University of Southern Queensland

Faculty of Health, Engineering and Sciences

Modelling Supply Channel Seepage and Analysing the Effectiveness Mitigation Options

A dissertation submitted by

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Abstract

Australia relies heavily on irrigation channels to supply water to farms away from natural water sources. Water is a precious resource for these remote communities, so water lost to channel seepage is money lost. Many channels already have seepage mitigation measures such as a polymer membrane lining or compacted clay, but there is some speculation into the cost effectiveness of implementing such measures. There is a knowledge gap in Australian channel projects into the end result of cost effectiveness for seepage mitigation. This project aims to help fill that gap to give planners a more comprehensive guide on seepage mitigation options.

This study focuses on the creation of a model to analyse seepage in supply channels and the associated costs with implementing various seepage mitigation methods. Seepage is analysed in three different ways for easy comparison which are, seepage values for soil types found from existing research, a seepage estimate from the U.S. created Moritz formula and finally the a site specific seepage value which can be measured or calculated by other means. The model seeks to find any net benefits gained from implementing seepage mitigation.

Three case studies were chosen in this study for the purposes of testing the model in a real world scenario. Two Queensland channels were chosen, one in the Bundaberg region and one near the township of St George, and one channel was chosen in Victoria near the town of Birchip.

From the testing of the case studies, it was found that there were large inconsistencies between the estimated values for seepage and the measured values on site. The model overestimated seepage losses by a factor of 10 or more in most cases. It was concluded that desktop approaches for seepage estimation should not be used for Australian channels until more sufficient seepage data exists. It is essential to have a measured seepage value for a proposed site before any seepage mitigation is considered.

The cost effectiveness results of the tested case studies all presented with very high negative net benefits. No costs were found to be any lower than at least $10,000 per ML of water saved. Significant economic gains would have to be found elsewhere for any of the case studies to be considered as an economically viable project for seepage mitigation.

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Limitations of Use

Certification

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

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

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Table of Contents

List of Figures

List of Tables

List of Abbreviations and Units

ANCID	Australian National Committee on Irrigation and Drainage
cm	centimetres
GMW	Goulburn Murray Water
FPP	Flexible Polypropylene
H/V	Horizontal over Vertical
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
L	litre
lps	litres per second
m	metre
MC	Main Channel
ML	megalitres
PVC	Polyvinyl Chloride
RL	Reduced Level
SKM	Sinclair Knight Merz
USBR	United States Bureau of Reclamation
UV	Ultraviolet
VLDPE	Very Low Density Polyethylene

1 Introduction

1.1 Overview

Supply channels are used throughout Australia, to distribute water to farms away from rivers. Channels are preferred over pipes for long distance water distribution due to their lower cost and ease of construction. However, channels also come with a number of disadvantages, the most relevant being water losses through evaporation and seepage. Much research has been done into how these losses can be reduced and a commonly used solution for seepage control is a channel liner. These linings come in many forms such as plastic, stones, clay, concrete or simply compacting the soil during the channel's construction. Lining a channel is a costly option and one that should be considered carefully when constructing a new channel. Sometimes it is not always cost effective option to line a channel due to size, volume of water or even how much evaporation occurs in the area. Some channels would have little to no gain in water recovery from the addition of a liner or any other mitigation measure. This project seeks to investigate how cost effective seepage mitigation options are in any given channel.

Figure 1.1: A typical irrigation channel in the Goulburn Murray Region (GMW 2015)

1.2 Need for the Study

There is a need in Australia for more current research into channel seepage mitigation. Many irrigation channels in Australia have undergone treatments for seepage mitigation, but little research has been done into the effectiveness of these linings and the costs saved. Millions of dollars are being spent across the country on new channel projects such as the government funded project in Trangie, New South Wales. A capital cost of $115 billion is being spent to line the channel network with a flexible membrane for seepage mitigation (Australian Government 2010).

This project will address the current needs for more information regarding seepage mitigation in Australia and seek to justify the costs of projects such as the channels in Trangie.

1.3 Aims

The aim of this project was to develop a tool which can evaluate the cost effectiveness of installing seepage mitigation in any proposed channel. The end goal was to have some form of model (such as an Excel document) which can take the variables of a proposed channel and output a report of a number of mitigation options, channel shapes and the cost effectiveness of each. This tool can then be used in the development of new supply channels to analyse options for seepage mitigation and determine if they are a wise financial investment.

1.4 Project Objectives

The objectives for this project are:

1. Identify appropriate desktop approaches to estimate channel seepage losses.
2. Review possible channel seepage mitigation methods and costs.
3. Develop a modelling tool that incorporates seepage loss estimates, costs of various seepage mitigation methods and the associated benefits.
4. Investigate the viability of mitigating seepage for a number of case studies.

1.5 Project Outcomes

Eventuating from this project will be a new model to help determine the cost effectiveness of seepage mitigation options in any given channel. Whilst some models already exist to for this purpose, this model will assist in adding to the existing knowledge of channel seepage mitigation feasibility. The main difference of this model will be its ability to assess channel seepage with different techniques such as existing soil data and the use of equations. This may aid professionals in seepage mitigation assessment for distribution channels or even farmers considering a possibility of lining on-farm channels.

As well as adding to the existing knowledge base on channel seepage mitigation, this completed model also serves the purpose of personal development. Through the process of formulating an idea, research, data collection and model creation, a substantial amount of personal development will be gained. A discussion paper which sparked the formulation of this research project was written by a mechanical engineer in Victoria by the name of Kevin Long. His paper titled 'The Channel Lining and Pipeline Deception in Victoria's Northern Foodbowl Project' discusses how the Victorian government's scheme to create water savings in the channel network through use of linings and other methods is economically flawed. Long states that the water savings are not substantial enough to justify the high costs of lining channels (Long & Poynton 2009). The proposed model from this research project could potentially evaluate the validity of Long's claims. This would further personal development and interest in the field.

2 Literature Review

This chapter gives a brief coverage of the literature reviewed which was relevant for the study. The literature has been sorted into relevant sections rather than the source it was derived from.

2.1 Overview

Research was conducted into previous studies on irrigation channels to first gain an idea of the typical seepage losses found in various soil types. Different mitigation methods were then investigated and findings reported to assess their suitability for inclusion in the project. The findings of water savings were varied, but all came to the conclusion that substantial savings are gained when a channel is lined.

2.2 Seepage Losses

2.2.1 Factors Affecting Seepage

Seepage is not a constant value in channels across the world. Generally, our seepage rates in Australia have been much less than the rates found in the USA where the majority of seepage research has been conducted (Smith 1982). These differing rates across channels are due to a number of factors at work.

Seepage is defined as water passing through the sides of and bed of a channel at a uniform rate. This is most commonly due to soil which is not adequate for channel construction (ANCID 2004). Seepage is mainly a factor of hydraulic conductivity of the soil and also the hydraulic gradient (Sonnichsen 1993). Generally it can be found that where there is low conductivity of the soil, there are high seepage losses. However this does not always apply and sometimes further research is required in the field (Akbar et al. 2013). The factors which can affect hydraulic conductivity include the soil type (this includes surface and sub-surface), temperature and porosity. Hydraulic gradient however is affected by atmospheric pressure, water depth, slope of channel and chemistry of soil and water (Sonnichsen 1993).

How much seepage is observed in a channel will usually be proportional to the permeability of the soil (defined by the listed factors above). In some cases, the amount of suspended solids in the water can affect seepage as the particles will create a natural lining over time and fill gaps within the soil. Finally, the depth of water can also affect the amount of seepage observed. As a general rule, the deeper the water, the higher the seepage rate (ANCID 2004).

2.2.2 Typical Seepage Values

SKM (2001) reported that seepages losses amount to 6% of the total water conveyed in the Northern Goulburn Murray district (Marsden Jacob Associates 2003). ANCID (2004) found from various surveys that the total water losses due to seepage were around 4% on average of the supplied water.

Much research has been conducted on seepage, especially in the United States of America. Sonnichsen (1993) constructed a graph showing how seepage changes for different soil types or linings (see Figure 2.1).

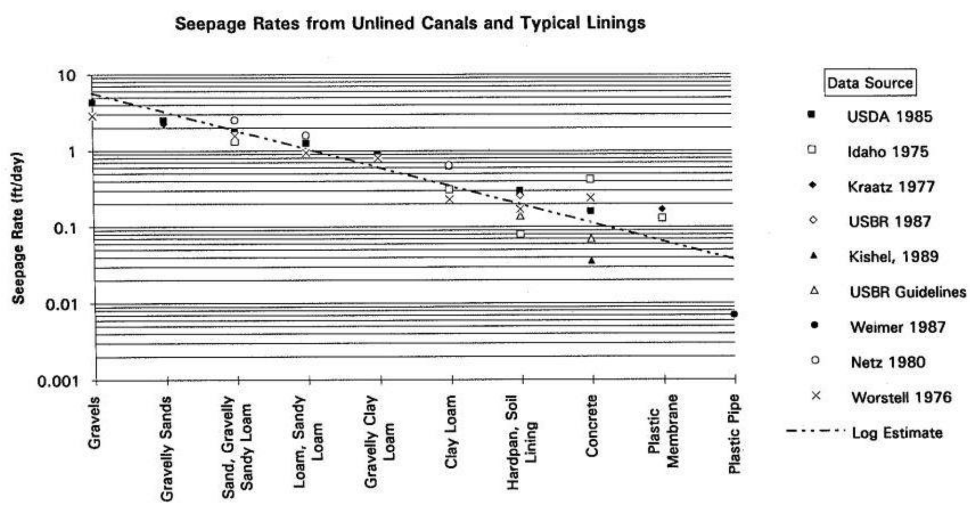

Figure 2.1: The relationship between soil type/lining and seepage rates (Sonnichsen 1993).

The values of seepage rates for soil varied from 6 to 60 $L.m^{-2}.day^{-1}$. Some have found however that the seepage rates found in USA are much greater than those observed in Australia. Smith (1982) observed that the Goulburn Murray district had seepage rates of less than 15 $L.m^{-2}.day^{-1}$. In 1975, values between 13 and 15 $L.m^{-2}.day^{-1}$ were observed in the area of Kerang and Shepparton which amounted to 210,000 ML per year (Smith 1982).

2.2.3 Estimating Seepage

To gauge an accurate value for seepage, measurements can be taken in the field using a variety of techniques. The most accurate of which is generally the ponding method (Fairley

2015). The ponding method involves damming both ends of a channel section and observing the drop in water head over time, taking evaporation into account to calculate seepage (Kinzli et al. 2010). However, it is not always possible to measure seepage due to time constraints, costs, or sometimes the channel is only in the planning stage. Rather than a direct measurement, sometimes an estimation method is needed. Many researchers have proposed formulae for estimating seepage within a channel.

Davis and Wilson

Davis and Wilson (1952) proposed a formula which could estimate the seepage losses in a lined canal (Bakry & Awad 1997) (Kraatz 1977).

$$S_L = 0.45C \frac{P_W L}{4*10^6 + 3650\sqrt{V}} H_W^{\frac{1}{3}}$$

(2.1) (Kraatz 1977)

Where S_L is Seepage losses [$m^3.m^{-1}.day^{-1}$]
L is Length of canal [m]
P_W is Wetted perimeter [m]
H_W is Water depth in the canal [m]
V is Velocity of flow [$m.s^{-1}$]
C is Constant value depending on lining: 10cm Concrete (1), 15cm Mass clay (4), Light asphalt (5), 7.6cm Clay (8), Asphalt or cement mortar (10)

Moritz Formula

The US Bureau of Reclamation also proposed a formula after extensive measurements on a network of local canals. This formula is commonly referred to as the Moritz formula.

$$S = 0.2C\sqrt{\frac{Q}{V}}$$

(2.2) (Kraatz 1977)

Where S is Seepage losses [$cusecs.mile^{-1}$]
Q is Discharge [cusecs]
V is Velocity [$ft.s^{-1}$]
C is Constant value for soil type: Cemented gravel and hardpan with sandy loam (0.34), Clay and clayey loam (0.41), Sandy loam (0.66), Volcanic ash (0.68), Sand or volcanic ash or clay (1.20), Sandy soil with rock (1.68), Sandy and gravelly soil (2.20)

U.S.S.R. Formula

The former Soviet Union also had a formula for which seepage was calculated.

$$S = \frac{1.16}{Q} Kq_r$$

(2.3) (Kraatz 1977)

Where S is Loss as percentage of discharge per km
Q is Canal discharge [$m^{-3}.s^{-1}$]
K is Saturated permeability [$m.day^{-1}$]
q_r is Reduced specific seepage loss, i.e. ratio of seepage velocity to saturated permeability of soil

Bouwer

Bower (1969) proposed a seepage formula for cases where the soil was uniform and deep, had a shallow impermeable layer and soils that lay over a shallow aquifer (Smith 1982).

$$I_S = \frac{\pi KD_W}{W_S \log_e \frac{4L}{W_S}}$$

(2.4) (Smith 1982)

Where I_S is Seepage rate
K is Hydraulic conductivity
D_W is Depth to the water table from water surface
W_S is Width of channel at water surface
L is Distance from centreline of channel to horizontal watertable point

2.2.4 Other Losses

As well as seepage, a number of other factors can contribute to the overall conveyance losses. One of the most prominent losses is evaporation, but is also one of the most difficult to mitigate. Other losses can occur through inaccurate meter readings from sometimes outdated equipment. Mechanical Detheridge wheels while simple, cheap and require little maintenance, often measure less than the actual volume of water being conveyed (Marsden Jacob Associates 2003). Many regions of Australia such as central west NSW are in the process of replacing these outdated Detheridge wheels with more accurate automated systems (Asghar et al. 2011).

2.3 Seepage Mitigation Methods

2.3.1 Earthen Lined Channels

Overview

Earthen lined channels are one of the easiest channel linings to implement as sometimes no extra material is required. Channels can be compacted in situ to create a more effective seal. Low permeability materials such as clay can be imported from other areas such as to line a gravelly channel with clay (ANCID 2004).

Effectiveness

Akbar et.al (2013) found that compaction of earthen channels in-situ could decrease the seepage losses by up to 74%. However ANCID (2004) found that a compacted earth lining can reduce seepage by 70 to 90% with an indicative liner permeability of 0.5 to 2 $L.m^{-2}.day^{-1}$, but only when using an imported clay material. Sonnichsen (1993) also found a reduction in seepage to below 24.4 $L.m^{-2}.day^{-1}$ when using compaction methods.

Costs

The upfront costs of compacting the soil in-situ is $\$10.m^{-2}$ while lining the channel with compacted clay costs $\$17.m^{-2}$.

Ongoing Considerations

It is predicted that the life of a compacted earthen channel will be around 20 years or up to 30 years when using imported clay. They would be a suitable choice for an area which is not irrigated all year round as earthen channels do not suffer the same wear and tear as other linings would during different climate conditions (Sonnichsen 1993) (ANCID 2004). Over time it has been observed that natural earthen lined channels form their own lining. Some evidence even proposes that the natural lining formed over time is almost equivalent to artificial linings. Some artificial linings can aid in this process of a natural lining being formed. (Smith 1982)

2.3.2 Hard Surface Linings

Overview

Channels lined with hard surfaces may include concrete, tiles, bricks or even asphalt. These linings have the advantage of low permeability and high durability. This technique for lining channels is more common in urban areas rather than regional channel networks due to the large costs associated with lining extensively long sections.

Effectiveness

It is estimated that a concrete lining can reduce seepage by 70 to 95% with an indicative liner permeability of less than 0.5 $L.m^{-2}.day^{-1}$ (ANCID 2004). The USBR (United States Bureau of Reclamation) defines a benchmark of 20 $L.m^{-2}.day^{-1}$ for a channel lined with concrete and made watertight with sealed joints, however they recommend using an assumed seepage rate of 30.4 $L.m^{-2}.day^{-1}$ to allow for the cracking that may occur through temperature changes overtime (Sonnichsen 1993) (ANCID 2004). Sonnichsen (1993) found that a concrete lining (unreinforced of thickness 76.2 mm) has a seepage rate of 21.3 $L.m^{-2}.day^{-1}$ when new, however the temperature changes in the ground caused cracking of the concrete which led to a new seepage rate of 73.1 $L.m^{-2}.day^{-1}$. Asphalt linings have been found to reduce seepage by up to 90% (ANCID 2004).

Kahlown and Kemper (2005) conducted their own study in Pakistan with hard surface linings of bricks, concrete and tiles. They found the most effective lining combination was to construct the channel with vertical walls from 34 cm brick masonry and the bed from 8 cm brick masonry with 10 cm of concrete underneath. They achieved savings of 0.09 lps per 100 m initially and 0.46 lps per 100 m after 24 years of conveyance (Kahlown & Kemper 2005).

Costs

The cost of lining a channel with concrete formwork comes in reasonably expensive at $\$52.50.m^{-2}$. Asphalt linings are significantly cheaper at only $\$35.m^{-2}$ (ANCID 2004). Kahlown and Kemper's combination of bricks and concrete costs around 183 Indian Rupees per m, or $3.75 Australian Dollars (Kahlown & Kemper 2005). This is unusually cheap compared to the cost of channel linings in Australia, therefore the cost may be more of a factor of cheaper labour or materials comparatively.

Ongoing Considerations

The main issue with any hard lined channel as discussed before is cracking. This is more prone in areas where there is significant swelling and shrinking of the soil. This also makes them less suitable for regions in which the channel does not operate throughout the whole year as there is greater exposure to the elements (ANCID 2004). Concrete channels can run into issues if not constructed properly such as large gaps between joints. However, this can be easily overcome by plastering the joints during construction (Kahlown & Kemper 2005). If well constructed and well looked after, a concrete lining can have an expected life of up to 50 years, while asphalt will only last 15 (Sonnichsen 1993) (ANCID 2004). Concrete is one of the most durable options for lining a channel, but is also one of the most expensive. It is therefore important to assess the area for suitability before deciding on any channel lining.

2.3.3 Flexible Membrane Linings

Overview

Flexible membranes are a common lining material throughout the world. They have the advantage of low cost, low permeability and ease of construction. Among commonly used materials are High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Very Low Density Polyethylene (VLDPE) and Flexible Polypropylene (FPP), the most common of which is HDPE. Flexible membranes may either be exposed (placed right on the channel bed) or covered (buried under a layer of soil or concrete). Covered linings are particularly advantageous, as a thinner material can be used and there is less exposure to the elements (ANCID 2004).

Figure 2.2: A channel being lined with a HDPE (ANCID 2004).

Effectiveness

Lining a channel with an impervious lining such as a flexible membrane can reduce the seepage by 60 to 80% depending on a number of factors such as the losses before lining and also the type of membrane (Smith 1982). ANCID (2004) however estimates that a geomembrane liner will reduce seepage by 85 to 95% with an indicative liner permeability of 0-0.5 $L.m^{-2}.day^{-1}$.

Costs

The cost of lining the entirety of the channel network with a membrane in the Goulbourn Murray District is \$20,000 to \$50,000 per ML of water saved. This is due to many of the channels having very low seepage rates and therefore less water saved overall (Marsden Jacob Associates 2003). ANCID gives the costs of lining a channel with a HDPE as in the range of \$7.1 to $13.69.m^{-2}$ depending on the thickness (ANCID 2004). A consideration in the cost of lining a channel with a flexible membrane is that the lining is likely to overlap, meaning that the cost per square metre may not relate directly to the amount of area to be covered (ANCID 2004).

Ongoing Considerations

Flexible membranes have the advantage of moving independently to the soil, therefore cracking is not an issue in areas where the soil often shrinks and swells. HDPE is the most commonly used material for flexible membrane lining applications as it is highly cost effective, has a high UV and chemical resistance and is therefore a good selection for an exposed lining. It is however less flexible than other options so requires well graded channels and needs to have its seams welded on site (ANCID 2004).

2.3.4 Low Cost Linings

Overview

A study was conducted in 2013 on alternative ‘low-cost’ materials to line channels. This study was conducted in the Southern Murray-Darling Basin and involved first identifying areas of high seepage by measuring the electrical conductivity of the soil. Two methods for seepage reduction were investigated by sealing the channel with either rice hull ash or water treatment plant sludge. These waste materials were assessed for any environmental hazard, but were found to be safe (Akbar et al. 2013).

Effectiveness

The waste materials were found to be surprisingly effective, decreasing seepage losses by 55 to 65% for waste water treatment sludge and 50 to 65% for rice hull ash. Rice hull ash was found to be particularly advantageous as it kept the soil moist while the channel was not in operation, preventing some soil shrinkage (Akbar et al. 2013).

Costs

The cost to reduce seepage with waste materials is \$400 to \$500 per ML for up to 20 GL. After that the costs become \$600 per ML up to 32 GL for sludge and 28 GL for rice hull ash (Akbar et al. 2013). These costs were worked in reverse to find that for rice hull ash there is an average cost of \$3.86.m^{-2}.

Ongoing Considerations

Rice hull ash is a very feasible and cost effective option for the region of the Southern Murray-Darling Basin as it is abundantly available in the area. Both the waste water materials however do not have a very long expected life (Akbar et al. 2013). For the purposes of the project, an expected life of 10 years was assumed for rice hull ash as it is half the life of a compacted channel.

2.3.5 Alternative Mitigation Methods

An alternative to a lining can be to create another path for the water to follow. Interceptor drains can be placed along the channel to encourage seepage into the drains rather than the soil. The water from these drains is fed back into the channels to recover the water rather than losing it to the soil. They have found to be effective under the right circumstances but can be rather expensive to construct due to the amount of drains needed (Smith 1982). Changing the channel geometry can also reduce seepage losses in some cases.

2.4 Cost Benefit Analysis

To understand the value of each proposed mitigation method, a cost benefit analysis must be carried out. A cost benefit analysis will compare the costs of channel seepage mitigation with the benefits they present. This may be the profit for each ML of water saved or other factors such as the lifespan of the mitigation.

2.4.1 Quantitative Analysis

To carry out a quantitative analysis, the costs of mitigation must be compared to the costs of the purchased water. Water is usually purchased in two ways, leased or purchased outright. Sunwater (2016) provides the latest values of water purchase prices. These prices for example can range from $176.50 per ML leased price per year in the Bundaberg region to $806.41 per ML from the Chinchilla Weir (Sunwater 2016).

2.4.2 Qualitative Analysis

Seepage mitigation selection often involves factors which are difficult to analyse mathematically. ANCID (2004) constructed a ranking system for different seepage mitigations and selection factors to give users of their own tool an idea of the available options (see Figure 2.3). A simple three level rating system is used to convey the suitability of each mitigation method for a number of different factors. This tool was not intended to be used solely for selecting a seepage mitigation method, but rather as a guide to where each might be most effective.

Techniques	Earth Liners						Hard Surface Liners				Flexible Membrane		Groundwater Interventions			
Parameters	Insitu compaction	Clay Lining	Bank Remodelling	Loose Earth Lining	Modified soil linings	Soil sealants	Concrete	Shotcrete	Pipelines	Grouted Fabric Mats	Exposed	Covered	Core Trenching	Groundwater Pumping	Vegetation	Tile Drains
Vertical Seepage	1	1	3	1	1	1	1	1	1	1	1	1	3	3	3	3
Lateral Seepage	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Prevention of seepage	1	1	1	1	1	1	1	1	1	1	1	1	2	3	3	3
Interception of seepage	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dispersive soil types	3	2	3	2	2	2	2	2	1	2	1	1	2	-	-	-
Expansive Soil types	2	1	2	2	2	2	3	3	3	3	2	1	2	-	-	-
Low Permeability soils	3	1	2	2	2	2	1	1	1	1	1	1	2	-	-	-
Rough/Rocky subgrade	3	1	2	2	2	2	2	2	2	2	3	3	2	-	-	-
High Groundwater (under pressure)	2	1	1	2	1	2	3	3	3	3	3	1	-	-	-	-
High water velocity	2	2	2	3	2	3	1	1	1	1	2	2	-	-	-	-
Small Channels size/capacity	3	3	2	2	2	2	2	2	1	2	1	2	-	-	-	-
Large Channels size/capacity	1	1	2	2	2	2	2	2	3	2	2	2	-	-	-	-
Short channel downtime	2	2	2	2	2	2	3	2	2	2	2	2	1	1	1	1
Frequent Water Level Changes	2	2	2	2	2	2	1	1	1	2	1	2	-	-	-	-
Windy installation conditions	1	1	1	2	2	2	1	1	1	2	3	3	1	2	2	2
Damp installation conditions	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2
Cold installation conditions	1	1	1	1	1	1	3	3	1	3	2	2	2	2	2	2
Hot installation conditions	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2
Temperature extremes	2	2	2	2	2	2	3	3	1	3	3	1	2	2	2	2
Low Risk to personal safety	2	2	2	2	2	2	2	2	1	2	3	2	1	1	1	1
Ability to withstand damage from:																
Vehicles	1	1	1	1	1	1	2	2	1	2	2	1	1	2	1	2
Fire	1	1	1	1	1	1	2	2	1	2	3	1	1	2	2	2
Animals (wild & domestic)	2	2	2	2	2	2	1	1	1	1	2	1	2	1	1	1
Vandalism	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	2
Ultra violet light	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Wind	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Mechanical Desilting	3	2	2	3	3	3	3	3	-	3	3	2	1	-	-	-

Legend: 1 (Green) – More suitable; 2 (Yellow) – Suitable; 3 (Red) – Less suitable;

Figure 2.3: ANCID's rating system for channel seepage mitigation techniques (ANCID 2004)

2.4.3 Channel Maintenance Costs

The 2004 ANCID channel seepage decision tool report contained values for ongoing maintenance costs relating to each seepage mitigation method. These costs were listed in

$\$.year^{-1}$, however these costs were specific to a previously analysed site (ANCID 2004). This made the results very unusable for a predictive mathematical seepage model. Each site to be analysed will have unique costs specific to that area making prediction of realistic maintenance costs unfeasible. These listed maintenance costs in the ANCID report were therefore used to aid in the creation of the ranking system for a qualitative analysis.

3 Methodology

This chapter outlines the steps involved in the creation of the seepage analysis model. It includes all thought processes and planning in the model creation, as well as all formulas.

3.1 Overview

This methodology takes the information from the literature review to create a new approach for modelling channel seepage. The model was created using Microsoft Excel and has been designed to run autonomously with programmed formulas. All formulas used in the creation of the model are listed in detail.

3.2 Developing a Model for Analysis

A number of models have been developed by various organisations to determine the suitability of a channel lining due to factors such as flow time and channel geometry (Kahlown & Kemper 2004). One such example is the ANCID Channel Seepage Decision Support Tool which runs in Microsoft Excel. This tool is designed to analyse the cost of installing a channel lining given set soil type and channel geometry. The tool is very in-depth and allows the user to input the exact profile of the channel with RL's and select how much of the profile should be lined (ANCID 2004). This model is very focused on analysing only one option at a time and is completely dependent on soil type. Through this project a new model for seepage analysis has been developed and has a range of options to calculate possible seepage. The new model will be able to estimate a value for seepage based on the literature and also based on seepage formulae. With this range of seepage values, a range of mitigation options can then be calculated with their estimated costs.

3.3 Seepage Calculator

The first part of the analysis model is the seepage calculation tool. This tool gives a reasonable estimate of existing seepage in any given channel so that on site measurements are not necessarily required. This tool also has an option for the user to enter a site specific value for seepage to be analysed along with seepage estimates. The tool therefore can give three values for seepage found from:

- Seepage values from the literature based on soil type
- Estimate of seepage from a formula
- Site specific value for seepage as entered by the user

All seepage rates will be in $L.m^{-2}.day^{-1}$ and apply to the entire length of the channel section.

3.3.1 Soil Type Analysis

From numerous case studies in Australia and overseas, seepage values for a range of different soil types can be found. As there is a wide spectrum of measurements across each different soil type, an upper and lower limit is listed and used in this model. This gives a final range of seepage to expect in the channel rather than a single value. All seepage rates are per area of channel. This is not how all the case studies have presented the data, but those with differing units were converted for simplicity. Table 3.1 lists the soil types to be analysed and the seepage range to be used.

Table 3.1: A list of different soil types and their typical seepage values

Soil Type	**Lower Seepage Limit [$L.m^{-2}.day^{-1}$]**	**Upper Seepage Limit [$L.m^{-2}.day^{-1}$]**	**Reference/s**
Clay and Clayey Loam	125_a	150_b	(Houk 1956)$_a$ (Swan 1978)$_b$
Sandy Loam	201_a	250_b	(Houk 1956)$_a$ (Swan 1978)$_b$
Gravelly Sandy	610	762	(Davis 1952)
Silty Loam	229_a	341_b	(Davis 1952)$_a$ (ICID 1967)$_b$
Sand and Clay	229_a	366_b	(Davis 1952)$_a$ (Houk 1956)$_b$
Very Gravelly	914	1829	(Davis 1952)

Impervious Clay Loam	76	107	(Davis 1952)
Sandy with rock	512		(Houk 1956)

To convert all the seepage rates for the individual channel sections to a loss in $ML.m^{-1}.day^{-1}$, the Equation 3.2.1 is used.

$$Vl_{DSL} = \frac{S\,P}{1000000} \tag{3.2.1}$$

Where Vl_{DSL} is Daily volume lost over the section per length [$ML.m^{-1}.day^{-1}$]
S is Seepage Rate [$L.m^{-2}.day^{-1}$]
P is Wetted Perimeter [m]

To obtain a value for the volume lost over each channel section, the resultant from Equation 3.2.1 is multiplied by the section length. This is demonstrated in Equation 3.2.2.

$$Vl_{DS} = Vl_{DSL}\,L_s \tag{3.2.2}$$

Where Vl_{DS} is Daily volume lost over the section [$ML.day^{-1}$]
Vl_{DSL} is Daily volume lost over the section per length [$ML.m^{-1}.day^{-1}$]
L_S is Section length [m]

The volume lost over the entire channel length can then be calculated by taking the sum of the volumes lost for each channel section. Equation 3.2.3 shows this simple relationship.

$$Vl_{DE} = \sum Vl_{DS} \tag{3.2.3}$$

Where Vl_{DE} is Daily volume lost over entire channel [$ML.day^{-1}$]
Vl_{DS} is Daily volume lost over each channel section [$ML.day^{-1}$]

3.3.2 Moritz Formula

A number of different formulae were listed in the literature in Section 2.2.3 and all have different applications for seepage estimation. The Davis and Wilson formula, while simplistic would not be a suitable choice for this model as the varying constant C is better suited for already lined channels. Bower's formula for seepage takes in a number of important factors, but relies too heavily on the depth of the water table, which would not be known in some cases for the application of this model. The former Soviet Union equation would be a suitable choice, but would still require some measurement of saturated permeability before the equation could be used. The equation also requires a ratio of seepage velocity to permeability, both of which would need to be measured in field and would defeat the purpose of this model. The final equation analysed was proposed by the U.S. Bureau of Reclamation and included components for discharge, velocity and a constant for soil type. This equation is the simplest and most applicable one to estimate seepage for the model. All the units in the USBR formula are in imperial measurements, so were converted so that metric units could be inputted and the resultant in $ML.m^{-1}.day^{-1}$ to compare with other seepage rates. Equation 3.2.4 shows the Moritz formula converted to work in metric units.

$$S = 0.2C\sqrt{10.764\,A} * \frac{3600 * 24 * 0.02383168}{1000 * 1.61 * 1000} \tag{3.2.4}$$

Where S is Seepage rate [$ML.m^{-1}.day^{-1}$]
C is Constant value for soil type
A is Cross sectional area of channel section [m^{-2}]

3.3.3 Measured Value

For comparison in the model, the user is also able to enter a site specific value for seepage. This can either be a measured or calculated value for the best approximation of seepage in the area of the proposed channel. This can not only test the accuracy of the model, but can also give the user a comparison of how the seepage would compare if other soils were used in construction. Equations 3.2.1, 3.2.2 and 3.2.3 are all applied in the same way as in Section 3.3.1 to the users inputted seepage values.

