University of Southern Queensland

Faculty of Engineering and Surveying

A validation of the model for effluent disposal using land irrigation (MEDLI).

A dissertation submitted by

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Abstract

Biological waste produced by intensive livestock farming is a valuable and useful product used in the agricultural industry for irrigation of crops. Manure and liquid effluent contains nutrients that can be effectively utilised in commercial cropping of livestock feed. It provides farmers with a low cost organic material and fertilizer, resulting in high yielding crops if carefully managed. The downside of using effluent in crop irrigation is the potentially high concentrations of chemicals and pathogens in effluent can, if mismanaged, reach toxic levels in the soil. This can lead to crop failure and in worst cases, land and water contamination.

It is a requirement of Queensland law that before an enterprise irrigates with effluent it must first obtain a regulation certificate. To fulfil this obligation an effluent irrigation scheme must be designed and modelled to the satisfaction of the regulatory authority. There are tools available which aid the designer of the effluent irrigation scheme in conducting water and nutrient balances. The software package recommended by the Queensland Government is; The Model for Effluent Disposal using Land Irrigation (MEDLI). The purpose of this program is to model; effluent volumes, concentrations of chemical constituents in effluent, point of deposition soil chemistry and nutrient uptake by plants.

Due to the absence of previously completed program validation, this research aimed to conduct validation of MEDLI software. Modelling scenarios were entered into the program using input variables that had been established from data collected from three beef cattle feedlots. Scenarios were set-up to try and best mimic site conditions, so a comparisons could be drawn between the simulated and observed datasets.

Results of the comparisons for all three sites found, often significant variation in the values of simulated and observed conditions. Weak correlation of the datasets could not be conclusively attributed to systematic errors in the model. Analytical errors such as; improperly defined inputs and inadequacy of sample sizing may have contributed to the bias found between datasets. A particularly notable conclusion of the analysis was that far greater definition is required around the required estimations of the pre-treatment and anaerobic pond chemistry inputs. A recommendation is; MEDLI literature which is supplied with the program, should provide considerably more detailed guidance on deriving accurate estimation of these input variables.

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Chapter 1 INTRODUCTION

1.1 Project Overview

A common industry practice for dealing with biological effluent from intensive livestock farming is to use the effluent in irrigation of cropping fields. Typically, during a rainfall event, effluent flows from stock holding yards to a sewage/stormwater reticulation system before entering a sedimentation system. The sedimentation system allows for heavy entrained solids to settle from the brine and the remaining effluent flows down an open channel and collects at a terminal holding pond. This effluent can then be applied to a specified waste utilisation area through normal irrigation practices.

The Queensland Government Department of Environment and Heritage Protection are responsible for the regulation of effluent disposal through land irrigation in the state of Queensland. Specifically, the regulator requires that proposed wastewater disposal through land irrigation is modelled in terms of three main stages of the process; storage, treatment and disposal. The aim of the modelling is to determine a water and nutrient balance using expected water/effluent volumes and mathematical algorithms to simulate nutrient retention values. This then determines a suitable size of irrigated land area for the disposal of the effluent. The modelling tool that is recommended by the Queensland Government is; The Model for Effluent Disposal using Land Irrigation (MEDLI).

MEDLI is computer software developed jointly by the Queensland Government Department of Natural Resources, Department of Primary Industries and CRC for Waste Management and Pollution Control. The software models the entirety of effluent stream from its creation to disposal and outputs data about the water balance, nutrient and salt loading throughout the effluent stream. This information can than be interpreted by the user in the design of an effluent irrigation scheme. The program requires the inputs of climate data, rainfall and effluent production variables to produce the simulated scenario.

1.2 Background

Effluent from feedlots can contain high and varying levels of nutrients, salts, organic matter and metals. It is for this reason that effluent is used for land irrigation, as the constituents within the effluent will be taken up by crops that are grown in the irrigation area. It is common industry practice to plant high yielding crops in waste utilisation areas to achieve high exchange rates from soil to plants (MLA, 2012). Compounds deposited in soils which are not utilised by the crop or found in excessive concentration are of particular interest when designing and monitoring an effluent irrigation scheme. Irrigation schedules need to be managed so that quantities of any particular compound do not reach contamination levels, creating risk of environmental degradation to the irrigation and surrounding areas or waterways. To achieve this, understanding of effluent quality is essential so that decisions can be made about the need for treatment or dilution of the wastewater.

Effluent quality refers to the concentration of the constituents in wastewater. The level of concentration can be reduced through shandying the effluent with overland water collected from outside the controlled drainage area (CDA) or bore water. Treatment of the effluent may also be a requirement if a particular constituent is considered in high concentration. Sweeten (n.d.) suggests the limiting factors on effluent application rates in beef cattle feedlots are typically, high concentrations of nitrogen, sodium and other soluble salts such as potassium and chloride.

In addition to effluent land irrigation, crops can also be subjected to applications of semi composted manure. This manure is collected from the holding yards and stockpiled to allow decomposition. Manure contains much higher levels of nutrient, salts and other compounds than effluent however it also has a high percentage of organic material which increases the exchange capacity and general structural quality of soils. Excessive amounts of organic matter in soil can lead to degradation of soil quality. Reduced soil aeration and exclusion of aerobic based microbes are symptoms of soils overly laden with organic matter. Whilst the practice of spreading manure on an effluent disposal site does occur in industry it is not a recommended practice in most guidelines. This is due to the high risk of causing nutrient toxicity in the soil. If manure is required on the effluent disposal site to improve the structure of the soil it should be included in the design of the effluent disposal scheme.

The management plan employed for effluent land irrigation is relative to the existing type and quality of soil and the grown crops potential to uptake soil compounds. Best practice for managing effluent utilisation areas is baseline and subsequent ongoing monitoring.

1.3 Project Objectives

The objective of this research project is to;

- Evaluate if MEDLI simulated predictions are accurate compared with observed data collected from the field in the areas of;
    1. Stored effluent chemical properties,
    2. Nutrients in the soil; and
    3. crop yields and harvested nutrients

In order to satisfy these project objectives, field sampling data will be collected from three different beef cattle feedlots. The field data will be used as the basis to input the required parameters in to MEDLI. A simulation in MEDLI will be run over the same time period as is covered by the field collected data. A statistical comparison of the simulated and real data will determine the accuracy of MEDLI predictions. Comparisons will be produced that fulfil the parameters (1, 2 and 3) listed above. The process of simulation and comparison will be repeated for three separate beef cattle feedlots to determine a final level of deviation in the data.

1.4 Assessment of Consequential Effects

The potential consequences of this project itself on the health and safety of people directly involved are very minimal. As this is a desktop study, and datasets collected from the field are retrospective there is almost no chance that any person or the environment would be adversely effected by the research project.

The effects that outcomes of this research may have on the feedlot industry are somewhat dependent on the final results that are presented and the traction that those result gain in the industry. It is the intention of this project to establish if a gap exists between real-world data and predicted data from the MEDLI program. If results indicate accuracy of the program in all areas to be analysed, then this will simply add validity to software that has already been used in industry for eighteen years.

If, however inaccuracy is found in the outputs of MEDLI compared with the measured data, this may necessitate or facilitate further, more in-depth research in to the reasons for the inaccuracies. The Queensland Government Department of Science, Information, Technology and Innovation (2016), states that MEDLI should be used as an estimation aid and results from it should not form the sole basis of decision making; therefore, no level of accuracy in the program outputs is provided by the department. As MEDLI is the software package that is recommended by the Queensland Government for the modelling and design of effluent irrigation schemes to achieve certification; it is reasonable to conclude that significant deviation of the datasets would warrant further investigation.

Chapter 2 LITERATURE REVIEW

2.1 Introduction

The beef cattle feedlot industry in 2012 had a production value of $2.7billion and has since seen considerable growth. With the rising global demand in the market this production is expected to see continued growth in the future (MLA, 2012). Increasing consumer demand for beef has lead to a significant growth in the feedlotting industry. The number of intensive beef cattle feedlots have increased in the last two decades with total head of cattle increasing from two hundred thousand in 1995 to almost one million in 2015 (ALFA, 2015). An increase in intensive production methods has seen a corresponding rise in intensified effluent outputs. To avoid environmental degradation caused by concentrated levels of nutrient and salts found in effluent being disposed into natural waterways; feedlots are designed with controlled drainage areas (CDA). A CDA is a restricted stormwater catchment area within the feedlot which captures all runoff and associated effluent. Pre-treatment of the effluent occurs in a sedimentation system which aims to remove solids from the effluent. The sedimentation system is drained periodically and the solids are collected and transported to a storage area to undergo natural decomposition. The decomposed material is either utilised on-site or sold as a commercial product. The effluent that passes through the sedimentation system is stored in a holding pond where it undergoes further treatment such as; aerobic and anaerobic moralisation, volatilisation, shandying and liming. If the effluent is to be disposed through irrigation this can only take place after treatment processes.

The purpose of this literature review is to establish current effluent production practices, treatment, disposal and the regulation of the intensive beef cattle feedlot industry. In addition, it will investigate factors which influence the amount of effluent that can be safely applied to soils.

2.2 Effluent Irrigation

Current beef cattle feedlot industry practices for capturing and storing effluent will be examined in the section. In addition, the factors effecting effluent production and utilisation are explored in relation to the beef cattle feedlotting industry.

2.2.1 Effluent Production

Since the focus of this research is on the beef cattle industry, an overview of effluent production within a typical beef cattle feedlot will be presented. The constituents of effluent are dependent on; cattle breed, type of ration provided, drinking water quality, stocking density, climatic conditions, pen cleaning practice and the amount of time effluent has been stored.

Different cattle breeds and feedlot operators have preferential ration requirements and this leads to different nutrient and salt outputs. The former Department of Primary Industries (DPI) (2000), guidelines advise that regular site specific sampling of effluent in the holding pond (if available) is preferred over using mass balance or empirical data for irrigation scheduling. Over a period of time, ranges for nutrient, salt and pH can be established of the particular site and used to advise appropriate shandying and irrigation application rates. The guidelines state that, at a minimum the following tests should be conducted on the effluent;

- pH
- Total Kjeldahl Nitrogen
- Ammonium Nitrate
- Total Phosphorus
- Inorganic Phosphorus
- Potassium
- Sodium Absorption Ratio
- Electrical Conductivity

If site data cannot be obtained, for instance in a new development, a mass balance approach can be used in the prediction of effluent outputs. Watts et al (1994) developed a modelling tool (BEEFBAL) to estimate the mass of nutrients and salts contained in effluent. This approach calculates the mass of the nutrients and salts leaving the feedlot and subtracting the mass of nutrient and salt content entering the feedlot through; drinking water, rations and new cattle. Empirical data has been collected on the typical constituents of effluent from three feedlots in Queensland. The Department of Primary Industries (1994), presented the data in Table 2.1.

Table 2.1 - Typical constituents of effluent in beef cattle feedlots (Qld DPI, 1994)

Parameter	Units	Average	Range
Total Kjeldahl Nitrogen	mg/L	764	440 - 890
Ammonium Nitrogen	mg/L	550	220 – 816
Nitrate Nitrogen	mg/L	0	Not Detected
Total Phosphorus	mg/L	81	50 – 101
Inorganic Phosphorus	mg/L	30	-
Potassium	mg/L	2053	1290 – 2800
Chloride	mg/L	2475	1991 – 2996
Acidity/Alkalinity	-	7.6	7.4 – 7.7
Electrical Conductivity	dS/m	13.6	12.5 – 16.2
Sodium Absorption Ratio	-	16.1	10.0 – 22.0

The data collected was from sites that utilise high salt bore water and may not be representative of data that would be expected at other feedlots.

2.2.2 Current Feedlot Practices

Current practice when establishing, renovating or expanding feedlots is to implement a controlled drainage area (CDA). This area captures all stormwater that may contain animal effluent and conveys it into a controlled drainage system. Open channel drains allow flow into a sedimentation system of which there are several types for pre-treatment, and then in to a holding pond for further treatment. Figure 2.1 provides a schematic from the National Guidelines for Beef Cattle Feedlots in Australia, of a feedlot with a CDA outlined.

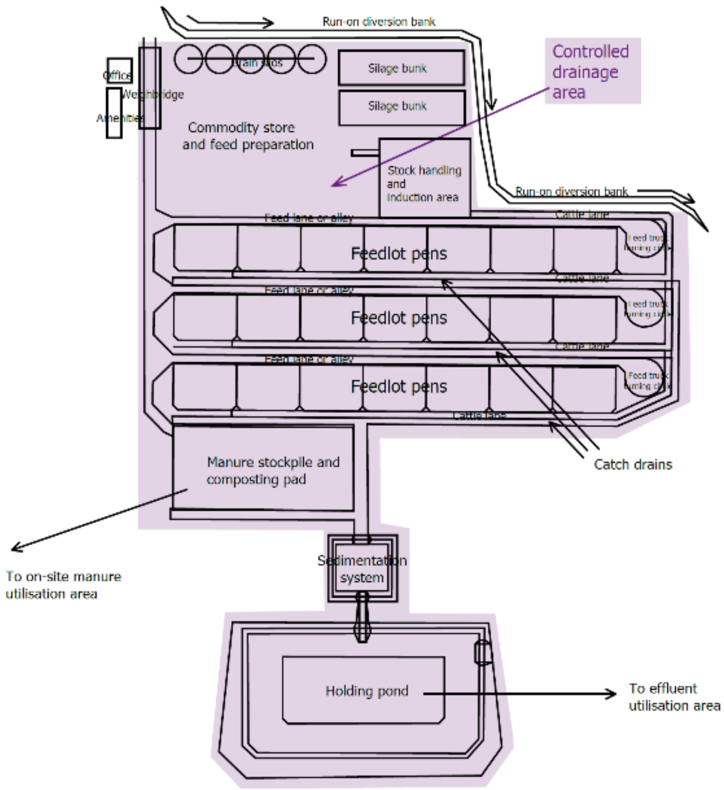


Figure 2.1 - Feedlot Controlled Drainage Area (MLA, 2012)

Through civil earth works and drainage design the effluent produced at a feedlot can be almost entirely contained from surrounding land. As suggested in the MLA National Guidelines (2012), the drainage system is typically designed to an average reoccurrence interval (ARI) of 20 years.

Pre-treatment of effluent occurs in the sedimentation system. Three types of systems typically used in the beef cattle feedlot industry have been defined as;

1. Sedimentation basins
2. Sedimentation terraces
3. Sedimentation ponds

The differences between each are described by the Department of Primary Industries, (2000) and is mostly dependent on the size and depth of the system. Regardless of the type in use the basic premise of function is the removal of as much entrained solids from the effluent as practicably possible. This is achieved by reducing the flow rate in the system to not more than 0.005 m/s to allow time for settlement.

From the sedimentation system the effluent progresses to either an evaporation system or a holding pond for further treatment. An evaporation system is a legacy means of dealing with effluent through evaporation only and is not now considered best industry practice. A holding pond stores effluent while it undergoes natural or induced treatment before application to land via irrigation. Naturally, aerobic and anaerobic microorganisms mineralise nutrients in the effluent which creates a more favourable product for land application. Induced treatment may be in the form of shandying, mixing in 'clean' water to reduce concentrations of nutrients and salts or treating acidic effluent with calcium carbonate ($CaCO^3$) to increase pH closer to neutrality.

A holding pond, in addition to being designed to an ARI of 20 years should be able to contain the balance of runoff from a 90 percentile wet year. This balance should be calculated using the average monthly evaporation loss and losses from irrigation. Software such as MEDLI are used as an aid to determine this water balance given the complexities of how much volume can be applied to the irrigation site. Methods other than MEDLI have been developed to calculate water balances for feedlots such as the; standard tabulated method (DPI, DNR, 1994), and site specific modelling using accepted hydrological practices.

The water balance of a feedlot is significantly impacted by the rate at which effluent can be applied to land. However, the limiting factor to effluent irrigation is typically the nutrient and salt balance with in the soil of the designated irrigation area. Capital investment in land and irrigating infrastructure is a factor which designers endeavour to minimise for their clients hence maximum application rates to minimal land area is pursued.

2.2.3 Environmental Implications

The benefits of the effluent irrigation are the reuse of water by sustainably managed means and the beneficial use of the nutrients to improve soil condition and growing capacity. The soil improvement benefits are only applicable up to a nutrient loading rate specific to the soil type and the crops which are being grown (Skerman,2000).

The negative impacts are that effluent irrigation can have the effect of raising contaminants including heavy metals and chlorinated compounds to toxic levels. Elevated contaminant levels in effluent can pose a significant threat to the irrigated land as they can initially reduce the productivity of the land and if unchecked eventually render the land unusable. Testing on effluent is required by state regulators to ensure it does not contain unacceptable levels as presented in the Guidelines for Agricultural Land Evaluation in Queensland (2013). Environmental Best Practice Guidelines for the Red Meat Processing industry (MLA,2006) outline possible adverse environmental impacts from improper effluent irrigation as;

- excessive nutrient accumulation in soils
- odour emissions from poorly treated effluent
- surface runoff from over-irrigation
- excessive salt accumulation in soils; and
- damage to the soil structure

Effluent from feedlots can contain high and varying levels of nutrients, salts, organic matter and metals. It is for this reason that effluent is used for land irrigation, as the constituents within the effluent will be taken up by crops that are grown in the irrigation area. It is common industry practice to plant high yielding crops in waste utilisation areas to achieve high exchange rates from soil to plants (MLA, 2012). Compounds deposited in soils which are not utilised by the crop or found in excessive concentration are of particular interest when designing and monitoring an effluent irrigation scheme. Irrigation schedules need to be managed so that levels of any particular compound do not reach contamination levels creating risk of environmental degradation to the irrigation and surrounding areas or waterways. By restricting application rates, the effluent can largely be prevented from entering natural waterways. To prevent excessive nutrient loading in soils, understanding of effluent quality is essential so that decisions can be made about the need for treatment or dilution of the wastewater (MLA, 2006)

Effluent quality refers to the concentration of the constituents in wastewater. The level of concentration can be reduced through shandying the effluent with overland water collected from outside the CDA or bore water. Treatment of the effluent may also be a requirement if a particular constituent is considered in high concentration. Sweeten (n.d.) suggests the limiting factors on effluent application rates in beef cattle feedlots are typically, high concentrations of nitrogen, sodium and other soluble salts such as potassium and chloride.

In addition to effluent land irrigation, crops are also subjected to applications of semi composted manure. This manure is collected from the holding yards, sedimentation ponds and holding ponds as sludge and stockpiled to allow decomposition. Manure contains high levels of nutrient, salts and other compounds (much higher than effluent) however it also has a high percentage of organic material which as previously stated increases the exchange capacity and general structural quality of soils. Excessive amounts of organic matter in soil can lead to degradation of soil quality. Reduced soil aeration and exclusion of aerobic based microbes are symptoms of soils overly laden with organic matter (Skerman, 2000). If manure is to be used on the cropping field it is of absolute importance that this be considered in the modelling of nutrient and salt balance for the effluent disposal scheme design.

The management plan employed for effluent land irrigation is relative to the existing type and quality of soil and the grown crops potential to mobilise soil compounds. Best practice for managing effluent utilisation areas is baseline and subsequent ongoing soil monitoring (DEC, 2003).

2.2.4 Site Establishment

The factors that require consideration for an appropriate effluent irrigation site are; climatic conditions, topography, soil suitability, proximity to surface and ground water and nearby neighbours. It is advisable that excess ponding of effluent be avoided as this can lead to a nutrient concentration in the soil at the point of ponding and an increased risk of ground water contamination (MLA, 2006). It is for this reason the DPI (1994) recommend a well graded uniform slope for effluent irrigation. MLA (2006), advise that a slope of up to ten percent is suitable, however grades over two percent may require the implementation of erosion control measures and catch drains. Slope grades between one and three percent are considered ideal.

The climatic conditions of the location in which the effluent irrigation is proposed should be considered during the design phase. Local rainfall patterns and evaporation rates will dictate if effluent applications are viable from the outset. If average annual evapotranspiration and the crops water requirements exceed annual rainfall, then irrigation will likely be suitable. In order to satisfy the governmental regulating body, a whole of enterprise water balance will generally be a requirement. Some commercially available water balance tools in the market are provided by MLA, (2006);

- MEDLI
- Effluent Irrigation Reuse Model (ERIM)
- PERFECT
- WASTLOAD

Soil that has not previously been contaminated, eroded, degraded or has any other restriction to healthy plant growth is recommended. Before a land area can be classified as an effluent utilisation area it should first undergo soil testing to establish any limitations of the soil which may affect its ability to accept effluent. In addition, initial testing can form a baseline for monitoring soil condition in the future after effluent irrigation has commenced. Surface layers and sub-surface soils should be tested as percolation of effluent into sub surface soil horizons can have impacts on crop health and ground water contamination levels (Swanson, Linderman, Ellis, 1974). Soil to be used as an effluent irrigation area should have good permeability, deep profile, moderate to slightly acidic pH, non-cracking clayey loam, be well structured and have suitable ionic condition (Skerman, 2006). The NSW DPI provides Table 2.2 as a guideline to the limitations of a soil to have effluent applied.

Table 2.2 describes sodicity measured in exchangeable sodium percentage (ESP). This is a measure presented as a percentage used to compare the amount of sodium (Na) in soil. The equation for ESP is;

$$ESP = \frac{Na}{\sum Ca + Mg + K + Na} \times 100$$

Soil that produces values of ESP above 6 percent are considered to be sodic (Tan, 2010).

Total salinity of a soil is typically measured in electrical conductivity (EC). The EC of soil is obtained by passing a current between two electrodes which penetrate the soil to the desired depth of measure. A greater concentration of dissolved salts in the soil solution will produce higher EC values (Tan, 2010).

Saturated hydraulic conductivity (K_{sat}) is an empirically or experimentally derived measure, in distance per time, of a soils ability to transmit water through the soil pores under saturated condition (Tan, 2010).

Table 2.2 - Limiting Soil Properties for Effluent Irrigation Sites (NSW DPI, 2003)

Property	Limitation			Restrictive Feature
	Nil/slight	Moderate	Severe	
Sodicity, ESP 0-40cm	<5	5 – 10	>10	Structural degradation and waterlogging
Sodicity, ESP 40-100cm	<10	>10	-	Structural degradation and waterlogging
Salinity, EC (dS/m)	<2	2 – 4	>4	Excess salt restricts plant growth
Depth of high water table (m)	>3	0.5 – 3	<0.5	Wetness, risk to groundwater
Depth to bedrock, Hardpan (m)	>1	0.5 – 1	<0.5	Restricts plant growth, excess runoff, waterlogging
Saturated Hydraulic Conductivity, K_{sat} (mm/h)	20 – 80	5 – 10 or >80	<5	Excess runoff, waterlogging, risk to ground water
Available Water Capacity (mm/m)	>100	<100	-	Little plant available water, risk to groundwater
Bulk Density (g/cm^3)				Restriction to root growth
Sandy Loam	<1.8	>1.8	-	
Loam and Clay Loam	<1.6	>1.6	-	
Clay	<1.4	>1.4	-	
Soil pH	6.0 - 7.5	3.5 – 6.0 or >7.5	<3.5	Reduces optimum growth
Effective Cation Exchange Capacity (cmol/kg)	>15	3 – 15	<3	Poor Nutrient Availability
Emersion Aggregate Test	4 – 8	2, 3	1	Poor structure
Phosphorus Sorption	>6000	2000 - 6000	<2000	Immobilisation of P

Existing surface and groundwater streams should be identified that may be impacted by applications of effluent to nearby land. A groundwater table that has a maximum height within half a meter of the natural ground level will typically be deemed unsuitable by the governing regulator. If the effluent utilisation area is located in close proximity to a creek which is feeding, or is in the catchment of, a municipal drinking water supply, the regulators are likely to impose very strict runoff and infiltration restrictions. It may or may not be financially viable to comply with these restrictions and a different location may need to be sort. Irrigation sites near to surface water bodies may require catch drains and contour banks to direct stormwater runoff to an amenable location. Direct runoff of effluent irrigation water should be controlled by suitable irrigation management practices, over application may have detrimental consequences to both the irrigation site and waterways (MLA, 2006).

Nuisance odour which causes distress to nearby residents, properties and public roads will also be taken into consideration by the regulator. If the location of the utilisation area is likely to impact the surrounding area, buffer zones will need to be put in place to elevate the risk. The spread of odour should be modelled prior to site selection and design of appropriate buffer zones undertaken. Proximity and prevailing winds will typically be considered during planning and actions such as site location and vegetated buffers can be manipulated to find a favourable solution to the impacts of odour to surroundings.

