production over border check. This is as a result of the much lower operational energy requirement of the border check system. Another interesting point is that of the low GHG associated with the energy production in Tasmania. This was a result of the fact that much of Tasmania’s electricity comes from renewable resources such as hydro and wind power generators.

5.2 Conclusions

The environmental impact and sustainability of agricultural activities is increasingly becoming an issue of great national significance. Not only is Australia in the midst of one of its worst droughts its ever experienced, but greater pressure is being put on everyone to reduce greenhouse gases. Therefore it is imperative that studies such as this are undertaken to provide the required knowledge so that the best possible irrigation system can be selected and implanted in the appropriate situations.

The first objective has been completely met. An in-depth analysis has been undertaken with the major focus being on the information presented by both Amaya (2000) and Lukose (2005). The conclusion was that some of the areas of both of their work were incomplete and in some cases inaccurate. The result of this is that some of the areas of their research had to be reworked due to the lesser amount of accuracy throughout their studies.

The second and third objectives have also been completely met. The life cycle analysis and greenhouse gas produced by each irrigation system was undertaken using realistic sets of data with the following outcomes:

	Associated Total Energy	Greenhouse Gas CO_2
Border Check:	4.6 GJ/ha/year	39-28783 kg/year
Centre Pivot:	6.2 GJ/ha/year	129-94376 kg/year
Subsurface Drip:	10.5 GJ/ha/year	122-89546 kg/year

The total embodied energy associated with each irrigation system shows that the total life cycle energy associated with border check irrigation is 75% of the total energy associated with centre pivot and about 50% of the energy associated with subsurface drip. The greenhouse gas produced during the production of the electricity for the border check system was about 35% of the amount produced by the other systems.

The forth and sixth objectives were not completely met. However, the major life cycle costs were determined and the outcome was that the setup costs and water costs would be the main contributors to the irrigation systems total life cycle costs. It was determined that the irrigation system setup costs were $1800-$2500, $2500-$4000, and $4500-$5500 per ha for border check, centre pivot and subsurface drip respectively. Another factor was the system expected lifespan which were 10-20, 15-25 and 7-10 years for border check, centre pivot and subsurface drip respectively. If the cost of water was low then the setup costs would be the main cost factor to consider. For this situation the border check system would be the cheapest, followed by centre pivot, and subsurface drip systems would be the most costly system to install. On the other hand if the cost of water increases enough the initial setup cost would be outweighed by the cost of water for the system. Water costs were found to be a greatly variable cost factor for any irrigation system.

The fifth objective, which was to predict the effect of widespread implantation of the irrigations systems would have on the power grid, was not undertaken. However, this could be an important factor for governments to consider if they were to encourage farmers to implement the irrigation systems that require a greater amount of power.

The overall conclusion that that can be drawn from this study is that if water prices are low, border check would be the most cost effective system of the three. However if water prices were to rise then centre pivot irrigation systems would be the best option in terms of price.

5.3 Recommendations for Further Work

1. The effect that widespread implementation of the different irrigation methods on power grids needs to be undertaken.
2. A complete life cycle cost analysis should be completed so that a more accurate evaluation and comparison of the different irrigation methods can be concluded not only in terms of life cycle energy, but also life cycle cost.
3. More studies into the life cycle energy of different technologies need to be undertaken in the engineering field in areas other then the built environment so that more information is available on the subject and therefore better analysis's can be made.
4. Using software tools such as SimaPro to assess the life cycle energy of the irrigation systems and provide more accurate representations of the life cycle energy associated with such systems.
5. Obtain more recent data from the field so that the analysis can be more accurate in terms of today's energy use, as much of the actual field data is quite dated.
6. Also an analysis of other irrigation systems could be undertaken so that a comparison between greater numbers of irrigation systems can de made.

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Appendix A – Project Specifications

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING
ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	Sunny JACOBS
TOPIC:	Comparison of life cycle energy consumption of alternative irrigation systems
SUPERVISOR:	Dr Guangnan Chen and Dr Joe Foley
SPONSORSHIP:	NCEA, CRCIF
PROJECT AIM:	The aim of this project is to determine and compare the energy consumption and costs of alternative irrigation systems, through a life cycle analysis

PROGRAMME: Issue A, 27 March 2006

1. Review the relevant research in life cycle assessment and irrigation technologies

2. Establish the energy consumption and greenhouse gas emissions of the three main irrigation technologies (border-check, centre pivot, and subsurface drip), through a life cycle energy analysis, using realistic sets of data

3. Compare the energy consumption and greenhouse gas emissions of the above irrigation technologies.

4. Calculate the life cycle costs and identify the practical limitations of the above irrigation technologies, with the aim to establish a right balance between water and energy.