3.3.4 Model Application

During the construction of the model, different naming conventions were used to represent the three types of seepage analysis. Due to the large task of rebuilding the entire model for the sake of name changes, the model has been left in the original convention. All screenshots of the model listed in Section 4 and the Appendices will have the original naming convention for the seepage analysis types. For reference, the following naming convention has been used:

Seepage Analysis Name		Model Convention
Soil Type Analysis	=	Literature
Moritz Formula	=	Moritz Formula
Measured Value	=	Expected Value

3.4 Mitigation Effectiveness

The next part of the model is the mitigation measurement tool. This part of the model takes all the calculated values for seepage from the seepage calculation tool and analyses them against different mitigation methods. The effectiveness of each mitigation method has been found from the literature. The seepage range is calculated against the effectiveness of each mitigation method to come up with a final range of water saved per day.

Table 3.2: The effectiveness and cost of each selected mitigation method

Mitigation Method	**Lower Effectiveness Limit [%]**	**Upper Effectiveness Limit [%]**	**Cost [$.m^{-2}]**	**Reference/s**
Compaction (in-situ)	55$_a$	74$_b$	10$_a$	(ANCID 2004)$_a$ (Sonnichsen 1993)$_b$
Compaction of imported clay	70	90	17	(ANCID 2004)
Concrete	70	95	52.5	(ANCID 2004)
Asphalt	90	90	35	(ANCID 2004)
HDPE (2mm)	93	93	12.12	(ANCID 2004)
LDPE (1.5mm)	94	94	16.54	(ANCID 2004)
Rice Hull Ash	50	60	3.86	(Akbar et al. 2013)

Firstly, the volume lost needs to be calculated over the entire year. Not all channels operate 365 days per year. Some only deliver water during the time when water is needed for the crop (irrigation season) and the channel remains dry for the rest of the year. Equation 3.3.1 applies the number of days the channel is irrigating to the volume lost.

$$Vl_{SLB} = Vl_{DSL}\, I_D \tag{3.3.1}$$

Where Vl_{SLB} is Yearly volume lost over the section per length before mitigation [ML.year^{-1}.m^{-1}]
Vl_{DSL} is Daily volume lost over the section per length [ML.m^{-1}.day^{-1}]
I_D is Number of irrigation days per year [days.year^{-1}]

To find how effective each mitigation method is, the following formula is used. This is applied to the upper and lower limits of the soil type. The upper effectiveness value is applied to the lower seepage value and vice versa to give the worst case scenario for seepage and a broad range of values. Equation 3.3.2 shows how the effectiveness is applied to the seepage values.

$$Vl_{SLA} = Vl_{SLB}\,(1 - E) \tag{3.3.2}$$

Where Vl_{SLA} is Yearly volume lost over the section per length after mitigation [ML.year^{-1}.m^{-1}]
Vl_{SLB} is Yearly volume lost over the section per length before mitigation [ML.year^{-1}.m^{-1}]
E is Effectiveness of mitigation method [%]

The volume saved by using mitigation can then be found using Equation 3.3.3.

$$Vs_{SL} = Vl_{SLB} - Vl_{SLA} \tag{3.3.3}$$

Where Vs_{SL} is Yearly volume saved over the section per length [ML.year^{-1}.m^{-1}]
Vl_{SLA} is Yearly volume lost over the section per length after mitigation [ML.year^{-1}.m^{-1}]
Vl_{SLB} is Yearly volume lost over the section per length before mitigation [ML.year^{-1}.m^{-1}]

To obtain a value for the volume saved over each channel section, the resultant from Equation 3.3.3 is multiplied by the section length. This is demonstrated in Equation 3.3.4.

$$Vs_S = Vs_{SL}\, L_s \tag{3.3.4}$$

Where Vs_S is Volume saved over the section [ML.year^{-1}]
Vs_{SL} is Volume saved over the section per length [ML.year^{-1}.m^{-1}]
L_S is Section length [m]

The volume saved over the entire channel length can then be calculated by taking the sum of the volumes saved for each channel section. Equation 3.3.5 shows this simple relationship.

$$Vs_E = \sum Vs_S \tag{3.3.5}$$

Where Vs_E is Volume saved over entire channel [ML.year^{-1}]
Vs_S is Volume saved over each channel section [ML.year^{-1}]

3.5 Cost Analysis

The cost analysis tool is used to determine which of the mitigation methods from the previous section is the most cost beneficial. To do this, the capital cost of each material needs to be known (listed in Table 3.2). These capital costs are the upfront costs associated with installing the channel. This includes the costs of materials, machinery, labour and others. This is all included in the mitigation costs (\$.m^{-2}) given by ANCID (2004). Calculating the yearly cost of each mitigation method over the entire channel is done with the Equation 3.4.1.

$$C_{CL} = \frac{M_C\, P}{M_{EL}} + \frac{M_{MC}}{L_S} \tag{3.4.1}$$

Where C_{CL} is Yearly capital costs of mitigation per length [\$.year^{-1}.m^{-1}]
M_C is Mitigation capital cost [\$.m^{-2}]
P is Wetted perimeter [m]
M_{EL} is Mitigation expected life [years]
M_{MC} is Mitigation maintenance costs [\$.year^{-1}]
L_S is Section length [m]

As reported in the literature review, the mitigation maintenance costs found in the literature were channel specific and were excluded from this model. However, the capability is still available as shown in Equation 3.4.1 for the user to enter maintenance costs if desired.

To have a better understanding of how beneficial in terms of dollars each mitigation method is, the cost per ML of water saved is calculated. Comparisons can then be drawn to find which mitigation method gives the lowest cost per ML saved. Equation 3.4.2 is used to determine the cost per ML saved each year.

$$C_{SL} = \frac{C_{CL}}{Vs_{SL}} \tag{3.4.2}$$

Where C_{SL} is Cost per ML saved per length [\$.ML^{-1}.m^{-1}]
C_{CL} is Yearly capital costs of mitigation per length [\$.year^{-1}.m^{-1}]
Vs_{SL} is Yearly volume saved over the section per length [ML.year^{-1}.m^{-1}]

To obtain a value for the cost per ML saved over each channel section, the resultant from Equation 3.4.2 is multiplied by the section length. This is demonstrated in Equation 3.4.3.

$$C_S = C_{SL} L_s \tag{3.4.3}$$

Where C_S is Cost per ML saved over the section [$.ML^{-1}]
C_{SL} is Cost per ML saved per length [$.ML^{-1}.m^{-1}]
L_S is Section length [m]

The cost per ML saved over the entire channel length can then be calculated by taking the sum of the volumes saved for each channel section. Equation 3.4.4 shows this simple relationship.

$$C_E = \sum C_S \tag{3.4.4}$$

Where C_E is Cost per ML saved over the entire channel [$.ML^{-1}]
C_S is Cost per ML saved over the section [$.ML^{-1}]

3.6 Benefit Analysis

3.6.1 Quantitative Analysis

The benefit tool compares the costs associated with channel mitigation with the value of the water saved. Due to the different types of ways water is purchased, two equations are used to compare the costs per ML saved and cost of the water. When the water is leased, Equation 3.5.1 is used.

$$N_S = W_C - C_S \tag{3.5.1}$$

Where N_S is Profit or loss per ML saved [$.ML^{-1}]
W_C is Water cost [$.ML^{-1}]
C_S is Cost per ML saved over the section [$.ML^{-1}]

When the water is purchased outright, the costs need to be calculated over the expected lifetime of the chosen mitigation method. Equation 3.5.2 shows this.

$$N_S = \frac{W_C}{M_{EL}} - C_S \tag{3.5.2}$$

Where N_S is Profit or loss per ML saved [$.ML^{-1}]
W_C is Water cost [$.ML^{-1}]
M_{EL} is Mitigation expected life [years]
C_S is Cost per ML saved over the section [$.ML^{-1}]

The profit or loss per ML saved over the entire channel length can then be calculated by taking the sum of the profits or losses for each channel section. Equation 3.5.3 shows this simple relationship.

$$N = \sum N_S \tag{3.5.3}$$

Where N is Profit or loss per ML saved over the entire channel [$.ML^{-1}]
N_S is Profit or loss per ML saved [$.ML^{-1}]

3.6.2 Qualitative Analysis

Other factors can also be considered when looking at the benefits of any seepage mitigation method. Factors such as ease of installation, effect on environment, temperature differences or exposure to the elements cannot always be analysed mathematically, but are still important in the decision making process. Table 3.3 has been created to analyse these factors qualitatively with weightings for each factor and mitigation method. This table is to be used as an addition to the model to aid the user in the decision making process for seepage mitigation. The table rates each factor between 1 to 5, with 1 being the least suitable choice and 5 being the most suitable.

Table 3.3: Weighting factors for a qualitative benefit analysis with 1 being the worst and 5 the best

	Factors					
Mitigation Method	**Ease of Installation**	**Infrequent Channel Use**	**Maintenance Costs**	**High Velocity Channels**	**Damage Resistance**	**Temperature Changes**
Asphalt	3	2	2	4	4	2
Compaction (in-situ)	4	3	5	2	4	4
Compaction of imported clay	4	3	4	2	5	3
Concrete	3	1	1	2	4	1
HDPE (2mm)	1	3	5	3	3	3
LDPE (1.5mm)	1	3	4	3	2	3
Rice Hull Ash	4	2	3	1	4	4

Table 3.3 was created with aid of the factors given by ANCID (2004) in Figure 2.3 and acquired knowledge of the behaviour of each mitigation method.

3.7 Case Studies Selection

To test the reliability of the model, case studies have been selected for comparison with the model outputs. The case studies will show how accurate the estimation of seepage is before and after applying seepage mitigation. This can give a benchmark of how useful the model is and will flag any problem areas which will need to be further researched. Two case studies were selected in Queensland, one in the Bundaberg area and one in the St George area. One case study was also selected in Victoria near the township of Birchip. It is expected that there may be little to no gains for the Queensland studies as the seepage is already very low. The channel in Victoria may benefit from some seepage mitigation as it has higher losses and many channels in Victoria have already undergone these processes with positive results.

3.7.1 Buckinbah B2/2 Channel

Fairley (2015) conducted an investigation into channel seepage in the St George area using the ponding method. Three sites were chosen, but only one site yielded useable results. These were from the Buckinbah B2/2 channel. This channel is part of a network which mainly irrigates for cotton farming and is fed by Beardmore Dam and the Balonne River. The St

George irrigation area lies in the northern region of the Murray-Darling Basin (Fairley 2015). Sunwater (2015) gives the price per ML as $103.88 when the water is leased.

Table 3.4: Channel characteristics of Buckinbah B2/2 (Fairley 2015)

Soil Type	Sand and clay
Lining type	Compacted earth
Channel Shape	Trapezoidal with H/V of 2
Bed width [m]	5.5
Water Depth [m]	1.1
Channel length [m] (Used in testing)	1393
Expected seepage [$L.m-^{2}.day^{-1}$]	8 ± 2 (95%)
Irrigation days [$days.year^{-1}$]	365

This channel already has a compacted earth lining in situ with the materials on site. Therefore, this study can be used to determine how well the model estimates seepage when using compacted earth.

3.7.2 Booyan Main Channel

The area of Bundaberg is known for its sugarcane, however the area does not receive enough rainfall annually for the crops. The Queensland government proposed a two part water supply scheme in the 1970s to supply water for existing farms in the area. This was a unique scheme for Queensland as a large scale network such as this one had never been constructed for established farms. Other crops grown in the area include melons, zucchini, tomatoes, macadamias, avocadoes, capsicum and beans. The major dams for the supply scheme are Fred Haigh and Paradise which supply much of the channel network (Sunwater 2015). The scheme also supplies water to urban areas such as the city of Bundaberg and other local communities.

The Booyan Main Channel is made up of many different sections of piped and earthen lined channels. Data was available for eight different sections of earthen channel all with varying depths and lengths. As the model is capable of analysing multiple sections, all eight were included in analysis.

Table 3.5: Channel characteristics of a Booyan MC section (GHD 2001)

Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Soil Type	Clay and Clayey Loam							
Lining type	None							
Channel shape	Trapezoidal with H/V of 2							
Bed width [m]	4	4	4	4	4	4	4	4
Water depth [m]	1.64	1.36	1.5	1.22	1.22	1.22	1.22	1.22
Section length [m]	450	1710.3	708	548.4	1384.6	691	394	815
Expected seepage [$L.m^{-2}.day^{-1}$]	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Irrigation days [$days.year^{-1}$]	365	365	365	365	365	365	365	365

3.7.3 Donald Main Channel, High Loss Sections

The Donald Main Channel was constructed in 1912 and lies within the Birchip district in Victoria serviced by Wimmera Mallee Water. The channel is designed for a capacity of $245ML.day^{-1}$ supplying around $30,000ML.year^{-1}$ and is fed by Lake Batyo Catyo. In 1998, Wimmera Mallee Water and Sinclair Knight Merz conducted a study into two sections of the Donald MC which were known to have high seepage losses named Ralstons and Sheridans.

This channel was selected primarily to be a contrast to the other two case studies as it is only irrigated 273 days per year and has higher measured losses than the Queensland sites.

Table 3.6: Channel characteristics of two sections in the Donald MC (Wimmera Mallee Water and Sinclaire Knight Merz 1998) (ANCID 2003) (Long & Poynton 2009)

Section	**Ralstons**	**Sheridans**
Soil Type	Sand and Clay	
Lining type	None	
Channel Shape	Trapezoidal with H/V of 3.23	
Bed width [m]	7	7
Water Depth [m]	1.2	1.2
Section length [m]	3500	2500
Expected seepage [$L.m^{-2}.day^{-1}$]	25 to 67	25 to 67
Irrigation days [$days.year^{-1}$]	273	273

4 Model Capability

This chapter demonstrates the capability of the created model to analyse seepage and the associated costs with mitigation. It contains screenshots from the model direct from Microsoft Excel to showcase the inputs and outputs of a sample analysis.

4.1 Overview

This model was developed as part of this dissertation for the purposes of analysing the case studies listed in Section 3.7.

4.1.1 Model Description

The model has been setup to analyse multiple sections of the same channel. This was done due to the often large variations in channel dimensions, water depths or even soil types along the length of the channel. There is currently a capacity of 10 sections that can be analysed within the model, but this could easily be modified to account for more. Each section is analysed individually throughout the model, as well as values for the entire channel easily accessible by summing each section. Formula's are permanently stored within the model and work seamlessly with any values entered by the user.

The simple colour coded format of the model makes clear to the user where data should be entered and where the resultants of formulas appear. All green cells are where user data entry is required, yellow cells are the formula results and cells without a colour are either labels or blank cells.

Throughout the model, upper and lower limits are used when a range of values exist. For example, there were a range of values for seepage found in the literature for similar soil types; hence an upper and lower limit was adopted for each to give a broad range of results. The upper and lower limits are then carried throughout the model to give a final range of costs. These upper and lower limits are always represented by '+' for upper and '-' for lower.

4.1.2 Model Environment

This model was created with Microsoft Excel (2007 edition) due to the relative ease of use of the program. Excel is a powerful tool for the creation of mathematical models due to the input of formulas available. This seepage model has been created to work autonomously, only requiring the user to enter the channel characteristics, proposed mitigation and the price of water in the area.

Provision has been made for 10 individual channel sections to be analysed, however the model could be easily modified to incorporate more. Any user with knowledge of Microsoft Excel could be instructed how the model can be expanded, which further justifies the selection of this program for the model creation.

4.2 Site Characteristics

The first part of the model is the site characteristics where the user enters all the necessary information about the channel into the interface shown in Figure 4.1.

1. Enter site characteristics

Channel Sections (May Change Name)	Section 1	Section 2	Section 3	Section 4
Soil type	None	None	None	None
Seepage (L/m^2/day) -	0	0	0	0
Seepage (L/m^2/day) +	0	0	0	0
Existing mitigation	None	None	None	None
Effectiveness (%) -	0	0	0	0
Effectiveness (%) +	0	0	0	0
Channel Shape	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal
Side slope: H/V (If Trapezoidal)				
Bed width (m)				
Water depth (m)				
Channel section length (m)				
Expected seepage (L/m^2/day) -				
Expected seepage (L/m^2/day) +				
Irrigation days/year				
Wetted perimeter (m)	0.000	0.000	0.000	0.000
Cross-sectional area (m^2)	0.0000	0.0000	0.0000	0.0000

Figure 4.1: A screenshot of the model interface to enter the site characteristics

The first steps are to select the soil type and if there is any existing mitigation for each section of the channel to be analysed (see Figure 4.2). Any number between 1 and 10 sections may be chosen for analysis. If less than 10 sections are chosen, any following sections must be left blank for the model to work correctly.

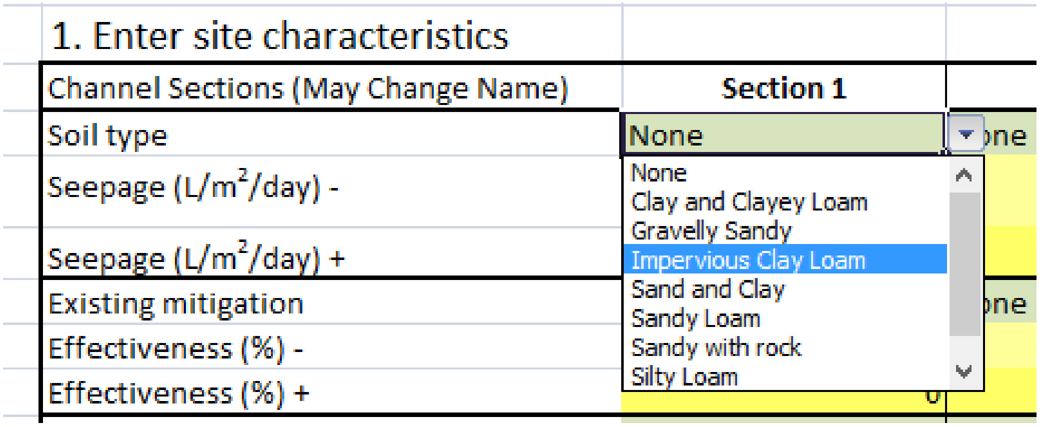

Figure 4.2: A demonstration of the drop down menu to select the soil type in each channel section

The user is then required to enter the side slope, bed width, water depth, section length, irrigation days per year and the upper and lower limits for expected seepage (if any). The expected seepage value is not required for the model to work, however only the literature and Moritz formula values for seepage will be calculated. This will sometimes be the case if no seepage data exists for the area yet. As mentioned earlier in the chapter, green cells are where the user may enter values and yellow cells are the formula resultants. Figure 4.3 shows how a typical data entry may look for a channel of three sections.

1. Enter site characteristics				
Channel Sections (May Change Name)	Section 1	Section 2	Section 3	Section 4
Soil type	Sand and Clay	Sand and Clay	Sandy with rock	None
Seepage (L/m^2/day) -	229	229	512	0
Seepage (L/m^2/day) +	366	366	512	0
Existing mitigation	None	None	Compaction of importe	None
Effectiveness (%) -	0	0	70	0
Effectiveness (%) +	0	0	90	0
Channel Shape	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal
Side slope: H/V (If Trapezoidal)	2	2	2	
Bed width (m)	4	4	4	
Water depth (m)	1.5	1.32	1.41	
Channel section length (m)	1750	980	1340	
Expected seepage (L/m^2/day) -	175	175		
Expected seepage (L/m^2/day) +	200	200		
Irrigation days/year	270			
Wetted perimeter (m)	10.708	9.903	10.306	0.000
Cross-sectional area (m^2)	10.5000	8.7648	9.6162	0.0000

Figure 4.3: A typical data entry for a channel of three sections

4.3 Seepage Calculations

The next part of the model calculates the seepage in the channel using the three methods as described in Section 3.2. These are the soil type analysis, Moritz formula and the measured value. The literature value is the estimated value for seepage based on the soil type from data found by research, the Moritz formula is an estimate of seepage from the USBR proposed formula and the estimated value is the seepage from a site measured seepage value. Figure 4.4 shows how the model looks before any data is entered.

2. Seepage Calculations				
Literature				
Expected Seepage (L/m2/day) -	0	0	0	0
Expected Seepage (L/m2/day) +	0	0	0	0
Volume Lost (ML/m/day) -	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/m/day) +	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/day) -	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/day) +	0.00000	0.00000	0.00000	0.00000
Volume Lost Over Channel (ML/day) -	0.00000			
Volume Lost Over Channel (ML/day) +	0.00000			
Moritz Formula				
Constant value	0.0	0.0	0.0	0.0
Expected seepage (ML/m/day)	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/m/day) -	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/m/day) +	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/day) -	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/day) +	0.00000	0.00000	0.00000	0.00000
Volume Lost Over Channel (ML/day) -	0.00000			
Volume Lost Over Channel (ML/day) +	0.00000			
Expected Value				
Volume Lost (ML/m/day) -	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/m/day) +	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/day) -	0.00000	0.00000	0.00000	0.00000
Volume Lost (ML/day) +	0.00000	0.00000	0.00000	0.00000
Volume Lost Over Channel (ML/day) -	0.00000			
Volume Lost Over Channel (ML/day) +	0.00000			

Figure 4.4: The seepage calculation section before any data is entered

When data is entered into Section 1 of the model, the seepage calculations are automatically calculated. It takes into account the soil type for the Moritz formula and selects the constant value accordingly. Values are shown for the volume lost over the section per length, the entire section and the entire channel for all three methods of seepage calculation. Figure 4.5 shows how the model might look with data entered for three sections of channel.

2. Seepage Calculations				
Literature				
Expected Seepage (L/m2/day) -	229	229	51.2	0
Expected Seepage (L/m2/day) +	366	366	153.6	0
Volume Lost (ML/m/day) -	0.00245	0.00227	0.00053	0.00000
Volume Lost (ML/m/day) +	0.00392	0.00362	0.00158	0.00000
Volume Lost (ML/day) -	4.29131	2.22248	0.70705	0.00000
Volume Lost (ML/day) +	6.85860	3.55209	2.12116	0.00000
Volume Lost Over Channel (ML/day) -	7.22085			
Volume Lost Over Channel (ML/day) +	12.53185			
Moritz Formula				
Constant value	1.2	1.2	1.7	0.0
Expected seepage (ML/m/day)	0.00388	0.00354	0.00519	0.00000
Volume Lost (ML/m/day) -	0.00388	0.00354	0.00052	0.00000
Volume Lost (ML/m/day) +	0.00388	0.00354	0.00156	0.00000
Volume Lost (ML/day) -	6.78520	3.47158	0.69609	0.00000
Volume Lost (ML/day) +	6.78520	3.47158	2.08827	0.00000
Volume Lost Over Channel (ML/day) -	10.95287			
Volume Lost Over Channel (ML/day) +	12.34505			
Expected Value				
Volume Lost (ML/m/day) -	0.00187	0.00173	0.00000	0.00000
Volume Lost (ML/m/day) +	0.00214	0.00198	0.00000	0.00000
Volume Lost (ML/day) -	3.27939	1.69840	0.00000	0.00000
Volume Lost (ML/day) +	3.74787	1.94103	0.00000	0.00000
Volume Lost Over Channel (ML/day) -	4.97779			
Volume Lost Over Channel (ML/day) +	5.68890			

Figure 4.5: The seepage calculations from the values entered in Figure 4.3. Note: the expected value is zero in the 3rd section because no expected values were entered for that section in the site characteristics.

4.4 Mitigation Calculations

Mitigation calculations are carried out in the next section of the model depending on the selection by the user. The effectiveness values for each mitigation were found from the literature and the full details are listed in Table 3.2. The mitigation calculations part of the model without any data entered is shown in Figure 4.6.

3. Mitigation Calculations				
Proposed Mitigation	None	None	None	None
Effectiveness (%) -	0	0	0	0
Effectiveness (%) +	0	0	0	0
Cost ($/m^2)	0	0	0	0
Expected Life (years)	0	0	0	0
Maintenance Costs ($/year)	0	0	0	0
Literature				
Before Mitiagtion (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
Before Mitiagtion (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
After Mitigation (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
After Mitigation (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year) -	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year) +	0.00000	0.00000	0.00000	0.00000
Volume Saved Over Channel (ML/year) -	0.000			
Volume Saved Over Channel (ML/year) +	0.000			
Moritz Formula				
Before Mitiagtion (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
Before Mitiagtion (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
After Mitigation (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
After Mitigation (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year) -	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year) +	0.00000	0.00000	0.00000	0.00000
Volume Saved Over Channel (ML/year) -	0.000			
Volume Saved Over Channel (ML/year) +	0.000			
Expected Value				
Before Mitiagtion (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
Before Mitiagtion (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
After Mitigation (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
After Mitigation (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year/m) -	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year/m) +	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year) -	0.00000	0.00000	0.00000	0.00000
Volume Saved (ML/year) +	0.00000	0.00000	0.00000	0.00000
Volume Saved Over Channel (ML/year) -	0.000			
Volume Saved Over Channel (ML/year) +	0.000			

Figure 4.6: The mitigation calculations section of the model before any data has been entered

The user may select a different mitigation method for each section using the drop down menu provided (see Figure 4.7).

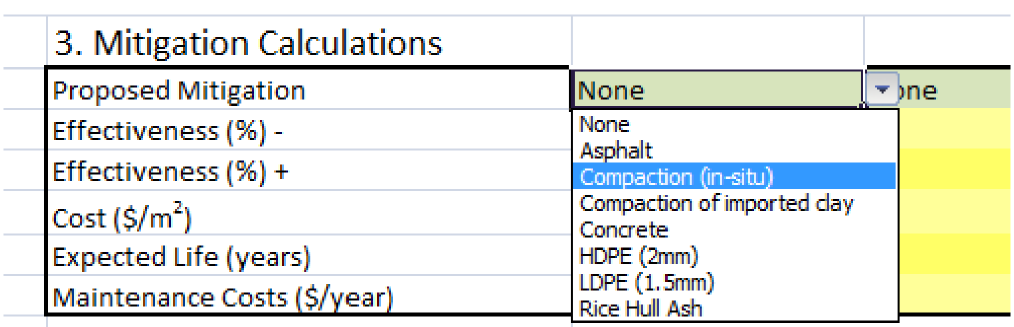

Figure 4.7: A demonstration of the drop down menu in the mitigation calculations section.

Any combination of mitigation methods may be selected to find the optimal conditions to prevent channel seepage. Again this is done for all three methods for channel seepage and displays the volume lost before and after mitigation and the volume saved per length, over the entire section and over the entire channel. Figure 4.8 shows how the mitigation calculations section would look with the values entered from Figure 4.3 and some proposed mitigations selected.

3. Mitigation Calculations				
Proposed Mitigation	HDPE (2mm)	HDPE (2mm)	Rice Hull Ash	None
Effectiveness (%) -	93	93	50	0
Effectiveness (%) +	93	93	60	0
Cost ($/$m^2$)	12.12	12.12	3.86	0
Expected Life (years)	30	30	10	0
Maintenance Costs ($/year)	0	0	0	0
Literature				
Before Mitiagtion (ML/year/m) -	0.66209	0.61232	0.14247	0.00000
Before Mitiagtion (ML/year/m) +	1.05818	0.97864	0.42740	0.00000
After Mitigation (ML/year/m) -	0.04635	0.04286	0.05699	0.00000
After Mitigation (ML/year/m) +	0.07407	0.06850	0.21370	0.00000
Volume Saved (ML/year/m) -	0.61574	0.56945	0.08548	0.00000
Volume Saved (ML/year/m) +	0.98411	0.91013	0.21370	0.00000
Volume Saved (ML/year) -	1077.54863	558.06486	114.54279	0.00000
Volume Saved (ML/year) +	1722.19562	891.92898	286.35698	0.00000
Volume Saved Over Channel (ML/year) -	1750.156			
Volume Saved Over Channel (ML/year) +	2900.482			
Moritz Formula				
Before Mitiagtion (ML/year/m) -	1.04686	0.95646	0.14026	0.00000
Before Mitiagtion (ML/year/m) +	1.04686	0.95646	0.42077	0.00000
After Mitigation (ML/year/m) -	0.07328	0.06695	0.05610	0.00000
After Mitigation (ML/year/m) +	0.07328	0.06695	0.21039	0.00000
Volume Saved (ML/year/m) -	0.97358	0.88950	0.08415	0.00000
Volume Saved (ML/year/m) +	0.97358	0.88950	0.21039	0.00000
Volume Saved (ML/year) -	1703.76439	871.71380	112.76640	0.00000
Volume Saved (ML/year) +	1703.76439	871.71380	281.91600	0.00000
Volume Saved Over Channel (ML/year) -	2688.245			
Volume Saved Over Channel (ML/year) +	2857.394			
Expected Value				
Before Mitiagtion (ML/year/m) -	0.50596	0.46793	0.00000	0.00000
Before Mitiagtion (ML/year/m) +	0.57824	0.53477	0.00000	0.00000
After Mitigation (ML/year/m) -	0.03542	0.03275	0.00000	0.00000
After Mitigation (ML/year/m) +	0.04048	0.03743	0.00000	0.00000
Volume Saved (ML/year/m) -	0.47055	0.43517	0.00000	0.00000
Volume Saved (ML/year/m) +	0.53777	0.49734	0.00000	0.00000
Volume Saved (ML/year) -	823.45419	426.46878	0.00000	0.00000
Volume Saved (ML/year) +	941.09050	487.39289	0.00000	0.00000
Volume Saved Over Channel (ML/year) -	1249.923			
Volume Saved Over Channel (ML/year) +	1428.483			

Figure 4.8: The mitigation calculations from the values entered in Figure 4.3

4.5 Cost Analysis Calculation

The cost analysis calculation section takes all the volumes saved and compares them to the costs of mitigation. Figure 4.9 shows how this section would look before data entry has occurred.