2.2.5 Effluent Utilisation

When effluent is applied to a cropping field, a net removal of nutrients takes place through plant uptake if the harvest is removed from site. If the crop is not removed from the site and/or used for cattle grazing, most of the nutrient will be recycled back to the soil. This scenario is not conducive to an effluent disposal scheme. It should always be the objective of an effluent disposal schedule to balance the nutrient and salt inputs with the harvested crop removed from site. This will reduce the chances of large quantities of nutrients and salts migrating below the root zone and into groundwater bodies. Whilst the soil acts as a significant sink for nutrient and salts it is the goal of designers not to rely on this as an aid, as this would ultimately be considered unsustainable (DPI, 1994).

At the core of any decision on the viability of an effluent reuse program is whether it is sustainable. No accumulation of substances in the soil should be allowed to reach toxic levels, thus it would be considered unsustainable land use. The environmental Best Practice Guidelines (MLA, 2006), state that the fate of all nutrients added to the soil will fall within one of the following categories;

- absorption of soluble nutrients and uptake by plants
- assimilation into the soil structure by micro-organisms
- leaching in to the sub strata and possibly ground water
- relocation by erosion
- fixation to exchange sites
- formation of immobilised compounds and;
- loss to the atmosphere through volatilisation.

Nitrogen (N) is often a limiting factor in the volume of effluent that can be applied to a land parcel. Excessive application of soluble N may lead to leaching into ground water or runoff of heavily N loaded soils into water courses during significant rain events. Of the total N found in effluent about 70 percent will typically be inorganic ammonium (NH_4^+) of which 15 percent will be lost to volatilisation during spray irrigating. As effluent contains almost no nitrate the other 30 percent is organic form nitrogen. Once in the soil some of the ammonium will be nitrified to nitrate which is highly mobile providing benefit to the crop but risk to the surrounding environment. Guidelines state that to minimise the potential for environmental contamination; the volume of total N applied to the crop should not exceed the N content of the harvested crop plus the storage capacity of the soil plus atmospheric losses. (Skerman, 2000).

Phosphorus (P) in effluent is found in both organic and inorganic forms. The P in effluent typically accounts for 6 percent of the total P excreted by the animals. The remainder being in the manure. If applications of manure are to be applied to crops in addition to effluent irrigation than this must be considered whilst modelling the nutrient balance. Organic P once delivered to the soil will be readily mineralised to orthophosphate and available to the crop. Inorganic P is not available for plant uptake as it is typically bound to compounds of iron, aluminium or calcium. The concentrations of these ions dictate the soils ability to sorb phosphorus. The solution concentration of orthophosphate and total inorganic P available to be sorbed in the soil is called the adsorption isotherm. This is the soils ability to ‘take up’ phosphorus (Skerman, 2000). Governing regulators will typically require a phosphorus sorption test be carried out on the proposed site prior to approval of the program. The test will produce a phosphorus sorption isotherm which provides an indication of the total phosphorus which can be sorbed by the soil (MLA, 2006).

2.3 Legislation, Regulation and Guidelines for Land Application of Effluent

The Queensland Government Department of Environment and Heritage (formally the Environmental Protection Agency, EPA), is the regulatory body responsible for ensuring compliance with environmental legislation in Queensland. It is this Department that is responsible for assessing applications of effluent disposal schemes through land irrigation.

The Environmental Protection Act 1994 is the legislative document that outlines the requirements for effluent disposal to be modelled. The process is considered under the Act to be an Environmentally Relevant Activity (ERA). Appendix B provides the relevant sections of the act that pertain to irrigated effluent disposal. Before effluent irrigation can proceed on a property, the land holder must obtain a registration certificate. This certifies that the effluent irrigation process and scheduling have been modelled and designed in accordance with the legislation outlined in Appendix B. Section 619 of the Act provides the authority for a representative of the Department of Environment and Heritage to issue a registration certificate.

In addition to the Act, other documents such as the; Environmental Protection Regulation 2008, Queensland Guidelines for the Safe Use of Recycled Water and Establishment and Operation of Beef Cattle Feedlots are documents that regulators may use to guide certification decisions. These same documents are all available for land holders and design consultancies.

The document that underpins all state legislation and regulation in effluent reuse is the; Guidelines for Sewage Systems - Effluent Management. This publication is a sub section of The National Water Quality Management Strategy produced by the Australian Government Department of Environment and Energy (1997). It sets out (but is not limited to) a national framework for effluent irrigation practices. The Guidelines for sewage systems establish the principles of land applications with effluent as;

- *"The build-up of any substance in the soil should not preclude sustainable use of the land in the long term*
- *The effluent is not detrimental to the vegetative cover*
- *Any change to the soil structure should not preclude the use of the land in the long term*
- *Any runoff to surface waters or percolation to groundwater should not compromise the agreed environmental values*
- *No gaseous emissions to cause nuisance odour*"

These principles serve as a guide for state authorities to develop their own legislative requirements (MLA, 2006).

In addition to the legislative and regulatory documents, design consultants also have a number of other ancillary resources to help with controlling and disposing of effluent streams. These include; NSW Environmental Guidelines – Use of Effluent by Irrigation (DEC,2004), Environmental Best Practise Guidelines for the Red Meat Processing Industry (MLA, 2006), National Guidelines for Beef Cattle Feedlots in Australia 3rd Edn (MLA, 2012) and Designing Better Feedlots (DPI, 1994). These documents provide an aid to fulfilling the regulatory requirements and contain well established principles of feedlot design.

2.4 Overview of Soil Nutrients & Soluble Salts

This section aims to provide an overview of soil characteristics which are pertinent to the utilisation of effluent in cropping fields. This includes an overview of the essential nutrients and salts found in soil and their role in plant growth. It is not the purpose to present here, an exhaustive review of soil science, but to establish current understanding of the mechanisms which effect nutrient and salt mobilisation and immobilisation.

2.4.1 Soil Nutrients

Nutrients are inorganic ions which are essential to the growth of plants. These nutrients are absorbed by the plant and assimilated in to the plant structure forming the fibrous tissue which makes up all parts of the plant. Healthy plants can obtain the essential compounds carbon (C), oxygen (O) and hydrogen (H) from the atmosphere and water applications respectively, through the process of photosynthesis. All other nutrients required for the plants growth must be obtained from the soil. The 14 nutrients absorbed from soil are classified in two categories; macronutrients and micronutrients (Table 2.3).

Table 2.3 - Soil Nutrient Categorisation (Singer and Munns, 2006)

Macronutrients	***Micronutrients***
Nitrogen (N)	Iron (Fe)
Potassium (K)	Chlorine (Cl)
Phosphorus (P)	Manganese (Mn)
Magnesium (Mg)	Zinc (Zn)
Sulphur (S)	Copper (Cu)
Calcium (Ca)	Silicon (Si)
	Boron (B)
	Molybdenum (Mo)

The difference between the two groups of nutrients is the quantities in which they are required by the plant. The macronutrients are found in plants in much greater concentrations than are micronutrients (trace elements). It is the macronutrients that are of importance when considering nutrients in terms of effluent irrigation. Specifically, the role of nitrogen, phosphorus and potassium will be addressed further in subsequent sections.

Humus is derived from the decay of organisms which have decomposed organic matter in the soil. The organic material from plants (green manure) and animals (animal manure) both contribute to the formation of humus. Micro-organisms which live in the soil consume the organic materials and convert them to energy, cells and CO_2. The death of these micro-organisms release CO_2 and nutrients previously held in cells to the humus where it can be taken up by plants. The CO2 released will provide other organism with carbon compound requirements (Singer and Munns, 2006).

2.4.2 Carbon in Soils

Organic material derived from plants typically contain high levels of carbohydrates. Woody, fibrous or husky green residues in particular can supply soils with bulk carbohydrate. The significance is, during decomposition aerobic micro-organisms utilise carbohydrate and oxygen in respiration and produce carbon dioxide as a by-product. Some carbon dioxide is lost to the atmosphere through diffusion however, when compared with atmospheric concentrations carbon dioxide can be held in soil air at much higher ratios. A high carbon dioxide concentration is closely associated with a lowering of soil pH. The formation of carbonic acid increases availability of hydrogen (H^+) ions in the soil thus promotes acidification. The role of soil pH will be considered further in section *2.4.7. Ion Exchange & pH.*

Animal manure and urea possess lower amounts of carbohydrate but are higher in nitrogen content. The carbohydrates that are present will be quickly decomposed by micro-organisms because they form simple compounds which are more readily used in energy production by aerobic organisms. Applications of animal waste to soil will create a surplus of nitrogen making nitrogen ions available to plants.

The carbon nitrogen ratio (C/N ratio) is a measure used to determine the relative rate of decay in soils and subsequent levels of free nitrogen ions. A high C/N ratio means high concentrations of carbon relative to nitrogen. This situation increases the dependence of microbes on free nitrogen ions in the soils which they assimilate, decreasing the nitrogen available to plants. The opposing situation; a low C/N ratio, mobilises free nitrogen ions due to the abundance of nitrogen when compared to available carbon i.e. there exists a nitrogen surplus in the soil (Singer and Munns, 2006).

2.4.3 The Nitrogen Cycle

Soil and plants act as sinks for nitrogen that originally existed in the atmosphere in its gaseous forms dinitrogen (N_2) and nitrous oxide (N_2O). The process of nitrogen moving through the biosphere is termed the ‘nitrogen cycle’. Nitrogen fixation a process of the nitrogen cycle, converts nitrogen from gaseous forms to other chemical forms that can be held in plant and organism cells or as free ions in the soil. Fixation is a naturally occurring process but can also be synthesised by human intervention to form synthetic fertiliser. Natural fixation occurs through rainfall and the bacteria (*Rhizobia*) that live in soil and root nodules of leguminous plants which fix nitrogen directly from the atmosphere and deposit it in humus through decomposition.

Water holds soluble nitrogen as Nitrate (NO_3^-), when water is applied to crops it can be taken up directly by plants. This converts the nitrate to organic nitrogen which are the building blocks of plant cells. Once a plant is harvested or dies the residue in the soil will be assimilated to ammonium (NH_4^+) by soil organisms. Aerobic organisms assimilate nitrogen to ammonium through nitrogen mineralisation which is a by-product of decomposing organism cells. Ammonium can then be re-assimilated by plants and micro-organisms to produce new organic nitrogen compounds. The preferred form of nitrogen for uptake by plants is nitrate, due to the plenitude and mobility of the soluble form. This localised soil nitrogen cycle is not perpetual as significant losses do occur to the total nitrogen cycle.

Nitrogen loss in the soil occurs in small part by volatilisation. Urea (CH_4N_2O) present in synthetic fertilisers and animal effluent is converted to gaseous form ammonia (NH_3) by bacteria in soils which possess the enzyme urease; it is at that point lost to the atmosphere (Singer & Munns, 2006).

Far greater loses of nitrogen can be attributed to the soluble phase of nitrogen. Nitrate is lost through natural migration and seepage of water through ground or surface pathways. If found in high concentrations nitrate can cause acute degradation to aquatic ecosystems. Eutrophication of natural water bodies is the process of unnatural quantities of nutrients (typically nitrate and phosphate) accumulating and promoting excessive growth of algae. Voluminous bacteria than feed on the decomposing algae creating an anoxic environment detrimental to other aquatic life.

Nitrification is the intermediary step that assimilates the free ammonium cations in soils to the soluble nitrate (NO_3^-) and nitrite (NO_2^-) forms. Bacteria (*Nitrosomonas*) oxidise ammonium to nitrite allowing the (*Nitrobacter*) bacteria to further oxidise the nitrite to nitrate (Tan, 2010).

Denitrification is, in contrast to nitrification, the deoxidisation or reduction of nitrate and responsible for further loses of nitrogen from soils. The process of denitrification is accelerated in anaerobic conditions due to organisms responsible for the process proliferating in anoxic waters. Anaerobic organisms (*Pseudo-monas* and *Bacillus*) utilise the enzyme *nitrate reductase* to dissimilate nitrate in a multi-step process. Nitrate (NO_3^-) is reduced to nitrite (NO_2^-) followed by nitric oxide (NO) then nitrous oxide (N_2O) and finally dinitrogen (N_2). The gaseous forms (NO, N_2O and N_2) are returned to the atmosphere at any point along the pathway if they are released by the bacteria as free compounds (Singer & Munns, 2006).

The microbes responsible for the decay of organic material require ammonium and nitrate for the creation of cell structures. When availability of organic material is plentiful with high nitrogen production (low C/N ratio), the surplus of nitrogen is released in to the soil as free ions. The result is mobilisation of nitrogen ions which are able to be absorbed through diffusion by plant roots and transported by mass flow in xylem to growth sites. At these sites the ions are reabsorbed from the xylem into the cell structures where further cell genesis reveals itself as plant growth. Alternatively, if decay of organic material is not providing adequate nitrogen supply (high C/N ratio), micro-organisms will assimilate all available nitrate and ammonium. A net deficit 'locks up' nitrogen in the organisms making it immobile and unavailable to plants. This will present itself in plants as symptoms of nitrogen deficiency (Singer & Munns, 2006).

2.4.4 Potassium

Potassium is an alkali salt and is present in soil in three forms. Unavailable potassium is held in the soil structure and is non exchangeable. Fixed potassium must be broken down to an ion as (K^+) before it is exchangeable. Potassium that is already in ion form is called exchangeable potassium (Schulte & Kelling, n.d.). The greatest issue caused to crops by potassium its contribution to salt levels in soil, which limits exchangeability of other nutrients (DEC, 2004).

2.4.5 Phosphorus

Phosphorous is typically found in soil at concentrations of 0.02 to 0.5 percent. Phosphorous in soils is can be found in three forms; ortho-phosphorous, poly-phosphorous and organic phosphorous; all three forms combined are measured and reported as total phosphorous. Ortho-phosphorous occurs in soils as a combination form of phosphate anion (PO_4^{3-}), which is an inorganic salt mineralised from decomposed organic phosphorus of phytin, nucleic acid and phospholipid origins (Thorne & Peterson, 1954). It is this form which is soluble and readily absorbed by plants whereas other forms are inactive and must first, if possible be broken down into ortho-phosphorous before absorption. P-sorption capacity is a measure of soils propensity to immobilise phosphorus. A higher capacity means the soil will adsorb available P, conversely lower capacity will result in more P remaining available. The availability of P in the soil of cropping land requires careful management due to the environmental impacts associated with soluble phosphates.

Uptake of phosphorus by plants is restricted largely be soil pH; negatively charged phosphate will readily associate itself with other minerals causing immobilisation, fixing it in solid state compounds. In acidic soils below pH 5.5 availability of minerals iron (Fe) and aluminium (Al) provide phosphate positively charged ions to which it can bond. This produces phosphates of aluminium and iron which render it insoluble, often permanently. Mildly acidic soil pH 5.7 - 6.7 provides conditions suitable to retain hydrogen bonded soluble phosphates as illustrated in Figure 2.2. As the soil pH becomes more neutral calcium (ca^{2+}) becomes the most plentiful ion associated with phosphate bonding. In alkaline soils above pH 7.3 phosphate will bond with calcium cations predominantly in the form of phosphate (PO_4^{3-}). Complex calcium-phosphate combinations in soil such as triphosphates ($Ca_3(PO_4)_2$) and apatite ($Ca_5(PO_4)_3(F,Cl,OH)$ form in soils above pH 7.5. Phosphate and calcium-phosphates are solid state compounds but considered active due to the relative ease in which they can be reduced to a soluble state. As the complexity of calcium-phosphate combinations increases (such as; crystalline octacalcium-phosphate, $Ca_8H_2(PO_4)_6.5H_2O$) they become inactive and fixed in the soil until the pH is reduced by some means.

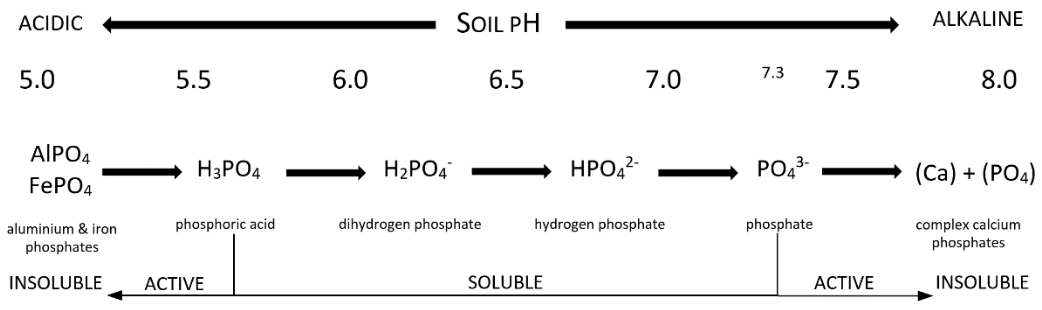


Figure 2.2 - The Effect of Soil pH on Phosphorus Mobilisation

Organic phosphorus is held in cell structures of organic organisms. Once the organic material is returned to the soil, micro organisms reduce the cell structures into simpler forms through mineralisation and return in to the soil in an active state. As presented above, depending on the soil pH and chemisty this active phoshate may remain active or soluble (available to plants) or become bonded and inactive (unavailable to plants).

2.4.6 Sulphur Magnesium & Calcium

These three elements account for the balance of soil macronutrients not yet discussed. All three are considered 'salts', as this is the form in which they are available to plants, however they all exist in soil as varied compounds and forms.

Sulphur (S), in both its elemental and organic states is found in soil humus, and is mineralised from organic form to inorganic S by micro-organism in the same way as nitrogen. The mineralisation process of organic S is a slow process due to the trace amounts required by micro-organisms. Soil holds in reserve a total of 0.5 percent nominally. The plant available form of S is sulphate (SO_4^{2-}), which is responsible for synthesis of protein from nitrogen compounds in the plant structure. Due to the mineralisation process, mobilisation and immobilisation of S in soils is intrinsically linked to the availability of nitrogen. This is because the factors influencing mobility of N are the same as for S (Singer and Munns, 2006).

The most plentiful calcium (Ca) and magnesium (Mg) based compounds found in soils are the exchangeable cations (Ca^{2+} and Mg^{2+}) that are held on colloids or in solution. These ionic forms are available for uptake by plants. Magnesium is utilised by the plant in chlorophyll production and phosphorous transport. Calcium is used by the plant to regulate cell production and metabolise nitrate (Spectrum Analytic, 2016).

The ratio of calcium to magnesium in soils has had a long history of debate regarding its significance to crop yields. Stevens et al (2005) conducted research to determine if one ion acts as an inhibitor to the other resulting in reduced yields. The conclusion of this research suggests that yield was unaffected by the concentration of one ion compared with the other.

2.4.7 Ion Exchange & pH

An important principle to understand when considering mobilisation of nutrients and salts in soil is cation exchange capacity (CEC). CEC is the ability of soils to absorb exchangeable acidic and base compounds at a specific pH. Acidic compounds found as cations in soils include; aluminium (Al^{3+}) and hydrogen (H^+). Alkaline compounds found as cations in soils include; sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). These compounds in the form of cations can be efficiently exchanged within the soil and passed as nutrients to a growing crop. Due to the high CEC in organic material, soil that is rich in organic matter possesses a higher potential for cation exchange. This has a significant implication for effluent land irrigation at feedlot sites; as the effluent irrigation process combined with typical applications of decomposed manure adds considerably to organic matter found in soil. Thus, potential exists for high compound exchange rates to occur from soil to crops and microorganism.

Acidity or alkalinity is tested using pH which is a negative logarithmic scale for measuring the amount of hydrogen in soil. The scale range is 1 to 14 with 1 being very acidic, 7 neutral and 14 very alkaline. Lower values indicate a high concentration of hydrogen ions with high concentrations producing a lower pH number (Tan, 1998). Crops generally have the highest potential for nutrient exchange within the pH range of 6 to 7.5. Effluent should be pH tested to ensure it falls within 5.5 to 8.5.

2.4.8 Soluble Salts

Sodicity is a term for the amount of exchangeable sodium soils, the measure of which is exchangeable sodium percentage (ESP). A symptom of sodicity is soil dispersion which degrades the soils structure and impedes plant growth. Sodium Absorption Ratio (SAR) is a measure of the amount of sodium in water. A SAR test can be conducted on effluent to determine if sodium contents will pose a risk to the utilisation area. Values above six will likely cause an increase in available exchangeable sodium and values below 3 will see a subsequent reduction of ESP.

Salinity is the total volume of soluble salts found in a soil. Electrical conductivity (EC) will increase if the amount of soluble salts increases. EC is used to measure that total salt levels of soil. Many of the soluble salts are readily taken up by the crop and are considered plant nutrients. The effects of high salinity are reduced growth potential.

Other soluble salts include; potassium, magnesium, sulphur and calcium. These salts are included in testing conducted for soil salinity as the total salinity of a soil is a useful tool for determining the behaviour of soil during cropping and effluent irrigation. These salts are discussed in more detail in the relevant sections.

2.4.9 Mechanisms Controlling Nutrient Mobility

The chemical processes that dictate the mobility of nutrients and salts has been detailed in their respective sections. Presented here are the factors that influence these chemical processes. This section takes a step back from the soil chemistry, whilst not completely separated from it, to determine what are the drivers of nutrient mobilisation.

As most nutrients are released to the soil through decomposition of organic matter and subsequent mineralisation, the rate of decay for organic materials in the soil dictates the availability of nutrients. Fresh organic matter and humus decay at different rates, with the former decaying a rapidly in comparison to humus. The potential for decay is limited by; Type of organic material, volume of organic material, available water, soil temperature, micro-organism abundance, oxygen concentration, pH and mineral toxicity.

The volume of organic compounds that are available to the soil microbes will dictate the proliferation of those microbes. The decaying process can be accelerated simply by the addition of more organic material. There are limiting factors to this notion such as all other factors influencing decay rate are required to be favourable for this to occur. The type of organic matter also has a significant baring on decay rates. Large, woody and fibrous particles such as crop residues will be slow to breakdown, whereas partially decomposed, finely chopped or simply structured materials will be rapidly decayed by soil microbes. Schemes such as effluent irrigation and manure applications provide scheduled applications of fast decaying organic matter, providing reduced fluctuations in the natural decay cycle (DEC,2004).

The availability of water in the soil effects mobility directly through osmotic potential. The more water that is available the greater is the mobility of soluble nutrients. This is due to bound nutrients being released in to solution in the presence of high water volumes. In addition, water also increases the decay rate of fresh organic matter and humus. This subsequently increase the rate of mineralisation of organic compounds. An oversupply of water will have the opposing effect and reduce decay rates as oxygen concentrations become limiting and aerobic metabolism in the soil slows. Aerobic respiration is a vital component to the decomposition of organic matter. A sharp decrease in decay rates occurs when soil oxygen drops below 10 percent. In fast rate decomposition conditions, it is the replacement of soil oxygen through diffusion and mass flow that creates a ceiling to the potential rate of decay.

The proliferation of micro-organisms can be restricted if the conditions of the soil are not conducive to supporting the population potential. Poor aeration of soil may also create a physical barrier holding within it organic matter that cannot be decomposed as it is inaccessible to the micro-organisms. As stated, lack or oversupply of water and anoxia are conditions that will limit micro-organism populations. Adsorption of enzymes and minerals on to clay colloids required for the growth of micro-organisms can have an impact on population numbers and subsequent decay rates. Potential hydrogen levels outside the range of 4.5 to 9.0 will not sustain microbe activity. Typically, a pH range that is conducive to crop growing conditions will be suitable for microbes. Toxic conditions, that is, an extreme concentration of any one mineral, element or compound will often limit the microbe population. In all but the worst cases, the soil microbe community, given enough time can overcome most toxicities, as microbes with the ability to assimilate the toxifying agent will proliferate the site and reduce the toxin back to normal ranges. The caveat here is that the source problem causing the toxicity must cease to exist for normal ranges to return. Long periods of some years or decades may be required to restore condition depending on what the agent is and its rate of breakdown (Singer & Munns, 2006).

The temperature of soil has an impact on decay rates due to the soil micro-organism having a preferential soil temperature range. This range is generally considered to be between 5°C and 40°C. Whilst this range is tolerable for most bacteria and fungi, decomposition will markedly increase above 25°C and be optimal at approximately 40°C.

2.5 Water and Nutrient Uptake in Plants

Foliar uptake of nutrients by plants is possible, as is the common case for leguminous plants, where nitrogen is extracted from the air and transported to the plants vascular system. It is however, much more likely that the significant majority of a plants nutrients are provided by the availability of mobile ions in the soil. It is well understood in literature and explained in Munns and Singer (2006), that the root zone responsible for uptake of nutrients and water is the 50mm-100mm behind the first 10mm of the growing root. Ionic and water uptake is achieved through three separate processes; root interception, mass flow and diffusion.

Tan (2010) explains that root interception is where the growing root comes into direct contact with the soluble ion in the soil and passes through the cell wall depending on intra-cellular ion concentrations. As the transpiration of water occurs and is lost to the atmosphere more water moves into the roots through mass flow following the principles of water potential. That is, water moves from a high water concentration to a low water concentration which is termed the water potential gradient. Soluble nutrients are also transported in to the plant along with the water following the same principle, only in this case the regulating factor is the ionic concentration gradient. Diffusion occurs when a concentration gradient is created by the uptake of nutrient close to the root creating a pathway for more nutrients in the soil solution to move toward the root. Diffusion can be further broken into three separate processes; simple diffusion, facilitated diffusion and active transport.