As time permits:

5. Predict the impact of the widespread use of theses systems on the local and regional power network and energy demand.

6. Compare costs of implementing the above irrigation technologies.

Appendix B - Life Cycle Energy Analysis

The purpose of this appendix is to provide an in-depth explanation of how the total life cycle energy was determined for all the irrigation system being investigated.

Initial Embodied Energy

Border Check

Table 20: Initial Embodied Energy – Border Check

Initial Embodied Energy- Border Check			
	EE used (GJ/ha)	Life (years)	EE/Area/Year (GJ/ha/year)
Land Forming			
Clearing fences, trees, etc.	1.9	20	0.095
Preparatory cultivation	5.45	20	0.2725
Land form: elevating scraper	3.1	20	0.155
Formation of channel pads	0.6	20	0.03
Formation of check-banks	0.4	20	0.02
Grading	7.9	7	1.129
Formation of channels	0.3	20	0.015
Cultivation	0.9	20	0.045
Sowing of pastures	0.4	10	0.04
Application of fertilizers	0.3	20	0.015
Total			**1.816**
Structure			
Concrete bay outlets	0.251	20	0.013
Operating System	0.16	20	0.008
Total			**0.021**
Instillation			
Water control structures inc. pump	0.5	20	0.025
Seed	0.2	20	0.01
Fertilizers	8.8	20	0.44
Total			**0.475**
Sum of Totals			**2.312**

For the specific details regarding most of the processes involved in table 20. Refer to Down et al, (1986). Other calculations undertaken to determine the values in table 20 is outlined in the following:

.

Structure;

The embodied energy (EE) of the concrete bay outlets was calculated as follows:

Reinforced Concrete Bay Outlet EE Calculations

Number of outlets = 30
Weight per outlet kg = 200
EE coefficient concrete in situ GJ/kg = 0.002
Reinforcing steel EE coefficient GJ/kg = 0.0089
Increase EE for manufacturing process % = 20
Total EE GJ = 15.041

Operating System

Weight of water pump kg = 100
EE of cast iron GJ/kg = 0.06
Increase in EE for manufacturing % = 60
Total EE GJ = 9.6

Reinforced concrete is assumed to be the material used to make the bay outlets. The number of outlets, weight per outlet, and the percentage increase of the embodied energy (EE) as a result of the manufacturing process comes from Amaya (2000). The EE coefficient of concrete in situ is 0.002 GJ/kg (www.boralgreen.shares.green.net.au). The EE for the reinforcing steel that is used to reinforce the concrete is 0.0089 GJ/kg (Briad 1997). The weight of the reinforcing steel is assumed to be 1% of the weight of the concrete. The material EE was increased by 20% to account for any manufacturing EE (Amaya 2000). The value was then divided by 60 ha and then by 20 years to get units of GJ/ha/year.

The operating system consists of a water pump that is made of cast iron and with an assumed weight of 100 kg (Amaya 2000). The EE of cast iron is assumed to be 0.06 GJ/kg (Amaya 2000). The material EE was increased by 60% to account for any manufacturing EE (Amaya 2000). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year

Centre Pivot

Initial Embodied Energy - Centre Pivot			
	EE used (GJ/ha)	Life (years)	EE/Area/Year (GJ/ha/year)
Land Forming			
Clearing fences, trees, etc.	1.9	20	0.095
Formation of drains (grading)			0.339
Cultivation	0.9	20	0.045
Sowing of pastures	0.4	10	0.040
Application of fertilizers	0.3	20	0.015
Total			**0.534**
Structure			
Centre Pivot Structure	15.16	20	0.758
PVC Water Mains	4.46	20	0.223
Operating System	0.304	20	0.015
Total			**0.996**
Instillation			
Overall Structure (inc. Pump)	0.099	20	0.005
Seed	0.2	20	0.01
Fertilizers	8.8	20	0.44
Total			**0.455**
Sum of Totals			**1.985**

Table 21: Initial Embodied Energy – Centre Pivot

To determine the values in table 21 is outlined in the following:

Land forming operations;

The EE of the Land forming operations associated with centre pivot irrigation are assumed to be similar to that of border check with the exception that formation on the drains is 30% of the grading done for border check irrigation systems (Amaya 2000; Down et al 1986).