4. Cost Analysis Calcualtion				
Yearly Cost per Length($/year/m)	0.00	0.00	0.00	0.00
Yearly Cost ($/year)	0.00	0.00	0.00	0.00
Literature				
Cost per ML Saved per Length ($/ML/m) -	$ -	$ -	$ -	$ -
Cost per ML Saved per Length ($/ML/m) +	$ -	$ -	$ -	$ -
Cost per ML Saved ($/ML) -	$ -	$ -	$ -	$ -
Cost per ML Saved ($/ML) +	$ -	$ -	$ -	$ -
Cost per ML Saved Over Channel ($/ML) -	$ -			
Cost per ML Saved Over Channel ($/ML) +	$ -			
Moritz Formula				
Cost per ML Saved per Length ($/ML/m) -	$ -	$ -	$ -	$ -
Cost per ML Saved per Length ($/ML/m) +	$ -	$ -	$ -	$ -
Cost per ML Saved ($/ML) -	$ -	$ -	$ -	$ -
Cost per ML Saved ($/ML) +	$ -	$ -	$ -	$ -
Cost per ML Saved Over Channel ($/ML) -	$ -			
Cost per ML Saved Over Channel ($/ML) +	$ -			
Expected Value				
Cost per ML Saved per Length ($/ML/m) -	$ -	$ -	$ -	$ -
Cost per ML Saved per Length ($/ML/m) +	$ -	$ -	$ -	$ -
Cost per ML Saved ($/ML) -	$ -	$ -	$ -	$ -
Cost per ML Saved ($/ML) +	$ -	$ -	$ -	$ -
Cost per ML Saved Over Channel ($/ML) -	$ -			
Cost per ML Saved Over Channel ($/ML) +	$ -			

Figure 4.9: The cost analysis calculations before any data has been entered

This section requires no user input and displays the costs per ML saved from the previous section. This is again done for each seepage calculation method and displays results per length, over the section and over the entire channel. Figure 4.10 demonstrates how this section calculates the costs.

4. Cost Analysis Calcualtion				
Yearly Cost per Length($/year/m)	4.33	4.00	3.98	0.00
Yearly Cost ($/year)	7570.70	3920.88	5330.53	0.00
Literature				
Cost per ML Saved per Length ($/ML/m) -	$ 4.40	$ 4.40	$ 18.61	$ -
Cost per ML Saved per Length ($/ML/m) +	$ 7.03	$ 7.03	$ 46.54	$ -
Cost per ML Saved ($/ML) -	$ 7,692.93	$ 4,308.04	$ 24,944.06	$ -
Cost per ML Saved ($/ML) +	$ 12,295.25	$ 6,885.34	$ 62,360.15	$ -
Cost per ML Saved Over Channel ($/ML) -	$ 36,945.02			
Cost per ML Saved Over Channel ($/ML) +	$ 81,540.73			
Moritz Formula				
Cost per ML Saved per Length ($/ML/m) -	$ 4.44	$ 4.50	$ 18.91	$ -
Cost per ML Saved per Length ($/ML/m) +	$ 4.44	$ 4.50	$ 47.27	$ -
Cost per ML Saved ($/ML) -	$ 7,776.15	$ 4,407.94	$ 25,337.00	$ -
Cost per ML Saved ($/ML) +	$ 7,776.15	$ 4,407.94	$ 63,342.50	$ -
Cost per ML Saved Over Channel ($/ML) -	$ 37,521.09			
Cost per ML Saved Over Channel ($/ML) +	$ 75,526.59			
Expected Value				
Cost per ML Saved per Length ($/ML/m) -	$ 8.04	$ 8.04	$ -	$ -
Cost per ML Saved per Length ($/ML/m) +	$ 9.19	$ 9.19	$ -	$ -
Cost per ML Saved ($/ML) -	$ 14,078.06	$ 7,883.71	$ -	$ -
Cost per ML Saved ($/ML) +	$ 16,089.21	$ 9,009.96	$ -	$ -
Cost per ML Saved Over Channel ($/ML) -	$ 21,961.77			
Cost per ML Saved Over Channel ($/ML) +	$ 25,099.16			

Figure 4.10: The cost analysis calculations from the values entered in Figure 4.3

4.6 Cost Benefit Analysis

The cost benefit analysis section compares the costs of the water against the costs of mitigation. Before the user enters any data, the cost benefit analysis section resembles Figure 4.11.

5. Cost Benefit Analysis				
Water Payment Scheme	Leased			
Water Cost ($/ML)				
Literature				
Profit or Loss per ML Saved ($/ML) -	$0.00	$0.00	$0.00	$0.00
Profit or Loss per ML Saved ($/ML) +	$0.00	$0.00	$0.00	$0.00
Profit or Loss Over Channel ($/ML) -	$0.00			
Profit or Loss Over Channel ($/ML) +	$0.00			
Moritz Formula				
Profit or Loss per ML Saved ($/ML) -	$0.00	$0.00	$0.00	$0.00
Profit or Loss per ML Saved ($/ML) +	$0.00	$0.00	$0.00	$0.00
Profit or Loss Over Channel ($/ML) -	$0.00			
Profit or Loss Over Channel ($/ML) +	$0.00			
Expected Value				
Profit or Loss per ML Saved ($/ML) -	$0.00	$0.00	$0.00	$0.00
Profit or Loss per ML Saved ($/ML) +	$0.00	$0.00	$0.00	$0.00
Profit or Loss Over Channel ($/ML) -	$0.00			
Profit or Loss Over Channel ($/ML) +	$0.00			

Figure 4.11: The cost benefit analysis section before any data is entered

The user must enter the price of water relevant to the area where the proposed or existing channel lies. As water is purchased in two different ways, the user has the option to enter if the water is purchased outright or leased by use of a drop down menu (see Figure 4.12).

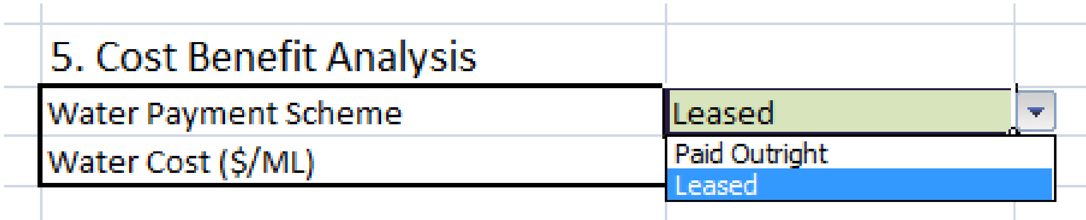

Figure 4.12: A demonstration of the drop down menu in the cost benefit analysis section

The model then automatically calculates whether a profit or loss is made for each ML of water with mitigation in mind. Figure 4.13 shows how the cost benefit analysis section would look with the data from Figures 4.3, 4.5 and a selected water cost in the model.

5. Cost Benefit Analysis				
Water Payment Scheme	Leased			
Water Cost ($/ML)	500			
Literature				
Profit or Loss per ML Saved ($/ML) -	-$11,795.25	-$6,385.34	-$61,860.15	$0.00
Profit or Loss per ML Saved ($/ML) +	-$7,192.93	-$3,808.04	-$24,444.06	$0.00
Profit or Loss Over Channel ($/ML) -	-$80,040.73			
Profit or Loss Over Channel ($/ML) +	-$35,445.02			
Moritz Formula				
Profit or Loss per ML Saved ($/ML) -	-$7,276.15	-$3,907.94	-$62,842.50	$0.00
Profit or Loss per ML Saved ($/ML) +	-$7,276.15	-$3,907.94	-$24,837.00	$0.00
Profit or Loss Over Channel ($/ML) -	-$74,026.59			
Profit or Loss Over Channel ($/ML) +	-$36,021.09			
Expected Value				
Profit or Loss per ML Saved ($/ML) -	-$15,589.21	-$8,509.96	$0.00	$0.00
Profit or Loss per ML Saved ($/ML) +	-$13,578.06	-$7,383.71	$0.00	$0.00
Profit or Loss Over Channel ($/ML) -	-$24,099.16			
Profit or Loss Over Channel ($/ML) +	-$20,961.77			

Figure 4.13: The cost benefit analysis section with data from Figures 4.3 and 4.5

4.7 Model Discussion

The model works well as it is fully autonomous, requiring only the user inputs of a proposed scenario. Results are given for all seepage analysis types and any desired seepage mitigation. Microsoft Excel is a good choice of program for the model to run in as it is simple to use and many users already have some familiarity with the its operation.

The model is currently limited to analyse 10 sections or less, but could be easily modified to incorporate as many sections as desired. Another limitation with the model is the lack of graphical output. Many cells full of numbers can be difficult to analyse for some users and graphs would help in making the outputs easier to read. This is something that could be easily incorporated in future iterations.

5 Case Study Results

This chapter contains a summary of the results for the selected case studies. For ease in reading, the results over the entire channel are displayed rather than every individual section. Graphs have also been provided for further analysis.

5.1 Buckinbah B2/2 Channel

5.1.1 Analysis Overview

The Buckinbah B2/2 channel was analysed according to the three seepage calculation options as outlined in Section 3.3, soil type analysis, Mortiz formula and the site measured seepage values. All mitigation measures were considered individually and the results are shown in the tables and figures listed within Section 5.1. The full results as shown by the seepage model are listed in Appendix B. A qualitative benefit analysis was also considered to aid in the selection of a suitable seepage mitigation measure.

5.1.2 Seepage Losses Before Mitigation

A range of seepage losses before mitigation were determined for each analysis type over the Buckinbah channel section. These results are shown in Table 5.1.

Table 5.1: Seepage losses before mitigation for Buckinbah B2/2

Seepage Calculation	**Volume Lost [ML.day^{-1}]**
Soil Type Analysis	0.864 to 2.39
Moritz Formula	1.26 to 2.18
Measured Value	0.0871 to 0.145

It is clear to see from Table 5.1 that the soil type analysis and Moritz formula have similar results, but the measured value has a much lower loss.

5.1.3 Effects After Mitigation

The effects on the channel after mitigation in Buckinbah B2/2 were compared to the volumes lost to obtain a range of volumes saved for each mitigation measure and seepage analysis type. The costs were then calculated and compared to the price of water to obtain either a profit or loss for each scenario. These results are shown in Table 5.2.

Table 5.2: Effects after mitigation for Buckinbah B2/2

		Mitigation Measures						
Seepage Calc.	**Unit**	Asphalt	Compaction (in-situ)	Compaction of Imported Clay	Concrete	HDPE (2mm)	LDPE (1.5mm)	Rice Hull Ash
Soil Type Analysis	Volume Saved Over Channel [ML.year^{-1}]	283.88 to 785.27	233.41 to 479.89	283.88 to 610.77	299.65 to 610.77	293.34 to 811.45	296.5 to 820.17	189.25 to 436.26
	Cost per ML Over Channel [$.ML^{-1}]	60,076 to $166,182	$21,066 to $43,310	$18,758 to $40,358	$34,758 to $70,846	$10,066 to $27,845	$20,386 to $56,393	$17,889 to $41,237
	Profit or Loss per ML Over Channel [$.ML^{-1}]	-$166,078 to -$59,972	-$43,206 to -$20,962	-$40,255 to -$18,654	-$70,742 to -$34,654	-$27,741 to -$9,962	-$56,289 to -$20,283	-$41,133 to -$17,785
Moritz Formula	Volume Saved Over Channel [ML.year^{-1}]	414.32 to 717.09	340.66 to 438.22	414.32 to 557.73	437.33 to 557.73	428.13 to 740.99	432.73 to 748.96	276.21 to 398.38
	Cost per ML Over Channel [$.ML^{-1}]	$65,788 to $113,864	$23,069 to $29,675	$20,542 to $27,653	$38,063 to $48,542	$11,023 to $19,079	$22,325 to $38,639	$19,590 to $28,255
	Profit or Loss per ML Over Channel [$.ML^{-1}]	-$113,761to -$65,684	-$29,571 to -$22,965	-$27,549 to -$20,438	-$48,438 to -$37,959	-$18,975 to -$10,919	-$38,536 to -$22,221	-$28,151 to -$19,486
Measured Value	Volume Saved Over Channel [ML.year^{-1}]	28.607 to 47.679	23.522 to 29.137	28.607 to 37.084	30.197 to 37.084	29.561 to 49.268	29.879 to 49.798	19.072 to 26.488
	Cost per ML Over Channel [$.ML^{-1}]	$989,447 to $1,649,078	$346,949 to $429,779	$308,950 to $400,490	$572,466 to $703,028	$165,789 to $276,316	$335,765 to $559,609	$294,629 to $409,207
	Profit or Loss per ML Over Channel [$.ML^{-1}]	-$1,648,974 to -$989,343	-$429,675 to -$346,845	-$400,387 to -$308,846	-$702,924 to -$572,362	-$276,212 to -$165,685	-$559,505 to -$335,661	-$409,103 to -$294,525

All the costs in Table 5.2 appear to be very high in terms of a price per ML. No available options return a profit when compared to the price of water in the St George area.

Figure 5.1 shows a graph of the volume saved using seepage mitigation in the Buckinbah B2/2 channel. For comparison, all three seepage calculations have been included for each available mitigation. This data was plotted from the information in Table 5.2. The upper and lower limits of the volumes saved have been plotted as a range on the chart.

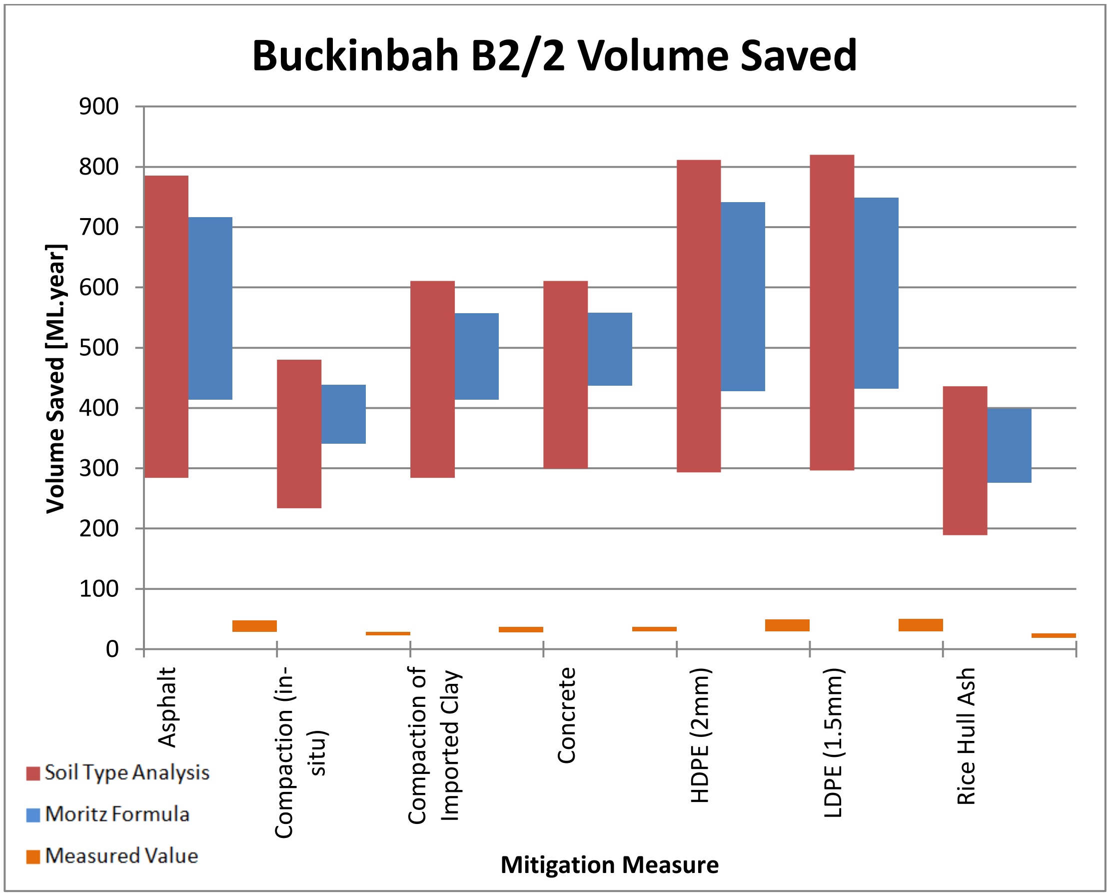

Figure 5.1: Possible range of volume saved for Buckinbah B2/2

Figure 5.1 magnitudes the difference between the estimated seepage values and the measured values for seepage. The plotted ranges help to compare different mitigation options and determine which is the most effective.

Figure 5.2 shows a graph of the installation costs of various mitigations in the Buckinbah B2/2 channel. For comparison, all three seepage calculations have been included for each available mitigation. This data was plotted from the information in Table 5.2. The upper and lower limits of the costs saved have been plotted as a range on the chart.

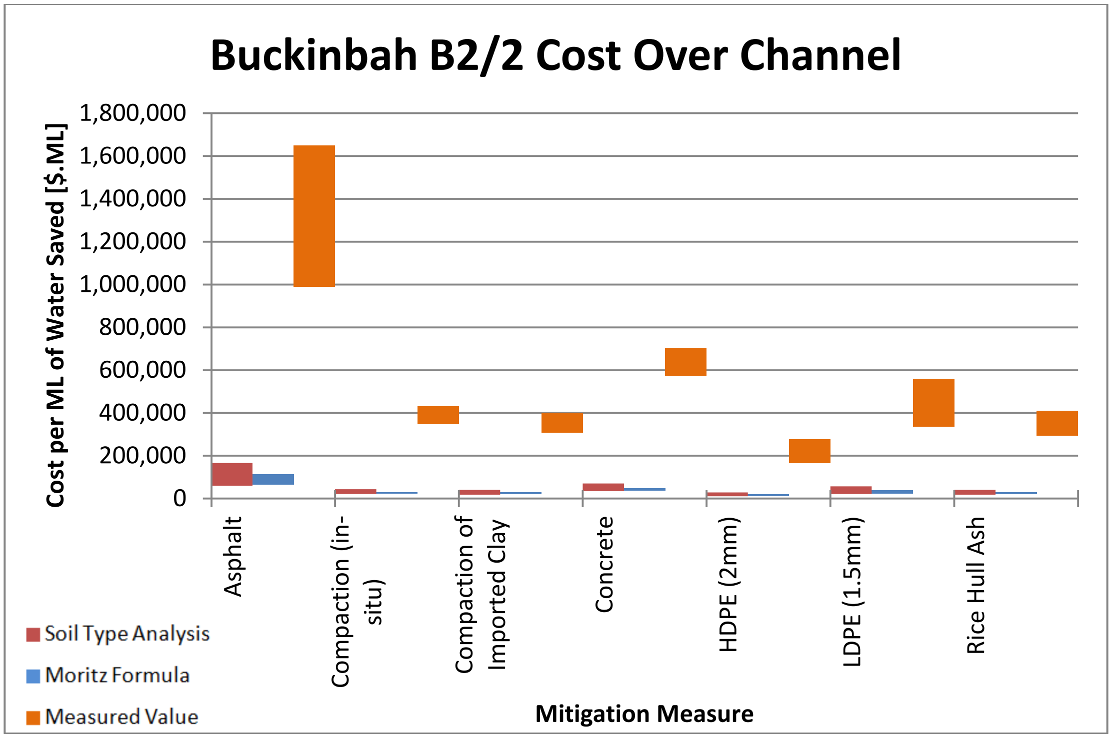

Figure 5.2: Possible range of mitigation costs for Buckinbah B2/2

Figure 5.2 is huge a contrast to Figure 5.1, as the measured values have now translated to the highest installation costs. Some mitigation measures like asphalt clearly stand above the rest for high costs, as there was less deviation between mitigations when no costs were considered.

5.1.4 Qualitative Benefit Analysis

As HDPE is the most cost effective mitigation measure, it is analysed further in Table 5.3 in accordance with some of the factors listed in Table 3.3. The weighting factors are to compare with the other available seepage mitigation options ranging from 1 being the lowest to 5 being the highest.

Table 5.3: A qualitative benefit analysis on HDPE in Buckinbah B2/2

Factor	**Weighting**	**Comment**
Ease of Installation	1	This low ranking is due to poor malleability of the material and the necessity for all joins to be heat sealed. HDPE is also difficult to install in wet or windy conditions or where there are extreme temperatures either hot or cold (ANCID 2004). The St George area can experience high winds and extreme heat, so these factors should be taken into account when scheduling installation.
Infrequent Channel Use	3	Infrequent channel use is unlikely to pose an issue, as the Buckinbah B2/2 channel is irrigated throughout the entire year.
Maintenance Costs	5	HDPE has one of the lowest maintenance costs making it not only the cheapest during construction, but also during its lifetime.
High Velocity Channels	3	High velocities are also unlikely to cause concern, as the channel has a very low capacity of 0.34 $m.s^{-1}$ allowing for a maximum velocity of 0.0267 $m.s^{-1}$ when the channel is flowing full (Fairley 2015).
Temperature Changes	3	Temperature changes may also be an issue for the extreme heat often experienced in the St George area, however HDPE compares well to other available options.

HDPE has relatively positive weighting factors compared to other mitigation options. Some of the factors can also be discarded due to the characteristics of the channel such as the high velocity or infrequent channel use. From both the quantitative and qualitative analyses, HDPE would still be the most suitable option for mitigating seepage in the Buckinbah B2/2 channel. The lowest installation and maintenance costs are at an advantage as well as the long life and durability of the material.

5.2 Booyan Main Channel

The Booyan Main Channel was analysed according to the three seepage calculation options as outlined in Section 3.3, soil type analysis, Mortiz formula and the site measured seepage values. All mitigation measures were considered individually and the results are shown in the tables and figures listed within Section 5.2. All earthen sections of the Booyan Main Channel were included for this analysis and the listed results show the outputs over the entire channel. The full results as shown by the seepage model are listed in Appendix C. A qualitative benefit analysis was also considered to aid in the selection of a suitable seepage mitigation measure.

5.2.1 Seepage Losses Before Mitigation

A range of seepage losses before mitigation were determined for each analysis type over the Booyan Main channel for all sections. These results are shown in Table 5.4.

Table 5.4: Seepage losses before mitigation for Booyan MC

Seepage Calculation	Volume Lost [$ML.day^{-1}$]
Soil Type Analysis	8.22 to 9.93
Moritz Formula	8.08
Measured Value	0.701

Again the Moritz formula result falls within the range of the estimated seepage from soil type analysis, but the measured value is well below these estimates.

5.2.2 Effects After Mitigation

The effects on the channel after mitigation in the Booyan MC were compared to the volumes lost to obtain a range of volumes saved for each mitigation measure and seepage analysis type as well as the costs and profit/loss margin. These results are shown in Table 5.5.

Table 5.5: Effects after mitigation for Booyan MC

		Mitigation Measures						
Seepage Calc.	**Unit**	Asphalt	Compaction (in-situ)	Compaction of Imported Clay	Concrete	HDPE (2mm)	LDPE (1.5mm)	Rice Hull Ash
Soil Type Analysis	Volume Saved Over Channel [ML.year^{-1}]	2717.1 to 3260.5	1992.5 to 2234.1	2536 to 2717.1	2536 to 2868.1	2807.7 to 3369.2	2837.9 to 3405.4	1811.4
	Cost per ML Over Channel [$.ML^{-1}]	$317,329 to $380,794	$99,242 to $111,271	$92,479 to $99,084	$162,339 to $183,597	$53,171 to $63,805	$107,684 to 129,221	$94,491
	Profit or Loss per ML Over Channel [$.ML^{-1}]	-$379,382 to -$315,917	-$109,859 to -$97,830	-$97,672 to -$91,067	-$182,185 to -$160,927	-$62,393 to -$51,759	-$127,809 to -$106,272	-$93,079
Moritz Formula	Volume Saved Over Channel [ML.year^{-1}]	2654.2	1622 to 2182.3	2064.4 to 2654.2	2064.4 to 2801.6	2742.6	2772.1	1474.5 to 1769.5
	Cost per ML Over Channel [$.ML^{-1}]	$390,061	$101,657 to $136,775	$94,729 to $121,795	$166,289 to $225,678	$65,358	$132,366	$96,791 to $116,149
	Profit or Loss per ML Over Channel [$.ML^{-1}]	-$388,649	-$135,363 to -$100,245	-$120,383 to -$93,317	-$244,266 to -$164,877	-$63,946	-$130,954	-$114,737 to -$95,379
Measured Value	Volume Saved Over Channel [ML.year^{-1}]	230.41	140.81 to 189.45	179.21 to 230.41	179.21 to 243.21	238.09	240.65	128.01 to 153.61
	Cost per ML Over Channel [$.ML^{-1}]	$4,490,499	$1,170,304 to $1,574,591	$1,090,550 to $1,402,135	$1,914,371 to $2,598,074	$752,417	$1,523,835	$1,114,285 to $1,337,142
	Profit or Loss per ML Over Channel [$.ML^{-1}]	-$4,489,087	-$1,573,179 to -$1,168,892	-$1,400,723 to -$1,089,138	-$2,596,662 to -$1,912,959	-$751,005	-$1,522,423	-$1,335,730 to -$1,112,873

All the costs in Table 5.5 again appear to be very high in terms of a price per ML. No available options return a profit when compared to the price of water in the Bundaberg area.

Figure 5.3 shows a graph of the volume saved using seepage mitigation in the Booyan Main Channel. For comparison, all three seepage calculations have been included for each available mitigation. This data was plotted from the information in Table 5.5. The upper and lower limits of the volumes saved have been plotted as a range on the chart.

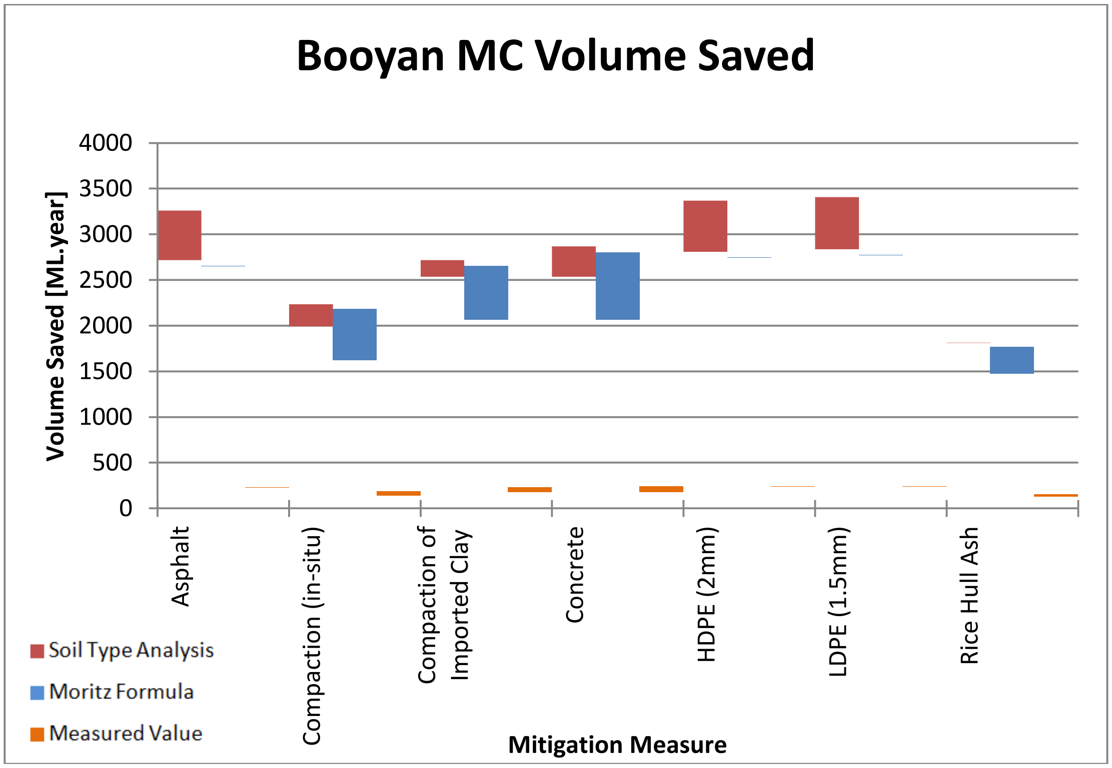

Figure 5.3: Possible range of volume saved for Booyan MC

Some of the results from Table 5.5 were singular values rather than a range. This is why some of the columns in Figure 5.3 appear as thin lines, as they represent a single value for the volume saved. There appears to be more of a variance between mitigation options when looking at the effectiveness of each compared to the Buckinbah B2/2 channel. Again the magnitude of differences can be seen between the measured values and estimated seepage values.

Figure 5.4 shows a graph of the installation costs of various mitigations in the Booyan MC created from the data in Table 5.5.

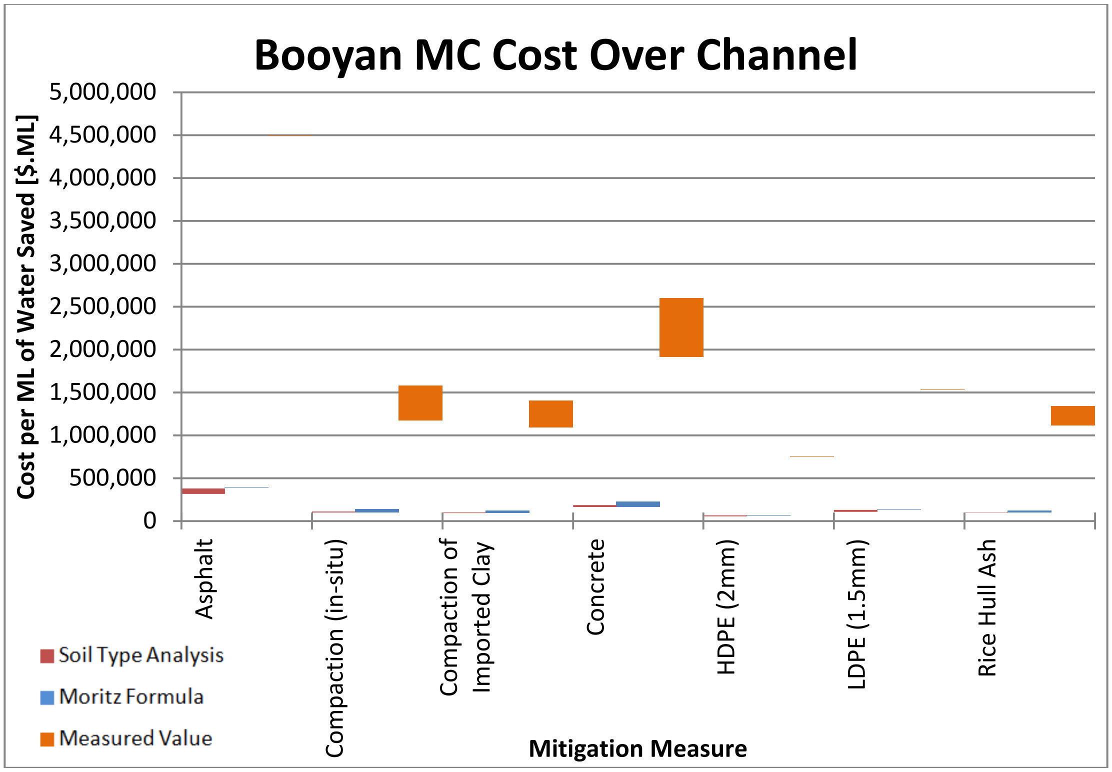

Figure 5.4: Possible range of mitigation costs for Booyan MC

Asphalt again is the highest cost mitigation per ML of water saved and thus skews all other values on the graph. The singular value for the measured seepage of asphalt can be seen at around $4,500,000 per ML as thin orange line. It is difficult to see any of the other ranges for soil type analysis and the Moritz formula because of this skew, however it can be seen that the measured values clearly result in higher installation costs.