Simple diffusion is where ions move passively along a concentration gradient and pass through the cell wall of the root. Facilitated diffusion uses transport proteins which facilitate the movement of ions by creating a pathway through the cell membrane for the ions to passively migrate along the concentration gradient. Active transport is the condition where ions move through the cell membrane from a low concentration gradient to high. This process requires the input of energy from the plant in the form of ATP which allows ionic flow against the concentration gradient through processes of primary and secondary active transport. The energy required for this process is derived from respiratory oxidisation of simple carbohydrates produced in photosynthesis. Primary active transport utilises enzymes which use polar repulsion to 'recognise' extracellular ions that are to be transported and pumps them through the cell membrane by opening and closing of external and internal pathways to force the ion in to the cell. Secondary active transport induces an electrochemical gradient by establishing proteins on the cell membrane which expel lower valency ions and allow higher valency ions to pass through the membrane, potentially against the concentration gradient.

An electrically balance state is required within the plant, which leads to exportation of hydrogen (H^+) if cation uptake is required and if anions are in need hydroxide (OH^-) and bicarbonate (HCO^{3-}) will be released. This situation leads to a reduction in the soil pH in the rhizosphere.

Once in the root cells, ions are transported to the root cortex where mass flow shuttles them into the plant xylem and throughout the plant. The ionic nutrients are then used by the plant in numerous processes to form the organic compounds leading to growth of the biomass (Tan, 2010).

2.6 Conclusion

This literature review has provided a synopsis of published literature that pertains to the governance of effluent irrigation scheme design. The current industry practices, utilisation, production of effluent and the impacts of irrigating with it in relation to a specific site have been explored. An overview of the science of nutrient and salt mobility within the soil have been presented to provide linkages with the theory of soil science and the measurement of field data and MEDLI modelling. Finally, plant water and nutrient uptake was reviewed to demonstrated the fate of nutrient and salt that is removed from site, thus providing completion of the water and nutrient balances that form the basis of this research project.

Chapter 3 MEDLI ANALYSIS

3.1 Introduction

MEDLI was originally developed by the Cooperative Research Center for Waste Management and Pollution Control, Queensland Government Department of Natural Resources and Queensland Government Department of Primary Industries. The software was initially released in 1996 and in 2015 the Queensland Government Department of Science, Information, Technology and Innovation (DSITI) released version 2 of the software package. Vieritz *et al* (2011), describes the initial commercial uptake of MEDLI as being below expectations. A total of 32 copies of the version 1 software were sold and of those, about 10 people became regular long term users. In a 2011 report, Vieritz *et al* looked at the role of MEDLI on sustainable effluent irrigation. The report highlighted that although the number of users was below expectations the program was estimated to be used in over 90 percent of Queensland's effluent irrigation designs. This same report cited high initial costs and difficulties in the usability of version 1 of the program, for not penetrating the market more substantially on a national level.

MEDLI software is used to simulate an effluent stream from the point of accumulated storage to disposal through irrigation practices. MEDLI has the ability to model industry specific effluent streams for piggeries, dairies, feedlots and sewage treatment plants.

This analysis aims to establish how MEDLI determines outputs for; plant growth, plant nutrient concentrations, total water balance and soil concentration balances for water, nitrogen, phosphorus, sodium and nitrate (Vieritz et al, 2011). Algorithms used to determine outputs will be presented and analysed to determine how each interacts within MEDLI. Calibration of the individual algorithms is not within the scope of this research; however, comment on their role as applied to the MEDLI as a whole will be detailed.

3.2 Model for Effluent Disposal using Land Irrigation

MEDLI® is software for the modelling of effluent streams of a variety of intensive wastewater production industries. These industries include; beef cattle feedlots, piggeries, dairies, abattoirs, food processing plants and municipal sewage plants. The industry which is to be modelled is selected at the commencement of modelling as different industries are modelled using different mathematical algorithms. Figure 3.1 provides a structural schematic of the simulation processes undertaken in MEDLI. The inputs that MEDLI requires are climate data and details of the operation e.g. number of animals and details about the feed.

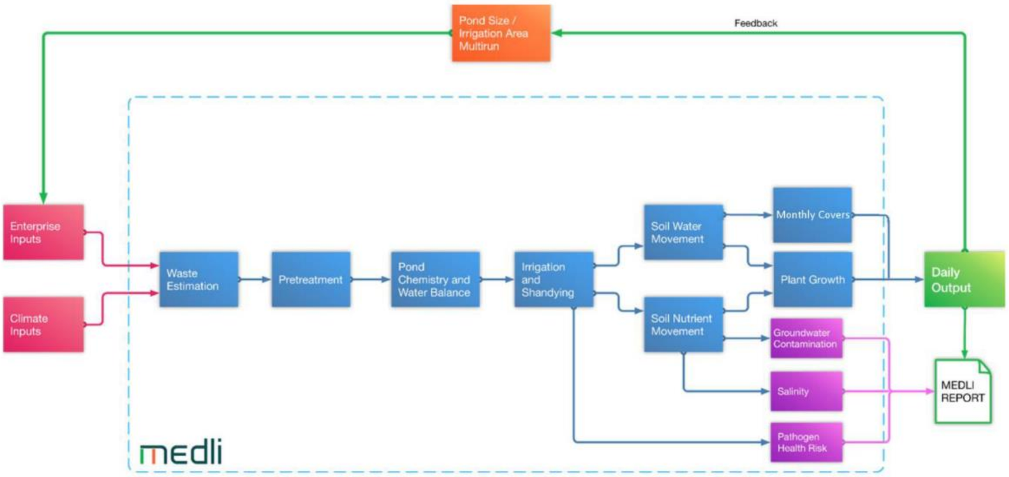


Figure 3.1 - Structural Schematic of MEDLI (DSITI, 2016)

The components of MEDLI have, by its creators been categorised in to nine separate modules. Multiple components are contained within modules and each component has been derived from an existing mathematical model or equation. The modules as outlined in the MEDLI version 2 Technical Manual (DSITI, 2016) are;

1. Climate Data
2. Waste Estimation and Pre-treatment
3. Pond Chemistry and Water Balance
4. Irrigation Scheduling and Effluent Shandying
5. Soil Water Movement
6. Nitrogen and Phosphorous Availability and Movement
7. Soil Salinisation
8. Plant Growth and Transpiration
9. Ground Water Transport

In addition to these modules, the user is required to input details of the enterprise to begin the process of developing a scenario. MEDLI is also capable of modelling the fate of pathogens in the system and produces a report on the health risks associated with the effluent irrigation scheme. Pond size and irrigation area optimisation is also included as an extended feature of MEDLI. This output is achieved by running the scenario multiple times to allow optimisation.

3.2.1 Climate Data

MEDLI uses climatic data to form the basis of water balance and crop growth outputs. The time series data (over the longest time period possible) required is; rainfall, temperature, pan evaporation and solar radiation. This site specific data is user defined and can be sourced from the Queensland Government Departments of Natural Resources and Mines; and Science, Information, Technology and Innovation. The CRC for Waste Management and Pollution Control, offer 'Weather Model' which is a stand-alone program for interpolation of missing climate data. Description of Daily Weather Model (Irish, 1995) discusses the methods of interpolation.

3.2.2 Waste Estimation and Pre-treatment

This module contains a considerable number of user inputs based on pre-determined industry specific input variables. As this research aims to validate MEDLI in terms of feedlot performance, this analysis will focus on the associated inputs and algorithms specific to that industry.

The waste estimation module uses mass balance as the basic principle for determining waste production within the context of a beef cattle operation. The input variables which are contained in this module are;

- effluent inflow (ML/day)
- total solids (mg/L)
- volatile solids (mg/L)
- total nitrogen (mg/L)
- total phosphorus (mg/L)
- total dissolved salts (mg/L) or electrical conductivity (dS/m)

MEDLI produces data in a daily time series for the waste stream for input in to the pre-treatment module. Empirical data for on-site effluent and manure production determined in the (DAMP) model by (Barth, 1985) have been adopted to calculate the following inputs for a feedlot enterprise;

- effluent inflow = 1 ML/day
- total solids = 25,000 mg/L

- volatile solids = 20,000 mg/L
- total nitrogen = 700 mg/L
- total phosphorus = 75 mg/L
- electrical conductivity = 8 dS/m

The user can select the option of having a pre-treatment system included in the modelling. Some enterprise specific screening option are available for selection. Feedlot pre-treatment is not included in this list. This module requires the user to make estimations on the removal from the effluent stream of the following parameters;

- Effluent Removed
- Nitrogen Removed
- Phosphorous Removed
- Volatile Solids Removed
- Total Solids Removed

These values are entered as a fraction removal from the effluent stream and simply applied as a multiplier to the waste estimation module values.

3.2.3 Pond Chemistry and Water Balance

The mass balance outputs derived from waste estimation are carried over to the pond chemistry module which calculates the nutrient values for effluent at the terminal pond. MEDLI can accommodate up to four ponds in series if required and is based on nutrient mass balance modelling by Casey, (1995). Aerobic, facultative and anaerobic pond conditions or combinations of these can be chosen by the user to best suit the design requirements.

An aerobic pond typically has a large surface area to depth ratio to promote organic matter decomposition through aerobic bacteria proliferation. Aerobic oxidation and photosynthesis are the principle processes that occur in an aerobic pond. The bacteria involved in aerobic decomposition cannot survive in anoxic conditions and if eutrophication of the pond results from excessive nutrient loading the pond system can fail.

Facultative ponds present an answer to the potential of a failing aerobic pond. In this type of system both aerobic and anaerobic bacteria co-exist with anaerobic decomposition in the surface layers and anaerobic in the bottom layers.

Anaerobic ponds have less surface area and are deeper than both previously mentioned systems. The principal process that takes place in an anaerobic pond is fermentation. Anaerobic bacteria are able to decompose high volumes and concentrations of organic compounds in a totally anoxic environment. A side effect of anaerobic pond conditions is the build-up of sludge on the pond floor which needs to be periodically removed and aerated to undergo further decomposition through aerobic means.

Figure 3.2 depicts the schematic of inputs and outputs that are considered in MEDLI.

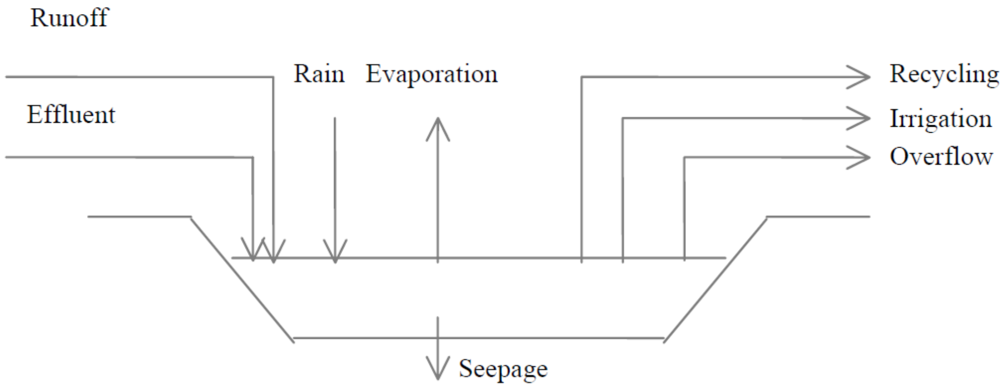


Figure 3.2 - Schematic of Pond Inputs and Outputs (Casey, Atenzi, 1998)

3.2.4 Irrigation Scheduling and Effluent Shandying

Two modules are contained within this section; irrigation scheduling and effluent shandying. Water quantity and quality outputs from the pond chemistry and water balance modules are used to provide baseline data for irrigation scheduling. In addition, rainfall data is used to determine if irrigation should take place. Three user selectable methods are provided for calculating field irrigation requirements. These are;

- Plant Available Water – a minimum soil moisture percentage is set in terms of plant available water capacity (PAWC), which will initiate irrigation once that minimum is reached.
- Soil Water Deficit – irrigation will take place when a maximum allowable reduction below field capacity, measured in millimetres, is attained
- Fixed Daily Irrigation – the quantity and interval of irrigation are defined and will be applied regardless of rainfall, provided there is pond water availability and quality requirements are met.

A maximum and minimum irrigation rate is set in mm/h or ML/day and the area to be irrigated in hectares.

The shandying module allows for additional quality water to be added to the pond effluent to boost supply or increase pond water quality. The total pond nitrogen, soluble salts or salinity are factors that may render pond water unusable for irrigation if maximum allowable tolerances are exceeded. This scenario would require water of higher quality to be supplemented before MEDLI would allow irrigation modelling to continue. The nitrogen, total soluble salts and salinity of the shandying water are user defined as is the available volume.

MEDLI generates a daily irrigation demand in ML/day based on the requirements of the cropping field and adjusts this output in accordance with minimum and maximum rates of application. MEDLI will apply irrigation over a period of days if the demand exceeds the maximum rate; this allows the required demand to be brought back into acceptable limits. If demand falls below the minimum allowable rate MEDLI will hold back irrigation until demand and minimum rate of application equilibrate.

The shandying module summates the total water in ML that is applied to the cropping field. The percentages and total volumes of applied water that were sourced from either the effluent pond or as shandying water are provided as outputs (Moffitt, 1998).

3.2.5 Soil Water Movement

The component used in this module of MEDLI is based on the Curve Number Method developed by USDA-SCS (1972). Modifications have been applied to the method which accommodate water retention from ground covers, such as crop residuals; and antecedent soil moisture. This module deals with evaporation of soil water, while transpiration will be considered in section *3.2.8 Plant Growth and Transpiration*.

The premise of the method is;

$$infiltration\ (I) = precipitation\ (P) - runoff(R)$$

Where:

P is determined as an input to the climate module and R is given as;

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where:

S is the retention parameter.

The retention parameter (S) is derived from a CN curve relationship for a bare land surface condition ($CN_{2(bare)}$) represented in Figure 3.3. The curves in the diagram represent various rainfall totals.

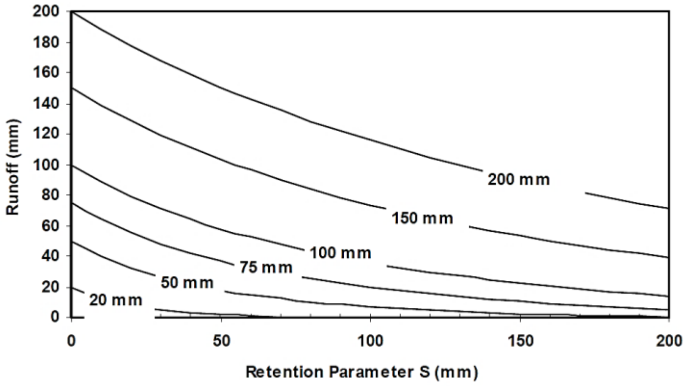


Figure 3.3 - CN Curve (Beecham, Vieritz, Littleboy, 1998)

Reduction in the curve number to allow for ground covering has been implemented using empirical data collected in Queensland by Granville et al., 1984. This data forms the basis of the following reduction factor graph;

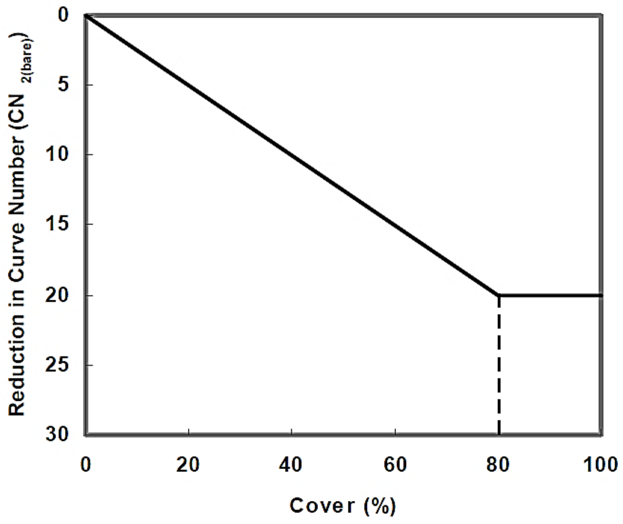


Figure 3.4 - CN2base Reduction Factor (Beecham, Vieritz, Littleboy, 1998)

The modification for allowance of antecedent soil moisture is applied to the retention parameter (S). It is based on the work of Knisel (1980), which determines water retention by layer of soils, with heavier weighting given to layers nearer the surface. This method uses layer parameters combined with soil water parameters for each layer to derive a final value for S.

Soil evaporation is calculated using the method described by Richie, (1972) and modifications to this method developed by Littleboy *et al*. (1980). This component allows for two stage drying of the soil and asserts that only the top two layers in the profile will be subjected to evaporative influences. Stage one predicts that the amount of radiation energy present at the soil surface will dictate the loss to evaporation. Stage 2, occurring after stage 1, will see the water supply or more specifically the capacity of soil to hold water as the limitation to evaporation. Figure 3.5 represents this case diagrammatically.

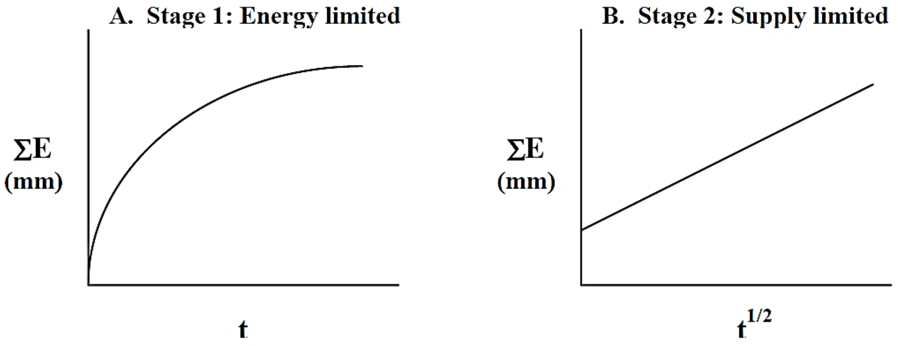


Figure 3.5 - Stage 1 and 2 Evaporation (Beecham, Vieritz, Littleboy, 1998)

Stage 1 soil evaporation is equal to the potential rate of pan evaporation and percentage crop cover; it is given as;

$$E_{pot} = pan \times pancoeff \times \left(\frac{100 - cover}{cover}\right)$$

Where:

E_{pot} = Potential Evaporation (mm)

pan = Pan Evaporation (mm)

$pancoeff$ = Cropping Coefficient

$cover$ = Projected Crop Cover (%) *(determined by CN_{2base} reduction factor)*

Stage 1 evaporation begins after infiltration and ceases once the user defined maximum evaporation value (U) has been reached. This maximum value is obtained from empirical data for field capacities at a given hydraulic conductivity (k_{sat}).

Stage 2 evaporation takes effect after stage one and the slope of cumulative evaporation is plotted against the square root of time. This gives a value of CONA which is an empirically determined value based on the work of Richie, (1974), (see figure 8). The equation used is;

$$SE_2 = CONA\left[\sqrt{(t)} - \sqrt{(t-1)}\right]$$

Where:

SE_2 = Stage 2 soil evaporation (mm)

$CONA$ = Slope of stage 2 soil drying (mm)

t = time since soil evaporation (days)

Deep drainage is determined for each soil layer in sequence beginning at the surface in terms of a saturated or unsaturated condition. Seepage to the next layer in saturated condition is calculated as the product of saturated hydraulic conductivity (k_{sat}) and a time coefficient (TimeFact) which is set at 0.5, however no derivation of this factor could be located during research. Once the upper storage limit is met for a layer the next layer will receive the product of excess water from the proceeding layer and a drainage factor. The method of determining a drainage factor is provided by Beecham, Vieritz, Littleboy, (1998).

3.2.6 Nitrogen and Phosphorus Availability and Movement

Nitrogen and phosphorus fluctuations within soil are modelled by MEDLI to ensure upper maximum limits are not exceeded. The way in which the modelling of nitrogen and phosphorus is handled by MEDLI will be dealt with in two distinct sections. Due to the complex and numerous nature of the algorithms in these sections, the processes will be described and applicable citations provided, but equations have been omitted.

Nitrogen is predominantly suspended in effluent in high quantities as ammonium (NH_4^+) and organic nitrogen. Once applied to the crop, nitrogen is converted to nitrate (NO_3^-) through nitrification. Nitrate is a soluble form of nitrogen, hence readily mobile in the soil water. Excess nitrogen in the soil solution can lead to groundwater contamination through seepage and eutrophication of natural water bodies from runoff.

The fate of all nitrogen in the soil is modelled by MEDLI and considered in one of the following processes; soil storage, surface runoff, groundwater seepage, crop uptake, denitrification and volatilisation.

The initial nitrification process of NH_4^+ and organic compounds is modelled using the CERES-MAIZE model (Godwin & Jones, 1992). The total volume of NH_4^+ nitrified is presented in (kg/ha/day).

The denitrification of soluble N into gaseous NO and N_2O is determined by first order kinetics equation described by Stanford et al., (1975). Desorption of previously adsorbed NH_4^+ and organic N is again calculated using first order kinetics, which has been implemented in MEDLI using the algorithms derived in the HSPF model (Johnson et al., 1984). It is recommended by MEDLI developers that if no site specific data is attainable, then setting the kinetic rates for desorption to zero will yield an overestimation of N leaching thus provide conservative modelling.

Both mineralisation and immobilisation are again derived via linear kinetic process, with the addition of corrections for soil moisture and temperature using a moisture scaling factor (Godwin & Jones, 1991) and the Arrhenius temperature correction relationship (Metcalf & Eddy, 1990) respectively.

Prediction of phosphorus (P) movement is partitioned into; adsorption, desorption, plant uptake and leaching. The HSPF model developed by Johnson et al., (1984) has been adopted in MEDLI to provide simulation of adsorption and desorption. The modelling is performed on each soil layer individually with different isotherms applied specifically to the soil type of each layer. The movement of P through the profile is determine using the mass flow approach. This is given as the product of P equilibrium concentration of the proceeding layer and the volume of water infiltrating the receiving profile.

3.2.7 Soil Salinisation

Estimation of soil salinity is determined using the mass balance approach as a simpler alternative to predictive methods used in other modules of MEDLI which are based on time series. The algorithm utilised in MEDLI has been adapted from the SaLF model (Shaw & Thorburn, 1985), which estimates the mass balance of salt leaching through the soil profile. The calculations are applied to two distinct soil zones; the root zone and below the root zone. The distinction here is necessary due to plant uptake of salt must be factored in the root zone calculation and leaching considered below the root zone.

The algorithm used in MEDLI to calculate below root zone mass balance is applied over a specific, used defined time period at steady state. It is given as;

$$C_d = \frac{D_i \times C_i}{D_d}$$

Where*:*

$C_d =$ Concentration of soil water below the root, approximated by electrical conductivity (EC) (dS/m)

$D_i =$ Depth of infiltrated rain (mm) + Depth of infiltrated irrigation (mm) over the specified time period

$C_i =$ Salt concentration of the infiltrated water approximated by electrical conductivity (EC) (dS/m)

$D_d =$ Quantity of water draining below the root zone (mm) calculated in the water balance module as deep drainage

A time period of at least five years is recommended to be used in MEDLI for the below root zone calculation. The assertion is; this period is the minimum required to validate the assumption of the steady state condition.

The average salinity within the root zone is derived by applying a concentration factor to the infiltrated water to attain an estimation of the soil solution salinity. The average leaching fraction (LF_k) is used to determine the concentration factor by the equation;

$$LF_k = \frac{D_{dk}}{D_i}$$

Where:

$LF_k =$ Average leaching fraction of each layer (mm)
$D_i =$ Depth of infiltrated rain (mm) + Depth of infiltrated irrigation (mm) over the specified time period
$D_{dk} =$ Water flow from the bottom of the k^{th} soil layer, (mm)

An assumption has been made that D_{dk} will reduce from unity from the surface down to the leaching fraction (LF) at the bottom of the root zone. From this point it will remain constant as no external loss of water is assumed beyond this point (Vieritz, Gardner, Shaw, 1998).

The average salinity for each soil layer is given by;

$$EC_k = \frac{C_i}{LF_k}$$

The average salinity in the root zone ($EC_{rootzone}$) is then determined by weighted average of EC for each soil layer k, as follows;

$$EC_{rootzone} = \frac{\sum_{k=1}^{num\ of\ layers}(wt_k \times EC_k)}{\sum_{k=1}^{num\ of\ layers} wt_k}$$

Where:

$wt_k =$ The weighting factor for each soil layer k

The weighting factor is calculated as the product of the total water use in a layer and the thickness of that layer. The weighted average method is deemed necessary to account for the higher leaching fraction and subsequent lower salinity in the more superior soil horizons. It is well established that plants will utilise water from upper layers in the profile to minimise salinity stress (Vieritz, Gardner, Shaw, 1998).