Structure;

EE for the total centre pivot structure was calculated as follows:

Centre Pivot Structure
Number of spans = 9
Weight per span kg = 2372
EE coefficient of galvanized steel MJ/kg = 34.8
Increase EE for manufacturing process % = 20
Total EE GJ = 891.49

Amount of concrete for pivot centre kg = 7200

EE coefficient concrete in situ MJ/kg = 2
Reinforcing steel EE coefficient MJ/kg = 8.9
Increase EE for manufacturing process % = 20
Total EE GJ = 18.05

8 " PVC Water Mains
Length (m) = 435
EE value MJ/m= 615.3
Total EE GJ = 267.66

Operating system
Motors to move spans = 9
Weight per motor kg = 10
Weight of water pump kg = 100
EE of cast iron GJ/kg = 0.06
Increase in EE for manufacturing % = 60
Total EE GJ = 18.24

Standard span lengths are 160 ft (approximately 48.77 meters) with a weight of about 5230 lbs (approximately 2372 kg) (Reinke broacher). Therefore to cover 60 ha, approx 9 spans would be required (the radius of the centre pivot circle is assumed to be approximately 435 meters). The standard centre pivot spans are made of galvanized steel (Wayne Brown 2006). This could possibly be due to the fact that galvanized steel offers the lowest cost per foot, and galvanized steel pipe is ideal for "mild" corrosive situations (www.waterservices.com.au). Galvanized steel has an embodied energy coefficient of 34.8 MJ/kg (www.vuw.ac.nz). After the EE of the material was calculated it a factor of 20% was added to the material to account for any EE that would be incurred during the manufacturing process (Amaya 2000). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year.

The operating system consists of a water pump that is made of cast iron and with an approximate weight of 78 kg (Amaya 2000). The EE of cast iron is assumed to be 0.06 GJ/kg (Amaya 2000). The material EE was increased by 60% to account for any manufacturing EE (Amaya 2000). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year.

The concrete base that supports the central point on the pivot structure was assumed to be made from reinforced concrete in situ. Approximately 3 cubic metres of concrete would be required (Wayne Brown). Concrete was determined to have a weight of 2400 kg/m^3 (www.hypertextbook.com). The EE coefficient of concrete in situ comes from www.boralgreen.shares.green.net.au. The EE for the reinforcing steel that is used to reinforce the concrete is 0.0089 GJ/kg (Briad 1997). The weight of the reinforcing steel was assumed to be 1% of the weight of the concrete. The material EE was increased by 20% to account for any manufacturing EE (Amaya 2000). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year.

The system would require an 8 inch water mains to supply the irrigation water to a centre pivot irrigation system that is big enough to irrigate 60 ha (Wayne Brown 2006). 435 m of water mains wound be the minium required for the system. The pipe used is assumed to be PVC-O 200/12 S2 which has an EE of 615.3 MJ/m (Ambros 2002). The EE was the divided by 60 ha years and then by 20 to get the EE into GJ/ha/year.

The operating system consists of a water pump and electric motor that propel the spans around the field. Each individual span of the entire centre pivot structure requires a motor to move it. The motors are made from cast iron that weigh approximately 10 kg each (Amaya 2000). The water pump is also made from cast iron and weighs approximately 100 kg (Amaya 2000). The EE of cast iron is 0.06 GJ/kg (Amaya 2000). The material EE was increased by 60% to account for any manufacturing EE (Amaya 2000). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year.

Installation;

The installation component, 0.01 GJ, to install the centre pivot structure was derived from Amaya (2000). The installation component of the water mains was assumed to be 2% in the EE of the mains. The Seed and fertilizer values were determined through Down et al (1986).