5.2.3 Qualitative Benefit Analysis

As HDPE is again the most cost effective mitigation measure, it is analysed further in Table 5.6 in accordance with some of the factors listed in Table 3.3. The weighting factors are to compare with the other available seepage mitigation options ranging from 1 being the lowest to 5 being the highest.

Table 5.6: A qualitative benefit analysis on HDPE in Booyan MC

Factor	**Weighting**	**Comment**
Ease of Installation	1	The Bundaberg area can experience high temperatures, so should be considered during the installation process.
Infrequent Channel Use	3	The Booyan MC is operational all year, so this factor will not be problematic in the decision making.
Maintenance Costs	5	HDPE has one of the lowest maintenance costs making it not only the cheapest during construction, but also during its lifetime.
Damage Resistance	3	Damage resistance is low compared to the other available mitigation options. Studies would have to be conducted to determine if the channel is prone to damage from animals or human interference.
Temperature changes	3	Temperature changes may also be an issue for the Bundaberg area due to the heat experienced in the summer months. The changes from hot to cold throughout the year may have an effect on the Booyan Channel lining. However compared to the other available options, HDPE performs quite well in this area.

HDPE has relatively positive weighting factors compared to other mitigation options. There are no factors which would discard HDPE from being a suitable option for this area. From both the quantitative and qualitative analyses, HDPE would still be the most suitable option for mitigating seepage in the Booyan Main Channel. The lowest installation and maintenance costs are at an advantage as well as the long life and durability of the material.

5.3 Donald Main Channel

The Donald Main Channel was analysed according to the three seepage calculation options as outlined in Section 3.3, soil type analysis, Mortiz formula and the site measured seepage values. All mitigation measures were considered individually and the results are shown in the tables and figures listed within Section 5.3. The two high loss sections of the Donald Main Channel were included for this analysis and the listed results show the outputs over the entire channel. The full results as shown by the seepage model are listed in Appendix D. A qualitative benefit analysis was also considered to aid in the selection of a suitable seepage mitigation measure.

5.3.1 Seepage Losses Before Mitigation

A range of seepage losses before mitigation were determined for each analysis type over the Donald Main channel for the two sections. These results are shown in Table 5.7.

Table 5.7: Seepage losses before mitigation for Donald MC

Seepage Calculation	**Volume Lost [ML.day^{-1}]**
Soil Type Analysis	20.8 to 33.2
Moritz Formula	25.9
Measured Value	2.27 to 6.08

Although the measured seepage for the Donald MC was higher than the other two case studies, the volume lost for the measured value is still well below the estimated values.

5.3.2 Effects After Mitigation

The effects on the channel after mitigation in the Donald MC were compared to the volumes lost to obtain a range of volumes saved for each mitigation measure and seepage analysis type as well as the costs and profit/loss margin. These results are shown in Table 5.8.

Table 5.8: Effects after mitigation for Donald MC

		Mitigation Measures						
Seepage Calc.	**Unit**	Asphalt	Compaction (in-situ)	Compaction of Imported Clay	Concrete	HDPE (2mm)	LDPE (1.5mm)	Rice Hull Ash
Soil Type Analysis	Volume Saved Over Channel [$ML.year^{-1}$]	5102.7 to 8155.4	4195.6 to 4983.9	5102.7 to 6343.1	5386.2 to 6343.1	5272.8 to 8427.3	5329.5 to 8517.9	3401.8 to 4530.8
	Cost per ML Over Channel [$\$.ML^{-1}$]	$155,683 to $248,821	$54,590 to $64,847	$48,611 to $60,428	$90,074 to $106,076	$26,086 to $41,692	$52,831 to $84,437	$46,358 to $61,743
	Profit or Loss per ML Over Channel [$\$.ML^{-1}$]	-$248,716 to -$155,578	-$64,742 to -$54,485	-$60,323 to -$48,506	-$105,971 to -$89,969	-$41,587 to -$25,981	-$84,332 to -$52,726	-$61,638 to -$46,253
Moritz Formula	Volume Saved Over Channel [$ML.year^{-1}$]	6372.5	3894.3 to 5239.6	4956.4 to 6372.5	4956.4 to 6726.6	6584.9	6655.8	3540.3 to 4248.4
	Cost per ML Over Channel [$\$.ML^{-1}$]	$199,240	$51,925 to $69,863	$48,387 to $62,212	$84,939 to $115,274	$33,384	$67,611	$49,440 to $59,328
	Profit or Loss per ML Over Channel [$\$.ML^{-1}$]	-$199,135	-$69,758 to -$51,820	-$62,107 to -$48,282	-$115,169 to -$84,834	-$33,279	-$67,506	-$59,223 to -$49,335
Measured Value	Volume Saved Over Channel [$ML.year^{-1}$]	557.06 to 1492.9	458.03 to 912.35	557.06 to 1161.2	588.01 to 1161.2	575.63 to 1542.7	581.82 to 1559.3	371.38 to 829.41
	Cost per ML Over Channel [$\$.ML^{-1}$]	$850,449 to $2,279,202	$298,209 to $594,001	$265,548 to $553,521	$492,045 to $971,660	$142,499 to $381,878	$288,597 to $773,439	$253,239 to $565,568
	Profit or Loss per ML Over Channel [$\$.ML^{-1}$]	-$2,279,097 to -$850,344	-$593,896 to -$298,104	-$553,416 to -$265,443	-$971,555 to -$491,940	-$381,793 to -$142,394	-$773,334 to -$288,492	-$565,463 to -$253,134

All the costs in Table 5.8 again appear to be very high in terms of a price per ML. No available options return a profit when compared to the price of water in the Birchip area.

Figure 5.5 shows a graph of the volume saved using seepage mitigation in the Donald Main Channel. For comparison, all three seepage calculations have been included for each available mitigation. This data was plotted from the information in Table 5.8. The upper and lower limits of the volumes saved have been plotted as a range on the chart.

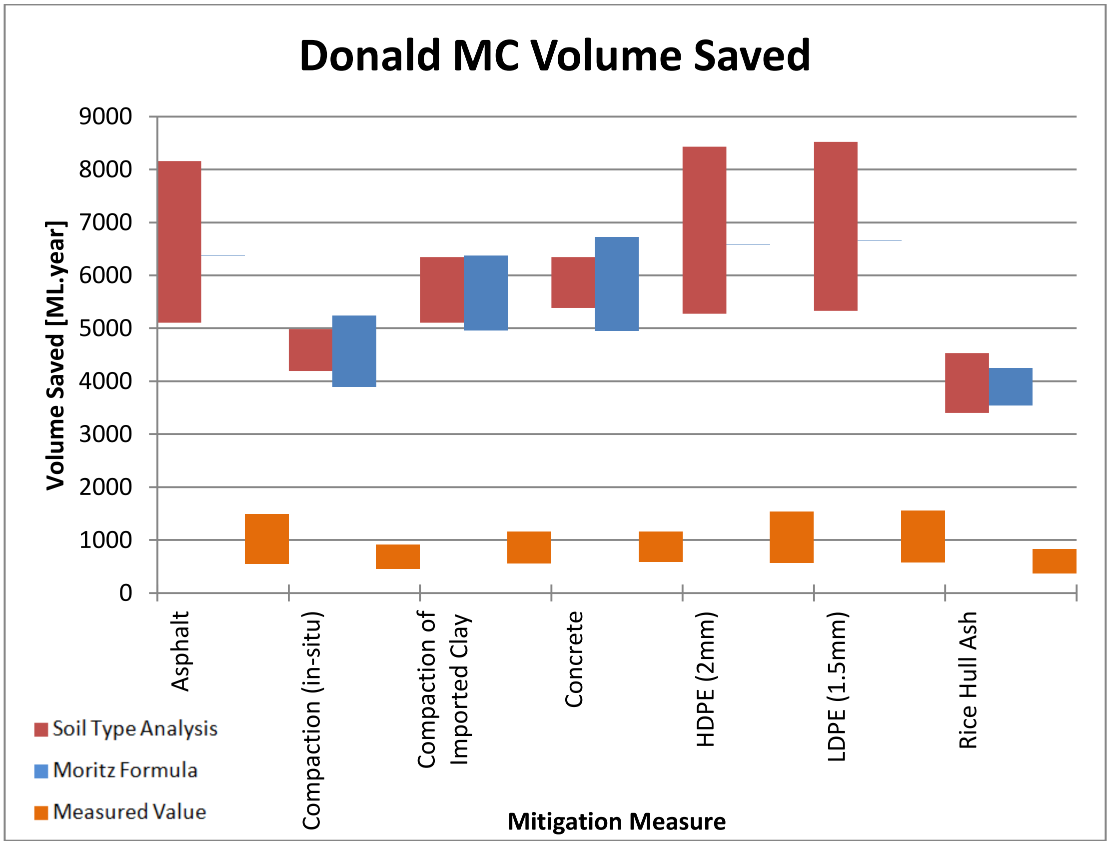

Figure 5.5: Possible range of volume saved for Donald MC

Again the magnitude of differences can be seen between the measured values and estimated seepage values. The ranges of volume saved appear to be smaller than those shown in the other two case studies.

Figure 5.6 shows a graph of the installation costs of various mitigations in the Donald MC created from the data in Table 5.8.

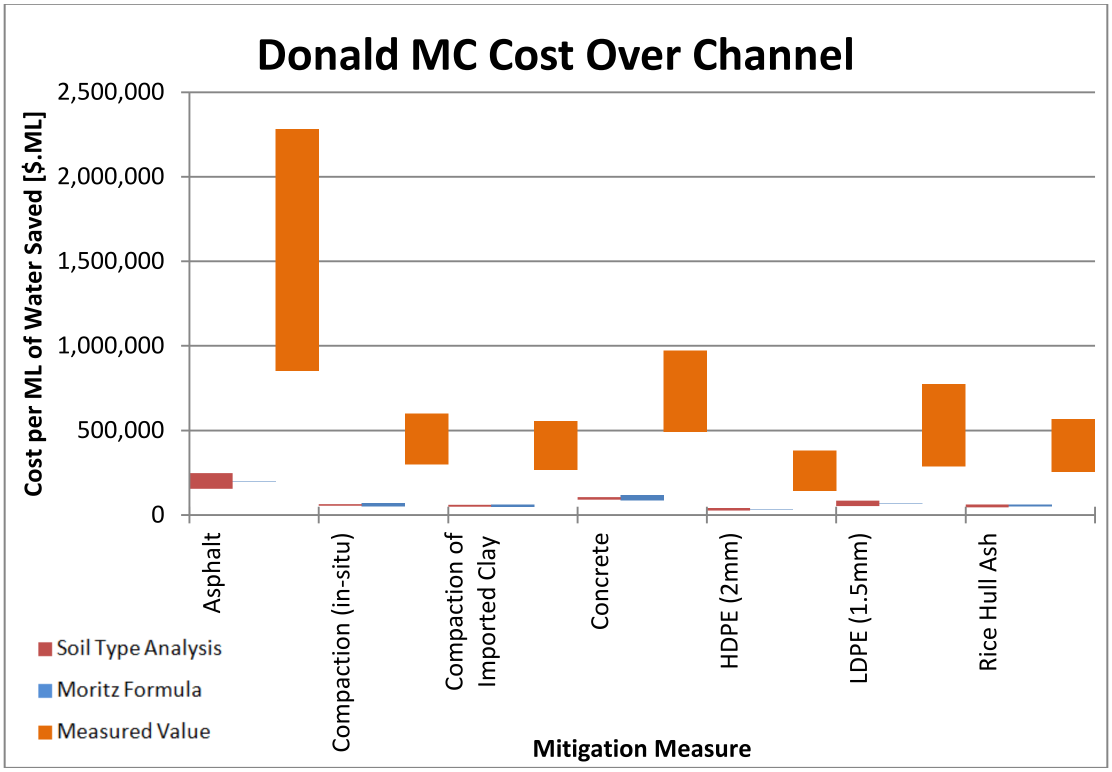

Figure 5.6: Possible range of mitigation costs for Donald MC

Asphalt again is the highest cost mitigation per ML of water saved and thus skews all other values on the graph. The range of costs for asphalt when analysed with the measured seepage values is greater than Buckinbah B2/2 or Booyan MC. HDPE appears to be the lowest cost option in all cases.

5.3.3 Qualitative Cost-Benefit Analysis

As HDPE is again the most cost effective mitigation measure, it is analysed further in the Table 5.9 in accordance with some of the factors listed in Table 3.3. The weighting factors are to compare with the other available seepage mitigation options ranging from 1 being the lowest to 5 being the highest.

Table 5.9: A qualitative benefit analysis on HDPE in Donald MC

Factor	**Weighting**	**Comment**
Ease of Installation	1	The Birchip area can experience high and low temperatures, so should be considered during the installation process. A mild day should be considered for installation.
Infrequent Channel Use	3	The Donald MC is not operational all year around, so this factor should be considered with care. The other mitigation options however do not have any greater performance than HDPE in this area, making it a good selection for this channel.
Maintenance Costs	5	HDPE has one of the lowest maintenance costs making it not only the cheapest during construction, but also during its lifetime.
High Velocity Channels	3	HDPE performs relatively well in comparison with other options. However irrigation channels generally do not have high velocities.
Temperature changes	3	Temperature changes may also be an issue for the Birchip area due to the heat experienced in the summer months and the high contrast of cold during the winter. However compared to the other available options, HDPE performs quite well in this area.

HDPE has relatively positive weighting factors compared to other mitigation options. There are no factors which would discard HDPE from being a suitable option for this area. The main issue is the shutdown of channel operation throughout the year, however HDPE is still the best performer here. From both the quantitative and qualitative analyses, HDPE would still be the most suitable option for mitigating seepage in the Donald Main Channel. The lowest installation and maintenance costs are at an advantage as well as the long life and durability of the material.

6 Analysis and Discussion

6.1 Measured vs Estimated Seepage Losses

6.1.1 Case Studies Analysis

The measured values for seepage losses were always much lower than the estimated values as given by soil types found from the literature and the Moritz formula. Fairley (2015) measured a field value for seepage in the Buckinbah B2/2 channel of 6 to 10 $L.m^{-2}.day^{-1}$. This is a very low seepage value, however it is already a compacted earth channel. When estimating seepage with literature soil type analysis values, compaction must be taken into account for the estimation. It was then found that the losses would be between 59.54 and 164.7 $L.m^{-2}.day^{-1}$ which is higher than the measured values would suggest by a factor of 10. When the losses are calculated over the whole channel, the resultant is in $ML.day^{-1}$. We can find that the soil type analysis method for seepage estimates around 0.86417 to 2.3905 $ML.day^{-1}$ where as the measured values give 0.087085 to 0.14514 $ML.day^{-1}$ (as found in Table 5.1) which is 10 to 16 times smaller. The results of the Moritz formula are within a reasonable margin of the calculations based on soil type from the literature (with the average values within 7% of each other). This could suggest that a formula in some form has been used to derive the seepage values for a range of soil types rather than measured values.

A similar problem exists for the Booyan Main Channel where a measured seepage loss exists of only 10.6 $L.m^{-2}.day^{-1}$. The channel has no existing seepage mitigation and yet an unusually low measured seepage loss where other studies have suggested that a clay and clayey loam channel could typically expect between 125 and 150 $L.m^{-2}.day^{-1}$. Again the Moritz formula derives a seepage value very close to what the literature suggests with the average seepage values being within 13% of each other. However as can be observed in Table 6.1, the Booyan MC measured value for seepage on the site is significantly less than the estimated methods.

Table 6.1: A comparison of the volume lost before mitigation for all three case studies

	Volume Lost [$ML.day^{-1}$]		
Seepage Calculation	**Buckinbah B2/2**	**Booyan MC**	**Donald MC**
Soil Type Analysis	0.864 to 2.39	8.22 to 9.93	20.8 to 33.2
Moritz Formula	1.26 to 2.18	8.08	25.9
Measured Value	0.0871 to 0.145	0.701	2.27 to 6.08

The 1998 case study by Wallaree Mallee Water and Sinclaire Knight Merz found greater seepage losses than what was measured in the Bundaberg and St George Regions. In the unmitigated sand and clay based Donald Main Channel, seepage varied between 25 and 67 $L.m^{-2}.day^{-1}$. Existing studies have found this soil to generally seep between 229 and 366 $L.m^{-2}.day^{-1}$, again more than the physical seepage measurement on site (in this case by a factor of 6), but closer than the two Queensland case studies.

6.1.2 Supporting Research

Smith (1982) conducted a study into channel seepage in the Murray-Darling Basin and found a general trend of much lower measured seepage rates in the region than those rates which were suggested by previous studies. Much of the study into channel seepage has been conducted overseas, primarily in the United States where seepage rates were found to be much higher than the Murray Darling Basin region (Smith 1982). Smith suggested that much of this data would not be relevant because of the significant differences. A suggestion of 30 $L.m^{-2}.day^{-1}$ or less was made by Kraatz (1971) for an effective threshold for channel seepage after mitigation had been applied, but Smith (1982) reports that this value is already greater than the seepage typically observed in an unaltered channel in the Goulburn Murray Irrigation District. Whilst Smith has made this assumption for the channel situation in regional Victoria, the case studies analysed in Queensland suggest that this rule may be applied to other areas of Australia also.

6.1.3 Aging of Channels

Research has been conducted by various parties into the concept of channel aging. Channel aging is where over time a channel will begin to develop its own natural lining to mitigate seepage (Smith 1982). It has even been observed that natural linings can give comparable seepage mitigation rates to artificial methods.

Smith (1973) conducted a case study into a channel in the Shepparton East region. It was found from mathematical modelling of the soils in the area that the channel had potential for seepage rates of 975 $L.m^{-2}.day^{-1}$, but measurements on site were only 38 $L.m^{-2}.day^{-1}$. Smith emphasised the importance of natural linings and suggested that this may be a cause for the large differences in seepage values.

The case study by Smith (1973) helps to explain the observed differences in the proposed seepage model. The estimated seepages are always larger than the measured seepage values on site for the tested case studies, sometimes by up to 16 times. The ageing of channels may account for some of the observed differences.

6.1.4 Ongoing Investigation

In all of the tested case studies (Buckinbah B2/2, Booyan MC, Donald MC), the estimated seepage from the soil type and the Moritz formula were all significantly higher than the values measured on site. As discussed in Section 6.1.2, much of the data for soil seepage has been conducted overseas where the seepage rates are typically higher than those observed in Australia. The natural ageing of channels also contributes to the large differences between measured and estimated seepage. Between these two factors, justification can be found for the observed differences, but other factors may also be involved.

Further studies should be conducted in Australia to have a more comprehensive guide on the amount of seepage that can be expected between various soil types. From this, an Australian specific formula could be developed to more accurately estimate seepage values. The natural aging of channels could also be factored in to estimate how the seepage rate changes over time. With this further investigation, Australia would not have to depend on the existing research which far overestimates the actual seepage rates.

6.2 Typical Water Savings for Mitigation Measures

6.2.1 Case Studies Analysis

Analysing the Buckinbah B2/2 channel case study, it can be found that LDPE seepage (when calculating seepage values with soil type analysis) has the highest volume saved of 296.5 to 820.17 $ML.year^{-1}$, however the concrete lining saves water in the range of 299.65 to 610.77 $ML.year^{-1}$ with the highest 'lower limit' comparable to the other methods.

It can be observed with all the mitigation methods using soil type analysis that the range of volumes saved is quite broad (in some cases up to 500 $ML.year^{-1}$ between the high and low ranges). The ranges of values for the volume saved also often overlap or are contained within one another (as shown in Figure 5.1 with the soil type analysis displayed in red) and are therefore difficult to analyse as ranges. When an average value is adopted for the range of volume saved in $ML.year^{-1}$, the following ranking can be found (see Table 6.2).

Table 6.2: Ranking of most effective mitigation to least in Buckinbah B2/2 using soil type analysis

Rank	Mitigation Method
1	LDPE (1.5mm)
2	HDPE (2mm)
3	Asphalt
4	Concrete
5	Compaction of Imported Clay
6	Compaction (in-situ)
7	Rice Hull Ash

This trend continues through all the seepage calculations for Buckinbah B2/2, as well as for the other two case studies analysed. LDPE is always the most effective, followed by HDPE and asphalt as shown in Table 6.2.

6.2.2 Most Effective Mitigation

LDPE is always this most effective mitigation option, regardless of the channel or the method used to calculate seepage. This is due to the values of mitigation effectiveness as obtained from the literature (see Table 3.2). LDPE has an effectiveness of 94% which is the highest comparable to all the other options. Concrete mitigates seepage from 70 to 95%, which explains the higher 'upper limit' of the volume saved for concrete in the case study results. From these researched percentages it can be easily concluded that LDPE is 1% more effective than HDPE, 4% more effective than asphalt and up to 24% more effective than concrete.

6.2.3 Other Observations

Due to the way the saved volume is calculated, LDPE will always give the best average case for seepage mitigation. Existing research suggests that an expressed percentage for seepage mitigation effectiveness will always be constant, regardless of the soil or other conditions. The seepage model by ANCID (2004) also works in this way. Further research should be carried out to determine if the effectiveness of the mitigation is reasonably consistent across various soil types.

6.3 Typical Costs of Mitigation Measures

6.3.1 Case Studies Analysis

Looking at the proposed case studies, a clear pattern can be seen. Asphalt as a seepage mitigation method is always the most expensive option. For the Buckinbah B2/2 channel, asphalt works out to a cost of $989,447 to $1,649,078 per ML when using the onsite measured values for seepage. This is over $200,000 higher than the second most expensive option, concrete. Most other mitigation options are in the range of $200,000 to $500,000 per ML when using measured seepage values meaning that asphalt can be up to three or four times more expensive than other available options. This trend is easily seen in Figure 5.2 where the costs for asphalt clearly stand above the other mitigation options for the measured seepage values (displayed as the orange columns). When seepage is calculated with the soil type analysis and Moritz formula, the same trend for asphalt is present. The costs for asphalt are double the costs for concrete and 3 or 4 times more than most of the other mitigation options. It is difficult to see this in Figure 5.2, as the high costs for asphalt with measured values skews the graphs lower values.

For the Booyan and Donald main channels, it can also be observed that asphalt has the highest cost per ML saved. This difference is always around three or four times more expensive than most of the other seepage mitigation options. Concrete is also always the second most expensive option, being around half the cost of asphalt per ML of water saved.

The most cost effective option is the High Density Polyethylene channel lining consistently for the three analysed case studies. It was estimated that the cost of lining the Buckinbah B2/2 channel with HDPE is $165,789 to $335,765 per ML saved when using measured seepage values. This is five times less than the most expensive option, asphalt. The Booyan and Donald channel case studies also show that HDPE is the cheapest option for mitigating channel seepage.

6.3.2 Lowest Cost Mitigation

HDPE has been shown to be the most cost effective option for mitigating channel seepage under the simulated conditions in the case studies. LDPE which was the most effective seepage mitigation is now ranked much lower when costs are taken into account. Table 6.3 shows the ranking of the most cost effective seepage mitigations as found by one of the case study scenarios.

Table 6.3: Ranking of most cost effective mitigation to least in Buckinbah B2/2 using measured values

Rank	Mitigation Method
1	HDPE (2mm)
2	Rice Hull Ash
3	Compaction of Imported Clay
4	Compaction (in-situ)
5	LDPE (1.5mm)
6	Concrete
7	Asphalt

This ranking is the same for all of the case studies except for the Buckinbah B2/2 channel when soil type analysis is used to calculate seepage. In this case the ordering of ranks 2 and 3 are swapped around.

This ranking list in Table 6.2 contrasts Table 6.1 where the most effective mitigation options are listed. LDPE was previously found to always save the most water compared to the other available options however the ranking of LDPE has been dropped to a 5 when costs are considered. HDPE, while less effective than LDPE has a much lower cost at only $12.12 per square metre compared to the relatively higher cost of LDPE’s $16.54 per square metre. HDPE also has an expected life 10 years longer than that of LDPE.

6.3.3 Other Observations

Another interesting difference to note between the most effective mitigation option and most cost effective option is the change of the rice hull ash position from 7 to 2. Whilst rice hull ash was the poorest performer in terms of volume saved, the low cost of the material outweighs this factor and makes it one of the more suitable choices for seepage mitigation. Rice hull ash works out to only $3.86 per square metre, which is more than 60% cheaper than the next available option.

The reasoning behind asphalt's high installation costs is due to the expected life of the material. Asphalt lasts only 15 years and has a relatively high cost of $35 per square metre. Comparing this to concrete which has an expected life of 50 years and a cost of $52.50 per square metre, two applications of asphalt will be made within the lifetime of the concrete, and the concrete will still be a more cost effective option. As discussed earlier, concrete is usually twice as cheap as asphalt expressed in $\$.ML^{-1}$.

6.4 Cost Benefit of Mitigation Measures

6.4.1 Case Studies Analysis

When first analysing the Buckinbah B2/2 channel, it is clear to see that there are negative net benefits with all the proposed mitigation options. In the case of the measured values for seepage, there can be a financial loss of up to $1.6 million dollars per ML when using asphalt. Whilst this is a ridiculous case and would never be funded, even the lowest values seen for this case study are still in the range of almost $-10,000 per ML. This figure is found for HDPE when seepage is calculated using the soil type analysis. There will always be negative net benefits for Buckinbah B2/2 due to the high mitigation costs and the comparative low value of water. Water in the St George area is leased for only $103.88 per ML, much lower than the costs of any of the mitigation options. The rankings for measured seepage from Table 6.2 will remain the same, as the costs are subtracted from the water values and thus do not affect the order of selections. This will be true for all cases.

For the Booyan Main Channel, the costs are even higher than the Buckinbah channel. Financial losses range from $51,000 to $4.5 million dollars per ML across the various mitigation options. HDPE again has fewer losses than the other options with financial losses of $51,759 to $62,393 per ML with soil type seepage analysis, $63,946 per ML with the Moritz formula and $751,005 per ML using the measured site value. Bundagerg's price of water is slightly higher than the St George area at $176 per ML when leased. This price however makes little difference when all the costs of mitigation are upwards of $50k per ML.

The Donald Main Channel also suffers huge potential economic losses when seepage mitigation is analysed. The worst cases can be seen when asphalt is selected using the measured seepage values with a financial loss of up to $2,279,097 per ML. The price of water in this area is $52.51 per ML leased, again far too low for any monetary gains when mitigating channel seepage.

6.4.2 Most Cost Beneficial Mitigation

HDPE continues to be the most cost effective option compared to all the other mitigation measures. As mentioned previously, the comparing the costs of the mitigation to the costs of the water will not change the order of cost effectiveness. While HDPE is the most cost effective option, it still has a very high cost, resulting in huge negative net benefits when analysed against the price of water.

For HDPE to be a viable option, the price of water would need to be much higher than it currently is. In the Buckinbah B2/2 Channel, water would need to have a value of at least $165,790 per ML for any profit to be made when using the measured seepage values. This is almost 1,600 times more expensive than it currently is.

6.4.3 Justification of Costs

The losses in all the channel case studies were incredibly high for all the seepage mitigation options. The issue was not in the value of water, but rather the high installation costs. For savings to be made, the water costs would need to be around $10,000 per ML at a minimum in the Buckinbah B2/2 channel. No water will ever be this valuable, considering it works out to $10 per litre.

Another factor to be considered is that only installation costs have been calculated and no ongoing maintenance costs were included. Allowing for maintenance costs (which the model has the capability of doing) would escalate costs even further.

There would have to be significantly more than monetary gains from seepage losses for any project like this to be approved. For example, a HDPE lining in the Buckinbah B2/2 channel would save around 29.9 to 49.8 ML per year (when using site measured seepage values) but the negative net benefits are in the range of $335,661 to $559,505 per ML saved, resulting in a total financial loss of $10,036,264 to $27,863,349 every year for the water saved with the lining. The Buckinbah and Donald Main Channels also have high economic losses when lined with HDPE with costs of $178,806,780 and $81,966,258 to $588,992,061 per year respectively. None of these cases would be a worthwhile pursuit for seepage mitigation as a standalone project. Significant dollars would have to be saved elsewhere for any of these mitigation measures to be feasible.

These installation costs may be significantly less if the seepage mitigation is considered as part of a channel upgrade or routine maintenance. Some channel remodelling would already be taking place and could therefore be subtracted from the capital costs of seepage mitigation. Costs would also be saved in the hire of equipment and employees.

6.4.4 Measured Seepage Values

It is clear from all of the case studies that although the measured values for seepage are well below the estimated values, there are still major monetary losses for all seepage analysis types. The fact that the model overestimates channel seepage by a factor of 10 makes little difference to profit or loss per ML of water saved. According to the three analysed case studies, there will always be a significant financial loss when installing measures to mitigate seepage. For any profit to be made in the Buckinbah B2/2 channel with water at the current pricing, the seepage losses would need to be upwards of 16,000 $L.m^{-2}.day^{-1}$. This figure more than eight times greater than seepage seen in very gravelly soil with an upper seepage limit of 1829 $L.m^{-2}.day^{-1}$.

6.5 Other Benefits

6.5.1 Case Studies Analysis

When HDPE was analysed against the other mitigation options for all the case studies, it was found to always be the most suitable option in regards to the listed factors in Table 3.3. These factors were ease of installation, infrequent channel use, maintenance costs, high velocity channels, damage resistance and temperature changes. The main factor where HDPE falls down is the ease of installation. This low ranking is due to poor malleability of the material and the necessity for all joins to be heat sealed. HDPE is also difficult to install in wet or windy conditions or where there are extreme temperatures either hot or cold (ANCID 2004).

6.5.2 Quantitative vs Qualitative Benefit Analysis

The qualitative benefit analysis did not change the result of which mitigation option to use. All mitigations had their own advantages and drawbacks, but no single mitigation had a sufficient combination of weighting factors to justify it over the most cost effective option.

If the results from the mitigation cost effectiveness had been within closer range of each other or there were profits instead of losses, a qualitative benefit analysis may have been a more important consideration in mitigation selection. The analysed case studies however make little difference with this qualitative analysis.

6.5.3 Benefits to Justify Costs

There may be other benefits to certain mitigations rather than cost savings for seepage which have not been discussed in this dissertation. Some mitigation may save costs in channel maintenance by preventing erosion. Materials like concrete would have a substantial effect on erosion prevention and materials like rice hull ash may have little impact. Other gains may be made in evaporation reduction, improvement of channel efficiency or greater safety for workers on site. Further work and research would need to be conducted into the possible additional benefits of seepage mitigation options.

7 Conclusions

This chapter summarises all the work done for this dissertation and the main results found. It also proposes further work for future investigation into Australian channel seepage.