The final step in determining root zone salinity is to covert the calculated field capacity average salinity ($EC_{rootzone}$) to a value in terms of saturated extract water ($EC_{rootzone.s.e.}$). The salinity of saturated extract water is the amount saline solution that is mobile and available for plant uptake. MEDLI divides the field capacity value by an empirically determined saturation extract factor of 2.2, assuming saturation extract is 2.2 times less concentrated than field capacity (Shaw *et al*. 1987).

$$EC_{rootzone.s.e.} = \frac{EC_{rootzone}}{2.2}$$

The influence of root zone salinity on crop yield is taken from the Maas Hoffman, (1977) equation.

$$Relative\ Yield = 100 - B \times EC_{rootzone.s.e.} - A$$

Where:

$Relative\ Yield =$ The yield relative to the potential unrestricted salinity yield(%)
$A =$ Saturation extract soil salinity threshold (dS/m) above which yield is restricted
$B =$ The rate of decline of yield with salinity increases above threshold (% per dS/m)

Coefficients A and B have been pre-defined for 112 species and are summarised by Shaw *et al*. (1987).

Outputs in the module are; root zone salinity (dS/m), below root zone salinity (dS/m), relative yield (%) and number of times the crop was salinity stressed relative to stress free yield (%).

3.2.8 Plant Growth and Transpiration

Three modules, all pertaining to plant growth are considered in the chapter. The interaction between plants and the growing medium are modelled in terms of;

- Plant Growth – estimates the total volume of biomass growth above ground (and root development by extension)
- Plant Transpiration and Soil Evaporation – estimates the volume of water uptake from the soil and evaporation
- Plant Nutrient Uptake – estimates nitrogen and phosphorus assimilation in the biomass

Plant Growth is further broken down to sub-components which are selected by the user depending on the intended use of the cropping land. The cropping options provided in MEDLI are;

1. Mown Pasture – estimates uptake in crops that are periodically mown to allow new growth from existing root stock
2. Harvested Fodder Crop – estimates the growth of sown and harvested crops
3. Rotated Cropping – two rotations per year of pasture or fodder crops are simulated
4. Monthly covers – estimates the growth of tree crops
5. Zero Cropping – this disables the plant growth module to simulate bare soil conditions

The first four of these sub-components have algorithms that simulate biomass growth with root development based on the type of crop. The list of algorithms used in the module is extensive and will not be covered in full detail. A summary of each will be provided. Vieritz, Gardner and Littleboy, (1998) provide detailed explanation of each component in Chapter 9 of the MEDLI user manual.

Both the mown pasture and harvested crop components have been adapted from; EPIC, (Sharpley and Williams, 1990), PERFECT, (Littleboy *et al*, 1989) GRASP, (McKeon *et al*, 1982) and the work of Muchow and Davis (1988).

Plant growth is simulated using a daily time series with inputs from climate data, nutrient, salinity and water supply calculated in other modules.

Above ground plant cover is estimated by converting climate data to thermal time as the basis of calculations. The premise of using thermal time is; it provides a simple and accurate estimation of green cover growth rates over a long time period (Australian Society of Plant Scientists). The growth rate is determined according to a fixed sine curve up to the growth potential limit of the plant. The effects of nutrient, salt and water stress on the plant are applied through various multiplying factors to reduce the estimated growth rate.

Root development of crops harvested from sown seed is modelled at a growth rate proportional to the potential green cover growth rate with a period of lag applied to the green cover rate to account for the developing roots. Mown crops assume the root development continues up to maximum rooting depth, thus harvesting provides the new minimum root depth is determine from the previous root depth achieved to provide a baseline for the next cycle of root development.

Water and salt uptake by plants are modelled in their respective modules, however to determine the nutrients removed from the soil, the total biomass volume must be calculated. This value is presented as a harvest yield in kg/ha and used in water and salt balance modules through an iterative process. Biomass volume is calculated per harvest and outputs are provided that give nitrate and phosphorus uptake values in kg/ha which attempt to account for N and P stresses during that harvest cycle (Vieritz, Gardner and Littleboy, 1998).

3.2.9 Ground Water Transport

Ground water modelling is used to determine the concentration of contaminants entering groundwater aquifers below the cropping area. It is worth noting, the MEDLI user manual (Dillon and sharma, 1998) provides a qualification of this module stating;

> *"validation of the predictions using this crude model should be obtained*
> *by ground water monitoring" …*

This qualification may indicate that decisions about an enterprises effluent irrigation licensing in terms of ground water contamination should not be made based solely on the outputs of this module.

The model adopted in MEDLI for groundwater contamination prediction is PLUME. Scant information is provided in the MEDLI user manual about the PLUME model and no reference provided. Independent research yielded no further details about the model. Information that is given states that PLUME is based on the analytical derivation of; Bear, (1979) and Armstrong, (1993).

Some algorithms used in this module are provide, but with no explanation of the terms used in the equations. Further research outside the scope of this project would be required to provide analysis of this module.

Explanation of the groundwater transport module in the MEDLI user manual appears to be inadequately resolved at the time of writing this analysis.

3.2.10 Pathogen Risk Assessment

MEDLI offers a pathogen risk assessment as an option that can be selected during the scenario set-up. It is not a requirement for modelling that this feature be enabled. The intention of modelling the fate of pathogens in the effluent stream is to map the survival of viral, bacterial and protozoan pathogens (DSITI, 2016). An assessment is modelled on the likelihood that pathogens may end up on the leaves of the crop and the risk of the pathogens being expelled into the air during irrigation. A quantitative risk is outputted detailing the risk that pathogens in the system will pose to humans on-site or ingesting the grown crop. Currently this component is in beta test phase and no details on how the risk assessment is quantitated has been released.

3.2.11 Pond Size and Irrigation Area Optimisation

An optimisation feature is provided in MEDLI by using the multi-run option to conduct consecutive runs of the model in an effort to derive minimum or maximum pond and irrigation areas possible for a system. The user is required to enter values of minimum and maximum allowable spill frequency, reliability of supply and percentage of effluent reuse. A cost is than applied per mega litre increase in pond size and per hectare increase in paddock size and reported to the user. Scant information is available of this feature and appears to be still under development.

3.2.12 Run Configuration

Four run options are provided in MEDLI which all perform different functions depending on the desired output required by the user.

- Full Run is the standard run that would be selected for a typical scenario that has been entered. A single run of the model takes place and the results are reported to the user at the completion of the run.
- Reliability of Supply Run would be used in the case that the user would prefer to determine what the irrigation requirements of the crop are. Two consecutive runs of the model are automatically conducted. The first applies no limitation to the water supply for the crop, whilst the second run is a *Full Run* which simulates exactly as the inputs of the scenario indicate. MEDLI can then compare the results and determine the frequency at which short supply will affect the crop and report this to the user as probability of exceedance of supply.
- Extended Run is used when a complete dataset for climate is not available. MEDLI in this case, will run through the available climate data multiple times until the completion of the required run period.
- Multi Run will allow MEDLI to make a determination on the optimal size of holding ponds and irrigation area. This is achieved by incrementally increasing the pond

and irrigation area size from the minimum specified up to the maximum specified by the user and performing a run of the model at each stepped increase. Optimum sizes are determined by reporting the point at which optimal water balance was achieved.

3.2.12 MEDLI Validation

The validation of MEDLI has, by admission of its creators, not been as rigorous as would normally be adopted for such a program. The reasons cited for this are; the model being to complex, the prohibitive expense of validation and lack of industry data to which simulation can be compared. The creators have provided an alternative strategy for the fulfilment of program validation;

1. Algorithms where checked independently of the code developers and tested to ensure the results of an algorithm were as expected,
2. Beta testing of the program by regulators of effluent irrigation schemes,
3. Testing on commercial projects by designers against their own calculation methods and,
4. Checks are made against experiments to ensure algorithm integrity.

A qualification is proposed by the developers that the model only be used by experienced effluent disposal designers who should employ common sense when assessing the outputs of MEDLI (Gardener and Davis, 1998)

Investigation during this project could find no reference to any independent validation using scientifically rigorous validation techniques, which compared MEDLI program outputs against data collected from the field over an extended time period.

Calibration of the individual algorithms used in MEDLI has been completed in most cases, by the creators of each algorithm or model. The citations in each section of this chapter provide reference to documentation of the calibration of each particular algorithm or model.

3.3 Conclusion

This analysis of MEDLI was conducted to provide context to the research project as a whole. It provides an overview of the modules that compartmentalise the program into manageable design tool. This analysis aimed to explain how simulation of the effluent stream is handled by MEDLI and to develop understanding of how a comparison between simulated and measured data would best be performed.

Chapter 4 METHODOLOGY

4.1 Overview

This project is a validation of MEDLI, a modelling software package designed to simulate and forecast effluent stream data. It is necessary then to establish what, in this case, constitutes a validation and how this will be achieved. It is the purpose of this methodology chapter to detail the process that will be followed to fulfil the project objectives.

There has been significant work completed previously to calibrate the algorithms used in MEDLI. Most of the algorithms used in the program are well established and have been used in various types of modelling tools over long periods. There exists a plenitude of literature that verifies the calibration of the individual algorithms implemented in MEDLI. Model validation however, is scarcely evidenced in literature and by admission of the program developers, MEDLI has not been adequately validated.

Verification analysis aims to provide confidence that a model is producing accurate data when compared to a historical event that is separate from that used in calibration. The calibrated model should be tested against measured data to ensure the integrity of the outputs. Repeating the validation process using multiple historical events provide further assurance that forecasting by the model can by relied on to produce quality data. This research project will attempt to validate the MEDLI program using historical data collected from three separate beef cattle feedlots over differing periods of time.

4.2 Compiling Datasets

Data which has been previously collected for other experimental research and ongoing environmental monitoring programs from three beef cattle feedlots will be used in this project. The initial step in compiling the measured datasets to be used was to extract the data that would be required for inputs in MEDLI. In addition, data that would be used to directly compare with the outputs of MEDLI was compiled. All data was categorised into three testing groups;

- Feedlot A
- Feedlot B
- Feedlot C

The parameters that would be used to perform statistical analysis between simulated and measured data was determined by evaluating what data from the field and MEDLI outputs could be directly compared without obfuscation or objectionable methods. That is, data that was measured over the same spatial confinements and using units that are directly comparable where selected in key areas of the effluent stream. The three testing points of; pond chemistry, soil chemistry and harvested crop properties where selected due to being located at critical points along the water and nutrient fate continua that had the greatest relevance to designing an effluent irrigation scheme. The particular variables determined to be directly comparable are listed below under their respective points along the effluent stream.

Pond Chemistry

- Total Nitrogen (mg/L)
- Total Phosphorous (mg/L)
- Total Dissolved Solids (mg/L)

Soil Chemistry

- Root Zone Nitrate (NO^{3-}) (mg/L)
- Root Zone Total Phosphorous (P) (mg/L)

Harvested Crop Properties

- Crop Yield (kg/ha)
- Nitrogen removed by plant(kg/ha)
- Phosphorous removed by plant (kg/ha)

These variables provide coverage of the major modelled components in MEDLI being; the water balance, nitrogen, phosphorous, soluble salts and the removal of these nutrients.

4.3 Development of MEDLI Inputs

Initially, a MEDLI familiarisation will be undertaken to learn the program. This will take the form of an informal sensitivity analysis to gain understanding about how various inputs effect the outputted results. As an analysis of the architecture of MEDLI software was conducted in this project; a reasonable understanding had been previously developed about the relationships and interaction of the various components of the software. The familiarisation process aims to uncover any oversights in the operation of the program and reduce the likelihood of issues arising during the case studies.

The case studies, in this case three beef cattle feedlots, will be simulated using the software. Measured data from the field will be used as inputs to best try and mimic the conditions that are present in the measured data. Some modules within MEDLI contain in-build settings that aim to provide the user with predefined data relevant to a specific enterprise or input parameter. This predetermined data will be utilised in this research where more competent data measured in the field could not be used. The following three sections will provide details about each scenario input parameters. Justification is provided as to how and why the inputs were selected in attempt to best simulate the conditions measured in the field.

4.3.1 Scenario 1

Scenario 1 aims to replicate the conditions at Feedlot A, the name and location of the feedlot have been withheld in all cases for this research project. The initial file and enterprise details were entered as presented in Table 4.1. Climate data was measured in the field; as MEDLI allows for climate data to be entered manually this approach was adopted. A default climate data file in (.p51) format was modified in Excel with the site specific climate data and imported in to MEDLI as 'Feedlot A'.

Table 4.1 - Scenario 1 Initial Setup

Scenario 1	
Enterprise	Feedlot A
Climate data	Field Measured/Manual Input
Run period	13 June 2009 - 12 June 2016
Location	Withheld

The second module to be populated is waste estimation. Limited data was acquired about on-site waste production for feedlot A. MEDLI provides a predefined 'Feedlot' setting which was used in this case. It was considered a reasonable approach as this data would likely be used in most scenarios in the absence of more competent data. In addition, this data has been calibrated and verified by the program creators as stated in the MEDLI User Manual, (2016) and should provide a sound estimation of waste values if the program is to accurately simulate the waste stream of a feedlot. Table 4.2 provides a summary of the values assigned to waste production for scenario 1.

Table 4.2 - Scenario 1 Waste Estimation

Waste Estimation	Feedlot
System Type	Generic
Inflow (ML/day)	1
Total Nitrogen (mg/L)	700
Total Phosphorous (mg/L)	75
Total Dissolved Solids (mg/L)	5120
Volatile Solids (mg/L)	20,000
Total Solids (mg/L)	25,000
Electrical Conductivity (dS/m)	8

Pre-treatment attempts to estimate the fraction removal of effluent, nutrients and solids from the waste stream. In this scenario a sediment basin is used to achieve a reduction in the solids entering the effluent holding pond. Based on the research of Lott *et al* (1994), and Lott and Skerman (1995), the removal fractions in Table 4.3 were considered to provide reasonable estimations for these parameters. It is worth noting; these values are objectionable and will be explored further in *Chapter 6 Discussion* of this paper. The research conducted in the cited literature does not establish these values directly as it was attempting to define the removal of organic matter in the sedimentation system. Using typical sediment values estimations were then derived by using the manure and effluent constituent values contained in research conducted by Lorimor and Powers (2004).

Table 4.3 - Scenario 1 Pre-treatment

Pre-treatment	Sediment Basin
Effluent Removed (fraction)	0.02
Nitrogen Removed (fraction)	0.6
Phosphorous Removed (fraction)	0.65
Volatile Solids Removed (fraction)	0.48
Total Solids Removed (fraction)	0.45

Defining the pond is the next set of input parameters required as detailed in Table 4.4. The initial inputs deal with the physical size and capacity of the pond and have been entered here to replicate the effluent holding pond at Feedlot A. Rainfall and evaporation potentials have been entered as this pond is uncovered and open to environmental conditions. Initialisation inputs pertain to whether the pond contains effluent and subsequent constituent fractions prior to the simulation run. In this case, the pond did contain effluent and chemical composition was known, so these values were entered. The nitrogen fraction of various N compounds that are held in effluent are well established in literature and also suggested in the MEDLI user manual. The fractions of pond Nitrate to Ammonium to organic N were entered as suggested. The sludge accumulation rate adopted, was defined in the MEDLI User Manual (2016), as no information to the contrary could be located, this value was used as a default. MEDLI requires the estimation of N, P and volatile solids (VS) remaining in solution after anaerobic moralisation. Research was conducted to find out suitable values for these inputs however, no transferable information could provide any insight beyond what was suggested in the user manual. Therefore, again these values were adopted as a default setting, which will undergo further appraisal in the *Chapter 6 Discussion*.

Table 4.4 - Scenario 1 Pond System

Pond System	Anaerobic
Number of Ponds	1
Pond Volume (ML)	94
Depth at Outlet	5
Side Slope (° from vertical)	66.66
Length : Breadth Ratio (m/m)	1
Height of Freeboard (m)	1
Pond Length (m)	141
Pond Breadth (m)	141
Drawdown Depth (m)	4.2
Rainfall Catchment Potential (fraction)	1
Evaporation Area Potential (fraction)	1
Leakage (mm/day)	0.5
Evaporation Coefficient (mm/mm)	0.71
Initial Pond Status	full
Are pond concentrations Initialised?	Yes
Initial Total Nitrogen (mg/L)	8
Initial Total Phosphorous (mg/L)	4
Initial Total Dissolved Solids (mg/L)	280
Nitrogen Transfer Coefficient	0.014
Desludging	When Dry
Nitrate fraction in pond	*0*
Ammonium fraction in pond	*0.8*
Organic nitrogen fraction in pond	*0.2*
Total Nitrogen fraction	*1*
Sludge Accumulation Rate (m^3/kg)	0.00303
Nitrogen fraction remaining in suspension	0.77
Phosphorous fraction remaining in suspension	0.77
Volatile Solids Loading Rate (kg/m^3/day)	0.067
Biological Activity Adjustment, 1 = no adjustment	1
Effluent Recycling?	No

No additional pump and shandying information was required to be provided in this case. No shandying of the effluent pond takes place and pump data is generic in nature and does not significantly impact on the outcomes of the model in terms of this research. Table 4.5 details the inputs for this module. The pump rate of zero is applied here to allow MEDLI to determine irrigation with no restrictions by the pumping station. Note, irrigation is still restricted by other factors such as water availability, quality and trigger points which will be defined in modules to come.

Table 4.5 - Scenario 1 Pump & Shandy

Pump & Shandy	Rate
Rate (ML/day)	0

Defining all parameters of the paddock is achieved within three separate 'tabs' of the paddock input section; Irrigation Operation, Planting Parameters and Soil parameters, the inputs are presented in Table 4.6. Before specific paddock data is entered, general information such as paddock name, area and pan coefficient are inputted. Pan Coefficient modifies the measured Class A pan value contained in the climate data, this is to account for the density of plant biomass reducing the evaporation potential. The default setting is 1 which is no adjustment to the pan evaporation and has been selected here as the best simulation of the site.

The first of the tabs to be defined is; *Irrigation Operation*, the start and stop dates are defined as well as the irrigation trigger points. Specified water deficit has been used as the trigger point in this situation as it offers consistent irrigation over the growing period and is based on evaporation therefore allowing for seasonal accuracy in irrigation akin to what would be applied in the field. A water deficit of 10mm was set as this allows the model to keep the field moisture content consistent and plant stress low. The irrigation method is flood as that is a known parameter, which is consistent with the selected irrigation stop point of at drained upper limit. Ammonium loss to volitation is set at 0.1 and is consistent with what the literature suggests for flood irrigation of effluent.

Crops grown on the paddock are defined in the *Planting Parameters* tab with the first selection being rotation or non-rotation. In this scenario non-rotation was selected as maize was grown for the entire test period. The default crop settings have been maintained for the selected maize crop option as no other site specific details were known.

The final tab to be defined in the paddock section is *Soil Parameters.* MEDLI contains a library of common soils of Australia hence, grey clay was chosen as this is consistent with the site conditions. Setting the paddock soil automatically populates the entirety of the soil input parameters. This was checked against the sporadic data that was known about the site which provided no changes to the default settings for grey clay soil group.

Table 4.6 - Scenario 1 Paddock

Paddock	EUA01
Paddock Area (ha)	50
Pan Coefficient (mm/mm)	1
Irrigation Start & End	13 June - 12 June
Irrigation Trigger	At specified soil water deficit
Soil Water deficit (mm)	10
Irrigation Method	Flood
Ammonium loss (fraction)	0.1
Irrigation Applied	To specified depth above DUL
Depth above DUL	0
Irrigation Overrides?	No
Cropping Regime	Non-rotation
Plant Model	Crop
Plant Crop	Maize
Crop Coefficient (mm/mm)	0.8
Maximum Root depth (mm)	2000
Radiation Use Efficiency (kg/ha/MJ/m^2)	20
Maximum Shoot Nitrogen (fraction dwt)	0.05
Maximum Shoot Phosphorous (fraction dwt)	0.0043
Leaf Area Development	Default for maize crop
Thresholds for growth responses	Default for maize crop
Paddock Soil	Grey Clay
Number of Soil Layers	4
Soil Layer Thickness	300, 600, 600, 300
Soil Parameters	Default for Grey Clays

The sections for pathogen risk assessment and ground water will not be considered in this research and were disable from the modelling as shown in Table 4.7. This does not affect the outputs important to this research and are in fact disable as the default setting.

Table 4.7 - Scenario 1 Pathogen Risk Assessment & Ground Water

Pathogen Risk Assessment	Disabled
Ground Water	Disabled

The final inputs required pertain to model run information. Four run options are selectable being; full run, reliability of supply run, extended run, and multi run. For this scenario the full run option was selected as the best option, section *3.2.11 Run Configuration* contains details of the differences in run options. Output configuration gives the user the ability to define the outputs required which are saved as a (.csv) file. This is in addition to the general output report in (.medr) file format that is produced containing a summary of all outputs. The outputs that were selected are those that would be compared in the statistical analysis of datasets; these are;

- Total Pond Nitrogen (mg/L)
- Total Pond Phosphorous (mg/L)
- Total Pond Dissolved Solids (mg/L)
- Soil Nitrate in Solution (mg/L)
- Total Soil Phosphorous (mg/kg)
- Dry Mass Crop Yield (kg/ha)
- Nitrogen Mass Removal by Plant (kg/ha)
- Phosphorous Mass Removal by Plant (kg/ha)

The above MEDLI outputs where selected as they are directly comparable to the measured data and offer sound coverage of model performance as stated in section *4.2 Compiling Datasets*

4.3.2 Scenario 2

This section aims to provide details of the MEDLI inputs for Scenario 2 which is based on information collected from Feedlot B. This section will not replicate information already provided in section *4.3.1 Scenario 1*. It will however, present the inputs used in the scenario and describe any differences not yet discussed in the previous section.

Initial setup consisted of entering the enterprise name; Feedlot B and defining the run period which was derived from the available measured data. Climate data was entered manually from records obtained on-site for rainfall, minimum and maximum average temperature, pan evaporation and solar radiation. Table 4.8 provides a summary of initial inputs.

Table 4.8 - Scenario 2 Initial Setup

Scenario 2	
Enterprise	Feedlot B
Climate data	Field Measured/Manual Input
Run period	01 Jan 2009 - 31 Dec 2016
Location	Withheld

As tabulated in Table 4.9, no change was made to the default feedlot waste estimations made by MEDLI.

Table 4.9 - Scenario 2 Waste Estimation

Waste Estimation	Feedlot
System Type	Generic
Inflow (ML/day)	1
Total Nitrogen (mg/L)	700
Total Phosphorous (mg/L)	75
Total Dissolved Solids (mg/L)	5120
Volatile Solids (mg/L)	20,000
Total Solids (mg/L)	25,000
Electrical Conductivity (dS/m)	8

Pre-treatment again remains unchanged from the first scenario which estimates removal fractions based on a sedimentation basin as this is the system employed at the site.

Table 4.10 - Scenario 2 Pre-treatment

Pre-treatment	Sediment Basin
Effluent Removed (fraction)	0.02
Nitrogen Removed (fraction)	0.6
Phosphorous Removed (fraction)	0.65
Volatile Solids Removed (fraction)	0.48
Total Solids Removed (fraction)	0.45

The dimensional details of the on-site effluent holding pond were entered, see Table 4.11. Also, initial pond constituent concentrations were defined in accordance with site specific data. All other parameters remain unchanged from the previous scenario.

Table 4.11 - Scenario 2 Pond System

Pond System	Anaerobic
Number of Ponds	1
Pond Volume (ML)	65*
Depth at Outlet	5
Side Slope (° from vertical)	66.66
Length : Breadth Ratio (m/m)	2*
Height of Freeboard (m)	1
Pond Length (m)	164*
Pond Breadth (m)	85*
Drawdown Depth (m)	4.5*
Rainfall Catchment Potential (fraction)	1
Evaporation Area Potential (fraction)	1
Leakage (mm/day)	0.5
Evaporation Coefficient (mm/mm)	0.71
Initial Pond Status	full
Are pond concentrations Initialised?	Yes
Initial Total Nitrogen (mg/L)	200*
Initial Total Phosphorous (mg/L)	35*
Initial Total Dissolved Solids (mg/L)	1615*
Nitrogen Transfer Coefficient	0.014
Desludging	When Dry
Nitrate fraction in pond	*0*
Ammonium fraction in pond	*0.8*
Organic nitrogen fraction in pond	*0.2*
Total Nitrogen fraction	*1*
Sludge Accumulation Rate (m^3/kg)	0.00303
Nitrogen fraction remaining in suspension	0.77
Phosphorous fraction remaining in suspension	0.77
Volatile Solids Loading Rate (kg/m^3/day)	0.067
Biological Activity Adjustment, 1 = no adjustment	1
Effluent Recycling?	No

* Indicates values changed from Scenario 1

The paddock area has been defined as 50ha in this case and irrigation is again flood type. This site utilises a rotation cropping procedure which has been defined in planting parameters. Maize and Barley were grown on site over the testing period as summer and winter crops respectively. The default plant growth inputs were accepted as providing a sound basis for growth rates. On site soil for at this feedlot is grey clay. Table 4.12 provides a summary.