Subsurface Drip

Initial Embodied Energy - Subsurface Drip			
	EE used (GJ/ha)	Life (years)	EE/Area/Year (GJ/ha/year)
Land Forming			
Clearing Fences, Trees, etc.	1.9	20	0.095
Formation of Drains (Grading)			0.339
Cultivation	0.9	20	0.045
Sowing of Pastures	0.4	10	0.04
Application of Fertilizers	0.3	20	0.015
Total			**0.534**
Structure			
Drip Tube Used incl. fittings, filters etc.	44.52	10	4.452
PVC Water Mains	7.95	20	0.397
Operating System	0.125	20	0.006
Total			**4.856**
Instillation			
Overall Structure (inc. Pump)	1.249	10	0.125
Seed	0.2	20	0.01
Fertilizers	8.8	20	0.44
Total			**0.575**
Sum of Totals			**5.964**

Table 22: Initial Embodied Energy – Subsurface Drip.

To determine the values in table 22 is outlined in the following:

Land forming operations;

The EE of the Land forming operations associated with subsurface drip irrigation are assumed to be similar to that of border check with the exception that formation on the drains is 30% of the grading done for border check irrigation systems (Amaya 2000; Down et al 1986).

Structure;

Drip Tube Used incl. fittings, filters etc.	
Total weight of polyethylene to make system kg =	20000
EE coefficient of polyethylene MJ/kg =	95.4
Increase EE for manufacturing Process % =	40
Total EE GJ =	2671.2

8 " PVC Water Mains	
Length (m)	775
EE value MJ/m	615.3
Total EE GJ =	476.86

Operating System	
Weight of water pump kg =	78
EE of cast iron GJ/kg =	0.06
Increase in EE for manufacturing % =	60
Total EE GJ =	7.488

From the t-tape website (www.t-tape.com) it was found that for a reel of T-TAPE TSX 1100 which would be suited to the subsurface drip irrigation of 60 ha. A real of the t-tape was of approximate weight of 85lbs (39 kg) and length of 2700 ft (823 m) per reel. At drip line spacing 2 m (Raine et al 2000), a 775 m *775 m (approximately 60 ha) field would require approximately 365 reels of drip line with a total weight of about 14235 kg. The drip tubing is made formed from a strip of thin but strong polyethylene plastic (www.t-tape.com). On top of this there are filters, dripper tube joiners, end pieces, drip takeoffs therefore it has been assumed that the total amount of polyethylene would be 20000 kg for a typical system (Amaya 2000). The EE of polyethylene was determined to be 95.4 MJ/kg (www.vuw.ac.nz). The material EE was increased by 40% to account for any manufacturing EE (Amaya 2000). The life of the drip tube is assumed to be 7-10 years (Raine et al 2000). The EE was therefore divided by 60 ha and then by 10 years to obtain GJ/ha/year.

The system would require an 8 inch water main to supply the irrigation water to a centre pivot irrigation system that is big enough to irrigate 60 ha (Wayne Brown 2006). 775 m of water mains wound be the minimum required for the system. The pipe used is assumed to be PVC-O 200/12 S2 which has an EE of 615.3 MJ/m (Ambros 2002). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year.

The operating system consists of a water pump that is made of cast iron and with an approximate weight of 78 kg (Amaya 2000). The EE of cast iron is assumed to be 0.06 GJ/kg (Amaya 2000). The material EE was increased by 60% to account for any manufacturing EE (Amaya 2000). The EE was the divided by 60 ha and then by 20 years to get the EE into GJ/ha/year.

Installation;

The installation component to install the subsurface drip system was derived from Amaya (2000) and was calculated as follows:

Calculating the EE of the Tractor: (Down et al. 1986; Amaya 2000)

Equipment = 134 kW 2WD tractor

Life of the tractor hr = 10000

Time taken hr = 40

Fuel used L/hr = 36

Total EE associated with the tractor GJ = 707

Calculations of the Installation Component of the Drip Tube: (Amaya 2000)

Fuel energy GJ = 40 hr * 36 L/hr * 0.038211 GJ/L = 55

Primary fuel energy GJ = 55 GJ * 1.12 = 61.62

Energy associated with tractor operation GJ = 707 * (40 / 10000) = 2.83

Energy associated with labour GJ = 40 hr * 0.00126 GJ/hr = 0.0504

Total Energy GJ = 61.62 + 2.83 + 0.0504 = 64.5

The EE was then divided by 60 ha and then by 10 years to get the EE into GJ/ha/year. The installation component of the water mains was assumed to be 2% in the EE of the mains. The EE was then divided by 60 ha and then by 20 years to get the EE into GJ/ha/year. The Seed and fertilizer values were determined through Down et al (1986).