7.1 Feasibility of Seepage Mitigation

7.1.1 Estimated Seepage Inconsistencies

From the results of this study, it can be clearly seen that there are major inconsistencies between the site specific measured seepage values and the seepage values estimated from the soil type analysis and Moritz formula. These methods overestimated the actual seepage values by a factor of 10 or more in most cases. The Donald Main Channel was the only exception to this rule, with seepage being overestimated by a factor of 6.

Evidence from the literature suggests that the overestimation of seepage is due to insufficient soil data for Australian channels. Much of the research into channel seepage has been conducted in the United States where the seepage values are typically higher than Australia. Many of Australia’s irrigation channels are constructed in hard clayey soils where seepage is already very low (Smith 1982).

This study found that measuring a seepage value on site is essential for any seepage mitigation project. The data available on estimated seepage for soil types is insufficient for a desktop analysis as it overestimates the actual seepage by a factor of 6 or more.

7.1.2 High Installation Costs

The analysed case studies showed that the cost of installation is always high for all types of mitigation. No analysed option had any costs less than around $10,000 per ML of water saved. Even considering that the estimated seepage values were too high for the proposed case studies, they did not make the proposed mitigation projects any more feasible. The installation costs were too high for all types of seepage analysis.

Despite the high installation costs, one seepage mitigation option was always more cost effective than the rest. HDPE was the best performer in comparison with all the other seepage mitigation measures.

7.1.3 High Losses

Due to the high installation costs, the financial losses were also very high. With the price of water ranging from around $50 to $200 per ML across the case studies, negative net benefits were always present when mitigation was considered. With mitigation costing thousands of dollars per ML saved, the result was millions of dollars to be potentially spent on recovering this lost water due to seepage.

Using any of the analysed seepage mitigation measures to recover lost water would be unfeasible as a standalone project. Significant cost savings in associated channel operation and maintenance would need to be present for any of the mitigation options to be considered economically viable.

7.2 Effectiveness of Model

The model was not very accurate at estimating seepage for Australian conditions. This was due to the insufficient data available for seepage which could accurately represent Australian supply channels. Most of this existing data for seepage was obtained from studies conducted in the United States where the seepage is typically higher. The seepage model generally overestimates seepage by a factor of 10, however the model's ability to enter a site specific seepage value allowed for greater accuracy in mitigation calculations.

The mitigation effectiveness calculations were seamless and accurate for the given seepage losses. The ability to select any seepage mitigation for each individual section gave the model a large amount of flexibility to find the most effective combination of mitigation options. Unfortunately this feature was not able to be tested on the selected case studies as there was not enough variance in the channel sections based on soil type or channel shape to gain an optimal combination.

The cost analysis of the model worked very well and gave the user a clear result of a profit or loss for a proposed scenario. As costs are constantly changing, the stored cost data is easily changeable by the user to suit future scenarios.

Overall the model was a successful pursuit. The model can autonomously calculate the seepage losses and associated costs for any given scenario, provided a site measured seepage value is used in the calculations. To improve the model accuracy for estimated seepage, further studies should be done to obtain more meaningful seepage data for Australian conditions. Future iterations of the model could also include a qualitative benefit analysis component to analyse other factors alongside cost savings for greater ease of use.

7.3 Further Work

To improve the ability to estimate seepage losses in Australian channels, further studies should be done into the effect of channel ageing as proposed by Smith (1982). The available data on soil seepage is insufficient for the tested case studies as much of it has been conducted overseas where seepage losses are higher.

Field surveys should be conducted on a range of soil types under Australian conditions to obtain a better data set of soil seepage values which could be used in the proposed model. From these field surveys, a new formula could be developed similar to the Moritz formula which could then be used for other applications beyond this model.

As all the case studies found that there are negative net benefits for any proposed mitigation, more case studies should be tested with the model to find a more beneficial scenario. Some channels may exist where the values for seepage are much higher and water is a higher price. Scenarios like this may even turn a profit for mitigating seepage.

7.4 Summary

From this study it has been found that there were always financial losses when implementing any type of seepage mitigation. The model was developed to calculate the seepage losses and associated costs, but using a measured seepage value from the proposed site is essential. The estimated values for seepage from the model based on literature were too large by a factor of six or more when compared with site specific measured values.

Further research needs to be conducted on other case studies in the model to find if any scenarios are profitable, as well as further research into the seepage generally found in Australian soils.

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Appendix A

ENG4111/4112 Research Project

Project Specification

For: David Taylor

Title: Analysing the cost effectiveness of liners in irrigation supply channels

Major: Civil Engineering

Supervisors: Justine Baillie

Sponsorship: None

Enrolment: ENG4111 – ONC S1, 2016
ENG4112 – ONC S2, 2016

Project Aim: The aim of this project is to develop a tool which can evaluate the cost effectiveness of installing a channel lining in any proposed channel. The end goal will be to have some form of model (such as an Excel document) which can take the variables of a proposed channel and output a report of a number of channel lining options, channel shapes and the cost effectiveness of each. This tool could then be used in the development of new supply channels to analyse options for channel linings and determine if they are a wise financial investment.

Programme: Issue A, 16th March 2016

1. Literature review to find the key variables in channel design.
2. Further research these key variables to collect meaningful data from existing channels and case studies.
3. Create the modeling tool using a computer program such as Matlab or Excel.
4. Test the model using existing case studies to check the validity of the outputs.
5. Determine the cost effectiveness of channel linings for the case studies in question.

Appendix B

Buckinbah B2/2 Results

Listed are the results for the Buckinbah B2/2 channel for all available seepage mitigations as shown in the model.

Site Characteristics

1. Enter site characteristics	
Channel Sections (May Change Name)	**Buckinbah B2/2**
Soil type	Sand and Clay
Seepage (L/m²/day) -	229
Seepage (L/m²/day) +	366
Existing mitigation	Compaction (in-situ)
Effectiveness (%) -	55
Effectiveness (%) +	74
Channel Shape	Trapezoidal
Side slope: H/V (If Trapezoidal)	2
Bed width (m)	5.5
Water depth (m)	1.1
Channel section length (m)	1393
Expected seepage (L/m²/day) -	6
Expected seepage (L/m²/day) +	10
Irrigation days/year	365
Wetted perimeter (m)	10.419
Cross-sectional area (m²)	8.4700

Seepage Calculations

2. Seepage Calculations	
Literature	
Expected Seepage (L/m2/day) -	59.54
Expected Seepage (L/m2/day) +	164.7
Volume Lost (ML/m/day) -	0.00062
Volume Lost (ML/m/day) +	0.00172
Volume Lost (ML/day) -	0.86417
Volume Lost (ML/day) +	2.39048
Volume Lost Over Channel (ML/day) -	0.86417
Volume Lost Over Channel (ML/day) +	2.39048
Moritz Formula	
Constant value	1.2
Expected seepage (ML/m/day)	0.00348
Volume Lost (ML/m/day) -	0.00091
Volume Lost (ML/m/day) +	0.00157
Volume Lost (ML/day) -	1.26124
Volume Lost (ML/day) +	2.18291
Volume Lost Over Channel (ML/day) -	1.26124
Volume Lost Over Channel (ML/day) +	2.18291
Expected Value	
Volume Lost (ML/m/day) -	0.00006
Volume Lost (ML/m/day) +	0.00010
Volume Lost (ML/day) -	0.08708
Volume Lost (ML/day) +	0.14514
Volume Lost Over Channel (ML/day) -	0.087085
Volume Lost Over Channel (ML/day) +	0.14514

Mitigation Calculations

Asphalt

3. Mitigation Calculations	
Proposed Mitigation	Asphalt
Effectiveness (%) -	9
Effectiveness (%) +	9
Cost ($/m^2)	3
Expected Life (years)	1
Maintenance Costs ($/year)	[illegible]
Literature	
Before Mitiagtion (ML/year/m) -	0.2264
Before Mitiagtion (ML/year/m) +	0.6263
After Mitigation (ML/year/m) -	0.02264
After Mitigation (ML/year/m) +	0.06263
Volume Saved (ML/year/m) -	0.2037
Volume Saved (ML/year/m) +	0.5637
Volume Saved (ML/year) -	283.8807
Volume Saved (ML/year) +	785.2730
Volume Saved Over Channel (ML/year) -	283.88
Volume Saved Over Channel (ML/year) +	785.27
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.3304
Before Mitiagtion (ML/year/m) +	0.5719
After Mitigation (ML/year/m) -	0.03304
After Mitigation (ML/year/m) +	0.05719
Volume Saved (ML/year/m) -	0.2974
Volume Saved (ML/year/m) +	0.5147
Volume Saved (ML/year) -	414.3159
Volume Saved (ML/year) +	717.0853
Volume Saved Over Channel (ML/year) -	414.31
Volume Saved Over Channel (ML/year) +	717.08
Expected Value	
Before Mitiagtion (ML/year/m) -	0.02281
Before Mitiagtion (ML/year/m) +	0.03803
After Mitigation (ML/year/m) -	0.00228
After Mitigation (ML/year/m) +	0.00380
Volume Saved (ML/year/m) -	0.02053
Volume Saved (ML/year/m) +	0.03422
Volume Saved (ML/year) -	28.6074
Volume Saved (ML/year) +	47.6790
Volume Saved Over Channel (ML/year) -	28.60
Volume Saved Over Channel (ML/year) +	47.67

Compaction (in-situ)

3. Mitigation Calculations	
Proposed Mitigation	Compaction (in-situ)
Effectiveness (%) -	55
Effectiveness (%) +	74
Cost ($/m^2)	10
Expected Life (years)	20
Maintenance Costs ($/year)	0
Literature	
Before Mitiagtion (ML/year/m) -	0.22643
Before Mitiagtion (ML/year/m) +	0.62636
After Mitigation (ML/year/m) -	0.058873
After Mitigation (ML/year/m) +	0.281864
Volume Saved (ML/year/m) -	0.16756
Volume Saved (ML/year/m) +	0.34450
Volume Saved (ML/year) -	233.41305
Volume Saved (ML/year) +	479.88909
Volume Saved Over Channel (ML/year) -	233.413
Volume Saved Over Channel (ML/year) +	479.889
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.33047
Before Mitiagtion (ML/year/m) +	0.57198
After Mitigation (ML/year/m) -	0.085923
After Mitigation (ML/year/m) +	0.257389
Volume Saved (ML/year/m) -	0.24455
Volume Saved (ML/year/m) +	0.31459
Volume Saved (ML/year) -	340.65979
Volume Saved (ML/year) +	438.21881
Volume Saved Over Channel (ML/year) -	340.660
Volume Saved Over Channel (ML/year) +	438.219
Expected Value	
Before Mitiagtion (ML/year/m) -	0.022818
Before Mitiagtion (ML/year/m) +	0.038031
After Mitigation (ML/year/m) -	0.005933
After Mitigation (ML/year/m) +	0.017114
Volume Saved (ML/year/m) -	0.016886
Volume Saved (ML/year/m) +	0.020917
Volume Saved (ML/year) -	23.52164
Volume Saved (ML/year) +	29.13716
Volume Saved Over Channel (ML/year) -	23.522
Volume Saved Over Channel (ML/year) +	29.137

Compaction of imported clay

3. Mitigation Calculations	
Proposed Mitigation	Compaction of importe
Effectiveness (%) -	70
Effectiveness (%) +	90
Cost ($/m^2)	17
Expected Life (years)	30
Maintenance Costs ($/year)	0
Literature	
Before Mitiagtion (ML/year/m) -	0.22643
Before Mitiagtion (ML/year/m) +	0.62636
After Mitigation (ML/year/m) -	0.022643
After Mitigation (ML/year/m) +	0.187909
Volume Saved (ML/year/m) -	0.20379
Volume Saved (ML/year/m) +	0.43846
Volume Saved (ML/year) -	283.88074
Volume Saved (ML/year) +	610.76793
Volume Saved Over Channel (ML/year) -	283.881
Volume Saved Over Channel (ML/year) +	610.768
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.33047
Before Mitiagtion (ML/year/m) +	0.57198
After Mitigation (ML/year/m) -	0.033047
After Mitigation (ML/year/m) +	0.171593
Volume Saved (ML/year/m) -	0.29743
Volume Saved (ML/year/m) +	0.40038
Volume Saved (ML/year) -	414.31597
Volume Saved (ML/year) +	557.73303
Volume Saved Over Channel (ML/year) -	414.316
Volume Saved Over Channel (ML/year) +	557.733
Expected Value	
Before Mitiagtion (ML/year/m) -	0.022818
Before Mitiagtion (ML/year/m) +	0.038031
After Mitigation (ML/year/m) -	0.002282
After Mitigation (ML/year/m) +	0.011409
Volume Saved (ML/year/m) -	0.020537
Volume Saved (ML/year/m) +	0.026621
Volume Saved (ML/year) -	28.60740
Volume Saved (ML/year) +	37.08366
Volume Saved Over Channel (ML/year) -	28.607
Volume Saved Over Channel (ML/year) +	37.084

Concrete

3. Mitigation Calculations	
Proposed Mitigation	Concrete
Effectiveness (%) -	70
Effectiveness (%) +	95
Cost ($/m^2)	52.5
Expected Life (years)	50
Maintenance Costs ($/year)	0
Literature	
Before Mitiagtion (ML/year/m) -	0.22643
Before Mitiagtion (ML/year/m) +	0.62636
After Mitigation (ML/year/m) -	0.011322
After Mitigation (ML/year/m) +	0.187909
Volume Saved (ML/year/m) -	0.21511
Volume Saved (ML/year/m) +	0.43846
Volume Saved (ML/year) -	299.65189
Volume Saved (ML/year) +	610.76793
Volume Saved Over Channel (ML/year) -	299.652
Volume Saved Over Channel (ML/year) +	610.768
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.33047
Before Mitiagtion (ML/year/m) +	0.57198
After Mitigation (ML/year/m) -	0.016524
After Mitigation (ML/year/m) +	0.171593
Volume Saved (ML/year/m) -	0.31395
Volume Saved (ML/year/m) +	0.40038
Volume Saved (ML/year) -	437.33352
Volume Saved (ML/year) +	557.73303
Volume Saved Over Channel (ML/year) -	437.334
Volume Saved Over Channel (ML/year) +	557.733
Expected Value	
Before Mitiagtion (ML/year/m) -	0.022818
Before Mitiagtion (ML/year/m) +	0.038031
After Mitigation (ML/year/m) -	0.001141
After Mitigation (ML/year/m) +	0.011409
Volume Saved (ML/year/m) -	0.021677
Volume Saved (ML/year/m) +	0.026621
Volume Saved (ML/year) -	30.19670
Volume Saved (ML/year) +	37.08366
Volume Saved Over Channel (ML/year) -	30.197
Volume Saved Over Channel (ML/year) +	37.084

HDPE (2mm)

3. Mitigation Calculations	
Proposed Mitigation	HDPE (2mm)
Effectiveness (%) -	93
Effectiveness (%) +	93
Cost ($/m^2)	12.12
Expected Life (years)	30
Maintenance Costs ($/year)	0
Literature	
Before Mitiagtion (ML/year/m) -	0.22643
Before Mitiagtion (ML/year/m) +	0.62636
After Mitigation (ML/year/m) -	0.015850
After Mitigation (ML/year/m) +	0.043846
Volume Saved (ML/year/m) -	0.21058
Volume Saved (ML/year/m) +	0.58252
Volume Saved (ML/year) -	293.34343
Volume Saved (ML/year) +	811.44883
Volume Saved Over Channel (ML/year) -	293.343
Volume Saved Over Channel (ML/year) +	811.449
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.33047
Before Mitiagtion (ML/year/m) +	0.57198
After Mitigation (ML/year/m) -	0.023133
After Mitigation (ML/year/m) +	0.040038
Volume Saved (ML/year/m) -	0.30734
Volume Saved (ML/year/m) +	0.53194
Volume Saved (ML/year) -	428.12650
Volume Saved (ML/year) +	740.98817
Volume Saved Over Channel (ML/year) -	428.126
Volume Saved Over Channel (ML/year) +	740.988
Expected Value	
Before Mitiagtion (ML/year/m) -	0.022818
Before Mitiagtion (ML/year/m) +	0.038031
After Mitigation (ML/year/m) -	0.001597
After Mitigation (ML/year/m) +	0.002662
Volume Saved (ML/year/m) -	0.021221
Volume Saved (ML/year/m) +	0.035368
Volume Saved (ML/year) -	29.56098
Volume Saved (ML/year) +	49.26830
Volume Saved Over Channel (ML/year) -	29.561
Volume Saved Over Channel (ML/year) +	49.268

LDPE (1.5mm)

3. Mitigation Calculations	
Proposed Mitigation	LDPE (1.5mm)
Effectiveness (%) -	94
Effectiveness (%) +	94
Cost ($/m^2)	16.54
Expected Life (years)	20
Maintenance Costs ($/year)	0
Literature	
Before Mitiagtion (ML/year/m) -	0.22643
Before Mitiagtion (ML/year/m) +	0.62636
After Mitigation (ML/year/m) -	0.013586
After Mitigation (ML/year/m) +	0.037582
Volume Saved (ML/year/m) -	0.21285
Volume Saved (ML/year/m) +	0.58878
Volume Saved (ML/year) -	296.49766
Volume Saved (ML/year) +	820.17408
Volume Saved Over Channel (ML/year) -	296.498
Volume Saved Over Channel (ML/year) +	820.174
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.33047
Before Mitiagtion (ML/year/m) +	0.57198
After Mitigation (ML/year/m) -	0.019828
After Mitigation (ML/year/m) +	0.034319
Volume Saved (ML/year/m) -	0.31065
Volume Saved (ML/year/m) +	0.53766
Volume Saved (ML/year) -	432.73001
Volume Saved (ML/year) +	748.95578
Volume Saved Over Channel (ML/year) -	432.730
Volume Saved Over Channel (ML/year) +	748.956
Expected Value	
Before Mitiagtion (ML/year/m) -	0.022818
Before Mitiagtion (ML/year/m) +	0.038031
After Mitigation (ML/year/m) -	0.001369
After Mitigation (ML/year/m) +	0.002282
Volume Saved (ML/year/m) -	0.021449
Volume Saved (ML/year/m) +	0.035749
Volume Saved (ML/year) -	29.87884
Volume Saved (ML/year) +	49.79806
Volume Saved Over Channel (ML/year) -	29.879
Volume Saved Over Channel (ML/year) +	49.798

Rice Hull Ash

3. Mitigation Calculations	
Proposed Mitigation	Rice Hull Ash
Effectiveness (%) -	50
Effectiveness (%) +	60
Cost ($/m^2)	3.86
Expected Life (years)	10
Maintenance Costs ($/year)	0
Literature	
Before Mitiagtion (ML/year/m) -	0.22643
Before Mitiagtion (ML/year/m) +	0.62636
After Mitigation (ML/year/m) -	0.090574
After Mitigation (ML/year/m) +	0.313182
Volume Saved (ML/year/m) -	0.13586
Volume Saved (ML/year/m) +	0.31318
Volume Saved (ML/year) -	189.25383
Volume Saved (ML/year) +	436.26281
Volume Saved Over Channel (ML/year) -	189.254
Volume Saved Over Channel (ML/year) +	436.263
Moritz Formula	
Before Mitiagtion (ML/year/m) -	0.33047
Before Mitiagtion (ML/year/m) +	0.57198
After Mitigation (ML/year/m) -	0.132190
After Mitigation (ML/year/m) +	0.285988
Volume Saved (ML/year/m) -	0.19828
Volume Saved (ML/year/m) +	0.28599
Volume Saved (ML/year) -	276.21064
Volume Saved (ML/year) +	398.38074
Volume Saved Over Channel (ML/year) -	276.211
Volume Saved Over Channel (ML/year) +	398.381
Expected Value	
Before Mitiagtion (ML/year/m) -	0.022818
Before Mitiagtion (ML/year/m) +	0.038031
After Mitigation (ML/year/m) -	0.009127
After Mitigation (ML/year/m) +	0.019015
Volume Saved (ML/year/m) -	0.013691
Volume Saved (ML/year/m) +	0.019015
Volume Saved (ML/year) -	19.07160
Volume Saved (ML/year) +	26.48833
Volume Saved Over Channel (ML/year) -	19.072
Volume Saved Over Channel (ML/year) +	26.488

Cost Analysis Calculation

Asphalt

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		24.31
Yearly Cost ($/year)		33866.36
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	43.13
Cost per ML Saved per Length ($/ML/m) +	$	119.30
Cost per ML Saved ($/ML) -	$	60,075.71
Cost per ML Saved ($/ML) +	$	166,181.89
Cost per ML Saved Over Channel ($/ML) -	$	60,075.71
Cost per ML Saved Over Channel ($/ML) +	$	166,181.89
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	47.23
Cost per ML Saved per Length ($/ML/m) +	$	81.74
Cost per ML Saved ($/ML) -	$	65,788.32
Cost per ML Saved ($/ML) +	$	113,864.40
Cost per ML Saved Over Channel ($/ML) -	$	65,788.32
Cost per ML Saved Over Channel ($/ML) +	$	113,864.40
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	710.30
Cost per ML Saved per Length ($/ML/m) +	$	1,183.83
Cost per ML Saved ($/ML) -	$	989,446.98
Cost per ML Saved ($/ML) +	$	1,649,078.30
Cost per ML Saved Over Channel ($/ML) -	$	989,446.98
Cost per ML Saved Over Channel ($/ML) +	$	1,649,078.30

Compaction (in-situ)

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		5.21
Yearly Cost ($/year)		7257.08
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	15.12
Cost per ML Saved per Length ($/ML/m) +	$	31.09
Cost per ML Saved ($/ML) -	$	21,065.51
Cost per ML Saved ($/ML) +	$	43,309.95
Cost per ML Saved Over Channel ($/ML) -	$	21,065.51
Cost per ML Saved Over Channel ($/ML) +	$	43,309.95
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	16.56
Cost per ML Saved per Length ($/ML/m) +	$	21.30
Cost per ML Saved ($/ML) -	$	23,068.63
Cost per ML Saved ($/ML) +	$	29,675.08
Cost per ML Saved Over Channel ($/ML) -	$	23,068.63
Cost per ML Saved Over Channel ($/ML) +	$	29,675.08
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	249.07
Cost per ML Saved per Length ($/ML/m) +	$	308.53
Cost per ML Saved ($/ML) -	$	346,948.94
Cost per ML Saved ($/ML) +	$	429,779.09
Cost per ML Saved Over Channel ($/ML) -	$	346,948.94
Cost per ML Saved Over Channel ($/ML) +	$	429,779.09

Compaction of imported clay

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		5.90
Yearly Cost ($/year)		8224.69
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	13.47
Cost per ML Saved per Length ($/ML/m) +	$	28.97
Cost per ML Saved ($/ML) -	$	18,758.33
Cost per ML Saved ($/ML) +	$	40,358.46
Cost per ML Saved Over Channel ($/ML) -	$	18,758.33
Cost per ML Saved Over Channel ($/ML) +	$	40,358.46
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	14.75
Cost per ML Saved per Length ($/ML/m) +	$	19.85
Cost per ML Saved ($/ML) -	$	20,542.07
Cost per ML Saved ($/ML) +	$	27,652.78
Cost per ML Saved Over Channel ($/ML) -	$	20,542.07
Cost per ML Saved Over Channel ($/ML) +	$	27,652.78
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	221.79
Cost per ML Saved per Length ($/ML/m) +	$	287.50
Cost per ML Saved ($/ML) -	$	308,949.77
Cost per ML Saved ($/ML) +	$	400,490.44
Cost per ML Saved Over Channel ($/ML) -	$	308,949.77
Cost per ML Saved Over Channel ($/ML) +	$	400,490.44

Concrete

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		10.94
Yearly Cost ($/year)		15239.86
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	24.95
Cost per ML Saved per Length ($/ML/m) +	$	50.86
Cost per ML Saved ($/ML) -	$	34,758.09
Cost per ML Saved ($/ML) +	$	70,845.96
Cost per ML Saved Over Channel ($/ML) -	$	34,758.09
Cost per ML Saved Over Channel ($/ML) +	$	70,845.96
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	27.32
Cost per ML Saved per Length ($/ML/m) +	$	34.85
Cost per ML Saved ($/ML) -	$	38,063.24
Cost per ML Saved ($/ML) +	$	48,542.19
Cost per ML Saved Over Channel ($/ML) -	$	38,063.24
Cost per ML Saved Over Channel ($/ML) +	$	48,542.19
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	410.96
Cost per ML Saved per Length ($/ML/m) +	$	504.69
Cost per ML Saved ($/ML) -	$	572,465.75
Cost per ML Saved ($/ML) +	$	703,028.12
Cost per ML Saved Over Channel ($/ML) -	$	572,465.75
Cost per ML Saved Over Channel ($/ML) +	$	703,028.12

HDPE (2mm)

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		4.21
Yearly Cost ($/year)		5863.72
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	7.23
Cost per ML Saved per Length ($/ML/m) +	$	19.99
Cost per ML Saved ($/ML) -	$	10,066.14
Cost per ML Saved ($/ML) +	$	27,845.04
Cost per ML Saved Over Channel ($/ML) -	$	10,066.14
Cost per ML Saved Over Channel ($/ML) +	$	27,845.04
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	7.91
Cost per ML Saved per Length ($/ML/m) +	$	13.70
Cost per ML Saved ($/ML) -	$	11,023.33
Cost per ML Saved ($/ML) +	$	19,078.85
Cost per ML Saved Over Channel ($/ML) -	$	11,023.33
Cost per ML Saved Over Channel ($/ML) +	$	19,078.85
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	119.02
Cost per ML Saved per Length ($/ML/m) +	$	198.36
Cost per ML Saved ($/ML) -	$	165,789.37
Cost per ML Saved ($/ML) +	$	276,315.61
Cost per ML Saved Over Channel ($/ML) -	$	165,789.37
Cost per ML Saved Over Channel ($/ML) +	$	276,315.61

Rice Hull Ash

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		4.02
Yearly Cost ($/year)		5602.46
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	12.84
Cost per ML Saved per Length ($/ML/m) +	$	29.60
Cost per ML Saved ($/ML) -	$	17,888.83
Cost per ML Saved ($/ML) +	$	41,236.85
Cost per ML Saved Over Channel ($/ML) -	$	17,888.83
Cost per ML Saved Over Channel ($/ML) +	$	41,236.85
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	14.06
Cost per ML Saved per Length ($/ML/m) +	$	20.28
Cost per ML Saved ($/ML) -	$	19,589.88
Cost per ML Saved ($/ML) +	$	28,254.64
Cost per ML Saved Over Channel ($/ML) -	$	19,589.88
Cost per ML Saved Over Channel ($/ML) +	$	28,254.64
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	211.51
Cost per ML Saved per Length ($/ML/m) +	$	293.76
Cost per ML Saved ($/ML) -	$	294,629.04
Cost per ML Saved ($/ML) +	$	409,207.00
Cost per ML Saved Over Channel ($/ML) -	$	294,629.04
Cost per ML Saved Over Channel ($/ML) +	$	409,207.00

LDPE (1.5mm)

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)		8.62
Yearly Cost ($/year)		12003.21
Literature		
Cost per ML Saved per Length ($/ML/m) -	$	14.63
Cost per ML Saved per Length ($/ML/m) +	$	40.48
Cost per ML Saved ($/ML) -	$	20,386.48
Cost per ML Saved ($/ML) +	$	56,393.24
Cost per ML Saved Over Channel ($/ML) -	$	20,386.48
Cost per ML Saved Over Channel ($/ML) +	$	56,393.24
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$	16.03
Cost per ML Saved per Length ($/ML/m) +	$	27.74
Cost per ML Saved ($/ML) -	$	22,325.04
Cost per ML Saved ($/ML) +	$	38,639.49
Cost per ML Saved Over Channel ($/ML) -	$	22,325.04
Cost per ML Saved Over Channel ($/ML) +	$	38,639.49
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$	241.04
Cost per ML Saved per Length ($/ML/m) +	$	401.73
Cost per ML Saved ($/ML) -	$	335,765.37
Cost per ML Saved ($/ML) +	$	559,608.96
Cost per ML Saved Over Channel ($/ML) -	$	335,765.37
Cost per ML Saved Over Channel ($/ML) +	$	559,608.96

Cost Benefit Analysis

Asphalt

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$166,078.01
Profit or Loss per ML Saved ($/ML) +	-$59,971.83
Profit or Loss Over Channel ($/ML) -	-$166,078.01
Profit or Loss Over Channel ($/ML) +	-$59,971.83
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$113,760.52
Profit or Loss per ML Saved ($/ML) +	-$65,684.44
Profit or Loss Over Channel ($/ML) -	-$113,760.52
Profit or Loss Over Channel ($/ML) +	-$65,684.44
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$1,648,974.42
Profit or Loss per ML Saved ($/ML) +	-$989,343.10
Profit or Loss Over Channel ($/ML) -	-$1,648,974.42
Profit or Loss Over Channel ($/ML) +	-$989,343.10

Compaction of imported clay

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$40,254.58
Profit or Loss per ML Saved ($/ML) +	-$18,654.45
Profit or Loss Over Channel ($/ML) -	-$40,254.58
Profit or Loss Over Channel ($/ML) +	-$18,654.45
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$27,548.90
Profit or Loss per ML Saved ($/ML) +	-$20,438.19
Profit or Loss Over Channel ($/ML) -	-$27,548.90
Profit or Loss Over Channel ($/ML) +	-$20,438.19
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$400,386.56
Profit or Loss per ML Saved ($/ML) +	-$308,845.89
Profit or Loss Over Channel ($/ML) -	-$400,386.56
Profit or Loss Over Channel ($/ML) +	-$308,845.89

Compaction (in situ)

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$43,206.07
Profit or Loss per ML Saved ($/ML) +	-$20,961.63
Profit or Loss Over Channel ($/ML) -	-$43,206.07
Profit or Loss Over Channel ($/ML) +	-$20,961.63
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$29,571.20
Profit or Loss per ML Saved ($/ML) +	-$22,964.75
Profit or Loss Over Channel ($/ML) -	-$29,571.20
Profit or Loss Over Channel ($/ML) +	-$22,964.75
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$429,675.21
Profit or Loss per ML Saved ($/ML) +	-$346,845.06
Profit or Loss Over Channel ($/ML) -	-$429,675.21
Profit or Loss Over Channel ($/ML) +	-$346,845.06

Concrete

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$70,742.08
Profit or Loss per ML Saved ($/ML) +	-$34,654.21
Profit or Loss Over Channel ($/ML) -	-$70,742.08
Profit or Loss Over Channel ($/ML) +	-$34,654.21
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$48,438.31
Profit or Loss per ML Saved ($/ML) +	-$37,959.36
Profit or Loss Over Channel ($/ML) -	-$48,438.31
Profit or Loss Over Channel ($/ML) +	-$37,959.36
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$702,924.24
Profit or Loss per ML Saved ($/ML) +	-$572,361.87
Profit or Loss Over Channel ($/ML) -	-$702,924.24
Profit or Loss Over Channel ($/ML) +	-$572,361.87

HDPE (2mm)

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$27,741.16
Profit or Loss per ML Saved ($/ML) +	-$9,962.26
Profit or Loss Over Channel ($/ML) -	-$27,741.16
Profit or Loss Over Channel ($/ML) +	-$9,962.26
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$18,974.97
Profit or Loss per ML Saved ($/ML) +	-$10,919.45
Profit or Loss Over Channel ($/ML) -	-$18,974.97
Profit or Loss Over Channel ($/ML) +	-$10,919.45
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$276,211.73
Profit or Loss per ML Saved ($/ML) +	-$165,685.49
Profit or Loss Over Channel ($/ML) -	-$276,211.73
Profit or Loss Over Channel ($/ML) +	-$165,685.49

Rice Hull Ash

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$41,132.97
Profit or Loss per ML Saved ($/ML) +	-$17,784.95
Profit or Loss Over Channel ($/ML) -	-$41,132.97
Profit or Loss Over Channel ($/ML) +	-$17,784.95
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$28,150.76
Profit or Loss per ML Saved ($/ML) +	-$19,486.00
Profit or Loss Over Channel ($/ML) -	-$28,150.76
Profit or Loss Over Channel ($/ML) +	-$19,486.00
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$409,103.12
Profit or Loss per ML Saved ($/ML) +	-$294,525.16
Profit or Loss Over Channel ($/ML) -	-$409,103.12
Profit or Loss Over Channel ($/ML) +	-$294,525.16

LDPE (1.5mm)

5. Cost Benefit Analysis	
Water Payment Scheme	Leased
Water Cost ($/ML)	103.88
Literature	
Profit or Loss per ML Saved ($/ML) -	-$56,289.36
Profit or Loss per ML Saved ($/ML) +	-$20,282.60
Profit or Loss Over Channel ($/ML) -	-$56,289.36
Profit or Loss Over Channel ($/ML) +	-$20,282.60
Moritz Formula	
Profit or Loss per ML Saved ($/ML) -	-$38,535.61
Profit or Loss per ML Saved ($/ML) +	-$22,221.16
Profit or Loss Over Channel ($/ML) -	-$38,535.61
Profit or Loss Over Channel ($/ML) +	-$22,221.16
Expected Value	
Profit or Loss per ML Saved ($/ML) -	-$559,505.08
Profit or Loss per ML Saved ($/ML) +	-$335,661.49
Profit or Loss Over Channel ($/ML) -	-$559,505.08
Profit or Loss Over Channel ($/ML) +	-$335,661.49

Appendix C

Booyan MC Results

Listed are the results for the Booyan Main Channel for all available seepage mitigations as shown in the model.