Table 4.12 - Scenario 2 Paddock

Paddock	EUA02
Paddock Area (ha)	50
Pan Coefficient (mm/mm)	1
Irrigation Start & End	01 Jan - 31 Dec
Irrigation Trigger	At specified soil water deficit
Soil Water deficit (mm)	10
Irrigation Method	Flood
Ammonium loss (fraction)	0.1
Irrigation Applied	To specified depth above DUL
Depth above DUL	0
Irrigation Overrides?	No
Cropping Regime	rotation
Plant Model	Crop
Plant Crop	Maize & Barley
Crop Coefficient (mm/mm)	0.8
Maximum Root depth (mm)	2000
Radiation Use Efficiency (kg/ha/MJ/m²)	20
Maximum Shoot Nitrogen (fraction dwt)	0.05
Maximum Shoot Phosphorous (fraction dwt)	0.0043
Leaf Area Development	Default for crops grown
Thresholds for growth responses	Default for crops grown
Paddock Soil	Grey Clay
Number of Soil Layers	4
Soil Layer Thickness	300, 600, 600, 300
Soil Parameters	Default for Grey Clays

Pump, shandy, pathogen risk assessment and ground water remain the same as for scenario 1. The full run option was used to simulate the scenario.

4.3.3 Scenario 3

Scenario 3 represents the Feedlot C and provided the largest measured dataset, ranging from 1997 to 2010. It was however an incomplete dataset with different measurements of pond, soil and harvest data taken over different periods. Initial inputs for this site are indicated in Table 4.13.

Table 4.13 - Scenario 3 Initial Setup

Scenario 3	
Enterprise	Feedlot C
Climate data	Field Measured/Manual Input
Run period	01 Jan 2005 - 31 Dec 2010
Location	Withheld

The waste estimation and pre-treatment modules remain unchanged from the previous scenarios and are presented Table 4.9 and 4.10 respectively.

The pond dimensions, capacity and initial effluent constituents were entered in accordance with the site specific measured data, see Table 4.15.

Table 4.14 - Scenario 3 Pond System

Pond System	Anaerobic
Number of Ponds	1
Pond Volume (ML)	49*
Depth at Outlet	5.5*
Side Slope (° from vertical)	66.66
Length : Breadth Ratio (m/m)	1
Height of Freeboard (m)	1
Pond Length (m)	98*
Pond Breadth (m)	98*
Drawdown Depth (m)	4.5
Rainfall Catchment Potential (fraction)	1
Evaporation Area Potential (fraction)	1
Leakage (mm/day)	0.5
Evaporation Coefficient (mm/mm)	0.71
Initial Pond Status	full
Are pond concentrations Initialised?	Yes
Initial Total Nitrogen (mg/L)	120*
Initial Total Phosphorous (mg/L)	240*
Initial Total Dissolved Solids (mg/L)	950*
Nitrogen Transfer Coefficient	0.014
Desludging	When Dry
Nitrate fraction in pond	*0*
Ammonium fraction in pond	*0.8*
Organic nitrogen fraction in pond	*0.2*
Total Nitrogen fraction	*1*
Sludge Accumulation Rate (m^3/kg)	0.00303
Nitrogen fraction remaining in suspension	0.77
Phosphorous fraction remaining in suspension	0.77
Volatile Solids Loading Rate (kg/m^3/day)	0.067
Biological Activity Adjustment, 1 = no adjustment	1
Effluent Recycling?	No

* Indicates values changed from previous scenarios

Paddock information from site was entered as shown in Table 4.16. The area to be irrigated is 40ha and a rotation cropping system is in place. Sorghum is grown as the summer crop and Lucerne in the winter as a silage crop. The default plant growth parameters were adopted. The site soil condition is most closely approximated to be red earth and as such was used as the default soil characteristics. No changes from the default settings were made for the soil condition.

Table 4.15 - Scenario 3 Paddock

Paddock	RD A
Paddock Area (ha)	40
Pan Coefficient (mm/mm)	1
Irrigation Start & End	01 Jan - 31 Dec
Irrigation Trigger	At specified soil water deficit
Soil Water deficit (mm)	10
Irrigation Method	Flood
Ammonium loss (fraction)	0.15
Irrigation Applied	To specified depth above DUL
Depth above DUL	0
Irrigation Overrides?	No
Cropping Regime	Rotation
Plant Model	Crop
Plant Crop	Sorghum & Lucerne
Crop Coefficient (mm/mm)	0.9
Maximum Root depth (mm)	3000
Radiation Use Efficiency (kg/ha/MJ/m^2)	10
Maximum Shoot Nitrogen (fraction dwt)	0.05
Maximum Shoot Phosphorous (fraction dwt)	0.0056
Leaf Area Development	Default for crops grown
Thresholds for growth responses	Default for crops grown
Paddock Soil	Red Earth
Number of Soil Layers	4
Soil Layer Thickness	100, 500, 600, 700
Soil Parameters	Default for Red Earth

Pump, shandy, pathogen risk assessment and ground water remain the same as for each of the previous scenarios. In this case the extended run option was used as a climate dataset for the entire period to be analysed was not attained. Extended run aims to remedy this situation by extending the climate data that is available and applying it to cover other years in the simulation. Data was available for the site from 1967 to 2010 however, considerable number of years were partially represented or not at all. This situation will be explored further in *Chapter 6 Discussion*.

4.4 Statistical Analysis

To determine how well the modelled data fits the measured data, a statistical analysis will be conducted. The coefficient of determination (R^2) and the coefficient of efficiency (E) will be used to compare simulated and observed data against a linear fit line. Coefficient of determination will be used as it is a well-established means of determining the correlation between two variables. A regression line is plotted as a line of best fit to the data points within a scatter plot and this regression line is compared with a linear line to determine the fit of data. A theoretically perfect data fit would return an R^2 value of 1.0. Typically, R^2 values below 0.4 represent weak correlation, 0.4 to 0.6 moderate and above 0.6 would show strong to very strong correlation as they approach 1.0. The equation used in R^2 analysis is given as;

$$\left[\frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sqrt{(y_i-\bar{y})}^2}}\right]^2 \qquad \text{Equation 1}$$

Where:

$x_i=$ Observed data values
$\bar{x}=$ Mean of observed data
$y_i=$ Predicted data values
$\bar{y}=$ Mean of predicted data values

In addition, a coefficient of efficiency (E) will be used to correlate the simulated and measured datasets. This method is similar to R^2, but differs slightly in that it is a measure of scatter around a linear line as opposed to fitting a regression line. The E method will be used in this case as it is commonly used in analysis of hydrological and water routing variables. The equation is;

$$\frac{\sum(x_i-\bar{x})^2-\sum(y_i-x_i)^2}{\sum(x_i-\bar{x})^2} \qquad \text{Equation 2}$$

Where:

$x_i=$ Observed data values
$\bar{x}=$ Mean of observed data
$y_i=$ Predicted data values

It may be that the simulated data does not replicate the fluctuations of the measured data for all of the parameters that will be compared. In this case, to determine how well the simulated data approximates the average of the measured data, a mean will be taken of both datasets and a percentage difference will be calculated to find the disparity between averaged data. The equation for calculating mean is;

$$\bar{X} = \frac{\sum x}{n} \qquad \text{Equation 3}$$

Where:

$\bar{X} =$ Mean of the data
$x =$ Values of data
$n =$ Number of data points

Whilst the percentage difference equation is given as;

$$\Delta V = \frac{v1 - v2}{v2} \times 100 \qquad \text{Equation 4}$$

Where:

$\Delta V =$ Percentage change in values
$v1 =$ Predicted value
$v2 =$ Observed value

Tables and graphs will be produced in Excel to numerically and graphically demonstrate the results of dataset comparisons, regression and linear fit.

Chapter 5 RESULTS

5.1 Scenario 1

Detailed in this section are the results obtained from the measured data and simulations carried out in MEDLI for Feedlot A. The results are presented in the following categories; Pond Chemistry, Soil Chemistry and Harvest Properties.

The period of analysis in Scenario 1 was June 2011 to April 2015. Data was collected from the field at the time intervals outlined in Table 5.1. To compare results the average MEDLI outputs for the months to be compared were calculated and presented in the below table. Data was not collected for TDS in March 2012. The results indicated that MEDLI data has significantly over estimated the measured data for the constituents of the effluent in the holding pond.

Table 5.1 - Scenario 1 - Pond Chemistry Comparison

	Scenario 1 - Feedlot A					
	Pond Chemistry					
	Measured Data			MEDLI Simulated Data		
	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)
Jun-11	19	9	2616	154	17.8	4388
Mar-12	28	32		174	21	5333
Jun-12	31	11	2322	174.8	21.2	5363
Jan-13	39.8	22.8	1186	180	21.9	5563
Jun-13	19	13	1346	173.8	21	5337
Apr-14	35	17	1514	178	21.8	5520
Jul-14	41	675	1800	178	21.8	5527
Apr-15	20	14	1176	177.8	21.7	5510

Figure 5.1 presents a graphical representation of the above values, which demonstrates the deviation of the simulated data from the measures.

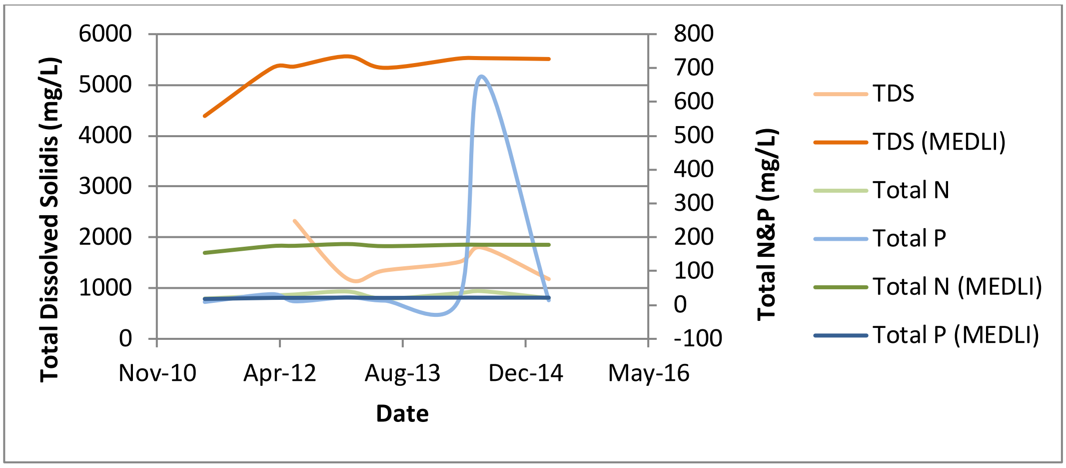


Figure 5.1 - Scenario 1 Measured & Simulated Pond Chemistry

Taking a look at the results individually reveals no correlation (R^2=0.33) between the simulated and measured pond nitrogen (Figure 5.2). An analysis of how well the MEDLI modelled data represented the average of the field measured data suggests a close to 497 percent over estimation of pond nitrogen.

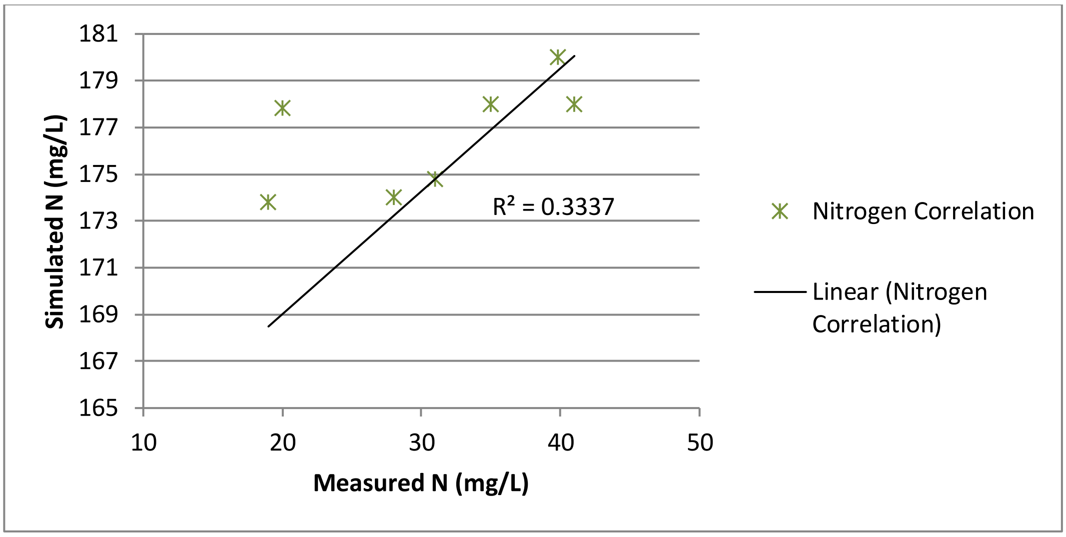


Figure 5.2 - Scenario 1 Regression Analysis of Pond Nitrogen

A similar result was found in the regression analysis of phosphorous as evidenced in Figure 5.3. An R^2 of 0.21 indicates weak correlation in the two datasets. The MEDLI simulated average pond phosphorous was 23.9 percent higher than the mean phosphorous level that was measured in the effluent pond over the four-year period of analysis.

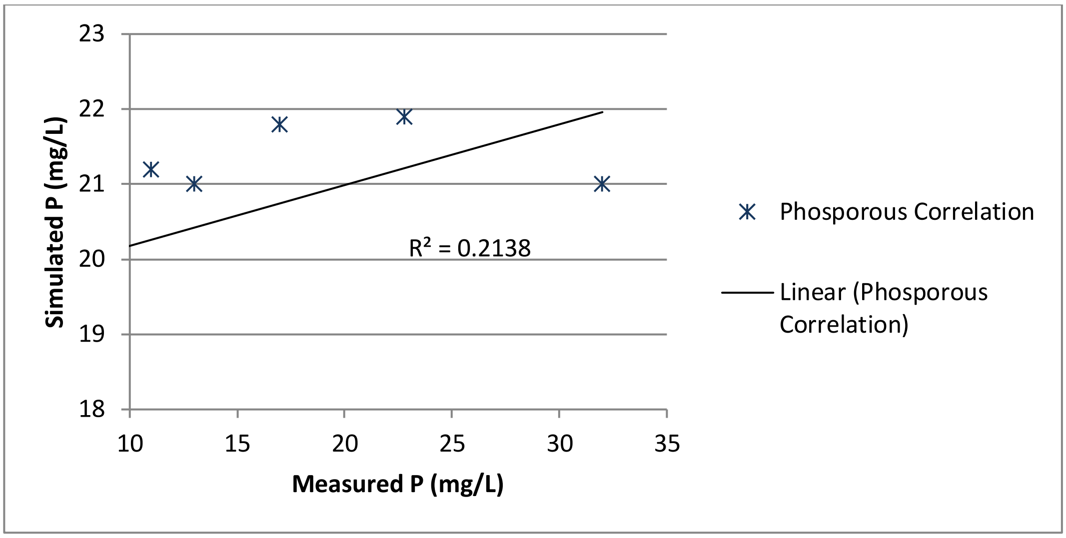


Figure 5.3 - Scenario 1 Regression Analysis of Pond Phosphorous

Total dissolved solids produced a moderate correlation of 0.57 in the comparison datasets (Figure 5.4). This is despite the data diverging and a 211 percent disparity between the mean values of each of datasets which can be clearly seen in Figure 5.1.

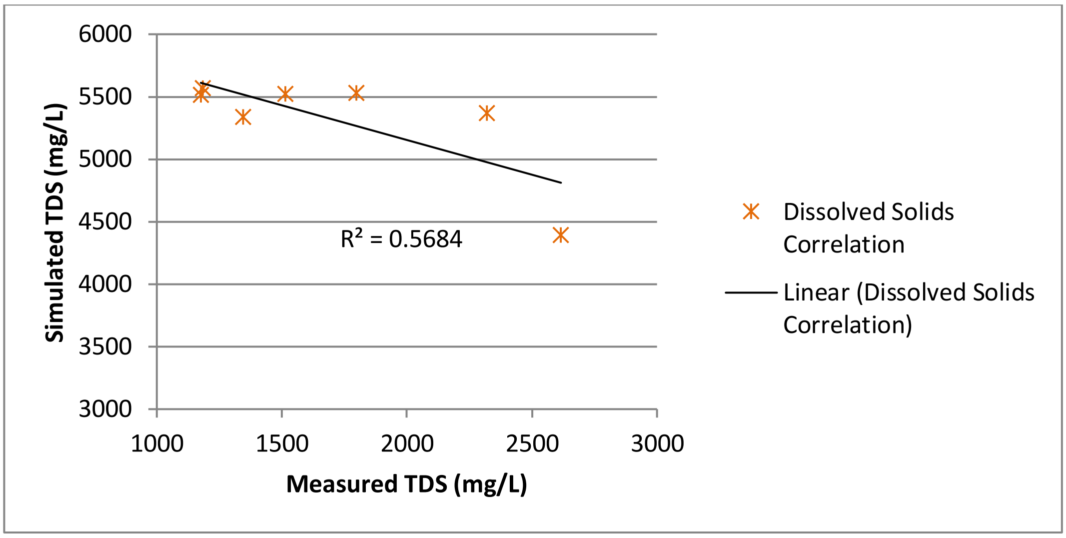


Figure 5.4 - Scenario 1 Regression Analysis of Pond Total Dissolved Solids

After continuing to produce regression analyses for the soil chemistry and harvest properties a conclusion was made that comparing the linear fit in the modelled data with that of the measured data presented little value in comparing results. Soil chemistry and harvest property data yielded very weak correlation in the data sets. Small sample sizes may have been a contributing factor however; another possible reason was thought to be that the field observed data had significantly more fluctuations in values than the modelled data. This indicated that MEDLI results were predicting the average monthly nutrient values rather than following the natural fluctuations in data. The compared results were showing generally weak correlation because of the large spread in the measured dataset; this resulted in a large spread of data around the regression line hence, weak correlation.

It was originally planned in the project methodology to conduct a coefficient of efficiency analysis comparing the MEDLI and observed dataset in addition to the coefficient of determination. After evaluation of the comparison methods at the completion of scenario 1 analysis; a decision was made to discontinue the comparison of data around a linear fit line.

A new strategy was adopted in comparing the results; this was to calculate the mean of both data sets and find the percentage difference in the values. Establishing how closely MEDLI predicted the mean value of the observed data was considered to offer a better method of comparing the two datasets.

Soil nutrient measurements from Feedlot A were only collected once per year for 5 years from 2011 to 2015. Such a low number of samples is not ideal for comparing datasets, therefore limited conclusions can be made about the nature of the relationships in the values. Average annual soil nitrate and total phosphorous was calculated from the MEDLI outputs and is presented in Table 5.2 along with the field values.

Table 5.2 - Scenario 1 Soil Chemistry Comparison

	Scenario 1 - Feedlot A			
	Soil Chemistry			
	Measured Data		MEDLI Simulated Data	
	Nitrate in Solution (mg/L)	Total Phosphorous in Soil (mg/kg)	Nitrate in Solution (mg/L)	Total Phosphorous in Soil (mg/kg)
2011	8	27	26	19
2012	10	35	73	35
2013	0	16	86	42
2014	24.5	146.5	123	48
2015	32	10	98	52

The observed phosphorous levels in the soil contained a significant outlier in 2014 of 142.5 mg/kg. Whilst the MEDLI total phosphorous data did not follow the same general trend as the observed, it did produce data that was within 17 percent of the average observed data. As with the pond nitrogen levels; soil nitrate was significantly overestimated in the

MEDLI results by almost 450 percent. These results are presented graphically in Figure 5.5.

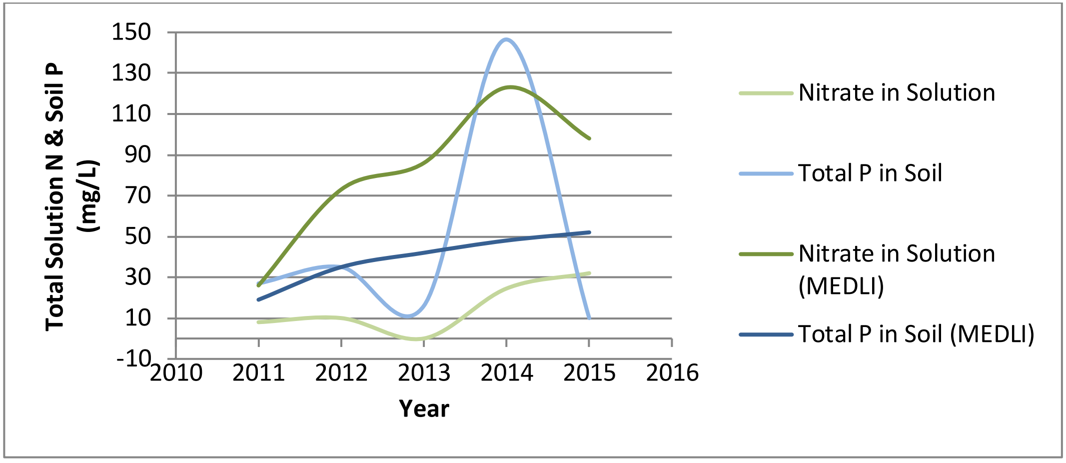


Figure 5.5 – Scenario 1 measure and Simulated Soil Chemistry

The final comparisons to be conducted for Feedlot A are the harvest properties. Only one year of observed data was available which was taken in July 2015. Despite the single sample it was interesting to note that the crop yield values were very closely matched with a 1.36 percent difference. The nitrogen removed from the biomass harvest showed a 71 percent overestimation in the MEDLI data and a 28 percent overestimation for phosphorous.

Table 5.3 - Scenario 1 Harvest Properties Comparison

	Scenario 1 - Feedlot A					
	Harvest Properties					
	Measured Data			MEDLI Simulated Data		
	Dry Mass Crop Yield (kg/ha)	Nitrogen Removal (kg/ha)	Phosphorous Removal (kg/ha)	Dry Mass Crop Yield (kg/ha)	Nitrogen Removal (kg/ha)	Phosphorous Removal (kg/ha)
Jul-15	12,100	149.1	22.3	12,264	255	28.5

When the nitrogen removed from the system is compared to nitrogen remaining in the soil; a net total increase in nitrogen is close to 380 percent more than the observed data suggests.

The same net analysis applied to phosphorous yields an 11 percent decrease in the MEDLI predicted soil phosphorous compared to the measured data from the field.

Generally, results indicate that MEDLI forecasts overestimate the nutrient and salt contained in the effluent stream. Offsetting this is that the amount of nutrient removed from the system is also over estimated. No observed data was available for total dissolved solids removed from the system thus no comparison could be made. Results for Feedlot A indicate a general trend of behaviour however, limited sample sizing has prevented any definitive conclusions.

5.2 Scenario 2

This scenario presents the results of data comparisons conducted on Feedlot B. The period that observed data spanned was two years, the simulation of the scenario was from January 2014 to December 2015. There were a number of issues with the observed data used in this scenario; Short run periods, such as the case presented here, provided less accurate simulation according to MEDLI literature. The reason provided in the literature is, some of the algorithms require minimum periods of five years to achieve a steady state scenario capable of outputting consistent and accurate results (Shaw *et al*. 1987). Total nitrogen values were not measured at the holding pond, instead nitrate values had been collected which provides little value in comparing pond chemistry as negligible levels of nitrate exist in stored effluent. No information on soil chemistry was available for the site and has been omitted from the results. Despite the questionable validity of the data for this site, the results are presented in Table 5.4 so that any trends in data can be discussed in relation to the other feedlots that were analysed.

Table 5.4 - Scenario 2 Pond Chemistry Comparison

	Scenario 2 - Feedlot B					
	Pond Chemistry					
	Measured Data			MEDLI Simulated Data		
	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)
Apr-14	Incomplete Data	20	7072	Incomplete Data	24	4564
Oct-14		2	8080		22	5476
May-15		35	5440		21	5375
Oct-15		6	5600		21	5472

Phosphorous returned a difference in mean values of 39.7 percent, although inspection of Figure 5.6 reveals that measured total phosphorous values produced a large spread. This combined with the low sample numbers may indicate that not enough samples were available to provide an indication on the likely trend.

MEDLI simulations produced a negative 20 percent difference in mean total dissolved solids compared with measured. This is in contrast to the more than 200 percent over estimation that was established for the same comparison in scenario 1.