Operational Energy

The energy consumed by the pumping system is given by the following equation for all the irrigation systems:

$$\text{Power Requirement kWh} = \frac{g}{3600} \times \frac{1000}{E_p} \times V \times H \qquad (1)$$

(Rural Water Commission of Victoria 1988)

Where:
g = gravity = 9.81
E_p = pump efficiency %
V = Volume of water pumped ML
H = head m

Border Check

Operational Energy - Border Check	
Operation	**EE/Area/Year GJ/ha/year**
Application of weedicides	negligible
Weedicides	0.06
Pumping of supply water	1.1772
Pumping of tail water	0.92
Total	**2.1572**

Table 23: Operational Energy – Border Check.

The following values where used to calculate the pumping energy required, as shown in table 23, for the supply water along with equation 1:

Calculating Pumping Energy
Depth of water applied m/ha/year = 1
Area irrigated m^2 = 600000
Volume of water applied V ML = 600
Pumping head H m = 9
Gravity g m/s^2 = 9.81
Pumping efficiency E_p = 0.75
Pumping energy required per year kWh = 19620
Energy Used GJ/ha/year = 1.1772

To convert from kWh to GJ a factor of 0.0036 was used (www.onlineconversion.com). It was then divided by 60 ha to get the energy use into units of GJ/ha/year. The pumping of the tail water, weedicide and application of weedicide values comes from Dawn et al (1986).

Centre Pivot

Operational Energy - Centre Pivot	
Operation	**EE/Area/Year GJ/ha/year**
Application of weedicides	negligible
Weedicides	0.06
Centre pivot structure operation	0.198
Pumping of supply water	3.662
Total	**3.920**

Table 24: Operational Energy – Centre Pivot.

The following values where used to calculate the pumping energy required, as shown in table 24, for the supply water along with equation 1:

Calculating Pumping Energy

Depth of water applied m/ha/year = 0.8
Area irrigated m^2 = 600000
Volume of water applied V ML = 480
Pumping Head H m = 35
Gravity g m/s^2 = 9.81
Pumping efficiency E_p = 0.75
Pumping energy required per year kWh = 61040
Energy used GJ/ha/year = 3.662

To convert from kWh to GJ a factor of 0.0036 was used (www.onlineconversion.com). It was then divided by 60 ha to get the energy use into units of GJ/ha/year. The weedicide and application of weedicide values comes from Dawn et al (1986).

The energy required to operate the motors that propel the centre pivot spans was calculated in the following way:

Centre Pivot Structure Operation

Number of motors = 9
Motor power each HP = 0.6
Motor Power Total kWh = 4.03
Operational Time hours/year = 817
Total energy used kWh = 3292.51
Total Energy used GJ/ha/year = 0.198

There is 1 motor required per span and there are 9 spans therefore 9 motors are required (Reinke broacher). The horse power of each motor is 0.6 (Amaya 2000). Total operational time can vary however is assumed to be 817 hours (Amaya 2000). To convert from kWh to GJ a factor of 0.0036 was used (www.onlineconversion.com). It was then divided by 60 ha to get the energy use into units of GJ/ha/year.

Subsurface Drip

Operational Energy - Subsurface Drip	
Operation	**EE/Area/Year GJ/ha/year**
Application of weedicides	negligible
Weedicides	0.06
Pumping of supply water	3.662
Total	**3.722**

Table 25: Operational Energy – Subsurface Drip.

The following values where used to calculate the pumping energy required, as shown in table 25, for the supply water along with equation 1:

Calculating Pumping Energy

Depth of water applied m/ha/year = 0.8
Area irrigated m^2 = 600000
Volume of water applied V ML = 480
Pumping Head H m = 35
Gravity g m/s^2 = 1000
Pumping efficiency E_p = 9.81
Pumping energy required per year kWh = 0.75
Energy used GJ/ha/year = 61040
Depth of water applied m/ha/year = 3.662

To convert from kWh to GJ a factor of 0.0036 was used (www.onlineconversion.com). It was then divided by 60 ha to get the energy use into units of GJ/ha/year. The weedicide and application of weedicide values comes from Dawn et al (1986).