Site Characteristics

1. Enter site characteristics								
Channel Sections (May Change Name)	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8
Soil type	Clay and Clayey Loam	Clay and Clayey Loam	Clay and Clayey Loam	Clay and Clayey Loam	Clay and Clayey Loam	Clay and Clayey Loam	Clay and Clayey Loam	Clay and Clayey Loam
Seepage (L/m²/day) -	125	125	125	125	125	125	125	125
Seepage (L/m²/day) +	150	150	150	150	150	150	150	150
Existing mitigation	None	None	None	None	None	None	None	None
Effectiveness (%) -	0	0	0	0	0	0	0	0
Effectiveness (%) +	0	0	0	0	0	0	0	0
Channel Shape	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal
Side slope: H/V (If Trapezoidal)	2	2	2	2	2	2	2	2
Bed width (m)	4	4	4	4	4	4	4	4
Water depth (m)	1.64	1.36	1.5	1.22	1.22	1.22	1.22	1.22
Channel section length (m)	450	1710.3	708	548.4	1384.6	691	394	815
Expected seepage (L/m²/day) -	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Expected seepage (L/m²/day) +	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Irrigation days/year	365							
Wetted perimeter (m)	11.334	10.082	10.708	9.456	9.456	9.456	9.456	9.456
Cross-sectional area (m²)	11.9392	9.1392	10.5000	7.8568	7.8568	7.8568	7.8568	7.8568

Seepage Calculations

2. Seepage Calculations								
Literature								
Expected Seepage (L/m2/day) -	125	125	125	125	125	125	125	125
Expected Seepage (L/m2/day) +	150	150	150	150	150	150	150	150
Volume Lost (ML/m/day) -	0.00142	0.00126	0.00134	0.00118	0.00118	0.00118	0.00118	0.00118
Volume Lost (ML/m/day) +	0.00170	0.00151	0.00161	0.00142	0.00142	0.00142	0.00142	0.00142
Volume Lost (ML/day) -	0.63755	2.15543	0.94768	0.64821	1.63660	0.81676	0.46571	0.96333
Volume Lost (ML/day) +	0.76507	2.58651	1.13721	0.77785	1.96392	0.98012	0.55885	1.15600
Volume Lost Over Channel (ML/day) -	8.27127							
Volume Lost Over Channel (ML/day) +	9.92552							
Moritz Formula								
Constant value	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Expected seepage (ML/m/day)	0.00141	0.00124	0.00132	0.00115	0.00115	0.00115	0.00115	0.00115
Volume Lost (ML/m/day) -	0.00141	0.00124	0.00132	0.00115	0.00115	0.00115	0.00115	0.00115
Volume Lost (ML/m/day) +	0.00141	0.00124	0.00132	0.00115	0.00115	0.00115	0.00115	0.00115
Volume Lost (ML/day) -	0.63567	2.11378	0.93791	0.62842	1.58665	0.79183	0.45149	0.93393
Volume Lost (ML/day) +	0.63567	2.11378	0.93791	0.62842	1.58665	0.79183	0.45149	0.93393
Volume Lost Over Channel (ML/day) -	8.07968							
Volume Lost Over Channel (ML/day) +	8.07968							
Expected Value								
Volume Lost (ML/m/day) -	0.00012	0.00011	0.00011	0.00010	0.00010	0.00010	0.00010	0.00010
Volume Lost (ML/m/day) +	0.00012	0.00011	0.00011	0.00010	0.00010	0.00010	0.00010	0.00010
Volume Lost (ML/day) -	0.05406	0.18278	0.08036	0.05497	0.13878	0.06926	0.03949	0.08169
Volume Lost (ML/day) +	0.05406	0.18278	0.08036	0.05497	0.13878	0.06926	0.03949	0.08169
Volume Lost Over Channel (ML/day) -	0.701403							
Volume Lost Over Channel (ML/day) +	0.701403							

Mitigation Calculations

Asphalt

3. Mitigation Calculations

Proposed Mitigation	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt
Effectiveness (%) -	90	90	90	90	90	90	90	90
Effectiveness (%) +	90	90	90	90	90	90	90	90
Cost ($/m^2)	35	35	35	35	35	35	35	35
Expected Life (years)	15	15	15	15	15	15	15	15
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.051713	0.04600	0.04886	0.04314	0.04314	0.04314	0.04314	0.04314
After Mitigation (ML/year/m) +	0.062055	0.05520	0.05863	0.05177	0.05177	0.05177	0.05177	0.05177
Volume Saved (ML/year/m) -	0.46541	0.41400	0.43971	0.38829	0.38829	0.38829	0.38829	0.38829
Volume Saved (ML/year/m) +	0.55850	0.49680	0.52765	0.46594	0.46594	0.46594	0.46594	0.46594
Volume Saved (ML/year) -	209.43667	708.05810	311.31158	212.93672	537.62251	268.30648	152.98517	316.45410
Volume Saved (ML/year) +	251.32400	849.66972	373.57390	255.52407	645.14702	321.96778	183.58221	379.74492
Volume Saved Over Channel (ML/year) -	2717.111							
Volume Saved Over Channel (ML/year) +	3260.534							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.051560	0.04511	0.04835	0.04183	0.04183	0.04183	0.04183	0.04183
After Mitigation (ML/year/m) +	0.051560	0.04511	0.04835	0.04183	0.04183	0.04183	0.04183	0.04183
Volume Saved (ML/year/m) -	0.46404	0.40600	0.43517	0.37644	0.37644	0.37644	0.37644	0.37644
Volume Saved (ML/year/m) +	0.46404	0.40600	0.43517	0.37644	0.37644	0.37644	0.37644	0.37644
Volume Saved (ML/year) -	208.81815	694.37567	308.10306	206.43741	521.21306	260.11716	148.31572	306.79521
Volume Saved (ML/year) +	208.81815	694.37567	308.10306	206.43741	521.21306	260.11716	148.31572	306.79521
Volume Saved Over Channel (ML/year) -	2654.175							
Volume Saved Over Channel (ML/year) +	2654.175							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.004385	0.00390	0.00414	0.00366	0.00366	0.00366	0.00366	0.00366
After Mitigation (ML/year/m) +	0.004385	0.00390	0.00414	0.00366	0.00366	0.00366	0.00366	0.00366
Volume Saved (ML/year/m) -	0.039467	0.03511	0.03729	0.03293	0.03293	0.03293	0.03293	0.03293
Volume Saved (ML/year/m) +	0.039467	0.03511	0.03729	0.03293	0.03293	0.03293	0.03293	0.03293
Volume Saved (ML/year) -	17.76023	60.04333	26.39922	18.05703	45.59039	22.75239	12.97314	26.83531
Volume Saved (ML/year) +	17.76023	60.04333	26.39922	18.05703	45.59039	22.75239	12.97314	26.83531
Volume Saved Over Channel (ML/year) -	230.411							
Volume Saved Over Channel (ML/year) +	230.411							

Compaction (in-situ)

3. Mitigation Calculations

Proposed Mitigation	Compaction (in-situ)	Compaction (in-situ)	Compaction (in-situ)	Compaction (in-situ)	Compaction (in-situ)	Compaction (in-situ)	Compaction (in-situ)	Compaction (in-situ)
Effectiveness (%) -	55	55	55	55	55	55	55	55
Effectiveness (%) +	74	74	74	74	74	74	74	74
Cost ($/m^2)	10	10	10	10	10	10	10	10
Expected Life (years)	20	20	20	20	20	20	20	20
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.134453	0.11960	0.12703	0.11217	0.11217	0.11217	0.11217	0.11217
After Mitigation (ML/year/m) +	0.279249	0.24840	0.26382	0.23297	0.23297	0.23297	0.23297	0.23297
Volume Saved (ML/year/m) -	0.34130	0.30360	0.32245	0.28474	0.28474	0.28474	0.28474	0.28474
Volume Saved (ML/year/m) +	0.38267	0.34040	0.36154	0.31926	0.31926	0.31926	0.31926	0.31926
Volume Saved (ML/year) -	153.58689	519.24261	228.29516	156.15360	394.25651	196.75809	112.18913	232.06634
Volume Saved (ML/year) +	172.20348	582.18110	255.96730	175.08131	442.04518	220.60755	125.78781	260.19559
Volume Saved Over Channel (ML/year) -	1992.548							
Volume Saved Over Channel (ML/year) +	2234.069							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.134056	0.11729	0.12572	0.10875	0.10875	0.10875	0.10875	0.10875
After Mitigation (ML/year/m) +	0.232020	0.20300	0.21759	0.18822	0.18822	0.18822	0.18822	0.18822
Volume Saved (ML/year/m) -	0.28358	0.24811	0.26594	0.23004	0.23004	0.23004	0.23004	0.23004
Volume Saved (ML/year/m) +	0.38154	0.33382	0.35781	0.30951	0.30951	0.30951	0.30951	0.30951
Volume Saved (ML/year) -	127.61109	424.34069	188.28521	126.15620	318.51909	158.96049	90.63738	187.48596
Volume Saved (ML/year) +	171.69492	570.93111	253.32919	169.73743	428.55296	213.87411	121.94848	252.25384
Volume Saved Over Channel (ML/year) -	1621.996							
Volume Saved Over Channel (ML/year) +	2182.322							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.011402	0.01014	0.01077	0.00951	0.00951	0.00951	0.00951	0.00951
After Mitigation (ML/year/m) +	0.019734	0.01755	0.01864	0.01646	0.01646	0.01646	0.01646	0.01646
Volume Saved (ML/year/m) -	0.024119	0.02145	0.02279	0.02012	0.02012	0.02012	0.02012	0.02012
Volume Saved (ML/year/m) +	0.032451	0.02887	0.03066	0.02707	0.02707	0.02707	0.02707	0.02707
Volume Saved (ML/year) -	10.85347	36.69314	16.13286	11.03485	27.86079	13.90424	7.92803	16.39935
Volume Saved (ML/year) +	14.60286	49.36896	21.70603	14.84689	37.48543	18.70752	10.66681	22.06459
Volume Saved Over Channel (ML/year) -	140.807							
Volume Saved Over Channel (ML/year) +	189.449							

Compaction of Imported Clay

3. Mitigation Calculations								
Proposed Mitigation	Compaction of importe	Compaction of importe	Compaction of importe	Compaction of importe	Compaction of importe	Compaction of importe	Compaction of importe	Compaction of importe
Effectiveness (%) -	70	70	70	70	70	70	70	70
Effectiveness (%) +	90	90	90	90	90	90	90	90
Cost ($/m^2)	17	17	17	17	17	17	17	17
Expected Life (years)	30	30	30	30	30	30	30	30
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.051713	0.04600	0.04886	0.04314	0.04314	0.04314	0.04314	0.04314
After Mitigation (ML/year/m) +	0.186166	0.16560	0.17588	0.15531	0.15531	0.15531	0.15531	0.15531
Volume Saved (ML/year/m) -	0.43439	0.38640	0.41039	0.36240	0.36240	0.36240	0.36240	0.36240
Volume Saved (ML/year/m) +	0.46541	0.41400	0.43971	0.38829	0.38829	0.38829	0.38829	0.38829
Volume Saved (ML/year) -	195.47422	660.85423	290.55748	198.74094	501.78101	250.41938	142.78616	295.35716
Volume Saved (ML/year) +	209.43667	708.05810	311.31158	212.93672	537.62251	268.30648	152.98517	316.45410
Volume Saved Over Channel (ML/year) -	2535.971							
Volume Saved Over Channel (ML/year) +	2717.111							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.051560	0.04511	0.04835	0.04183	0.04183	0.04183	0.04183	0.04183
After Mitigation (ML/year/m) +	0.154680	0.13533	0.14506	0.12548	0.12548	0.12548	0.12548	0.12548
Volume Saved (ML/year/m) -	0.36092	0.31577	0.33847	0.29278	0.29278	0.29278	0.29278	0.29278
Volume Saved (ML/year/m) +	0.46404	0.40600	0.43517	0.37644	0.37644	0.37644	0.37644	0.37644
Volume Saved (ML/year) -	162.41411	540.06997	239.63572	160.56243	405.38793	202.31335	115.35667	238.61849
Volume Saved (ML/year) +	208.81815	694.37567	308.10306	206.43741	521.21306	260.11716	148.31572	306.79521
Volume Saved Over Channel (ML/year) -	2064.359							
Volume Saved Over Channel (ML/year) +	2654.175							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.004385	0.00390	0.00414	0.00366	0.00366	0.00366	0.00366	0.00366
After Mitigation (ML/year/m) +	0.013156	0.01170	0.01243	0.01098	0.01098	0.01098	0.01098	0.01098
Volume Saved (ML/year/m) -	0.030697	0.02731	0.02900	0.02561	0.02561	0.02561	0.02561	0.02561
Volume Saved (ML/year/m) +	0.039467	0.03511	0.03729	0.03293	0.03293	0.03293	0.03293	0.03293
Volume Saved (ML/year) -	13.81351	46.70037	20.53273	14.04436	35.45919	17.69630	10.09022	20.87191
Volume Saved (ML/year) +	17.76023	60.04333	26.39922	18.05703	45.59039	22.75239	12.97314	26.83531
Volume Saved Over Channel (ML/year) -	179.209							
Volume Saved Over Channel (ML/year) +	230.411							

Concrete

3. Mitigation Calculations								
Proposed Mitigation	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete
Effectiveness (%) -	70	70	70	70	70	70	70	70
Effectiveness (%) +	95	95	95	95	95	95	95	95
Cost ($/m^2)	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5
Expected Life (years)	50	50	50	50	50	50	50	50
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.025856	0.02300	0.02443	0.02157	0.02157	0.02157	0.02157	0.02157
After Mitigation (ML/year/m) +	0.186166	0.16560	0.17588	0.15531	0.15531	0.15531	0.15531	0.15531
Volume Saved (ML/year/m) -	0.43439	0.38640	0.41039	0.36240	0.36240	0.36240	0.36240	0.36240
Volume Saved (ML/year/m) +	0.49127	0.43700	0.46413	0.40986	0.40986	0.40986	0.40986	0.40986
Volume Saved (ML/year) -	195.47422	660.85423	290.55748	198.74094	501.78101	250.41938	142.78616	295.35716
Volume Saved (ML/year) +	221.07204	747.39466	328.60667	224.76654	567.49043	283.21240	161.48435	334.03488
Volume Saved Over Channel (ML/year) -	2535.971							
Volume Saved Over Channel (ML/year) +	2868.062							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.025780	0.02256	0.02418	0.02091	0.02091	0.02091	0.02091	0.02091
After Mitigation (ML/year/m) +	0.154680	0.13533	0.14506	0.12548	0.12548	0.12548	0.12548	0.12548
Volume Saved (ML/year/m) -	0.36092	0.31577	0.33847	0.29278	0.29278	0.29278	0.29278	0.29278
Volume Saved (ML/year/m) +	0.48982	0.42855	0.45935	0.39735	0.39735	0.39735	0.39735	0.39735
Volume Saved (ML/year) -	162.41411	540.06997	239.63572	160.56243	405.38793	202.31335	115.35667	238.61849
Volume Saved (ML/year) +	220.41916	732.95210	325.21990	217.90616	550.16934	274.56812	156.55548	323.83938
Volume Saved Over Channel (ML/year) -	2064.359							
Volume Saved Over Channel (ML/year) +	2801.630							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.002193	0.00195	0.00207	0.00183	0.00183	0.00183	0.00183	0.00183
After Mitigation (ML/year/m) +	0.013156	0.01170	0.01243	0.01098	0.01098	0.01098	0.01098	0.01098
Volume Saved (ML/year/m) -	0.030697	0.02731	0.02900	0.02561	0.02561	0.02561	0.02561	0.02561
Volume Saved (ML/year/m) +	0.041660	0.03706	0.03936	0.03476	0.03476	0.03476	0.03476	0.03476
Volume Saved (ML/year) -	13.81351	46.70037	20.53273	14.04436	35.45919	17.69630	10.09022	20.87191
Volume Saved (ML/year) +	18.74691	63.37907	27.86585	19.06020	48.12319	24.01641	13.69387	28.32616
Volume Saved Over Channel (ML/year) -	179.209							
Volume Saved Over Channel (ML/year) +	243.212							

HDPE (2mm)

3. Mitigation Calculations

Proposed Mitigation	HDPE (2mm)	HDPE (2mm)	HDPE (2mm)	HDPE (2mm)	HDPE (2mm)	HDPE (2mm)	HDPE (2mm)	HDPE (2mm)
Effectiveness (%) -	93	93	93	93	93	93	93	93
Effectiveness (%) +	93	93	93	93	93	93	93	93
Cost ($/m^2)	12.12	12.12	12.12	12.12	12.12	12.12	12.12	12.12
Expected Life (years)	30	30	30	30	30	30	30	30
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.036199	0.03220	0.03420	0.03020	0.03020	0.03020	0.03020	0.03020
After Mitigation (ML/year/m) +	0.043439	0.03864	0.04104	0.03624	0.03624	0.03624	0.03624	0.03624
Volume Saved (ML/year/m) -	0.48093	0.42780	0.45436	0.40123	0.40123	0.40123	0.40123	0.40123
Volume Saved (ML/year/m) +	0.57711	0.51336	0.54523	0.48148	0.48148	0.48148	0.48148	0.48148
Volume Saved (ML/year) -	216.41789	731.66003	321.68863	220.03461	555.54326	277.25003	158.08468	327.00257
Volume Saved (ML/year) +	259.70147	877.99204	386.02636	264.04154	666.65192	332.70004	189.70161	392.40309
Volume Saved Over Channel (ML/year) -	2807.682							
Volume Saved Over Channel (ML/year) +	3369.218							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.036092	0.03158	0.03385	0.02928	0.02928	0.02928	0.02928	0.02928
After Mitigation (ML/year/m) +	0.036092	0.03158	0.03385	0.02928	0.02928	0.02928	0.02928	0.02928
Volume Saved (ML/year/m) -	0.47951	0.41953	0.44968	0.38898	0.38898	0.38898	0.38898	0.38898
Volume Saved (ML/year/m) +	0.47951	0.41953	0.44968	0.38898	0.38898	0.38898	0.38898	0.38898
Volume Saved (ML/year) -	215.77875	717.52153	318.37317	213.31866	538.58683	268.78773	153.25958	317.02171
Volume Saved (ML/year) +	215.77875	717.52153	318.37317	213.31866	538.58683	268.78773	153.25958	317.02171
Volume Saved Over Channel (ML/year) -	2742.648							
Volume Saved Over Channel (ML/year) +	2742.648							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.003070	0.00273	0.00290	0.00256	0.00256	0.00256	0.00256	0.00256
After Mitigation (ML/year/m) +	0.003070	0.00273	0.00290	0.00256	0.00256	0.00256	0.00256	0.00256
Volume Saved (ML/year/m) -	0.040783	0.03628	0.03853	0.03402	0.03402	0.03402	0.03402	0.03402
Volume Saved (ML/year/m) +	0.040783	0.03628	0.03853	0.03402	0.03402	0.03402	0.03402	0.03402
Volume Saved (ML/year) -	18.35224	62.04477	27.27920	18.65894	47.11007	23.51080	13.40558	27.72982
Volume Saved (ML/year) +	18.35224	62.04477	27.27920	18.65894	47.11007	23.51080	13.40558	27.72982
Volume Saved Over Channel (ML/year) -	238.091							
Volume Saved Over Channel (ML/year) +	238.091							

LDPE (1.5mm)

3. Mitigation Calculations

Proposed Mitigation	LDPE (1.5mm)	LDPE (1.5mm)	LDPE (1.5mm)	LDPE (1.5mm)	LDPE (1.5mm)	LDPE (1.5mm)	LDPE (1.5mm)	LDPE (1.5mm)
Effectiveness (%) -	94	94	94	94	94	94	94	94
Effectiveness (%) +	94	94	94	94	94	94	94	94
Cost ($/m^2)	16.54	16.54	16.54	16.54	16.54	16.54	16.54	16.54
Expected Life (years)	20	20	20	20	20	20	20	20
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.031028	0.02760	0.02931	0.02589	0.02589	0.02589	0.02589	0.02589
After Mitigation (ML/year/m) +	0.037233	0.03312	0.03518	0.03106	0.03106	0.03106	0.03106	0.03106
Volume Saved (ML/year/m) -	0.48610	0.43240	0.45925	0.40554	0.40554	0.40554	0.40554	0.40554
Volume Saved (ML/year/m) +	0.58332	0.51888	0.55110	0.48665	0.48665	0.48665	0.48665	0.48665
Volume Saved (ML/year) -	218.74496	739.52735	325.14765	222.40058	561.51685	280.23122	159.78451	330.51873
Volume Saved (ML/year) +	262.49396	887.43282	390.17718	266.88069	673.82022	336.27746	191.74142	396.62247
Volume Saved Over Channel (ML/year) -	2837.872							
Volume Saved Over Channel (ML/year) +	3405.446							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.030936	0.02707	0.02901	0.02510	0.02510	0.02510	0.02510	0.02510
After Mitigation (ML/year/m) +	0.030936	0.02707	0.02901	0.02510	0.02510	0.02510	0.02510	0.02510
Volume Saved (ML/year/m) -	0.48466	0.42404	0.45451	0.39317	0.39317	0.39317	0.39317	0.39317
Volume Saved (ML/year/m) +	0.48466	0.42404	0.45451	0.39317	0.39317	0.39317	0.39317	0.39317
Volume Saved (ML/year) -	218.09895	725.23681	321.79653	215.61241	544.37808	271.67792	154.90753	320.43055
Volume Saved (ML/year) +	218.09895	725.23681	321.79653	215.61241	544.37808	271.67792	154.90753	320.43055
Volume Saved Over Channel (ML/year) -	2772.139							
Volume Saved Over Channel (ML/year) +	2772.139							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.002631	0.00234	0.00249	0.00220	0.00220	0.00220	0.00220	0.00220
After Mitigation (ML/year/m) +	0.002631	0.00234	0.00249	0.00220	0.00220	0.00220	0.00220	0.00220
Volume Saved (ML/year/m) -	0.041221	0.03667	0.03894	0.03439	0.03439	0.03439	0.03439	0.03439
Volume Saved (ML/year/m) +	0.041221	0.03667	0.03894	0.03439	0.03439	0.03439	0.03439	0.03439
Volume Saved (ML/year) -	18.54957	62.71192	27.57252	18.85957	47.61663	23.76361	13.54973	28.02799
Volume Saved (ML/year) +	18.54957	62.71192	27.57252	18.85957	47.61663	23.76361	13.54973	28.02799
Volume Saved Over Channel (ML/year) -	240.652							
Volume Saved Over Channel (ML/year) +	240.652							

Rice Hull Ash

3. Mitigation Calculations								
Proposed Mitigation	Rice Hull Ash	Rice Hull Ash	Rice Hull Ash	Rice Hull Ash	Rice Hull Ash	Rice Hull Ash	Rice Hull Ash	Rice Hull Ash
Effectiveness (%) -	50	50	50	50	50	50	50	50
Effectiveness (%) +	60	60	60	60	60	60	60	60
Cost ($/m^2)	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86
Expected Life (years)	10	10	10	10	10	10	10	10
Maintenance Costs ($/year)	0	0	0	0	0	0	0	0
Literature								
Before Mitiagtion (ML/year/m) -	0.51713	0.46000	0.48856	0.43143	0.43143	0.43143	0.43143	0.43143
Before Mitiagtion (ML/year/m) +	0.62055	0.55200	0.58627	0.51772	0.51772	0.51772	0.51772	0.51772
After Mitigation (ML/year/m) -	0.206851	0.18400	0.19542	0.17257	0.17257	0.17257	0.17257	0.17257
After Mitigation (ML/year/m) +	0.310277	0.27600	0.29314	0.25886	0.25886	0.25886	0.25886	0.25886
Volume Saved (ML/year/m) -	0.31028	0.27600	0.29314	0.25886	0.25886	0.25886	0.25886	0.25886
Volume Saved (ML/year/m) +	0.31028	0.27600	0.29314	0.25886	0.25886	0.25886	0.25886	0.25886
Volume Saved (ML/year) -	139.62444	472.03873	207.54105	141.95782	358.41501	178.87099	101.99012	210.96940
Volume Saved (ML/year) +	139.62444	472.03873	207.54105	141.95782	358.41501	178.87099	101.99012	210.96940
Volume Saved Over Channel (ML/year) -	1811.408							
Volume Saved Over Channel (ML/year) +	1811.408							
Moritz Formula								
Before Mitiagtion (ML/year/m) -	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
Before Mitiagtion (ML/year/m) +	0.51560	0.45111	0.48353	0.41826	0.41826	0.41826	0.41826	0.41826
After Mitigation (ML/year/m) -	0.206240	0.18044	0.19341	0.16730	0.16730	0.16730	0.16730	0.16730
After Mitigation (ML/year/m) +	0.257800	0.22555	0.24176	0.20913	0.20913	0.20913	0.20913	0.20913
Volume Saved (ML/year/m) -	0.25780	0.22555	0.24176	0.20913	0.20913	0.20913	0.20913	0.20913
Volume Saved (ML/year/m) +	0.30936	0.27066	0.29012	0.25096	0.25096	0.25096	0.25096	0.25096
Volume Saved (ML/year) -	116.01008	385.76426	171.16837	114.68745	289.56281	144.50953	82.39762	170.44178
Volume Saved (ML/year) +	139.21210	462.91712	205.40204	137.62494	347.47537	173.41144	98.87715	204.53014
Volume Saved Over Channel (ML/year) -	1474.542							
Volume Saved Over Channel (ML/year) +	1769.450							
Expected Value								
Before Mitiagtion (ML/year/m) -	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
Before Mitiagtion (ML/year/m) +	0.043852	0.03901	0.04143	0.03659	0.03659	0.03659	0.03659	0.03659
After Mitigation (ML/year/m) -	0.017541	0.01560	0.01657	0.01463	0.01463	0.01463	0.01463	0.01463
After Mitigation (ML/year/m) +	0.021926	0.01950	0.02072	0.01829	0.01829	0.01829	0.01829	0.01829
Volume Saved (ML/year/m) -	0.021926	0.01950	0.02072	0.01829	0.01829	0.01829	0.01829	0.01829
Volume Saved (ML/year/m) +	0.026311	0.02340	0.02486	0.02195	0.02195	0.02195	0.02195	0.02195
Volume Saved (ML/year) -	9.86679	33.35740	14.66623	10.03169	25.32799	12.64022	7.20730	14.90850
Volume Saved (ML/year) +	11.84015	40.02888	17.59948	12.03802	30.39359	15.16826	8.64876	17.89021
Volume Saved Over Channel (ML/year) -	128.006							
Volume Saved Over Channel (ML/year) +	153.607							

Cost Analysis Calculations

Asphalt

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	26.45	23.52	24.99	22.06	22.06	22.06	22.06	22.06
Yearly Cost ($/year)	11901.02	40234.66	17689.95	12099.91	30549.83	15246.23	8693.22	17982.17
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 47.35	$ 47.35	$ 47.35	$ 47.35	$ 47.35	$ 47.35	$ 47.35	$ 47.35
Cost per ML Saved per Length ($/ML/m) +	$ 56.82	$ 56.82	$ 56.82	$ 56.82	$ 56.82	$ 56.82	$ 56.82	$ 56.82
Cost per ML Saved ($/ML) -	$ 21,308.98	$ 80,988.33	$ 33,526.13	$ 25,968.54	$ 65,565.36	$ 32,721.12	$ 18,657.20	$ 38,592.93
Cost per ML Saved ($/ML) +	$ 25,570.78	$ 97,186.00	$ 40,231.35	$ 31,162.25	$ 78,678.44	$ 39,265.35	$ 22,388.64	$ 46,311.52
Cost per ML Saved Over Channel ($/ML) -	$ 317,328.60							
Cost per ML Saved Over Channel ($/ML) +	$ 380,794.32							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 56.99	$ 57.94	$ 57.42	$ 58.61	$ 58.61	$ 58.61	$ 58.61	$ 58.61
Cost per ML Saved per Length ($/ML/m) +	$ 56.99	$ 57.94	$ 57.42	$ 58.61	$ 58.61	$ 58.61	$ 58.61	$ 58.61
Cost per ML Saved ($/ML) -	$ 25,646.52	$ 99,101.01	$ 40,650.32	$ 32,143.34	$ 81,155.49	$ 40,501.55	$ 23,093.50	$ 47,769.55
Cost per ML Saved ($/ML) +	$ 25,646.52	$ 99,101.01	$ 40,650.32	$ 32,143.34	$ 81,155.49	$ 40,501.55	$ 23,093.50	$ 47,769.55
Cost per ML Saved Over Channel ($/ML) -	$ 390,061.27							
Cost per ML Saved Over Channel ($/ML) +	$ 390,061.27							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09
Cost per ML Saved per Length ($/ML/m) +	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09	$ 670.09
Cost per ML Saved ($/ML) -	$ 301,542.17	$ 1,146,061.28	$ 474,426.35	$ 367,479.39	$ 927,811.76	$ 463,034.76	$ 264,016.92	$ 546,126.38
Cost per ML Saved ($/ML) +	$ 301,542.17	$ 1,146,061.28	$ 474,426.35	$ 367,479.39	$ 927,811.76	$ 463,034.76	$ 264,016.92	$ 546,126.38
Cost per ML Saved Over Channel ($/ML) -	$ 4,490,499.03							
Cost per ML Saved Over Channel ($/ML) +	$ 4,490,499.03							