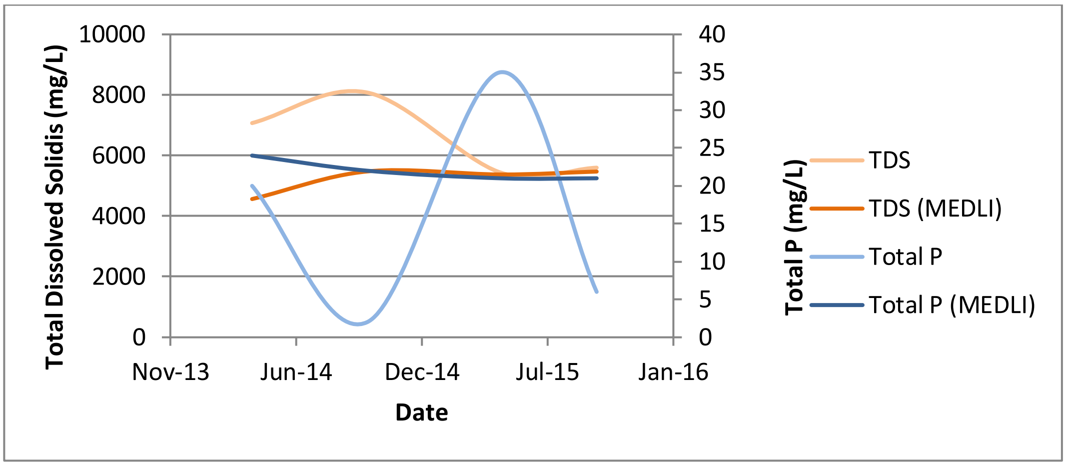


Figure 5.6 - Scenario 2 Measured and Simulated Pond Chemistry

Harvest data was measured on two occasions with yield and nutrient removal values for each occasion presented in Table 5.5. The 2014 harvest simulated yield was inflated by 18 percent whilst in 2015 the yield was underestimated by 14 percent.

As was the case in scenario 1 the modelled nitrogen removal was significantly above that of the measured data. In this case the difference was an increase of 65 and 78 percent for the years 2014 and 2015 respectively.

Despite the increased simulated phosphorous in the effluent pond, the removal of nutrient was underestimated by MEDLI. This resulted in a net increase of almost 100 percent in the total effluent stream phosphorus mass when compared with the observed data.

As with scenario 1, it is difficult draw definitive conclusions from the results detailed for scenario 2. The low sample size and incomplete dataset prevent the establishment of any definitive bias in the data.

Table 5.5 - Scenario 2 Harvest Properties Comparison

	Scenario 2 - Feedlot B					
	Harvest Properties					
	Measured Data			MEDLI Simulated Data		
	Dry Mass Crop Yield (kg/ha)	Nitrogen Removal (kg/ha)	Phosphorous Removal (kg/ha)	Dry Mass Crop Yield (kg/ha)	Nitrogen Removal (kg/ha)	Phosphorous Removal (kg/ha)
Aug-14	6,200	76.4	11.4	7,354	126	5.8
Mar-15	11,700	144	21.6	10,076	256	2.1

5.3 Scenario 3

Scenario 3 will demonstrate trends that were found during analysis of Feedlot C. The time period the scenario covers is 13 years, from 1997 to 2010. Observed data was collected over different periods of time during the 13-year total observation period. The consequence of this is, comparisons of pond chemistry, soil chemistry and harvest properties will be produced over varying periods of time. Despite this, scenario 3 presents the most competent results with good sample sizing and overlap where different time period observations are utilised.

Effluent pond chemistry was compared monthly from 1997 to 2005, with observed data generally becoming more sporadic from 2002 onwards as detailed in Appendix C. The exception to this is total dissolved solids which have measured values spanning from November 1998 to June 2002.

The results of the pond chemistry analysis have been produced in a graph shown in Figure 5.7. Clear trends are visible in the data that indicate that MEDLI is attempting to simulate the average of nutrient and salt loadings as opposed to mimicking the natural fluctuations in the values.

Also evident in Figure 5.7 is the averaged simulated effluent nitrogen is trending above the mean of the observed data. The percentage difference in the values is 19.6 and as can be seen the measured values gradually trend downward until the final outlier whilst the MEDLI data stays consistent throughout the simulated period.

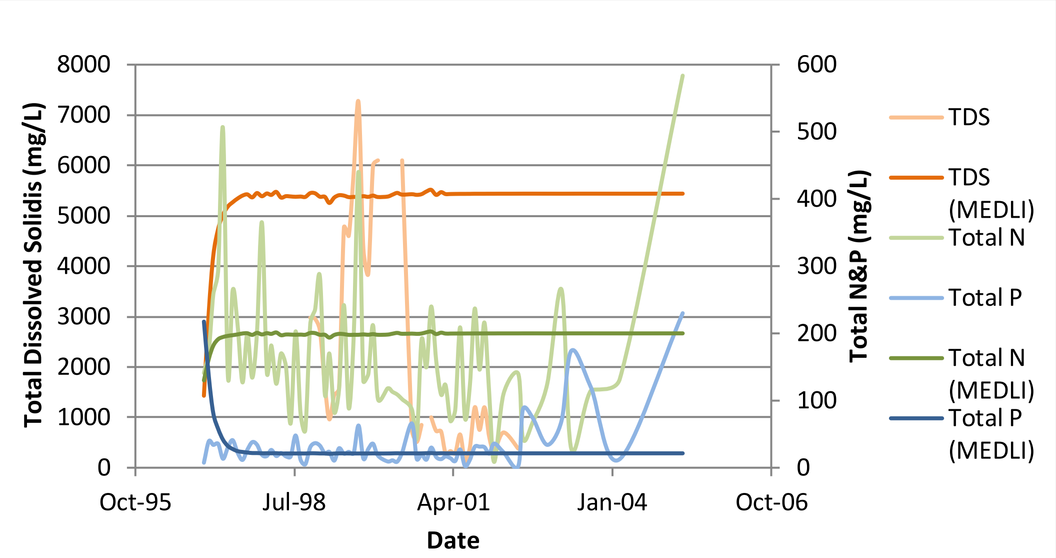


Figure 5.7 - Scenario 3 Measured and Simulated Pond Chemistry

The simulated phosphorous closely approximates the average of the observed values with a 13.4 percent underestimation. The majority of deviation in averages can be accounted for from 2001 onwards where data becomes more sporadic.

As with scenario 1, the total dissolved solids in the pond are simulated well above the observed average at 142 percent above measure pond dissolved solids.

Nutrient levels in the soil were recorded on-site over six years from 2005 to 2010 (Table 5.6).

Table 5.6 - Scenario 3 Pond Chemistry Comparison

	Scenario 3 - Feedlot C			
	Soil Chemistry			
	Measured Data		MEDLI Simulated Data	
	Nitrate in Solution (mg/L)	Total Phosphorous in Soil (mg/kg)	Nitrate in Solution (mg/L)	Total Phosphorous in Soil (mg/kg)
2005	7	168	469	500
2006	8	176	625	528
2007	10	147	580	573
2008	9	91	311	587
2009	12	143	682	595
2010	10	59	263	609

Vast separation of the MEDLI and observed data can be seen in Figure 5.8. Simulated solution nitrate was predicted at over 5000 percent higher whilst total soil phosphorous was overestimated by 333 percent.

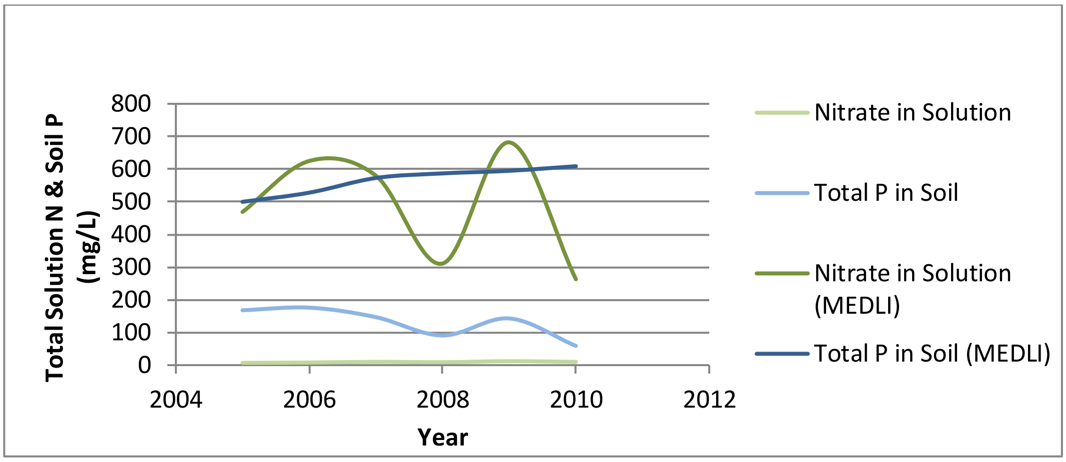


Figure 5.8 - Scenario 3 Measured and Simulated Soil Chemistry

Observed harvest properties were only available for July 2010 and a comparison of measured and modelled values can be seen in Table 5.7. The average modelled crop yield is 18 percent below the mean of the measured data.

Table 5.7 - Scenario 3 Harvest Properties Comparison

	Scenario 3 - Feedlot C					
	Harvest Properties					
	Measured Data			MEDLI Simulated Data		
	Dry Mass Crop Yield (kg/ha)	Nitrogen Removal (kg/ha)	Phosphorous Removal (kg/ha)	Dry Mass Crop Yield (kg/ha)	Nitrogen Removal (kg/ha)	Phosphorous Removal (kg/ha)
Jul-10	6,500	158	20.4	5,319	251	15.75

As with both preceding scenarios the amount of nitrogen removed during the harvest is considerably higher in the modelled scenario. With the average lying 59 percent above the measured mean the MEDLI data is presenting a reasonably consistent trend in over predicting nitrogen removal through plant biomass harvesting.

Phosphorous, in this scenario sees the MEDLI result falling 23 percent below the measured values. Out of the four dates that harvest properties were available three under predicted phosphorous removal.

5.4 Interpretation of Results

Contained in this section will be a summary of the results and general trends that were observed during the analysis. Some issue arose whilst setting up and modelling the scenarios which will be detailed and the implications of these issues on the results will be discussed.

5.4.1 Summary of results

A general trend of the results across all scenarios is that MEDLI appears to overestimate the amount of nitrogen within the effluent stream. Offsetting this is that MEDLI simulates more nitrogen uptake into plants, which is subsequently removed during harvest, than was measured. Although more nitrogen is removed the net outcome is that MEDLI is over predicting the nitrate levels that remain in the soil.

Total effluent pond phosphorous is typically under predicted by MEDLI. However, total soil phosphorous remains higher than the average of measured levels due to MEDLI forecasting below average measured phosphorous removal.

Harvest properties provided the closest trend relationships between observed and modelled datasets. Figure 5.9 shows a graphical representation of all scenarios combine with plots of crop yield, nitrogen removed and phosphorous removed. Although the sample size is small the plots of simulated values do replicate fluctuations in the measured data reasonably closely. The graph also presents the relationships in over and under prediction of nitrogen and phosphorous removal between MEDLI and observed data.

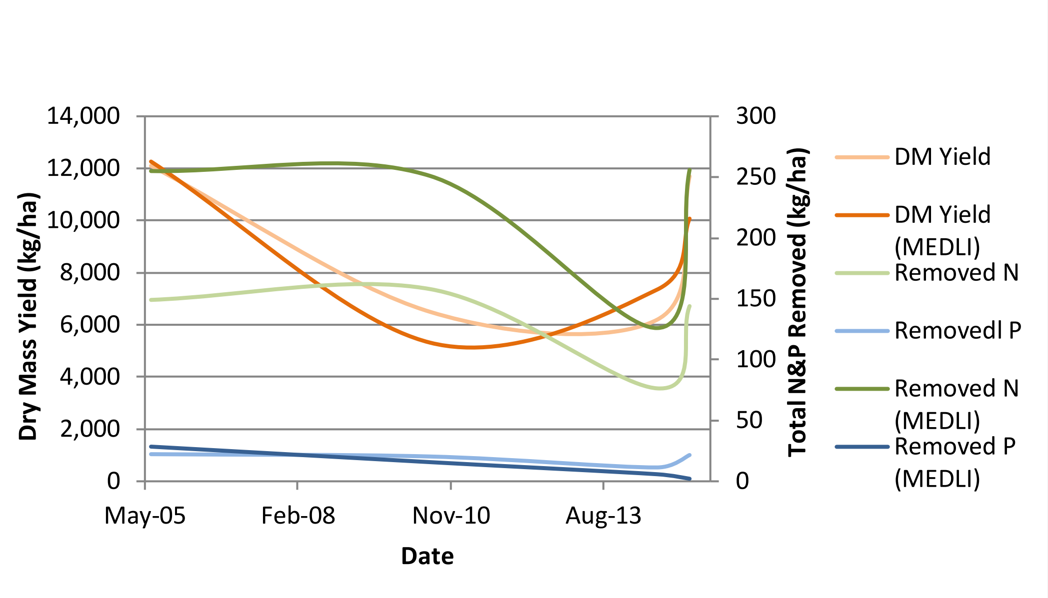


Figure 5.9 - Combined Scenarios Harvest Properties

5.4.2 Modelling Problem Analysis

As discussed previously in the results analysis, sample size was a factor considered to negatively impact the validity of the results. To provide increased confidence in appraisal of MEDLI performance, larger sample numbers would have provided a greater potential to evaluate trends in the data. The two greatest issues with the observed data is considered to be the short time durations for which observed data was available and the lack of frequency in the collection of the data. In many case yearly averages were compared which may not be considered adequate given the compounding effect of short modelling periods.

A significant issue that arose during the model setup and input phase was in determining suitable values for effluent, nutrient and salt removal during the pre-treatment process. The role of the pre-treatment module is to estimate the effects that entrained solid settling with in the sedimentation system has on removing effluent and solids from the effluent stream. The user inputs that are required in MEDLI for this component of the program are;

- Effluent Volume
- Nitrogen
- Phosphorous
- Volatile Solids and;
- Total Solids

All parameters require the input of a fraction value between zero and one that will be removed from the effluent stream. As stated in the methodology, assumptions of these values were made based on the research of Lott *et al* (1994), Lott and Skerman (1995) and Lorimor and Powers (2004). The literature states that a solids removal range of at least 50 percent is typical in a beef cattle sedimentation basins. Of the percentage of settled solids nitrogen and phosphorous account for 60 to 80 percent and 65 to 75 percent respectively. These ranges provide a broad base from which an estimation can be made on total nutrient removal. The percentage of total dissolved solids removed in pre-treatment is largely due to dilution of the effluent hence, low values of electrical conductivity.

What was unclear during scenario setup was how to derive accurate values for these inputs. No details were found in MEDLI Technical Reference, (2016) or MEDLI User Manual, (2016) regarding how to establish suitable input values.

A similar situation presented in entering anaerobic pond chemistry values in the pond system input section. Inputs of anaerobic pond chemistry are required to define the level of nutrient remaining in suspension after anaerobic moralisation processes and settlement of entrain solids in the effluent holding pond. The inputs that need to be defined are;

- Sludge Accumulation Rate (m^3/kg)
- Nitrogen fraction remaining in suspension (as a fraction of 0 to 1)
- Phosphorous fraction remaining in suspension (as a fraction of 0 to 1)
- Maximum design loading rate of volatile solids (m^3/kg/day)
- Biological Activity Ratio Adjustor (multiplier with 1 = no adjustment)

Again, no guidance could be located in MEDLI, or any other literature regarding determination of suitable inputs. Using the literature cited previously, a crude estimation was made to define the variables so progression of modelling could continue.

It was considered that ambiguity surrounding these input values would present outputs which would be equally ambiguous. A sensitivity analysis was considered the best approach in determining what the impact of changing these variables would have on model outputs.

5.5 MEDLI Sensitivity Analysis

The aim of this sensitivity analysis is to attempt to define the model output differences seen in varying the pre-treatment and anaerobic pond chemistry inputs.

The methodology used in this analysis was to use the pre-existing scenario 1 model as a baseline for comparison. A second run of the model was conducted with changes made only to the pre-treatment inputs as indicated in Table 5.8.

Table 5.8 - Sensitivity Analysis Pre-treatment Inputs

Scenario 1		
Pre-treatment Input Parameter	**Original Input**	**Sensitivity Analysis Input**
Nitrogen Removal Fraction	0.6	0.7
Phosphorous Removal Fraction	0.65	0.75
Total Solids Removal Fraction	0.45	0.55

The model would be run a third time with pre-treatment values returned to baseline and anaerobic pond chemistry values as defined in Table 5.9.

Table 5.9 - Sensitivity Analysis Pond System Inputs

Scenario 1		
Pond System Input Parameter	**Original Input**	**Sensitivity Analysis Input**
Nitrogen Fraction Remaining in Suspension	0.77	0.87
Phosphorous Fraction Remaining in Suspension	0.77	0.87

T

The results of the analysis on pond chemistry with a 10 percent increase in nitrogen removal at pre-treatment are shown in Figure 5.10. It can be seen, as expected, that increasing removal rates, yielded a decrease in the nutrient and dissolved solids in the effluent pond.

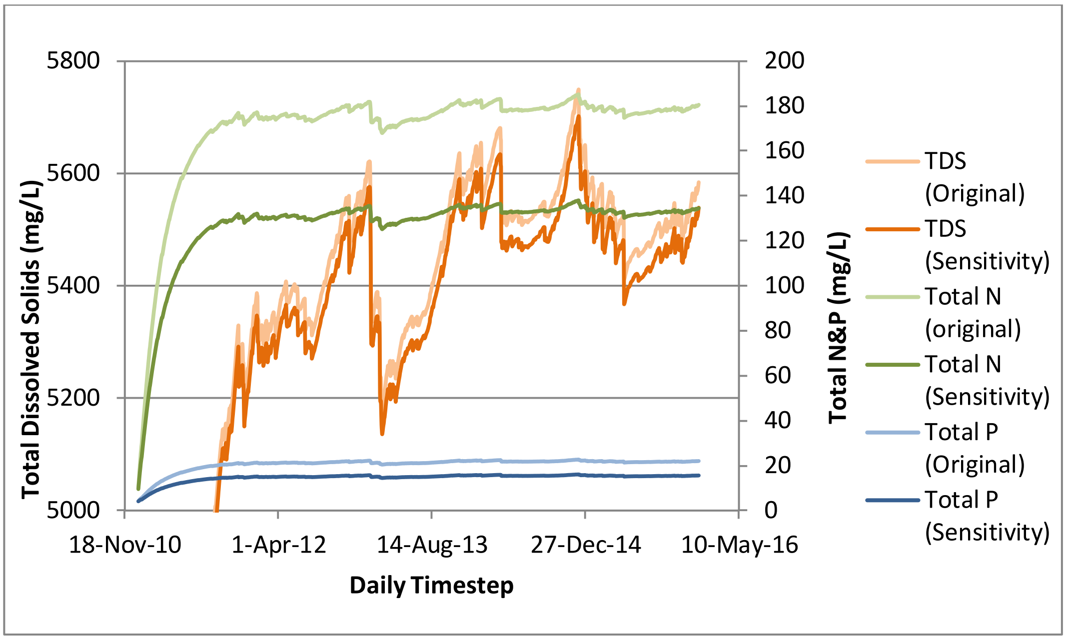


Figure 5.10 – Pre-treatment Sensitivity Analysis of Effluent Pond

Total nitrogen in the effluent pond decreased 34 percent with an increase of 10 percent nitrogen removal during pre-treatment. This is a higher than expected result however, does not account for the near 500 percent overestimation of pond nitrogen that was found when comparing scenario 1 MEDLI and observed outputs.

The same 10 percent increase applied to phosphorous removal during pre-treatment saw a corresponding 40.5 percent decrease in the total phosphorous in the effluent holding pond. Compared with the original scenario 1 results where MEDLI predicted 23.9 above the observed mean, this result would have had a significant impact on the results. If this change had been applied to the original scenario MEDLI would have returned a pond phosphorous mean that was predicting 16.6 percent below the mean of measured data.

The total dissolved solids provided a contrasting result from the pond nutrients, with almost no change in the outputs between the original and sensitivity inputs. A 10 percent increase, produced a 0.77 percent decrease in the TDS in the pond. This result shows that the output changed by significantly less than the increase in the removal rate that was applied to TDS.

The effects of the changes to the pre-treatment values on soil chemistry are represented in Figure 5.11. As would be expected a decrease in the values has resulted from the additional removal of nutrients.

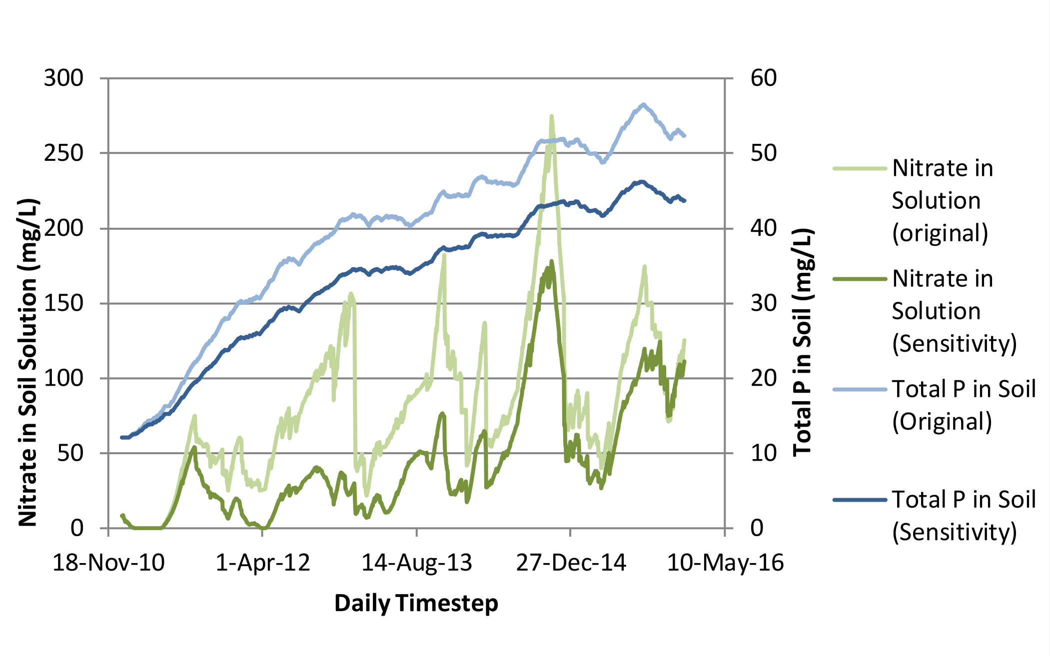


Figure 5.11 – Pre-treatment Sensitivity Analysis of Soil Nutrients

Nitrate in soil solution reduced by 81.5 percent compared with the original data. As the original data was overestimating soil nitrate by 450 percent, the only effect would be a reduction in the above average prediction.

Total soil phosphorous was reduced by 18.6 percent which would have brought it closely in line with observed average.

The sensitivity analysis of the anaerobic pond chemistry revealed a linear relationship in the changes between the original data and that used in the sensitivity analysis (Figure 5.12). A 10 percent increase in the nutrients remaining in suspension found a corresponding increase in pond nutrients of 12.9 percent. This was the case for both pond nitrogen and phosphorous values.

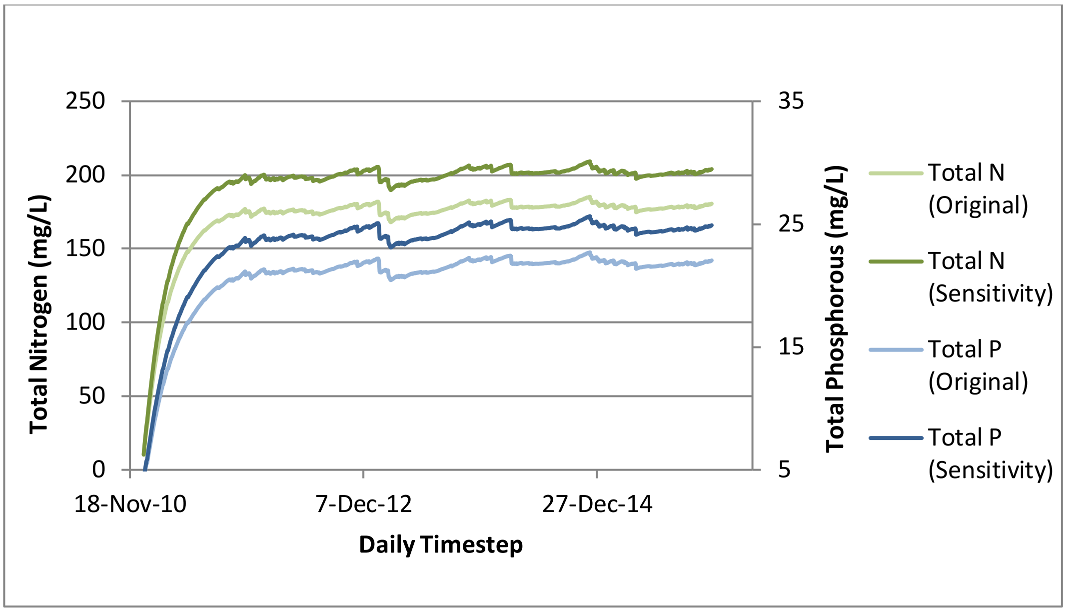


Figure 5.12 – Anaerobic Pond Chemistry Sensitivity Analysis of Effluent Pond

Chapter 6 DISCUSSION

6.1 Accuracy Assessment Background

The objective of this research was to establish if MEDLI accurately predicts the chemical properties of pond effluent, soil nutrient values, harvest yields and subsequent effluent stream nutrient removal specific to beef cattle feedlots.