Appendix C – Economic and Environmental Analysis

Operational costs

Average regional reference price per region for each month (0000-2400) and average peak price (peak period covers 7:00am to 10:00pm EST weekdays excluding bank holidays) over the financial year. RRP (Regional Reference Price) is expressed in $/MWh.												
	NSW		QLD		SA		SNOWY		TAS		VIC	
Date	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**
31/07/2005	24.3	27.63	18.55	20.75	30.79	37.43	25.07	28.65	112.34	115.77	26.51	32.3
31/08/2005	28.47	36.82	20.33	24.2	33.18	43.62	28.99	37.4	107.2	141.34	30	40.15
30/09/2005	28.63	36.04	23.99	30.54	31.34	38.75	28.58	35.58	69.35	77.7	29.14	37.3
31/10/2005	47.39	86.12	25.36	36.84	30.15	37.91	22.7	27.51	82.38	102.17	22.64	28.44
30/11/2005	57.49	103.82	19.84	24.54	40.62	63.78	39.54	64.34	57.64	59.19	30.7	46.09
31/12/2005	71.55	138.04	57.3	112.22	46.59	76.22	43.8	73.57	42.82	46.71	34.24	52.01
31/01/2006	26.84	35	29.84	47.99	72.71	91.42	43.05	63.38	36.9	41.03	53.44	69.5
28/02/2006	64.45	122.5	54.34	97.12	31.48	47.75	39.7	67.28	32.44	35.57	56	105.26
31/03/2006	22.58	27.25	19.67	24.16	29.6	35.95	23.1	27.87	28.4	32.53	23.36	29.05
30/04/2006	20.61	24.55	21.63	32.38	27.89	35.8	21.23	25.11	33.36	34	22.59	29.47
31/05/2006	25.45	32.17	23.17	29.84	38.56	52.84	25.67	31.82	33.76	47.59	28.25	37.92
30/06/2006	31.47	38.72	25.25	30.53	39.22	48.79	32.35	39.16	41.39	53.14	34.61	42.99

Table 26: Average Monthly Electricity Prices; 2005 – 2006.
Source: www.nemmco.com.au.

From the data in table 26 the average Regional Reference Price (RRP) and average peak Regional Reference Price (RRP) for the year 2005 – 2006 was calculated. The results are shown in table 27.

Average RRP and Peak RRP for the Finical Year of 2005 - 2006 $/MWh												
	NSW		QLD		SA		SNOWY		TAS		VIC	
Year	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**	**RRP**	**Peak RRP**
2005 - 2006	37.44	59.06	28.27	42.59	37.68	50.86	31.15	43.47	56.50	65.56	32.62	45.87

Table 27: Average Electricity Price for the 2005 – 2006 Finical Year

Calculating Electricity Costs;

To calculate the electricity, the following equation was employed:

Electricity Cost $/ha/year = (Electricity required MWh/year * Electricity Price $/MWh)/60 (2)

Border Check:

Due to the fact that a border check irrigation system requires labour to operate, it will have to operate under peak power rates in most cases. Therefore, these are the values that were used from table 27 as the power costs from each area. The power required was calculated in appendix B. Equation 2 was then used to obtain the $/ha/year.

Centre Pivot and Subsurface Drip:

Due to the fact that both irrigation systems are easily automated they can operate all hours and so incur peak and off peak power rates. Due to this fact the average RRP is used as the cost of power in each area. The power required was calculated in appendix B Utilising these facts and equation 2 the electricity cost was determined in $/ha/year.

Greenhouse Gas

Fuel	**Energy**		**Greenhouse $CO_2^{(1)}$**	
Electricity				
NSW, ACT	3.6	MJ/kWh	0.968	kg/kWh
Victoria	3.6	MJ/kWh	1.467	kg/kWh
Queensland	3.6	MJ/kWh	1.04	kg/kWh
SA	3.6	MJ/kWh	1.109	kg/kWh
WA	3.6	MJ/kWh	1.032	kg/kWh
Tasmania	3.6	MJ/kWh	0.002	kg/kWh
NT	3.6	MJ/kWh	0.756	kg/kWh
Australia average	3.6	MJ/kWh	1.051	kg/kWh
Canada average	3.6	MJ/kWh	0.22	kg/kWh

Table 28: Energy and Greenhouse CO_2 related to Electricity Production around Australia.
Source:www.aie.org.au

Table 28 shows the greenhouse gas produced during electricity production in kg of CO_2 per kWh. In order to calculate the total GHG that would be produced to power the irrigation systems, the power requirement which was determined in appendix B was used along with the values in table 28.