Compaction (in-situ)

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	5.67	5.04	5.35	4.73	4.73	4.73	4.73	4.73
Yearly Cost ($/year)	2550.22	8621.71	3790.70	2592.84	6546.39	3267.05	1862.83	3853.32
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 14.81	$ 14.81	$ 14.81	$ 14.81	$ 14.81	$ 14.81	$ 14.81	$ 14.81
Cost per ML Saved per Length ($/ML/m) +	$ 16.60	$ 16.60	$ 16.60	$ 16.60	$ 16.60	$ 16.60	$ 16.60	$ 16.60
Cost per ML Saved ($/ML) -	$ 6,664.20	$ 25,328.40	$ 10,485.01	$ 8,121.44	$ 20,505.00	$ 10,233.25	$ 5,834.88	$ 12,069.60
Cost per ML Saved ($/ML) +	$ 7,471.98	$ 28,398.51	$ 11,755.92	$ 9,105.85	$ 22,990.45	$ 11,473.64	$ 6,542.13	$ 13,532.59
Cost per ML Saved Over Channel ($/ML) -	$ 99,241.76							
Cost per ML Saved Over Channel ($/ML) +	$ 111,271.07							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 14.85	$ 15.10	$ 14.96	$ 15.28	$ 15.28	$ 15.28	$ 15.28	$ 15.28
Cost per ML Saved per Length ($/ML/m) +	$ 19.98	$ 20.32	$ 20.13	$ 20.55	$ 20.55	$ 20.55	$ 20.55	$ 20.55
Cost per ML Saved ($/ML) -	$ 6,683.94	$ 25,827.48	$ 10,594.19	$ 8,377.13	$ 21,150.56	$ 10,555.42	$ 6,018.58	$ 12,449.59
Cost per ML Saved ($/ML) +	$ 8,992.93	$ 34,749.71	$ 14,254.01	$ 11,271.04	$ 28,457.12	$ 14,201.84	$ 8,097.72	$ 16,750.36
Cost per ML Saved Over Channel ($/ML) -	$ 101,656.89							
Cost per ML Saved Over Channel ($/ML) +	$ 136,774.73							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 174.64	$ 174.64	$ 174.64	$ 174.64	$ 174.64	$ 174.64	$ 174.64	$ 174.64
Cost per ML Saved per Length ($/ML/m) +	$ 234.97	$ 234.97	$ 234.97	$ 234.97	$ 234.97	$ 234.97	$ 234.97	$ 234.97
Cost per ML Saved ($/ML) -	$ 78,587.25	$ 298,683.93	$ 123,643.93	$ 95,771.66	$ 241,804.22	$ 120,675.08	$ 68,807.50	$ 142,330.23
Cost per ML Saved ($/ML) +	$ 105,735.57	$ 401,865.65	$ 166,357.29	$ 128,856.41	$ 325,336.59	$ 162,362.84	$ 92,577.36	$ 191,498.86
Cost per ML Saved Over Channel ($/ML) -	$ 1,170,303.80							
Cost per ML Saved Over Channel ($/ML) +	$ 1,574,590.57							

Compaction of Imported Clay

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	6.42	5.71	6.07	5.36	5.36	5.36	5.36	5.36
Yearly Cost ($/year)	2890.25	9771.27	4296.13	2938.55	7419.25	3702.66	2111.21	4367.10
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 13.80	$ 13.80	$ 13.80	$ 13.80	$ 13.80	$ 13.80	$ 13.80	$ 13.80
Cost per ML Saved per Length ($/ML/m) +	$ 14.79	$ 14.79	$ 14.79	$ 14.79	$ 14.79	$ 14.79	$ 14.79	$ 14.79
Cost per ML Saved ($/ML) -	$ 6,210.05	$ 23,602.31	$ 9,770.47	$ 7,567.98	$ 19,107.62	$ 9,535.87	$ 5,437.24	$ 11,247.08
Cost per ML Saved ($/ML) +	$ 6,653.62	$ 25,288.19	$ 10,468.36	$ 8,108.55	$ 20,472.45	$ 10,217.00	$ 5,825.61	$ 12,050.45
Cost per ML Saved Over Channel ($/ML) -	$ 92,478.62							
Cost per ML Saved Over Channel ($/ML) +	$ 99,084.24							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 13.84	$ 14.07	$ 13.94	$ 14.23	$ 14.23	$ 14.23	$ 14.23	$ 14.23
Cost per ML Saved per Length ($/ML/m) +	$ 17.80	$ 18.09	$ 17.93	$ 18.30	$ 18.30	$ 18.30	$ 18.30	$ 18.30
Cost per ML Saved ($/ML) -	$ 6,228.44	$ 24,067.39	$ 9,872.22	$ 7,806.24	$ 19,709.19	$ 9,836.09	$ 5,608.42	$ 11,601.18
Cost per ML Saved ($/ML) +	$ 8,007.99	$ 30,943.79	$ 12,692.85	$ 10,036.59	$ 25,340.39	$ 12,646.40	$ 7,210.83	$ 14,915.80
Cost per ML Saved Over Channel ($/ML) -	$ 94,729.17							
Cost per ML Saved Over Channel ($/ML) +	$ 121,794.64							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 162.74	$ 162.74	$ 162.74	$ 162.74	$ 162.74	$ 162.74	$ 162.74	$ 162.74
Cost per ML Saved per Length ($/ML/m) +	$ 209.23	$ 209.23	$ 209.23	$ 209.23	$ 209.23	$ 209.23	$ 209.23	$ 209.23
Cost per ML Saved ($/ML) -	$ 73,231.67	$ 278,329.17	$ 115,217.83	$ 89,245.00	$ 225,325.71	$ 112,451.30	$ 64,118.40	$ 132,630.69
Cost per ML Saved ($/ML) +	$ 94,155.00	$ 357,851.79	$ 148,137.21	$ 114,743.57	$ 289,704.49	$ 144,580.24	$ 82,437.94	$ 170,525.18
Cost per ML Saved Over Channel ($/ML) -	$ 1,090,549.76							
Cost per ML Saved Over Channel ($/ML) +	$ 1,402,135.41							

Concrete

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	11.90	10.59	11.24	9.93	9.93	9.93	9.93	9.93
Yearly Cost ($/year)	5355.46	18105.60	7960.48	5444.96	13747.43	6860.81	3911.95	8091.98
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 24.22	$ 24.22	$ 24.22	$ 24.22	$ 24.22	$ 24.22	$ 24.22	$ 24.22
Cost per ML Saved per Length ($/ML/m) +	$ 27.40	$ 27.40	$ 27.40	$ 27.40	$ 27.40	$ 27.40	$ 27.40	$ 27.40
Cost per ML Saved ($/ML) -	$ 10,901.23	$ 41,431.93	$ 17,151.26	$ 13,284.96	$ 33,541.86	$ 16,739.44	$ 9,544.63	$ 19,743.33
Cost per ML Saved ($/ML) +	$ 12,328.77	$ 46,857.53	$ 19,397.26	$ 15,024.66	$ 37,934.25	$ 18,931.51	$ 10,794.52	$ 22,328.77
Cost per ML Saved Over Channel ($/ML) -	$ 162,338.63							
Cost per ML Saved Over Channel ($/ML) +	$ 183,597.26							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 24.30	$ 24.70	$ 24.48	$ 24.99	$ 24.99	$ 24.99	$ 24.99	$ 24.99
Cost per ML Saved per Length ($/ML/m) +	$ 32.97	$ 33.52	$ 33.22	$ 33.91	$ 33.91	$ 33.91	$ 33.91	$ 33.91
Cost per ML Saved ($/ML) -	$ 10,933.52	$ 42,248.33	$ 17,329.87	$ 13,703.21	$ 34,597.87	$ 17,266.45	$ 9,845.12	$ 20,364.91
Cost per ML Saved ($/ML) +	$ 14,838.34	$ 57,337.01	$ 23,519.11	$ 18,597.22	$ 46,954.25	$ 23,433.04	$ 13,361.24	$ 27,638.10
Cost per ML Saved Over Channel ($/ML) -	$ 166,289.28							
Cost per ML Saved Over Channel ($/ML) +	$ 225,678.31							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 285.67	$ 285.67	$ 285.67	$ 285.67	$ 285.67	$ 285.67	$ 285.67	$ 285.67
Cost per ML Saved per Length ($/ML/m) +	$ 387.70	$ 387.70	$ 387.70	$ 387.70	$ 387.70	$ 387.70	$ 387.70	$ 387.70
Cost per ML Saved ($/ML) -	$ 128,552.19	$ 488,584.02	$ 202,255.44	$ 156,662.27	$ 395,540.80	$ 197,399.03	$ 112,554.58	$ 232,822.30
Cost per ML Saved ($/ML) +	$ 174,463.69	$ 663,078.31	$ 274,489.53	$ 212,613.08	$ 536,805.38	$ 267,898.68	$ 152,752.65	$ 315,973.12
Cost per ML Saved Over Channel ($/ML) -	$ 1,914,370.64							
Cost per ML Saved Over Channel ($/ML) +	$ 2,598,074.44							

HDPE (2mm)

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	4.58	4.07	4.33	3.82	3.82	3.82	3.82	3.82
Yearly Cost ($/year)	2060.58	6966.34	3062.89	2095.01	5289.49	2639.78	1505.17	3113.48
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 7.93	$ 7.93	$ 7.93	$ 7.93	$ 7.93	$ 7.93	$ 7.93	$ 7.93
Cost per ML Saved per Length ($/ML/m) +	$ 9.52	$ 9.52	$ 9.52	$ 9.52	$ 9.52	$ 9.52	$ 9.52	$ 9.52
Cost per ML Saved ($/ML) -	$ 3,570.48	$ 13,570.21	$ 5,617.56	$ 4,351.23	$ 10,985.98	$ 5,482.67	$ 3,126.16	$ 6,466.54
Cost per ML Saved ($/ML) +	$ 4,284.58	$ 16,284.25	$ 6,741.07	$ 5,221.47	$ 13,183.17	$ 6,579.21	$ 3,751.39	$ 7,759.85
Cost per ML Saved Over Channel ($/ML) -	$ 53,170.82							
Cost per ML Saved Over Channel ($/ML) +	$ 63,804.98							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 9.55	$ 9.71	$ 9.62	$ 9.82	$ 9.82	$ 9.82	$ 9.82	$ 9.82
Cost per ML Saved per Length ($/ML/m) +	$ 9.55	$ 9.71	$ 9.62	$ 9.82	$ 9.82	$ 9.82	$ 9.82	$ 9.82
Cost per ML Saved ($/ML) -	$ 4,297.27	$ 16,605.13	$ 6,811.27	$ 5,385.86	$ 13,598.22	$ 6,786.34	$ 3,869.49	$ 8,004.15
Cost per ML Saved ($/ML) +	$ 4,297.27	$ 16,605.13	$ 6,811.27	$ 5,385.86	$ 13,598.22	$ 6,786.34	$ 3,869.49	$ 8,004.15
Cost per ML Saved Over Channel ($/ML) -	$ 65,357.73							
Cost per ML Saved Over Channel ($/ML) +	$ 65,357.73							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28
Cost per ML Saved per Length ($/ML/m) +	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28	$ 112.28
Cost per ML Saved ($/ML) -	$ 50,525.68	$ 192,031.28	$ 79,493.74	$ 61,573.97	$ 155,461.92	$ 77,584.99	$ 44,238.04	$ 91,507.63
Cost per ML Saved ($/ML) +	$ 50,525.68	$ 192,031.28	$ 79,493.74	$ 61,573.97	$ 155,461.92	$ 77,584.99	$ 44,238.04	$ 91,507.63
Cost per ML Saved Over Channel ($/ML) -	$ 752,417.26							
Cost per ML Saved Over Channel ($/ML) +	$ 752,417.26							

LDPE (1.5mm)

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	9.37	8.34	8.86	7.82	7.82	7.82	7.82	7.82
Yearly Cost ($/year)	4218.06	14260.31	6269.82	4288.55	10827.73	5403.70	3081.13	6373.40
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 16.07	$ 16.07	$ 16.07	$ 16.07	$ 16.07	$ 16.07	$ 16.07	$ 16.07
Cost per ML Saved per Length ($/ML/m) +	$ 19.28	$ 19.28	$ 19.28	$ 19.28	$ 19.28	$ 19.28	$ 19.28	$ 19.28
Cost per ML Saved ($/ML) -	$ 7,231.13	$ 27,483.11	$ 11,376.97	$ 8,812.33	$ 22,249.38	$ 11,103.80	$ 6,331.25	$ 13,096.38
Cost per ML Saved ($/ML) +	$ 8,677.35	$ 32,979.73	$ 13,652.37	$ 10,574.80	$ 26,699.25	$ 13,324.56	$ 7,597.51	$ 15,715.65
Cost per ML Saved Over Channel ($/ML) -	$ 107,684.35							
Cost per ML Saved Over Channel ($/ML) +	$ 129,221.22							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 19.34	$ 19.66	$ 19.48	$ 19.89	$ 19.89	$ 19.89	$ 19.89	$ 19.89
Cost per ML Saved per Length ($/ML/m) +	$ 19.34	$ 19.66	$ 19.48	$ 19.89	$ 19.89	$ 19.89	$ 19.89	$ 19.89
Cost per ML Saved ($/ML) -	$ 8,703.06	$ 33,629.58	$ 13,794.54	$ 10,907.73	$ 27,539.83	$ 13,744.06	$ 7,836.70	$ 16,210.43
Cost per ML Saved ($/ML) +	$ 8,703.06	$ 33,629.58	$ 13,794.54	$ 10,907.73	$ 27,539.83	$ 13,744.06	$ 7,836.70	$ 16,210.43
Cost per ML Saved Over Channel ($/ML) -	$ 132,365.93							
Cost per ML Saved Over Channel ($/ML) +	$ 132,365.93							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39
Cost per ML Saved per Length ($/ML/m) +	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39	$ 227.39
Cost per ML Saved ($/ML) -	$ 102,327.28	$ 388,911.89	$ 160,994.92	$ 124,702.85	$ 314,849.68	$ 157,129.23	$ 89,593.22	$ 185,326.08
Cost per ML Saved ($/ML) +	$ 102,327.28	$ 388,911.89	$ 160,994.92	$ 124,702.85	$ 314,849.68	$ 157,129.23	$ 89,593.22	$ 185,326.08
Cost per ML Saved Over Channel ($/ML) -	$ 1,523,835.15							
Cost per ML Saved Over Channel ($/ML) +	$ 1,523,835.15							

Rice Hull Ash

4. Cost Analysis Calcualtion								
Yearly Cost per Length($/year/m)	4.38	3.89	4.13	3.65	3.65	3.65	3.65	3.65
Yearly Cost ($/year)	1968.77	6655.96	2926.42	2001.67	5053.82	2522.16	1438.11	2974.76
Literature								
Cost per ML Saved per Length ($/ML/m) -	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10
Cost per ML Saved per Length ($/ML/m) +	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10	$ 14.10
Cost per ML Saved ($/ML) -	$ 6,345.21	$ 24,116.01	$ 9,983.12	$ 7,732.69	$ 19,523.49	$ 9,743.42	$ 5,555.58	$ 11,491.87
Cost per ML Saved ($/ML) +	$ 6,345.21	$ 24,116.01	$ 9,983.12	$ 7,732.69	$ 19,523.49	$ 9,743.42	$ 5,555.58	$ 11,491.87
Cost per ML Saved Over Channel ($/ML) -	$ 94,491.39							
Cost per ML Saved Over Channel ($/ML) +	$ 94,491.39							
Moritz Formula								
Cost per ML Saved per Length ($/ML/m) -	$ 14.14	$ 14.38	$ 14.25	$ 14.54	$ 14.54	$ 14.54	$ 14.54	$ 14.54
Cost per ML Saved per Length ($/ML/m) +	$ 16.97	$ 17.25	$ 17.10	$ 17.45	$ 17.45	$ 17.45	$ 17.45	$ 17.45
Cost per ML Saved ($/ML) -	$ 6,364.00	$ 24,591.21	$ 10,087.09	$ 7,976.14	$ 20,138.15	$ 10,050.17	$ 5,730.49	$ 11,853.67
Cost per ML Saved ($/ML) +	$ 7,636.80	$ 29,509.45	$ 12,104.50	$ 9,571.37	$ 24,165.79	$ 12,060.20	$ 6,876.58	$ 14,224.41
Cost per ML Saved Over Channel ($/ML) -	$ 96,790.92							
Cost per ML Saved Over Channel ($/ML) +	$ 116,149.10							
Expected Value								
Cost per ML Saved per Length ($/ML/m) -	$ 166.28	$ 166.28	$ 166.28	$ 166.28	$ 166.28	$ 166.28	$ 166.28	$ 166.28
Cost per ML Saved per Length ($/ML/m) +	$ 199.53	$ 199.53	$ 199.53	$ 199.53	$ 199.53	$ 199.53	$ 199.53	$ 199.53
Cost per ML Saved ($/ML) -	$ 74,825.54	$ 284,386.92	$ 117,725.51	$ 91,187.39	$ 230,229.86	$ 114,898.77	$ 65,513.91	$ 135,517.36
Cost per ML Saved ($/ML) +	$ 89,790.64	$ 341,264.31	$ 141,270.61	$ 109,424.86	$ 276,275.83	$ 137,878.52	$ 78,616.70	$ 162,620.83
Cost per ML Saved Over Channel ($/ML) -	$ 1,114,285.26							
Cost per ML Saved Over Channel ($/ML) +	$ 1,337,142.31							

Cost Benefit Analysis

Asphalt

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$25,394.28	-$97,009.50	-$40,054.85	-$30,985.75	-$78,501.94	-$39,088.85	-$22,212.14	-$46,135.02
Profit or Loss per ML Saved ($/ML) +	-$21,132.48	-$80,811.83	-$33,349.63	-$25,792.04	-$65,388.86	-$32,544.62	-$18,480.70	-$38,416.43
Profit or Loss Over Channel ($/ML) -	-$379,382.32							
Profit or Loss Over Channel ($/ML) +	-$315,916.60							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$25,470.02	-$98,924.51	-$40,473.82	-$31,966.84	-$80,978.99	-$40,325.05	-$22,917.00	-$47,593.05
Profit or Loss per ML Saved ($/ML) +	-$25,470.02	-$98,924.51	-$40,473.82	-$31,966.84	-$80,978.99	-$40,325.05	-$22,917.00	-$47,593.05
Profit or Loss Over Channel ($/ML) -	-$388,649.27							
Profit or Loss Over Channel ($/ML) +	-$388,649.27							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$301,365.67	-$1,145,884.78	-$474,249.85	-$367,302.89	-$927,635.26	-$462,858.26	-$263,840.42	-$545,949.88
Profit or Loss per ML Saved ($/ML) +	-$301,365.67	-$1,145,884.78	-$474,249.85	-$367,302.89	-$927,635.26	-$462,858.26	-$263,840.42	-$545,949.88
Profit or Loss Over Channel ($/ML) -	-$4,489,087.03							
Profit or Loss Over Channel ($/ML) +	-$4,489,087.03							

Compaction (in-situ)

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$7,295.48	-$28,222.01	-$11,579.42	-$8,929.35	-$22,813.95	-$11,297.14	-$6,365.63	-$13,356.09
Profit or Loss per ML Saved ($/ML) +	-$6,487.70	-$25,151.90	-$10,308.51	-$7,944.94	-$20,328.50	-$10,056.75	-$5,658.38	-$11,893.10
Profit or Loss Over Channel ($/ML) -	-$109,859.07							
Profit or Loss Over Channel ($/ML) +	-$97,829.76							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$8,816.43	-$34,573.21	-$14,077.51	-$11,094.54	-$28,280.62	-$14,025.34	-$7,921.22	-$16,573.86
Profit or Loss per ML Saved ($/ML) +	-$6,507.44	-$25,650.98	-$10,417.69	-$8,200.63	-$20,974.06	-$10,378.92	-$5,842.08	-$12,273.09
Profit or Loss Over Channel ($/ML) -	-$135,362.73							
Profit or Loss Over Channel ($/ML) +	-$100,244.89							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$105,559.07	-$401,689.15	-$166,180.79	-$128,679.91	-$325,160.09	-$162,186.34	-$92,400.86	-$191,322.36
Profit or Loss per ML Saved ($/ML) +	-$78,410.75	-$298,507.43	-$123,467.43	-$95,595.16	-$241,627.72	-$120,498.58	-$68,631.00	-$142,153.73
Profit or Loss Over Channel ($/ML) -	-$1,573,178.57							
Profit or Loss Over Channel ($/ML) +	-$1,168,891.80							

Compaction of Imported Clay

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$6,477.12	-$25,111.69	-$10,291.86	-$7,932.05	-$20,295.95	-$10,040.50	-$5,649.11	-$11,873.95
Profit or Loss per ML Saved ($/ML) +	-$6,033.55	-$23,425.81	-$9,593.97	-$7,391.48	-$18,931.12	-$9,359.37	-$5,260.74	-$11,070.58
Profit or Loss Over Channel ($/ML) -	-$97,672.24							
Profit or Loss Over Channel ($/ML) +	-$91,066.62							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$7,831.49	-$30,767.29	-$12,516.35	-$9,860.09	-$25,163.89	-$12,469.90	-$7,034.33	-$14,739.30
Profit or Loss per ML Saved ($/ML) +	-$6,051.94	-$23,890.89	-$9,695.72	-$7,629.74	-$19,532.69	-$9,659.59	-$5,431.92	-$11,424.68
Profit or Loss Over Channel ($/ML) -	-$120,382.64							
Profit or Loss Over Channel ($/ML) +	-$93,317.17							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$93,978.50	-$357,675.29	-$147,960.71	-$114,567.07	-$289,527.99	-$144,403.74	-$82,261.44	-$170,348.68
Profit or Loss per ML Saved ($/ML) +	-$73,055.17	-$278,152.67	-$115,041.33	-$89,068.50	-$225,149.21	-$112,274.80	-$63,941.90	-$132,454.19
Profit or Loss Over Channel ($/ML) -	-$1,400,723.41							
Profit or Loss Over Channel ($/ML) +	-$1,089,137.76							

Concrete

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$12,152.27	-$46,681.03	-$19,220.76	-$14,848.16	-$37,757.75	-$18,755.01	-$10,618.02	-$22,152.27
Profit or Loss per ML Saved ($/ML) +	-$10,724.73	-$41,255.43	-$16,974.76	-$13,108.46	-$33,365.36	-$16,562.94	-$9,368.13	-$19,566.83
Profit or Loss Over Channel ($/ML) -	-$182,185.26							
Profit or Loss Over Channel ($/ML) +	-$160,926.63							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$14,661.84	-$57,160.51	-$23,342.61	-$18,420.72	-$46,777.75	-$23,256.54	-$13,184.74	-$27,461.60
Profit or Loss per ML Saved ($/ML) +	-$10,757.02	-$42,071.83	-$17,153.37	-$13,526.71	-$34,421.37	-$17,089.95	-$9,668.62	-$20,188.41
Profit or Loss Over Channel ($/ML) -	-$224,266.31							
Profit or Loss Over Channel ($/ML) +	-$164,877.28							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$174,287.19	-$662,901.81	-$274,313.03	-$212,436.58	-$536,628.88	-$267,722.18	-$152,576.15	-$315,796.62
Profit or Loss per ML Saved ($/ML) +	-$128,375.69	-$488,407.52	-$202,078.94	-$156,485.77	-$395,364.30	-$197,222.53	-$112,378.08	-$232,645.80
Profit or Loss Over Channel ($/ML) -	-$2,596,662.44							
Profit or Loss Over Channel ($/ML) +	-$1,912,958.64							

HDPE (2mm)

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$4,108.08	-$16,107.75	-$6,564.57	-$5,044.97	-$13,006.67	-$6,402.71	-$3,574.89	-$7,583.35
Profit or Loss per ML Saved ($/ML) +	-$3,393.98	-$13,393.71	-$5,441.06	-$4,174.73	-$10,809.48	-$5,306.17	-$2,949.66	-$6,290.04
Profit or Loss Over Channel ($/ML) -	-$62,392.98							
Profit or Loss Over Channel ($/ML) +	-$51,758.82							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$4,120.77	-$16,428.63	-$6,634.77	-$5,209.36	-$13,421.72	-$6,609.84	-$3,692.99	-$7,827.65
Profit or Loss per ML Saved ($/ML) +	-$4,120.77	-$16,428.63	-$6,634.77	-$5,209.36	-$13,421.72	-$6,609.84	-$3,692.99	-$7,827.65
Profit or Loss Over Channel ($/ML) -	-$63,945.73							
Profit or Loss Over Channel ($/ML) +	-$63,945.73							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$50,349.18	-$191,854.78	-$79,317.24	-$61,397.47	-$155,285.42	-$77,408.49	-$44,061.54	-$91,331.13
Profit or Loss per ML Saved ($/ML) +	-$50,349.18	-$191,854.78	-$79,317.24	-$61,397.47	-$155,285.42	-$77,408.49	-$44,061.54	-$91,331.13
Profit or Loss Over Channel ($/ML) -	-$751,005.26							
Profit or Loss Over Channel ($/ML) +	-$751,005.26							

LDPE (1.5mm)

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$8,500.85	-$32,803.23	-$13,475.87	-$10,398.30	-$26,522.75	-$13,148.06	-$7,421.01	-$15,539.15
Profit or Loss per ML Saved ($/ML) +	-$7,054.63	-$27,306.61	-$11,200.47	-$8,635.83	-$22,072.88	-$10,927.30	-$6,154.75	-$12,919.88
Profit or Loss Over Channel ($/ML) -	-$127,809.22							
Profit or Loss Over Channel ($/ML) +	-$106,272.35							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$8,526.56	-$33,453.08	-$13,618.04	-$10,731.23	-$27,363.33	-$13,567.56	-$7,660.20	-$16,033.93
Profit or Loss per ML Saved ($/ML) +	-$8,526.56	-$33,453.08	-$13,618.04	-$10,731.23	-$27,363.33	-$13,567.56	-$7,660.20	-$16,033.93
Profit or Loss Over Channel ($/ML) -	-$130,953.93							
Profit or Loss Over Channel ($/ML) +	-$130,953.93							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$102,150.78	-$388,735.39	-$160,818.42	-$124,526.35	-$314,673.18	-$156,952.73	-$89,416.72	-$185,149.58
Profit or Loss per ML Saved ($/ML) +	-$102,150.78	-$388,735.39	-$160,818.42	-$124,526.35	-$314,673.18	-$156,952.73	-$89,416.72	-$185,149.58
Profit or Loss Over Channel ($/ML) -	-$1,522,423.15							
Profit or Loss Over Channel ($/ML) +	-$1,522,423.15							

Rice Hull Ash

5. Cost Benefit Analysis								
Water Payment Scheme	Leased							
Water Cost ($/ML)	176.5							
Literature								
Profit or Loss per ML Saved ($/ML) -	-$6,168.71	-$23,939.51	-$9,806.62	-$7,556.19	-$19,346.99	-$9,566.92	-$5,379.08	-$11,315.37
Profit or Loss per ML Saved ($/ML) +	-$6,168.71	-$23,939.51	-$9,806.62	-$7,556.19	-$19,346.99	-$9,566.92	-$5,379.08	-$11,315.37
Profit or Loss Over Channel ($/ML) -	-$93,079.39							
Profit or Loss Over Channel ($/ML) +	-$93,079.39							
Moritz Formula								
Profit or Loss per ML Saved ($/ML) -	-$7,460.30	-$29,332.95	-$11,928.00	-$9,394.87	-$23,989.29	-$11,883.70	-$6,700.08	-$14,047.91
Profit or Loss per ML Saved ($/ML) +	-$6,187.50	-$24,414.71	-$9,910.59	-$7,799.64	-$19,961.65	-$9,873.67	-$5,553.99	-$11,677.17
Profit or Loss Over Channel ($/ML) -	-$114,737.10							
Profit or Loss Over Channel ($/ML) +	-$95,378.92							
Expected Value								
Profit or Loss per ML Saved ($/ML) -	-$89,614.14	-$341,087.81	-$141,094.11	-$109,248.36	-$276,099.33	-$137,702.02	-$78,440.20	-$162,444.33
Profit or Loss per ML Saved ($/ML) +	-$74,649.04	-$284,210.42	-$117,549.01	-$91,010.89	-$230,053.36	-$114,722.27	-$65,337.41	-$135,340.86
Profit or Loss Over Channel ($/ML) -	-$1,335,730.31							
Profit or Loss Over Channel ($/ML) +	-$1,112,873.26							

Appendix D

Donald MC Results

Listed are the results for the Buckinbah B2/2 channel for all available seepage mitigations as shown in the model.