Accuracy is defined by the International Organisation for Standardisation (ISO 5725-1) as;

> *"The closeness of agreement between a test result and the accepted reference value".*
>
> *"The term accuracy, when applied to a set of test results, involves a combination of random components and a common systematic error or bias component".*

What constitutes close is subjective, however in practical terms for this research it is dependent on the impacts that deviation from closeness has on environmental and stakeholder outcomes.

The result of inaccuracy in water and nutrient balances in this predictive tool may have environmental impacts if the predictions are underestimated or financial impacts on the stakeholders if predictions are overestimated. What constitutes an acceptable level of error is a topic of further research. Implications on the environment and financial ramifications to enterprises would need to be established, weighted and appraised. Conducting this level of analysis on the effects of MEDLI model inaccuracy falls outside the scope of this project.

In fulfilling the objectives of the research project, the aim has been to demonstrate if inaccuracy is apparent in the predictive modelling of MEDLI and establish a level of deviation from observed data.

6.2 MEDLI Performance Evaluation

This section aims to evaluate the performance of MEDLI. To provide clarity around the findings of the research project, this evaluation will be presented in three sections;

- General Evaluation
- Model Error Evaluation; and
- Input Sensitivity Evaluation

Comments on the general use and experience with the MEDLI program for a first time user will be provided along with a summary of the results and errors found during analysis. Finally, a justification will be presented for the requirement of the sensitivity analysis and evaluation of the findings detailed.

6.2.1 General Evaluation

MEDLI version 2 was released on June 2015 and was used in throughout this analysis. The user interface and general usability of the program is considered to be very good. MEDLI has a clearly defined and easy to follow process of data input. It will not allow a modelling run to be completed unless all information vital to achieving a successful model has been entered. Clear indication is given, by way of red colouring of the input parameter tab when incomplete or invalid data is entered. Daily data outputs are customisable in terms of what information is output to .csv format which allowed for analysis of the outputs to be undertaken with minimal deliberation. With the exception of defining some input variables which will be discussed in section *6.2.3 Input Sensitivity Evaluation* issues with implementing, running and outputting a model from MEDLI were minimal.

6.2.2 Model Error Evaluation

The results of this research indicate that some variation exists in predictive data produce in MEDLI and observed data collected in the field. Errors in the modelling may be due to one or more of the following;

- Differences between inputs and field conditions
- Incorrect assumptions or estimations of inputs
- Systematic or bias errors in the model
- Poor competency of observed data

Where possible field data was used to populate the inputs for each scenario. Notable exceptions to this were the waste estimation and soil parameters. The built-in feedlot data was used for waste estimation which was deemed an acceptable compromise to not having site specific data. When setting up a model for a greenfield site, this pre-defined waste estimation would likely be used and should provide accurate outputs if the model is to be considered valid.

Soil parameters were again defined using default settings for the type of soil that is present on-site. The soil type was acquired for the site conditions so for the same reasons as stated previously, selecting the soil type and allowing MEDLI to populate the required parameters is considered acceptable and should not impact the validity of this research.

Selecting the correct estimations of particular inputs was found to be an issue during the analysis process and was the subject of a separate sensitivity analysis. This will be detailed further in the following section *6.2.3 Input Sensitivity Evaluation.*

The results of model accuracy analyses did suggest systematic errors are present in the model. Typically, MEDLI over predicated the volume of nutrient and dissolved solid loading in the effluent stream. In particular, nitrogen in all cases was overestimated, with values significantly above the average of measured values in scenario 1. Total pond nitrogen was closer to observed values in scenario 3 which provide the greatest sample size. However, nitrate in soil solution returned values which were severely above the average field values for the same scenario. This situation was repeated in the scenario 3 for phosphorous which showed pond levels within acceptable deviation, but total soil phosphorous of extremely high levels when compared with observed data.

The reasons for these bias errors have not yet been resolved and may or may not be a result of the interaction between algorithms or the competency of the algorithms themselves used the model. Given that errors are occurring between the pond chemistry and soil nutrient handling modules; it is reasonable to suggest that irrigation volumes or soil parameters would be likely sources of error. As shandying of the effluent did not take place at any of the feedlots this component should present no source of error.

The values of crop yield produced in MEDLI did correlate well with the observed data. Nutrient removal was typically overestimated by a moderate amount in the simulated data. The inputs of plant growth or the algorithms driving this module could both be sources of error.

Competency of observed data can be considered dichotomously as; whether the quality of data was adequate and if quantity of data provided a sample size large enough to produce statistically significant results.

The collection of testing samples was conducted using methods which are in accordance with the Office of Environment and Heritage (OEH), New South Wales. Testing of samples was undertaken in a National Association of Testing Authorities, Australia (NATA) accredited facility in accordance with OEH procedures. This ensures that the quality of the sampling should not provide a high potential for contributing errors in the analysis.

The quantity of data available presented some level of uncertainty in the statistical significance of the results. Scenario 1 had a moderate number of samples, while scenario 2 had a low number of samples and is considered to be of limited value. Scenario 3 had a good sample size for pond chemistry and moderate sample size for soil chemistry. All scenarios had a low sample size for harvest properties. Larger sample sizes over periods in excess of 10 years would provide more reliable results than what has been presented in this research. That is not to suggest that there is not merit in the results obtained from conducting these comparison analyses. Some trends have presented throughout the scenarios and provide a basis from which further research could be conducted.

6.2.3 Input Sensitivity Evaluation

An issue arising during the establishment of the scenarios was estimating suitable values for inputs within the pre-treatment and anaerobic pond chemistry sections. No guidance is given in MEDLI literature provided with the program about estimating these inputs. How to suitably determine these inputs was a significant issue when conducting validation of the program. As was determined using a sensitivity analysis a 10 percent increase in pre-treatment inputs has a dramatic impact on MEDLI outputs. Inputs for anaerobic pond chemistry had a lesser impact on outputs with a close to linear change in the results.

These variables could be used to fine tune the results that were achieved in validation and it is probable that they contributed to the systematic bias that presented in the results. These two input sections of MEDLI required further research to determine if solid empirical data is available in literature for accurate estimation of these variables. As previously stated some literature on the matter was found that provided some guidance however, the information that was found provided a wide range of values that may be applicable. In addition, nutrient, salt and total solid removal from sedimentation systems was not the main focus of the Lott *et al* (1994), Lott and Skerman (1995) and Lorimor and Powers (2004) research, and only provide moderate guidance on the matter.

A recommendation formulated from conducting this research is that this lack of information about these inputs in MEDLI literature be addressed in an update to the provided MEDLI literature. This would enable designers of effluent irrigation schemes some confidence that they’re conducting modelling with the highest possible accuracy.

Chapter 7 CONCLUSION

7.1 Research Conclusion

The objective of this research was to conduct validation of MEDLI software and determine if there was correlation between simulated and observed data for beef cattle feedlot effluent streams.

A literature review determined that it is a legislated requirement of the Queensland Government, that all prospective effluent irrigation schemes are modelled. It is not a requirement that MEDLI is utilised in this modelling although, it was jointly developed by Queensland Government Departments and recommended as the preferred method.

Further review of current and past literature detailed current design practices and operational procedures for beef cattle feedlots. A review of present knowledge on the mechanisms that dictate nutrient and salt mobilisation in soils and factors influencing plant uptake was undertaken. The aim was to gain a greater understanding of the effluent stream in a beef cattle feedlot, from the starting point of waste production to the end point of harvesting organic compounds in the crop biomass.

Analysis of MEDLI Technical Reference, (2016) and MEDLI User Manual, (2016) was conducted. Gaining an understanding of the program in operation terms and the mathematical algorithms which underpin the program aimed to provided clear understanding of all facets of the MEDLI. This also provided appreciation of the module relationships and knowledge of how values were derived and could be suitably managed.

The validation was conducted which determined that systematic bias may be present in MEDLI. Analytical errors such as; improperly defined inputs, inadequacy of sample sizing and scenario set-up errors may have contributed to the bias found in the data. This resulted in the recommendation of further clarity being provided in MEDLI literature to better define the pre-treatment and anaerobic pond chemistry input variables.

7.2 Future Research

The course of this research uncovered some potential areas that could be further researched to increase the body of knowledge surrounding the use of MEDLI software.

MEDLI contains pre-defined values for the estimation of waste production in different types of enterprises, these include; feedlot, piggery, dairy and sewage treatment plant. Currently, MEDLI literature provides limited explanation of these pre-defined values and research on the appropriateness of these values would provide beneficial insight and confidence in the figures which have been used.

Further research in to pre-treatment and anaerobic pond chemistry input variables would allow for additional accuracy in setting up a scenario. This research would need to be conducted for each of the enterprise types and using pre-treatment methods applicable to those enterprises.

Conducting the research suggested previously would ultimately allow for better definitions and estimations to be made on the inputs that were found in this research to be lacking clarity. Completing these suggested research projects would allow for validation research to be conducted using more robust methods with fewer unknown or poorly defined input variables.

If further validation was conducted on MEDLI it is recommended that much larger sampling sizes be used over periods of a least a decade to provide confidence in the statistical significance and accuracy of the findings. In addition, more complete data in the area of soil profiles would also be beneficial in eliminating sources of error when setting up a scenario.

REFERENCES

Armstrong, D. 1993, *Conceptual Modelling*, Chapter 13, Notes of 12th AWRC Groundwater School, Adelaide.

Australian Government Department of Agriculture and Water Resources, 1994, *National Water Quality Management Strategy,* Aus.

Australian Government Department of Environment and Energy, 1997, *The National Water Quality Management Strategy for Sewage Systems - Effluent Management,* Aus.

Australian Lot Feeders Association 2015, 'Quarterly Feedlot Survey Results', *Australian Lot Feeders Association*, Viewed 31 October 2015, < http://feedlots.com.au/industry/quarterly-survey/>

Australian Society of Plant Scientists, New Zealand Society of Plant Biologists and New Zealand Institute of Agricultural and Horticultural Science. 2010, *Plants in Action: Adaptation in Nature, Performance in Cultivation Ch 14.3.2 Thermal Time*, University of Queensland, Aus. Retrieved Aug 22, 2016, from http://plantsinaction.science.uq.edu.au/edition1/?q=content/14-3-2-thermal-time

Barth, C.L. and J. Kroes 1985, *Livestock Waste Lagoon Sludge Characterization In Agricultural Waste Utilization and Management*. Proceedings of the Fifth International Symposium on Livestock Wastes, 660-671. St. Joseph, Michigan: American Society of Agricultural Engineers.

Bear, J. 1979, *Hydraulics of Groundwater*, McGraw-Hill, New York.

Beecham R., Vieritz A.M., Gardner, T., Littleboy M. 1998, *MEDLI version 1.2 Technical Manual, Ch 6 Soil Water Movement*, State of Queensland, Department of Natural Resources, Department of Primary Industries and Cooperative Research Centre for Waste Management and Pollution Control Limited, Aus.

Casey, K.D. 1995, *Computer design model of anaerobic lagoons for pig wastes*. In Proceedings of. 7th International Symposium, 521-531. ASAE, Chicago, Illinois, USA.

Casey, K.D., Gardner, E.A. and McGahan, E.J. 1995, *Characterization of piggery anaerobic lagoons in southern Queensland*. In Proceedings of 5th Biennial Conference, Australian Pig Science Association, Canberra, Aus.

Dillon P., Sharma P. 1998, *MEDLI version 1.2 Technical Manual, Ch 10 Ground Water Transport*, State of Queensland, Department of Natural Resources, Department of Primary Industries and Cooperative Research Centre for Waste Management and Pollution Control Limited, Aus.

Environmental Protection Act 1994 (Qld) (Aus).

Environmental Protection Regulation 2008 (Qld) (Aus).

Gardner, T. Davis, R. 1998, *MEDLI version 1.2 Technical Manual*, State of Queensland, Department of Natural Resources, Department of Primary Industries and Cooperative Research Centre for Waste Management and Pollution Control Limited, Aus.

Glanville, S.G., Freebairn, D.F. and Silburn, D.M. 1984, *Using curve numbers from simulated rainfall to describe the runoff characteristics of contour bay catchments*. Proceedings, Conference on Agricultural Engineering, Institution of Engineers Australia, Bundaberg, Queensland, 27-30 August 1984.

Godwin D.C. and A. C. Jones 1991, *Nitrogen dynamics in soil plant system. Modelling plant and soil* systems - *Agronomy Monograph no. 31*. Madison, USA.

International Organization for Standardization 1994, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*, ISO 5725-1:1994, International Organization for Standardization, Geneva.

Johnson R.C., J.C. Imhoff, J.L. Kittle and A.S. Donigan 1984, *Hydrological Simulation Program - Fortran (HSPF): User Manual for Release 8.0*. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia

Knisel, W.G. 1980, CREAMS: *A field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*. Conservation Research Report No. 26, U.S. Department of Agriculture. 640p.

Littleboy, M. Silburn, D.M. Freebairn, D.R. Woodruff and Hammer, G.L. 1989, *PERFECT, A computer simulation model of productivity erosion runoff functions to evaluate conservation techniques*, Queensland Department of Primary Industries.

Lorimor, J. and Powers, W. 2004, Manure Charicteristics, MidWest Plan Service, USA.

Lott, S. and Skerman, A. 1995, *Design of Feedlot Sedimentation Basins*, Proc. Feedlot Waste Management Conference, Royal Pines Resort, Gold Coast, Qld

Lott, S. Loch, R. and Watts, P. 1994, *Settling Characteristics of Feedlot Faeces and Manure*, Transactions of ASAE 37(1) 281-285.

Maas, E.V. and Hoffman, G.J. 1977, *Crop salt tolerance - current assessment*. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers. 103: 115-130.

McKeon, G.M., Rickert, K.G., Ash, A.J., Cooksley, D.G. and Scattini, W.J. 1982, *Pasture production model*. Proceedings of the Australian Society of Animal Production. 14: 202-204.

Meat and Livestock Australia, 2006, Environmental Best Practice Guidelines for the Red Meat Processing Industry, Aus.

Meat and Livestock Australia, 2012. *National Guidelines for Beef Cattle Feedlots in Australia 3rd Edn*, Meat and Livestock Australia.

Metcalf and Eddy Inc 1990, *Wastewater Engineering: Treatment disposal reuse, Second Edition*. McGraw Hill, New York, USA.

Moffitt C. 1998, *MEDLI version 1.2 Technical Manual, Ch 8 Soil Salinisation*, State of Queensland, Department of Natural Resources, Department of Primary Industries and Cooperative Research Centre for Waste Management and Pollution Control Limited, Aus.

Muchow, RC. and Davis, R. 1988, *Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment. II. Radiation interception and biomass accumulation*, Field Crops Research. 18: 17-30.

New South Wales Department of Environment and Conservation, 2004, *Environmental Guidelines – Use of Effluent by Irrigation*, Aus.

NSW Department of Environment and Conservation 2003, 'Environmental Guidelines Use of Effluent by Land Irrigation', *NSW Department of Environment and Conservation*, Viewed 31 October 2015,
< http://www.environment.nsw.gov.au/resources/water/effguide.pdf>

Queensland Government 2013, 'Guidelines for Agricultural Land Evaluation in Queensland Second edition' *Queensland Government*, Viewed 31 October 2015,
<https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0004/111685/land-evaluation-guidelines-queensland.pdf>

Queensland Government Department of Natural Resources, Department of Primary Industries and CRC for Waste Management and Pollution Control 2003, 'MEDLI® Technical Description Version 2.0 – 2003', *Queensland Government*, Viewed 31 October 2015,
<http://www2.dpi.qld.gov.au/extra/pdf/ilsu/MEDLItechnicaldescription.pdf>

Queensland Government Department of Primary Industries, 1994, *Designing Better Feedlots*, Aus.

Queensland Government Department of Science, Information, Technology and Innovation, 2016, *Model for Effluent Disposal using Land Irrigation Version 2, Technical Reference*, Aus

Queensland Government Department of Science, Information, Technology and Innovation, 2016, *Model for Effluent Disposal using Land Irrigation Version 2, User Manual*, Aus

Ritchie, J.T. 1972, *Model for predicting evaporation with incomplete cover*. Water Resources Research. v. 8, pp 1204-1213.

Sharpley, A.N. and Williams, J.R. 1990, *EPIC—Erosion/Productivity Impact Calculator: 1. Model Documentation*. U.S. Department of Agriculture Technical Bulletin No. 1768. 235 pp.

Shaw, R.J, Hughes, K.K, Thorburn, P.J., and Dowling, A.J. 1987, *Principles of landscape, soil and water salinity - Processes and management options, Part A. In "Landscape, soil and water salinity"*. Proceedings of the Brisbane Regional Salinity Workshop, Brisbane, May 1987. Brisbane, May 1987. Queensland Department of Primary Industries Publication QC87003.

Shaw, R.J. & Thorburn, P.J. 1985, *Prediction of leaching fraction from soil properties, irrigation water and rainfall*. Irrigation Science 6:73-83.

Singer M.J. Munns D.N. 2006, *Soils: An Introduction, 6th Edn*, Pearson, USA.

Skerman A, 2000, *Reference Manual for the Establishment and Operation of Beef Cattle Feedlots in Queensland*, Department of Primary Industries (Qld).

Stanford G., Pol R. A. V. and Dzienia S. 1975, *Denitrification rates in relation to total and extractable soil carbon*. Soil Sciences Society Amer. Proc., v. 39, pp 284-289.

Schulte, E & Kelling, K n.d., ‘Understanding Plant Nutrients Soil and Applied Potassium’, *University of Wisconsin*, Viewed 31 October 2015, <http://corn.agronomy.wisc.edu/Management/pdfs/a2521.pdf>

Swanson, N, P Linderman, C, L Ellis J R 1974, ‘Irrigation of Perennial Forage Crops With Feedlot Runoff’, *ASABE*, Viewed 31 October 2015, <http://elibrary.asabe.org.ezproxy.usq.edu.au/azdez.asp?search=1&JID=3&AID=36807&v=17&i=1&CID=t1974&T=2&urlRedirect=>

Sweeten, J, M n.d., ‘Cattle Feedlot Waste Management Practices - For Water and Air Pollution Control’ *ASABE*, Viewed 31 October 2015, < http://tammi.tamu.edu/Sweeten.pdf>

Tan, K, H 2010, ‘Principles of Soil Chemistry. 4th Edition, CRC Press.

Thorne D.W. Peterson H.B. 1954, *Irrigated Soils*, Constable and Company Limited, UK.

Uren,N, C, Nicholas, C, Leeper, G, W 1993. ‘Soil Science: An Introduction. 4th ed’, *Melbourne University Press*.

Vieritz A.M., Gardner, T., Littleboy, M. 1998, *MEDLI version 1.2 Technical Manual, Ch 9 Plant Growth and Transpiration*, State of Queensland, Department of Natural Resources, Department of Primary Industries and Cooperative Research Centre for Waste Management and Pollution Control Limited, Aus.

Vieritz A.M., Gardner, T., Shaw, R.J. 1998, *MEDLI version 1.2 Technical Manual, Ch 8 Soil Salinisation*, State of Queensland, Department of Natural Resources, Department of Primary Industries and Cooperative Research Centre for Waste Management and Pollution Control Limited, Aus.

Vieritz A.M., Ramsay I.R., Haworth L. F. J., Tennakoon S. and Gardnera E.A. 2011, *Sustainable Effluent Irrigation over the Past Decade*, Department of Environment and Resource Management, Queensland, Aus.

Appendix A - Project Specification

Project Specifications

For: MARK LOWRY

Topic: A VALIDATION OF THE MODEL FOR EFFLUENT DISPOSAL USING LAND IRRIGATION (MEDLI)

Major: CIVIL ENGINEERING

Supervisors: DR MALCOLM GILLIES
DR SIMON LOTT (WATERBIZ PTY LTD)

Sponsorship: WATERBIZ PTY LTD

Project aim: EVALUATE IF MEDLI SIMULATED PREDICTIONS ARE ACCURATE COMPARED WITH MEASURED DATA COLLECTED FROM THE FIELD

Program

1) Research background information related to governance of effluent schemes, current practices, mechanisms of soil nutrient mobilisation and plant uptake
2) Research and develop understanding of MEDLI software including the algorithms used in determination of nutrient and water balances
3) Collate field data obtained from feedlot proprietor records on relevant operational conditions, soil nutrients, harvested crop properties and climatic conditions.
4) Simulate collected field conditions in MEDLI and analyse the results.
5) Present comparisons between the field data and MEDLI data and discuss implications of the obtained results.

As Time Permits

6) Determine if effluent pond and disposal area optimization outputs from MEDLI are accurate.

AGREED

____________________ **(Student)** ____________________

(Supervisor)

_____/_____/_____ _____/_____/_____

____

(Supervisor)

_____/_____/_____

____

(Supervisor)

_____/_____/_____

Appendix B - Environmental Protection Act (excerpt)

80 Working out optimum amount

(1) The person must work out the optimum amount of nitrogen and phosphorus that can be applied to soil on the relevant agricultural property.

(2) The working out must use the results of soil tests required under section 81.

(3) A regulation may prescribe a methodology for working out the optimum amount.

(4) If a prescribed methodology applies for the application of nitrogen or phosphorus to soil on the property, the optimum amount must be worked out under the methodology.

81 Soil testing

(1) The person must cause—

(a) soil tests of the relevant agricultural property to be carried out to test the characteristics of the soil to allow the optimum amount to be worked out; and

(b) reports to be prepared for each of the tests that shows its results.

(2) The tests and the reports must be carried out or prepared by a person with appropriate experience or qualifications.

(3) A regulation may prescribe—

(a) the intervals at which the tests must be carried out; and

(b) a methodology for carrying out the tests.

(4) The carrying out of the tests must comply with the regulation.

82 Restriction on application of fertiliser

Fertiliser containing nitrogen or phosphorus must not be applied to soil on the relevant agricultural property if doing so may result in more than the optimum amount of nitrogen or phosphorus being applied to the soil.