Site Characteristics

1. Enter site characteristics		
Channel Sections (May Change Name)	**Ralstons**	**Sheridans**
Soil type	Sand and Clay	Sand and Clay
Seepage (L/m^2/day) -	229	229
Seepage (L/m^2/day) +	366	366
Existing mitigation	None	None
Effectiveness (%) -	0	0
Effectiveness (%) +	0	0
Channel Shape	Trapezoidal	Trapezoidal
Side slope: H/V (If Trapezoidal)	3.23	3.23
Bed width (m)	7	7
Water depth (m)	1.2	1.2
Channel section length (m)	3500	2500
Expected seepage (L/m^2/day) -	25	25
Expected seepage (L/m^2/day) +	67	67
Irrigation days/year	273	
Wetted perimeter (m)	15.115	15.115
Cross-sectional area (m^2)	13.0512	13.0512

Seepage Calculations

2. Seepage Calculations		
Literature		
Expected Seepage (L/m2/day) -	229	229
Expected Seepage (L/m2/day) +	366	366
Volume Lost (ML/m/day) -	0.00346	0.00346
Volume Lost (ML/m/day) +	0.00553	0.00553
Volume Lost (ML/day) -	12.11469	8.65335
Volume Lost (ML/day) +	19.36234	13.83024
Volume Lost Over Channel (ML/day) -	20.76803	
Volume Lost Over Channel (ML/day) +	33.19258	
Moritz Formula		
Constant value	1.2	1.2
Expected seepage (ML/m/day)	0.00432	0.00432
Volume Lost (ML/m/day) -	0.00432	0.00432
Volume Lost (ML/m/day) +	0.00432	0.00432
Volume Lost (ML/day) -	15.12946	10.80676
Volume Lost (ML/day) +	15.12946	10.80676
Volume Lost Over Channel (ML/day) -	25.93622	
Volume Lost Over Channel (ML/day) +	25.93622	
Expected Value		
Volume Lost (ML/m/day) -	0.00038	0.00038
Volume Lost (ML/m/day) +	0.00101	0.00101
Volume Lost (ML/day) -	1.32256	0.94469
Volume Lost (ML/day) +	3.54447	2.53177
Volume Lost Over Channel (ML/day) -	2.26725	
Volume Lost Over Channel (ML/day) +	6.07624	

Mitigation Calculations

Asphalt

3. Mitigation Calculations		
Proposed Mitigation	Asphalt	Asphalt
Effectiveness (%) -	90	90
Effectiveness (%) +	90	90
Cost ($/m^2)	35	35
Expected Life (years)	15	15
Maintenance Costs ($/year)	0	0
Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.09449	0.09449
After Mitigation (ML/year/m) +	0.15103	0.15103
Volume Saved (ML/year/m) -	0.85045	0.85045
Volume Saved (ML/year/m) +	1.35924	1.35924
Volume Saved (ML/year) -	2976.57842	2126.12744
Volume Saved (ML/year) +	4757.32621	3398.09015
Volume Saved Over Channel (ML/year) -	5102.706	
Volume Saved Over Channel (ML/year) +	8155.416	
Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.11801	0.11801
After Mitigation (ML/year/m) +	0.11801	0.11801
Volume Saved (ML/year/m) -	1.06209	1.06209
Volume Saved (ML/year/m) +	1.06209	1.06209
Volume Saved (ML/year) -	3717.30803	2655.22002
Volume Saved (ML/year) +	3717.30803	2655.22002
Volume Saved Over Channel (ML/year) -	6372.528	
Volume Saved Over Channel (ML/year) +	6372.528	
Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.01032	0.01032
After Mitigation (ML/year/m) +	0.02765	0.02765
Volume Saved (ML/year/m) -	0.09284	0.09284
Volume Saved (ML/year/m) +	0.24882	0.24882
Volume Saved (ML/year) -	324.95398	232.10998
Volume Saved (ML/year) +	870.87666	622.05475
Volume Saved Over Channel (ML/year) -	557.064	
Volume Saved Over Channel (ML/year) +	1492.931	

Compaction (in-situ)

3. Mitigation Calculations		
Proposed Mitigation	Compaction (in-situ)	Compaction (in-situ)
Effectiveness (%) -	55	55
Effectiveness (%) +	74	74
Cost ($/m^2)	10	10
Expected Life (years)	20	20
Maintenance Costs ($/year)	0	0
Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.24569	0.24569
After Mitigation (ML/year/m) +	0.67962	0.67962
Volume Saved (ML/year/m) -	0.69926	0.69926
Volume Saved (ML/year/m) +	0.83064	0.83064
Volume Saved (ML/year) -	2447.40892	1748.14923
Volume Saved (ML/year) +	2907.25490	2076.61065
Volume Saved Over Channel (ML/year) -	4195.558	
Volume Saved Over Channel (ML/year) +	4983.866	
Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.30683	0.30683
After Mitigation (ML/year/m) +	0.53104	0.53104
Volume Saved (ML/year/m) -	0.64905	0.64905
Volume Saved (ML/year/m) +	0.87327	0.87327
Volume Saved (ML/year) -	2271.68824	1622.63446
Volume Saved (ML/year) +	3056.45327	2183.18090
Volume Saved Over Channel (ML/year) -	3894.323	
Volume Saved Over Channel (ML/year) +	5239.634	
Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.02682	0.02682
After Mitigation (ML/year/m) +	0.12441	0.12441
Volume Saved (ML/year/m) -	0.07634	0.07634
Volume Saved (ML/year/m) +	0.15206	0.15206
Volume Saved (ML/year) -	267.18438	190.84599
Volume Saved (ML/year) +	532.20240	380.14457
Volume Saved Over Channel (ML/year) -	458.030	
Volume Saved Over Channel (ML/year) +	912.347	

Compaction of Imported Clay

3. Mitigation Calculations

Proposed Mitigation	Compaction of importe	Compaction of importe
Effectiveness (%) -	70	70
Effectiveness (%) +	90	90
Cost ($/m^2)	17	17
Expected Life (years)	30	30
Maintenance Costs ($/year)	0	0
Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.09449	0.09449
After Mitigation (ML/year/m) +	0.45308	0.45308
Volume Saved (ML/year/m) -	0.85045	0.85045
Volume Saved (ML/year/m) +	1.05718	1.05718
Volume Saved (ML/year) -	2976.57842	2126.12744
Volume Saved (ML/year) +	3700.14260	2642.95900
Volume Saved Over Channel (ML/year) -	5102.706	
Volume Saved Over Channel (ML/year) +	6343.102	
Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.11801	0.11801
After Mitigation (ML/year/m) +	0.35403	0.35403
Volume Saved (ML/year/m) -	0.82607	0.82607
Volume Saved (ML/year/m) +	1.06209	1.06209
Volume Saved (ML/year) -	2891.23958	2065.17113
Volume Saved (ML/year) +	3717.30803	2655.22002
Volume Saved Over Channel (ML/year) -	4956.411	
Volume Saved Over Channel (ML/year) +	6372.528	
Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.01032	0.01032
After Mitigation (ML/year/m) +	0.08294	0.08294
Volume Saved (ML/year/m) -	0.09284	0.09284
Volume Saved (ML/year/m) +	0.19353	0.19353
Volume Saved (ML/year) -	324.95398	232.10998
Volume Saved (ML/year) +	677.34851	483.82036
Volume Saved Over Channel (ML/year) -	557.064	
Volume Saved Over Channel (ML/year) +	1161.169	

Concrete

3. Mitigation Calculations

Proposed Mitigation	Concrete	Concrete
Effectiveness (%) -	70	70
Effectiveness (%) +	95	95
Cost ($/m^2)	52.5	52.5
Expected Life (years)	50	50
Maintenance Costs ($/year)	0	0
Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.04725	0.04725
After Mitigation (ML/year/m) +	0.45308	0.45308
Volume Saved (ML/year/m) -	0.89770	0.89770
Volume Saved (ML/year/m) +	1.05718	1.05718
Volume Saved (ML/year) -	3141.94389	2244.24563
Volume Saved (ML/year) +	3700.14260	2642.95900
Volume Saved Over Channel (ML/year) -	5386.190	
Volume Saved Over Channel (ML/year) +	6343.102	
Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.05900	0.05900
After Mitigation (ML/year/m) +	0.35403	0.35403
Volume Saved (ML/year/m) -	0.82607	0.82607
Volume Saved (ML/year/m) +	1.12109	1.12109
Volume Saved (ML/year) -	2891.23958	2065.17113
Volume Saved (ML/year) +	3923.82514	2802.73224
Volume Saved Over Channel (ML/year) -	4956.411	
Volume Saved Over Channel (ML/year) +	6726.557	
Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.00516	0.00516
After Mitigation (ML/year/m) +	0.08294	0.08294
Volume Saved (ML/year/m) -	0.09800	0.09800
Volume Saved (ML/year/m) +	0.19353	0.19353
Volume Saved (ML/year) -	343.00697	245.00498
Volume Saved (ML/year) +	677.34851	483.82036
Volume Saved Over Channel (ML/year) -	588.012	
Volume Saved Over Channel (ML/year) +	1161.169	

HDPE (2mm)

3. Mitigation Calculations

Proposed Mitigation	HDPE (2mm)	HDPE (2mm)
Effectiveness (%) -	93	93
Effectiveness (%) +	93	93
Cost ($/m^2)	12.12	12.12
Expected Life (years)	30	30
Maintenance Costs ($/year)	0	0

Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.06615	0.06615
After Mitigation (ML/year/m) +	0.10572	0.10572
Volume Saved (ML/year/m) -	0.87880	0.87880
Volume Saved (ML/year/m) +	1.40454	1.40454
Volume Saved (ML/year) -	3075.79770	2196.99836
Volume Saved (ML/year) +	4915.90375	3511.35982
Volume Saved Over Channel (ML/year) -	5272.796	
Volume Saved Over Channel (ML/year) +	8427.264	

Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.08261	0.08261
After Mitigation (ML/year/m) +	0.08261	0.08261
Volume Saved (ML/year/m) -	1.09749	1.09749
Volume Saved (ML/year/m) +	1.09749	1.09749
Volume Saved (ML/year) -	3841.21829	2743.72735
Volume Saved (ML/year) +	3841.21829	2743.72735
Volume Saved Over Channel (ML/year) -	6584.946	
Volume Saved Over Channel (ML/year) +	6584.946	

Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.00722	0.00722
After Mitigation (ML/year/m) +	0.01935	0.01935
Volume Saved (ML/year/m) -	0.09594	0.09594
Volume Saved (ML/year/m) +	0.25712	0.25712
Volume Saved (ML/year) -	335.78578	239.84698
Volume Saved (ML/year) +	899.90588	642.78991
Volume Saved Over Channel (ML/year) -	575.633	
Volume Saved Over Channel (ML/year) +	1542.696	

LDPE (1.5mm)

3. Mitigation Calculations

Proposed Mitigation	LDPE (1.5mm)	LDPE (1.5mm)
Effectiveness (%) -	94	94
Effectiveness (%) +	94	94
Cost ($/m^2)	16.54	16.54
Expected Life (years)	20	20
Maintenance Costs ($/year)	0	0

Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.05670	0.05670
After Mitigation (ML/year/m) +	0.09062	0.09062
Volume Saved (ML/year/m) -	0.88825	0.88825
Volume Saved (ML/year/m) +	1.41965	1.41965
Volume Saved (ML/year) -	3108.87079	2220.62199
Volume Saved (ML/year) +	4968.76293	3549.11638
Volume Saved Over Channel (ML/year) -	5329.493	
Volume Saved Over Channel (ML/year) +	8517.879	

Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.07081	0.07081
After Mitigation (ML/year/m) +	0.07081	0.07081
Volume Saved (ML/year/m) -	1.10929	1.10929
Volume Saved (ML/year/m) +	1.10929	1.10929
Volume Saved (ML/year) -	3882.52172	2773.22980
Volume Saved (ML/year) +	3882.52172	2773.22980
Volume Saved Over Channel (ML/year) -	6655.752	
Volume Saved Over Channel (ML/year) +	6655.752	

Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.00619	0.00619
After Mitigation (ML/year/m) +	0.01659	0.01659
Volume Saved (ML/year/m) -	0.09697	0.09697
Volume Saved (ML/year/m) +	0.25988	0.25988
Volume Saved (ML/year) -	339.39637	242.42598
Volume Saved (ML/year) +	909.58228	649.70163
Volume Saved Over Channel (ML/year) -	581.822	
Volume Saved Over Channel (ML/year) +	1559.284	

Rice Hull Ash

3. Mitigation Calculations

Proposed Mitigation	Rice Hull Ash	Rice Hull Ash
Effectiveness (%) -	50	50
Effectiveness (%) +	60	60
Cost ($/m^2)	3.86	3.86
Expected Life (years)	10	10
Maintenance Costs ($/year)	0	0

Literature		
Before Mitiagtion (ML/year/m) -	0.94495	0.94495
Before Mitiagtion (ML/year/m) +	1.51026	1.51026
After Mitigation (ML/year/m) -	0.37798	0.37798
After Mitigation (ML/year/m) +	0.75513	0.75513
Volume Saved (ML/year/m) -	0.56697	0.56697
Volume Saved (ML/year/m) +	0.75513	0.75513
Volume Saved (ML/year) -	1984.38561	1417.41829
Volume Saved (ML/year) +	2642.95900	1887.82786
Volume Saved Over Channel (ML/year) -	3401.804	
Volume Saved Over Channel (ML/year) +	4530.787	

Moritz Formula		
Before Mitiagtion (ML/year/m) -	1.18010	1.18010
Before Mitiagtion (ML/year/m) +	1.18010	1.18010
After Mitigation (ML/year/m) -	0.47204	0.47204
After Mitigation (ML/year/m) +	0.59005	0.59005
Volume Saved (ML/year/m) -	0.59005	0.59005
Volume Saved (ML/year/m) +	0.70806	0.70806
Volume Saved (ML/year) -	2065.17113	1475.12223
Volume Saved (ML/year) +	2478.20535	1770.14668
Volume Saved Over Channel (ML/year) -	3540.293	
Volume Saved Over Channel (ML/year) +	4248.352	

Expected Value		
Before Mitiagtion (ML/year/m) -	0.10316	0.10316
Before Mitiagtion (ML/year/m) +	0.27647	0.27647
After Mitigation (ML/year/m) -	0.04126	0.04126
After Mitigation (ML/year/m) +	0.13823	0.13823
Volume Saved (ML/year/m) -	0.06190	0.06190
Volume Saved (ML/year/m) +	0.13823	0.13823
Volume Saved (ML/year) -	216.63598	154.73999
Volume Saved (ML/year) +	483.82036	345.58597
Volume Saved Over Channel (ML/year) -	371.376	
Volume Saved Over Channel (ML/year) +	829.406	

Cost Calculations

Asphalt

4. Cost Analysis Calcualtion				
Yearly Cost per Length($/year/m)		35.27		35.27
Yearly Cost ($/year)		123439.31		88170.93
Literature				
Cost per ML Saved per Length ($/ML/m) -	$	25.95	$	25.95
Cost per ML Saved per Length ($/ML/m) +	$	41.47	$	41.47
Cost per ML Saved ($/ML) -	$	90,815.21	$	64,868.01
Cost per ML Saved ($/ML) +	$	145,145.71	$	103,675.50
Cost per ML Saved Over Channel ($/ML) -	$	155,683.22		
Cost per ML Saved Over Channel ($/ML) +	$	248,821.21		
Moritz Formula				
Cost per ML Saved per Length ($/ML/m) -	$	33.21	$	33.21
Cost per ML Saved per Length ($/ML/m) +	$	33.21	$	33.21
Cost per ML Saved ($/ML) -	$	116,223.24	$	83,016.60
Cost per ML Saved ($/ML) +	$	116,223.24	$	83,016.60
Cost per ML Saved Over Channel ($/ML) -	$	199,239.84		
Cost per ML Saved Over Channel ($/ML) +	$	199,239.84		
Expected Value				
Cost per ML Saved per Length ($/ML/m) -	$	141.74	$	141.74
Cost per ML Saved per Length ($/ML/m) +	$	379.87	$	379.87
Cost per ML Saved ($/ML) -	$	496,095.02	$	354,353.59
Cost per ML Saved ($/ML) +	$	1,329,534.66	$	949,667.62
Cost per ML Saved Over Channel ($/ML) -	$	850,448.61		
Cost per ML Saved Over Channel ($/ML) +	$	2,279,202.28		

Compaction (in-situ)

4. Cost Analysis Calcualtion				
Yearly Cost per Length($/year/m)		7.56		7.56
Yearly Cost ($/year)		26451.28		18893.77
Literature				
Cost per ML Saved per Length ($/ML/m) -	$	9.10	$	9.10
Cost per ML Saved per Length ($/ML/m) +	$	10.81	$	10.81
Cost per ML Saved ($/ML) -	$	31,844.29	$	22,745.92
Cost per ML Saved ($/ML) +	$	37,827.55	$	27,019.68
Cost per ML Saved Over Channel ($/ML) -	$	54,590.22		
Cost per ML Saved Over Channel ($/ML) +	$	64,847.23		
Moritz Formula				
Cost per ML Saved per Length ($/ML/m) -	$	8.65	$	8.65
Cost per ML Saved per Length ($/ML/m) +	$	11.64	$	11.64
Cost per ML Saved ($/ML) -	$	30,289.84	$	21,635.60
Cost per ML Saved ($/ML) +	$	40,753.60	$	29,109.72
Cost per ML Saved Over Channel ($/ML) -	$	51,925.44		
Cost per ML Saved Over Channel ($/ML) +	$	69,863.32		
Expected Value				
Cost per ML Saved per Length ($/ML/m) -	$	49.70	$	49.70
Cost per ML Saved per Length ($/ML/m) +	$	99.00	$	99.00
Cost per ML Saved ($/ML) -	$	173,955.40	$	124,253.86
Cost per ML Saved ($/ML) +	$	346,500.35	$	247,500.25
Cost per ML Saved Over Channel ($/ML) -	$	298,209.25		
Cost per ML Saved Over Channel ($/ML) +	$	594,000.59		

Compaction of Imported Clay

4. Cost Analysis Calcualtion				
Yearly Cost per Length($/year/m)		8.57		8.57
Yearly Cost ($/year)		29978.12		21412.94
Literature				
Cost per ML Saved per Length ($/ML/m) -	$	8.10	$	8.10
Cost per ML Saved per Length ($/ML/m) +	$	10.07	$	10.07
Cost per ML Saved ($/ML) -	$	28,356.59	$	20,254.70
Cost per ML Saved ($/ML) +	$	35,249.67	$	25,178.34
Cost per ML Saved Over Channel ($/ML) -	$	48,611.29		
Cost per ML Saved Over Channel ($/ML) +	$	60,428.01		
Moritz Formula				
Cost per ML Saved per Length ($/ML/m) -	$	8.06	$	8.06
Cost per ML Saved per Length ($/ML/m) +	$	10.37	$	10.37
Cost per ML Saved ($/ML) -	$	28,225.64	$	20,161.17
Cost per ML Saved ($/ML) +	$	36,290.11	$	25,921.51
Cost per ML Saved Over Channel ($/ML) -	$	48,386.82		
Cost per ML Saved Over Channel ($/ML) +	$	62,211.62		
Expected Value				
Cost per ML Saved per Length ($/ML/m) -	$	44.26	$	44.26
Cost per ML Saved per Length ($/ML/m) +	$	92.25	$	92.25
Cost per ML Saved ($/ML) -	$	154,903.14	$	110,645.10
Cost per ML Saved ($/ML) +	$	322,886.99	$	230,633.56
Cost per ML Saved Over Channel ($/ML) -	$	265,548.24		
Cost per ML Saved Over Channel ($/ML) +	$	553,520.55		

Concrete

4. Cost Analysis Calcualtion				
Yearly Cost per Length($/year/m)		15.87		15.87
Yearly Cost ($/year)		55547.69		39676.92
Literature				
Cost per ML Saved per Length ($/ML/m) -	$	15.01	$	15.01
Cost per ML Saved per Length ($/ML/m) +	$	17.68	$	17.68
Cost per ML Saved ($/ML) -	$	52,543.09	$	37,530.78
Cost per ML Saved ($/ML) +	$	61,877.91	$	44,198.50
Cost per ML Saved Over Channel ($/ML) -	$	90,073.86		
Cost per ML Saved Over Channel ($/ML) +	$	106,076.41		
Moritz Formula				
Cost per ML Saved per Length ($/ML/m) -	$	14.16	$	14.16
Cost per ML Saved per Length ($/ML/m) +	$	19.21	$	19.21
Cost per ML Saved ($/ML) -	$	49,547.80	$	35,391.29
Cost per ML Saved ($/ML) +	$	67,243.44	$	48,031.03
Cost per ML Saved Over Channel ($/ML) -	$	84,939.09		
Cost per ML Saved Over Channel ($/ML) +	$	115,274.48		
Expected Value				
Cost per ML Saved per Length ($/ML/m) -	$	82.01	$	82.01
Cost per ML Saved per Length ($/ML/m) +	$	161.94	$	161.94
Cost per ML Saved ($/ML) -	$	287,026.41	$	205,018.86
Cost per ML Saved ($/ML) +	$	566,801.62	$	404,858.30
Cost per ML Saved Over Channel ($/ML) -	$	492,045.27		
Cost per ML Saved Over Channel ($/ML) +	$	971,659.92		

HDPE (2mm)

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)	6.11	6.11
Yearly Cost ($/year)	21372.63	15266.17
Literature		
Cost per ML Saved per Length ($/ML/m) -	$ 4.35	$ 4.35
Cost per ML Saved per Length ($/ML/m) +	$ 6.95	$ 6.95
Cost per ML Saved ($/ML) -	$ 15,216.78	$ 10,869.13
Cost per ML Saved ($/ML) +	$ 24,320.27	$ 17,371.62
Cost per ML Saved Over Channel ($/ML) -	$ 26,085.91	
Cost per ML Saved Over Channel ($/ML) +	$ 41,691.89	
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$ 5.56	$ 5.56
Cost per ML Saved per Length ($/ML/m) +	$ 5.56	$ 5.56
Cost per ML Saved ($/ML) -	$ 19,474.09	$ 13,910.06
Cost per ML Saved ($/ML) +	$ 19,474.09	$ 13,910.06
Cost per ML Saved Over Channel ($/ML) -	$ 33,384.15	
Cost per ML Saved Over Channel ($/ML) +	$ 33,384.15	
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$ 23.75	$ 23.75
Cost per ML Saved per Length ($/ML/m) +	$ 63.65	$ 63.65
Cost per ML Saved ($/ML) -	$ 83,124.49	$ 59,374.64
Cost per ML Saved ($/ML) +	$ 222,773.64	$ 159,124.03
Cost per ML Saved Over Channel ($/ML) -	$ 142,499.13	
Cost per ML Saved Over Channel ($/ML) +	$ 381,897.67	

Rice Hull Ash

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)	5.83	5.83
Yearly Cost ($/year)	20420.39	14585.99
Literature		
Cost per ML Saved per Length ($/ML/m) -	$ 7.73	$ 7.73
Cost per ML Saved per Length ($/ML/m) +	$ 10.29	$ 10.29
Cost per ML Saved ($/ML) -	$ 27,042.17	$ 19,315.84
Cost per ML Saved ($/ML) +	$ 36,016.87	$ 25,726.34
Cost per ML Saved Over Channel ($/ML) -	$ 46,358.01	
Cost per ML Saved Over Channel ($/ML) +	$ 61,743.21	
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$ 8.24	$ 8.24
Cost per ML Saved per Length ($/ML/m) +	$ 9.89	$ 9.89
Cost per ML Saved ($/ML) -	$ 28,839.97	$ 20,599.98
Cost per ML Saved ($/ML) +	$ 34,607.96	$ 24,719.97
Cost per ML Saved Over Channel ($/ML) -	$ 49,439.94	
Cost per ML Saved Over Channel ($/ML) +	$ 59,327.93	
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$ 42.21	$ 42.21
Cost per ML Saved per Length ($/ML/m) +	$ 94.26	$ 94.26
Cost per ML Saved ($/ML) -	$ 147,722.92	$ 105,516.37
Cost per ML Saved ($/ML) +	$ 329,914.53	$ 235,653.24
Cost per ML Saved Over Channel ($/ML) -	$ 253,239.30	
Cost per ML Saved Over Channel ($/ML) +	$ 565,567.77	

LDPE (1.5mm)

4. Cost Analysis Calcualtion		
Yearly Cost per Length($/year/m)	12.50	12.50
Yearly Cost ($/year)	43750.42	31250.30
Literature		
Cost per ML Saved per Length ($/ML/m) -	$ 8.81	$ 8.81
Cost per ML Saved per Length ($/ML/m) +	$ 14.07	$ 14.07
Cost per ML Saved ($/ML) -	$ 30,817.82	$ 22,012.73
Cost per ML Saved ($/ML) +	$ 49,254.69	$ 35,181.92
Cost per ML Saved Over Channel ($/ML) -	$ 52,830.56	
Cost per ML Saved Over Channel ($/ML) +	$ 84,436.61	
Moritz Formula		
Cost per ML Saved per Length ($/ML/m) -	$ 11.27	$ 11.27
Cost per ML Saved per Length ($/ML/m) +	$ 11.27	$ 11.27
Cost per ML Saved ($/ML) -	$ 39,439.95	$ 28,171.39
Cost per ML Saved ($/ML) +	$ 39,439.95	$ 28,171.39
Cost per ML Saved Over Channel ($/ML) -	$ 67,611.34	
Cost per ML Saved Over Channel ($/ML) +	$ 67,611.34	
Expected Value		
Cost per ML Saved per Length ($/ML/m) -	$ 48.10	$ 48.10
Cost per ML Saved per Length ($/ML/m) +	$ 128.91	$ 128.91
Cost per ML Saved ($/ML) -	$ 168,348.11	$ 120,248.65
Cost per ML Saved ($/ML) +	$ 451,172.94	$ 322,266.39
Cost per ML Saved Over Channel ($/ML) -	$ 288,596.76	
Cost per ML Saved Over Channel ($/ML) +	$ 773,439.33	

Cost Benefit Calculations

Asphalt

5. Cost Benefit Analysis		
Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$145,093.20	-$103,622.99
Profit or Loss per ML Saved ($/ML) +	-$90,762.70	-$64,815.50
Profit or Loss Over Channel ($/ML) -	-$248,716.19	
Profit or Loss Over Channel ($/ML) +	-$155,578.20	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$116,170.73	-$82,964.09
Profit or Loss per ML Saved ($/ML) +	-$116,170.73	-$82,964.09
Profit or Loss Over Channel ($/ML) -	-$199,134.82	
Profit or Loss Over Channel ($/ML) +	-$199,134.82	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$1,329,482.15	-$949,615.11
Profit or Loss per ML Saved ($/ML) +	-$496,042.51	-$354,301.08
Profit or Loss Over Channel ($/ML) -	-$2,279,097.26	
Profit or Loss Over Channel ($/ML) +	-$850,343.59	

Compaction (in-situ)

5. Cost Benefit Analysis		
Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$37,775.04	-$26,967.17
Profit or Loss per ML Saved ($/ML) +	-$31,791.78	-$22,693.41
Profit or Loss Over Channel ($/ML) -	-$64,742.21	
Profit or Loss Over Channel ($/ML) +	-$54,485.20	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$40,701.09	-$29,057.21
Profit or Loss per ML Saved ($/ML) +	-$30,237.33	-$21,583.09
Profit or Loss Over Channel ($/ML) -	-$69,758.30	
Profit or Loss Over Channel ($/ML) +	-$51,820.42	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$346,447.84	-$247,447.74
Profit or Loss per ML Saved ($/ML) +	-$173,902.89	-$124,201.35
Profit or Loss Over Channel ($/ML) -	-$593,895.57	
Profit or Loss Over Channel ($/ML) +	-$298,104.23	

Compaction of Imported Clay

5. Cost Benefit Analysis		
Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$35,197.16	-$25,125.83
Profit or Loss per ML Saved ($/ML) +	-$28,304.08	-$20,202.19
Profit or Loss Over Channel ($/ML) -	-$60,322.99	
Profit or Loss Over Channel ($/ML) +	-$48,506.27	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$36,237.60	-$25,869.00
Profit or Loss per ML Saved ($/ML) +	-$28,173.13	-$20,108.66
Profit or Loss Over Channel ($/ML) -	-$62,106.60	
Profit or Loss Over Channel ($/ML) +	-$48,281.80	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$322,834.48	-$230,581.05
Profit or Loss per ML Saved ($/ML) +	-$154,850.63	-$110,592.59
Profit or Loss Over Channel ($/ML) -	-$553,415.53	
Profit or Loss Over Channel ($/ML) +	-$265,443.22	

Concrete

5. Cost Benefit Analysis		
Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$61,825.40	-$44,145.99
Profit or Loss per ML Saved ($/ML) +	-$52,490.58	-$37,478.27
Profit or Loss Over Channel ($/ML) -	-$105,971.39	
Profit or Loss Over Channel ($/ML) +	-$89,968.84	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$67,190.93	-$47,978.52
Profit or Loss per ML Saved ($/ML) +	-$49,495.29	-$35,338.78
Profit or Loss Over Channel ($/ML) -	-$115,169.46	
Profit or Loss Over Channel ($/ML) +	-$84,834.07	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$566,749.11	-$404,805.79
Profit or Loss per ML Saved ($/ML) +	-$286,973.90	-$204,966.35
Profit or Loss Over Channel ($/ML) -	-$971,554.90	
Profit or Loss Over Channel ($/ML) +	-$491,940.25	

HDPE (2mm)

5. Cost Benefit Analysis		
Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$24,267.76	-$17,319.11
Profit or Loss per ML Saved ($/ML) +	-$15,164.27	-$10,816.62
Profit or Loss Over Channel ($/ML) -	-$41,586.87	
Profit or Loss Over Channel ($/ML) +	-$25,980.89	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$19,421.58	-$13,857.55
Profit or Loss per ML Saved ($/ML) +	-$19,421.58	-$13,857.55
Profit or Loss Over Channel ($/ML) -	-$33,279.13	
Profit or Loss Over Channel ($/ML) +	-$33,279.13	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$222,721.13	-$159,071.52
Profit or Loss per ML Saved ($/ML) +	-$83,071.98	-$59,322.13
Profit or Loss Over Channel ($/ML) -	-$381,792.65	
Profit or Loss Over Channel ($/ML) +	-$142,394.11	

LDPE (1.5mm)

5. Cost Benefit Analysis		
Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$49,202.18	-$35,129.41
Profit or Loss per ML Saved ($/ML) +	-$30,765.31	-$21,960.22
Profit or Loss Over Channel ($/ML) -	-$84,331.59	
Profit or Loss Over Channel ($/ML) +	-$52,725.54	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$39,387.44	-$28,118.88
Profit or Loss per ML Saved ($/ML) +	-$39,387.44	-$28,118.88
Profit or Loss Over Channel ($/ML) -	-$67,506.32	
Profit or Loss Over Channel ($/ML) +	-$67,506.32	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$451,120.43	-$322,213.88
Profit or Loss per ML Saved ($/ML) +	-$168,295.60	-$120,196.14
Profit or Loss Over Channel ($/ML) -	-$773,334.31	
Profit or Loss Over Channel ($/ML) +	-$288,491.74	

Rice Hull Ash

5. Cost Benefit Analysis

Water Payment Scheme	Leased	
Water Cost ($/ML)	52.51	
Literature		
Profit or Loss per ML Saved ($/ML) -	-$35,964.36	-$25,673.83
Profit or Loss per ML Saved ($/ML) +	-$26,989.66	-$19,263.33
Profit or Loss Over Channel ($/ML) -	-$61,638.19	
Profit or Loss Over Channel ($/ML) +	-$46,252.99	
Moritz Formula		
Profit or Loss per ML Saved ($/ML) -	-$34,555.45	-$24,667.46
Profit or Loss per ML Saved ($/ML) +	-$28,787.46	-$20,547.47
Profit or Loss Over Channel ($/ML) -	-$59,222.91	
Profit or Loss Over Channel ($/ML) +	-$49,334.92	
Expected Value		
Profit or Loss per ML Saved ($/ML) -	-$329,862.02	-$235,600.73
Profit or Loss per ML Saved ($/ML) +	-$147,670.41	-$105,463.86
Profit or Loss Over Channel ($/ML) -	-$565,462.75	
Profit or Loss Over Channel ($/ML) +	-$253,134.28	