Appendix C - Results Data

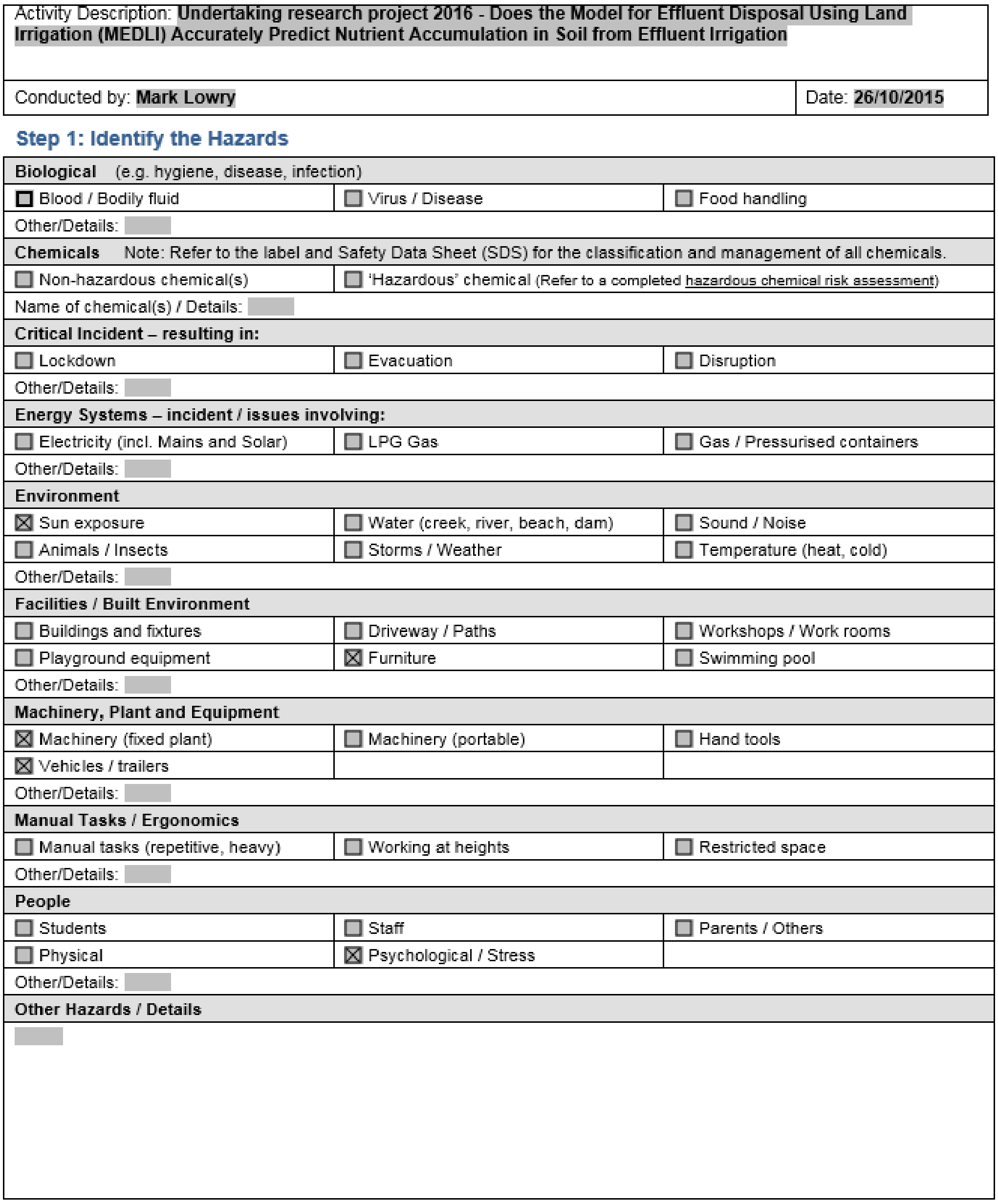
Table C.1 - Scenario 3 Pond Chemistry Comparison

	Scenario 3 - Feedlot C					
	Pond Chemistry					
	Measured Data			MEDLI Simulated Data		
	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Total Dissolved Solids (mg/L)
Jan-97	141	7.5		130	218	1429
Feb-97	174	39.5		162	135	3108
Mar-97	258	34.0		182	81	4211
Apr-97	295	35.5		191	58	4742
May-97	505	13.3		195	42	5021
Jun-97	136	30.3		196	32	5185
Jul-97	264	41.0		197	28	5269
Aug-97	212	22.4		198	25	5343
Sep-97	127	11.6		200	23	5401
Oct-97	200	26.6		200	23	5425
Nov-97	134	38.1		198	22	5366
Dec-97	202	34.2		201	22	5452
Jan-98	365	19.2		198	21	5388
Feb-98	142	17.4		200	22	5443
Mar-98	182	26.5		199	21	5414
Apr-98	125	17.4		201	22	5475
May-98	170	22.0		197	21	5362
Jun-98	151	16.9		198	21	5390
Jul-98	66.1	16.7		198	21	5384
Aug-98	203	48.0		198	21	5377
Sep-98	80.6	11.8		198	21	5382
Oct-98	56.6	5.1		198	21	5375
Nov-98	214	30.6	2976	201	22	5450
Dec-98	235	36.6	2958	200	22	5447
Jan-99	284	32.8	2720	198	21	5378
Feb-99	109	21.3	1628	198	21	5376
Mar-99	170	23.6	960	194	21	5254
Apr-99	82.3	10.6	1450	198	21	5362
May-99	116	29.0	1570	199	21	5409
Jun-99	242	20.9	4770	199	21	5400
Jul-99	88.5	23.6	4600	198	21	5371
Aug-99	194	21.7	5846	198	21	5375
Sep-99	440	62.8	7248	198	21	5374
Oct-99	129	13.7	4360	198	21	5390
Nov-99	139	27.9	3850	198	21	5376
Dec-99	212	35.7	6000	199	21	5401

Jan-00	102	18.0	6100	198	21	5373
Mar-00	118	9.4		198	21	5381
Apr-00	113	11.0	3500	200	21	5419
May-00	109	9.0		201	22	5454
Jun-00	102	22.6	6100	199	21	5421
Aug-00	87	66.0	760	200	21	5428
Sep-00	45	13.0	510	199	21	5416
Oct-00	190	20.0	850	200	21	5429
Nov-00	150	12.0		202	22	5483
Dec-00	240	30.0	1000	203	22	5515
Jan-01	160	16.0	730	199	21	5415
Feb-01	109	12.8	720	201	22	5469
Mar-01	123	16.8	290	200	21	5432
Apr-01	69.4	14.2	330	200	21	5433
May-01	86.2	10.0	290	200	21	5434
Jun-01	209	27.2	660	200	21	5435
Jul-01	74	2.7	130	200	21	5435
Aug-01	122	11.7	400	200	21	5436
Sep-01	237	31.2	1200	200	21	5437
Oct-01	146	31.4	750	200	21	5437
Nov-01	216	30.6	1200	200	21	5438
Dec-01	110	21	610	200	21	5438
Jan-02	8.6	36	340	200	21	5438
Mar-02	110	23	700	200	21	5439
Jun-02	140	2.1	380	200	21	5439
Jul-02	43	87		200	21	5440
Sep-02	68	74		200	21	5440
Dec-02	125	34.0		200	21	5439
Mar-03	265	70		200	21	5439
May-03	28.2	174		200	21	5439
Sep-03	114.76	120.00		200	21	5439
Mar-04	131.93	12.87		200	21	5439
Apr-05	583.61	230		200	21	5439

Appendix D – Risk Assessment

As this project is a desktop analysis and comparison of modelling software and previously collected field data, the risk of health impacts or injury is generally considered very low. During the information gathering phase of the project there may arise a need to speak face to face with a feedlot proprietor; this situation would require travel to site and exposure to feedlot conditions. This aspect has been identified as the main source of risk for the project. A risk assessment based on the Queensland Government Department of Education, Training and Employment (2012), has been conducted to assess the project risks. Figures 2, 3 & 4 provide details of the risk assessment. In addition to a health and injury risk assessment Figure 5 details an assessment of the risks to not completing the project in the timeframe required.



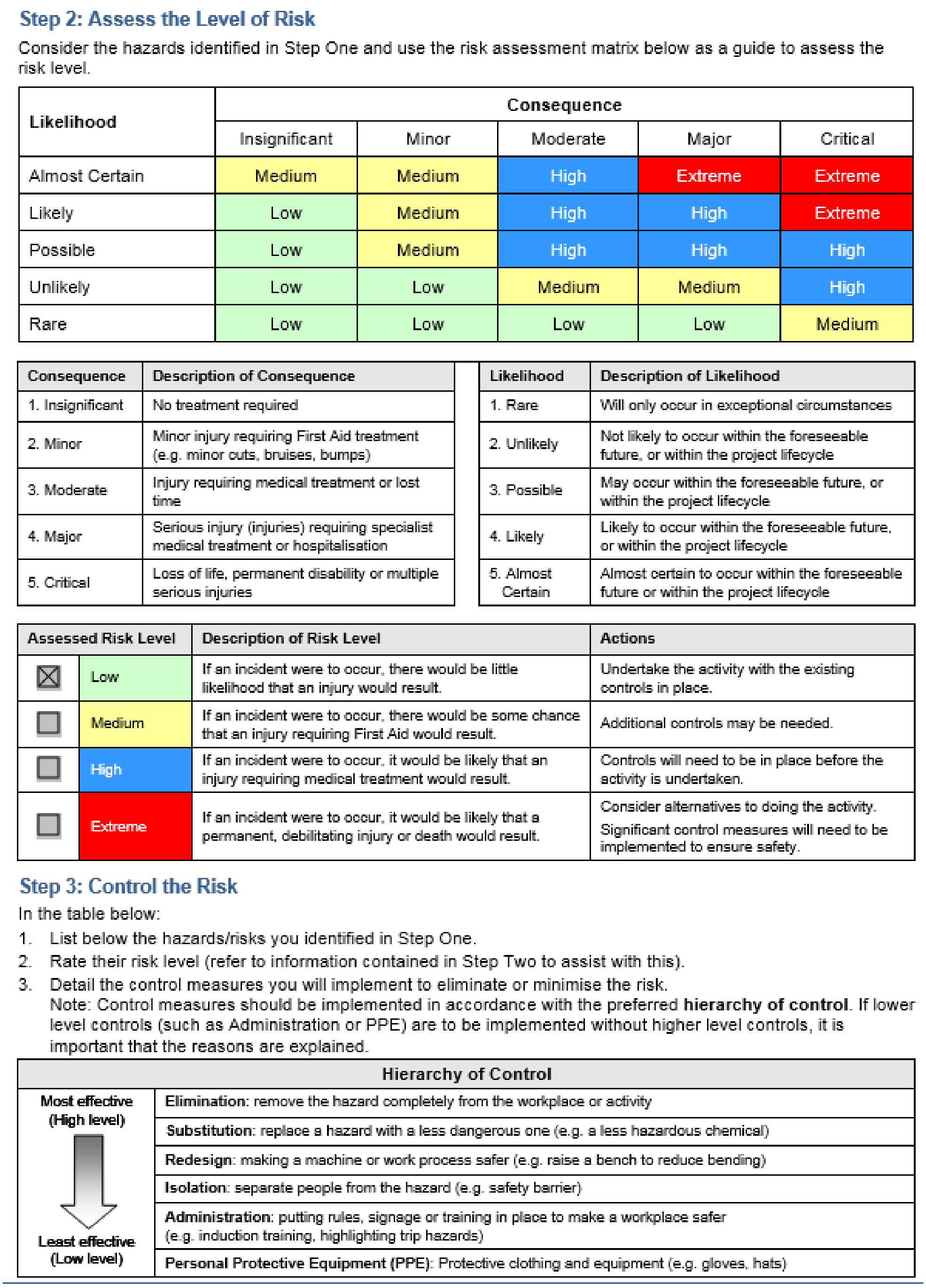
Activity Description: **Undertaking research project 2016 - Does the Model for Effluent Disposal Using Land Irrigation (MEDLI) Accurately Predict Nutrient Accumulation in Soil from Effluent Irrigation**	
Conducted by: **Mark Lowry**	Date: **26/10/2015**

Step 1: Identify the Hazards

Biological (e.g. hygiene, disease, infection)		
☐ Blood / Bodily fluid	☐ Virus / Disease	☐ Food handling
Other/Details:		
Chemicals Note: Refer to the label and Safety Data Sheet (SDS) for the classification and management of all chemicals.		
☐ Non-hazardous chemical(s)	☐ 'Hazardous' chemical (Refer to a completed hazardous chemical risk assessment)	
Name of chemical(s) / Details:		
Critical Incident – resulting in:		
☐ Lockdown	☐ Evacuation	☐ Disruption
Other/Details:		
Energy Systems – incident / issues involving:		
☐ Electricity (incl. Mains and Solar)	☐ LPG Gas	☐ Gas / Pressurised containers
Other/Details:		
Environment		
☒ Sun exposure	☐ Water (creek, river, beach, dam)	☐ Sound / Noise
☐ Animals / Insects	☐ Storms / Weather	☐ Temperature (heat, cold)
Other/Details:		
Facilities / Built Environment		
☐ Buildings and fixtures	☐ Driveway / Paths	☐ Workshops / Work rooms
☐ Playground equipment	☒ Furniture	☐ Swimming pool
Other/Details:		
Machinery, Plant and Equipment		
☒ Machinery (fixed plant)	☐ Machinery (portable)	☐ Hand tools
☒ Vehicles / trailers		
Other/Details:		
Manual Tasks / Ergonomics		
☐ Manual tasks (repetitive, heavy)	☐ Working at heights	☐ Restricted space
Other/Details:		
People		
☐ Students	☐ Staff	☐ Parents / Others
☐ Physical	☒ Psychological / Stress	
Other/Details:		
Other Hazards / Details		

Figure D.1 - Hazard Identification **Source:**

https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CC0QFjADahUKEwit04WGtOzIAhVP3mMKHSEtAiw&url=http%3A%2F%2Feducation.qld.gov.au%2Fhealth%2Fdocs%2Fhealthsafety%2Fhealth-safety-risk-assessment-template.doc&usg=AFQjCNFiNyqKtwulV3jclalkXsv7-cdl7g&bvm=bv.106379543,d.dGY&cad=rja



Step 2: Assess the Level of Risk

Consider the hazards identified in Step One and use the risk assessment matrix below as a guide to assess the risk level.

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Critical
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	High	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Low	Medium

Consequence	Description of Consequence
1. Insignificant	No treatment required
2. Minor	Minor injury requiring First Aid treatment (e.g. minor cuts, bruises, bumps)
3. Moderate	Injury requiring medical treatment or lost time
4. Major	Serious injury (injuries) requiring specialist medical treatment or hospitalisation
5. Critical	Loss of life, permanent disability or multiple serious injuries

Likelihood	Description of Likelihood
1. Rare	Will only occur in exceptional circumstances
2. Unlikely	Not likely to occur within the foreseeable future, or within the project lifecycle
3. Possible	May occur within the foreseeable future, or within the project lifecycle
4. Likely	Likely to occur within the foreseeable future, or within the project lifecycle
5. Almost Certain	Almost certain to occur within the foreseeable future or within the project lifecycle

Assessed Risk Level		Description of Risk Level	Actions
☒	Low	If an incident were to occur, there would be little likelihood that an injury would result.	Undertake the activity with the existing controls in place.
☐	Medium	If an incident were to occur, there would be some chance that an injury requiring First Aid would result.	Additional controls may be needed.
☐	High	If an incident were to occur, it would be likely that an injury requiring medical treatment would result.	Controls will need to be in place before the activity is undertaken.
☐	Extreme	If an incident were to occur, it would be likely that a permanent, debilitating injury or death would result.	Consider alternatives to doing the activity. Significant control measures will need to be implemented to ensure safety.

Step 3: Control the Risk

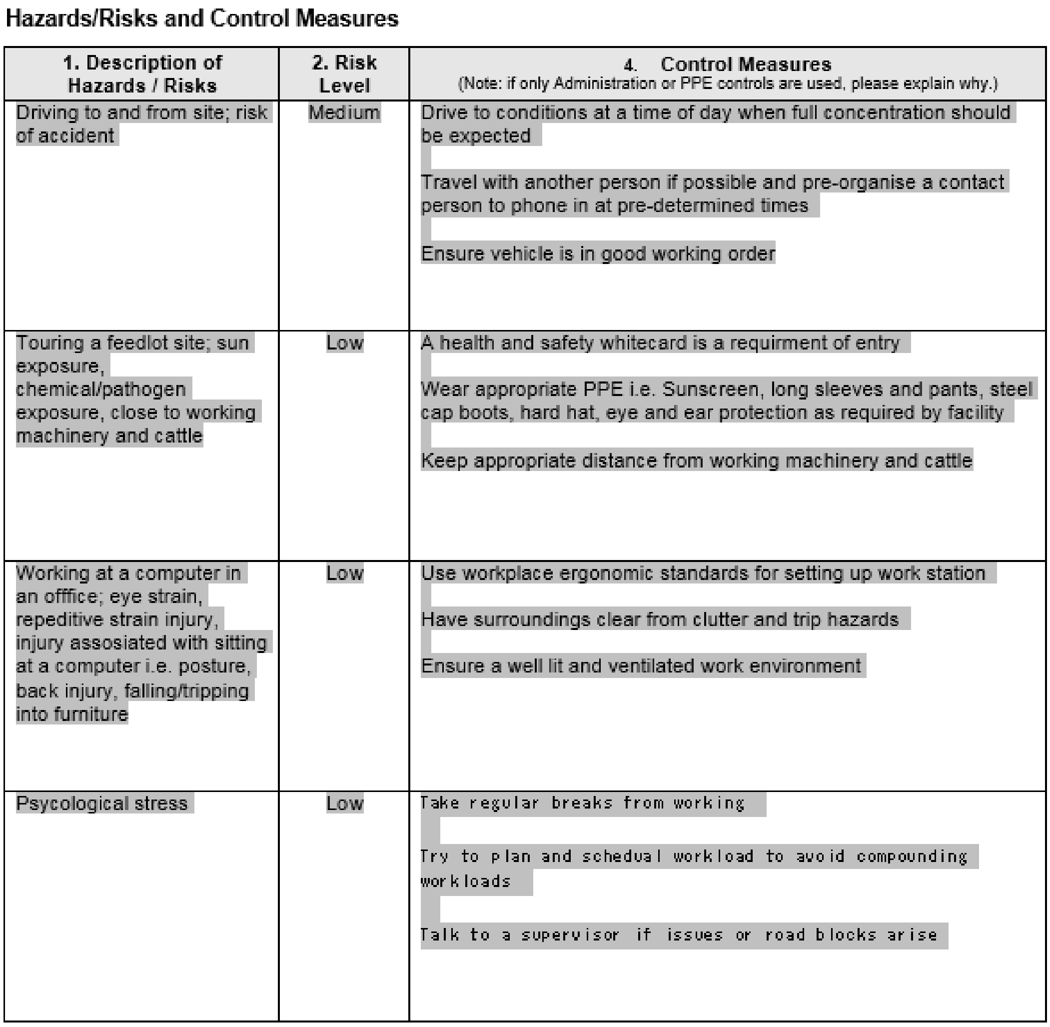
In the table below:

1. List below the hazards/risks you identified in Step One.
2. Rate their risk level (refer to information contained in Step Two to assist with this).
3. Detail the control measures you will implement to eliminate or minimise the risk.
   Note: Control measures should be implemented in accordance with the preferred **hierarchy of control**. If lower level controls (such as Administration or PPE) are to be implemented without higher level controls, it is important that the reasons are explained.

Hierarchy of Control	
Most effective (High level)	**Elimination**: remove the hazard completely from the workplace or activity
	Substitution: replace a hazard with a less dangerous one (e.g. a less hazardous chemical)
	Redesign: making a machine or work process safer (e.g. raise a bench to reduce bending)
	Isolation: separate people from the hazard (e.g. safety barrier)
	Administration: putting rules, signage or training in place to make a workplace safer (e.g. induction training, highlighting trip hazards)
Least effective (Low level)	**Personal Protective Equipment (PPE)**: Protective clothing and equipment (e.g. gloves, hats)

Figure D.2 – Level of Risk Source:

https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CC0QFjADahUKEwit04WGtOzIAhVP3mMKHSEtAiw&url=http%3A%2F%2Feducation.qld.gov.au%2Fhealth%2Fdocs%2Fhealthsafety%2Fhealth-safety-risk-assessment-template.doc&usg=AFQjCNFiNyqKtwulV3jclalkXsv7-cdl7g&bvm=bv.106379543,d.dGY&cad=rja

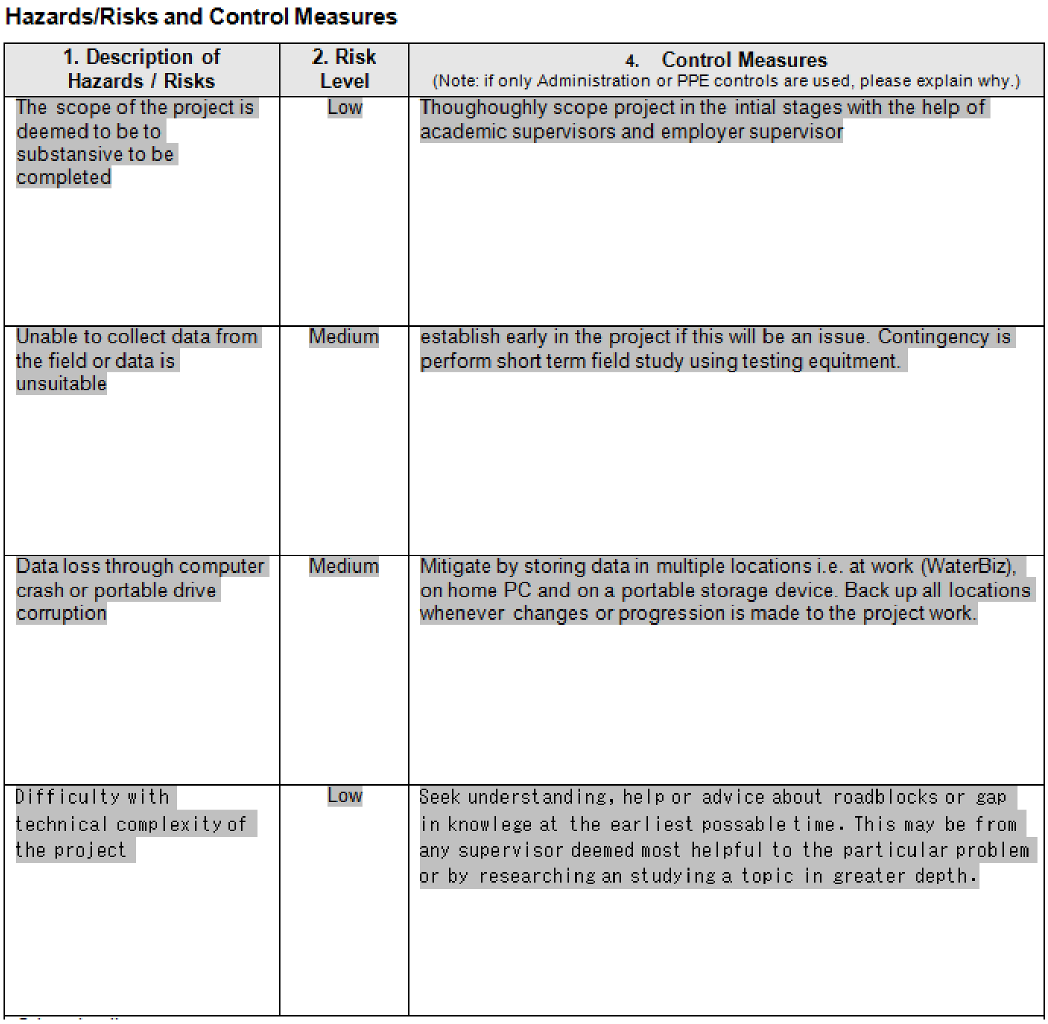


Hazards/Risks and Control Measures

1. Description of Hazards / Risks	2. Risk Level	4. Control Measures (Note: if only Administration or PPE controls are used, please explain why.)
Driving to and from site; risk of accident	Medium	Drive to conditions at a time of day when full concentration should be expected Travel with another person if possible and pre-organise a contact person to phone in at pre-determined times Ensure vehicle is in good working order
Touring a feedlot site; sun exposure, chemical/pathogen exposure, close to working machinery and cattle	Low	A health and safety whitecard is a requirment of entry Wear appropriate PPE i.e. Sunscreen, long sleeves and pants, steel cap boots, hard hat, eye and ear protection as required by facility Keep appropriate distance from working machinery and cattle
Working at a computer in an offfice; eye strain, repeditive strain injury, injury assosiated with sitting at a computer i.e. posture, back injury, falling/tripping into furniture	Low	Use workplace ergonomic standards for setting up work station Have surroundings clear from clutter and trip hazards Ensure a well lit and ventilated work environment
Psycological stress	Low	Take regular breaks from working Try to plan and schedual workload to avoid compounding workloads Talk to a supervisor if issues or road blocks arise

Figure D.3 - Personal Hazard Identification **Source:**

https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CC0QFjADahUKEwit04WGtOzIAhVP3mMKHSEtAiw&url=http%3A%2F%2Feducation.qld.gov.au%2Fhealth%2Fdocs%2Fhealthsafety%2Fhealth-safety-risk-assessment-template.doc&usg=AFQjCNFiNyqKtwuIV3jclalkXsv7-cdl7g&bvm=bv.106379543,d.dGY&cad=rja



Hazards/Risks and Control Measures

1. Description of Hazards / Risks	2. Risk Level	4. Control Measures (Note: if only Administration or PPE controls are used, please explain why.)
The scope of the project is deemed to be to substansive to be completed	Low	Thoughoughly scope project in the intial stages with the help of academic supervisors and employer supervisor
Unable to collect data from the field or data is unsuitable	Medium	establish early in the project if this will be an issue. Contingency is perform short term field study using testing equitment.
Data loss through computer crash or portable drive corruption	Medium	Mitigate by storing data in multiple locations i.e. at work (WaterBiz), on home PC and on a portable storage device. Back up all locations whenever changes or progression is made to the project work.
Difficulty with technical complexity of the project	Low	Seek understanding, help or advice about roadblocks or gap in knowlege at the earliest possable time. This may be from any supervisor deemed most helpful to the particular problem or by researching an studying a topic in greater depth.

Figure D.4 - Project Risk Identification **Source:**

https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CC0QFjADahUKEwit04WGtOzIAhVP3mMKHSEtAiw&url=http%3A%2F%2Feducation.qld.gov.au%2Fhealth%2Fdocs%2Fhealthsafety%2Fhealth-safety-risk-assessment-template.doc&usg=AFQjCNFiNyqKtwulV3jclalkXsv7-cdl7g&bvm=bv.106379543,d.dGY&cad=rja