Investing in Land Restoration in Manitoba

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Abstract

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Tillage erosion is the dominant soil erosion process in hummocky landscapes. The topsoil lost from the convex upper slope positions (i.e., hilltops knolls, ridges) gradually makes its way to the concave lower slope positions (i.e., foot slopes, toe slopes/depressions), while reducing yield capability in the knolls. The accumulation of topsoil in the concave lower slope positions does not increase yield potential. Landscape restoration is a process by which organic-rich topsoil is removed from lower slope positions and is moved to the knoll positions where it is applied and incorporated as additional topsoil. Field studies on this matter have shown increases in crop yield productivity due to land restoration on the convex upper slope positions.

Using a model developed in STELLA ®, this research examines the net monetary benefit of landscape restoration in specific landscape scenarios modeled after areas in Manitoba which are prone to tillage erosion. This study demonstrates that farming operations in hummocky landscapes, experiencing topsoil loss at knolls benefit from landscape restoration as it can lead to positive net returns. In this study, the research shows that landscape restoration, in the Rural Municipality of Lorne (South Western Manitoba), led to revenues greater than restoration costs for arable land used for agricultural purposes. Depending on soil conditions and tillage choices the payback period for landscape restoration ranged from 8 to 18 years.

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Chapter 1: Problem Introduction

Landscape restoration has been studied as a way to restore topsoil levels on hummocky landscapes, while increasing yield potential and improving the quality of the land. Preliminary studies have suggested that landscape restoration is a beneficial management strategy in terms of yield and soil health; however, the assessment of economic benefit is incomplete.

The study of landscape restoration was part of the “Economic Assessment of Restoring Eroded Land” strategic project. This project included: 1) a study of the impact of landscape restoration on greenhouse gas emissions (Erb, 2005),” 2) a preliminary economic feasibility study on landscape restoration (Bosma, 2004), and 3) a field study of the impact of landscape restoration on crop productivity and soil properties in Manitoba (Smith, 2008). This thesis expands on the “Economic Assessment of Restoring Eroded Land” strategic project and examines the costs and benefits of landscape restoration through the incorporation of new variables including a focus on the time value of money.

The preliminary economic feasibility study of land restoration developed by Bosma (2004) was used as a starting point for this study. The original model focused on the relationship between topsoil depth and crop yield, and the annuity derived from the practice in order to assess the feasibility of landscape restoration. The original model had its limitations, as it assumed that many variables remained constant. For the purposes of this study, those variables have been expanded, and resulting computer model includes optimal crop rotations and more specific production costs for the original and additional variables. Major changes to the model on the input section include:

- The original computer model had a set crop rotation of canola, flax and barley, and one could only change the crop price and expenses. Yield was assumed in the underlying model for each crop. The model was expanded to include crop price, yield, cost of production factors for each possible crop in a rotation, as well as, the number of years the crop is included in the rotation. Crops such as alfalfa or tame hays can be included in a crop rotation for up to 5 years. The model will now properly account for the changes in yield over time.
- With respect to the field characteristics portion, the major addition to the computer model, defined the rate of tillage erosion variable. In the original model, the relationship between soil loss and tillage erosion was defined by a graph. Rather than use the graph, the new model used a formula which gives similar results to the graph.
- In terms of restoration specifics, the option to rent the scraper and the operator or to perform the restoration with one's own equipment was added. The cost of running the tractor and scraper were also included, as was the option to change the hourly wage and fuel costs. As well, the option to not restore a field was included as a control. The inclusion of this control allowed the researcher to more accurately determine the benefits of land restoration.
- The output generated in the original computer model was limited. It focused on the annuity generated from the investment of landscape restoration, the number of days and the cost of completing the initial and subsequent restorations. It outlined the effects of restoration, with respect to the net present value of the investment in a graph but that portion, but did not elaborate on the topic beyond the graph. Due to these limitations the new model included additional parameters and an expanded output section which was separated into two sections: 1) the restoration effects on the landscape and 2) the economic impact of restoration. The first section has the capability, throughout the course of the simulation, generates a graph which displays the varying topsoil depths through for the different positions of the landscape. This

- The new model (LandRec), used in this study was developed to determine the costs of benefits of landscape restoration as a practice from both a soil science and economic point of view. This model simulates a specific field's terrain characteristics, erosion rates and other factors affecting production. A restoration simulation is performed according to the field's specifications, generating the cost of restoration, revenues and typical expenses for a specified length of time. At the end of the simulation, additional revenues attributed to landscape restoration are highlighted. Both the original (Bosma, 2004) model and LandRec, the new model, were developed using STELLA ® , an electronic modeling program.

This study serves three purposes. First, to examine the net monetary benefit of landscape restoration in specific landscape scenarios in areas of Manitoba that are prone to tillage erosion. Secondly, the study also examines the inter-relationship between cropping practices, and landscape restoration, as well as, the frequency of restoration required to maintain a specific topsoil depth.

Lastly, this study examines the effect that landscape restoration has on a larger scale, and determines the monetary impact if all agricultural land requiring restoration in a municipality were restored.

Landscape restoration is a timely research topic for producers and industry, as it explores, a way of increasing soil productivity and increasing potential revenue. Landscape restoration can be costly depending on the field in question, and as with any type of investment, the expense of restoration must be worth the reward. While benefits derived from landscape restoration are not solely economic, it is prudent to use a cost/benefit analysis of the land restoration project as an objective tool. The cost-benefit analysis can then confirm whether revenues generated from improved soil health will offset the cost of the restoration or an investment in new technology, even down to specific fields. This paper demonstrates, through the additional realistic variables, the ability of the computer model to assist a farmer's decision to restore or not restore a specific field based on costs. It also demonstrates the investment returns realized by the farmer which can be attributed to improve soil quality.

Chapter 2: Soil Literature Review

Background

Factors such as water and tillage erosion, often result in soil and productivity losses on knolls in hummocky landscapes. The soil lost from the knoll gradually makes its way to the concave lower slope positions (i.e., foot slopes, toe slopes/depressions)[1]. The soil loss in the convex upper slope positions (i.e., hilltops knolls, ridges) results in decreased yields for that portion of the landscape; a decrease in soil health and, over time, can result in a complete loss of topsoil. In the concave lower slope positions, the accumulation of topsoil over time does not result in increased yield potential. In addition, concave lower slope positions are often prone to excess moisture, salinity and weed presence, which hinders the crop's yield potential.

To correct or offset production losses from lost soil, previous studies have proposed practices such as: increased frequency of manure application (Dormaar et al., 1988; Dormaar et al., 1997; Larney et al, 2000b), application of commercial fertilizer (Massee and Waggoner, 1985, Mielke and Schepers, 1986; Massee 1990; Verity and Anderson, 1990; Larney et al., 1995; Larney et al., 2000a) and conservation tillage (Mueller et al., 1984; Grevers et al., 1986; McCarthy et al., 1993; Hussain et al., 1999). While these practices have had some level of success in field trials, none of them have successfully corrected the problem of soil erosion on the convex upper slope positions of a field. For the most part, these practices are seen as coping measures, masking the extent of the problem. For example, one can increase the amount of commercial fertilizer that is applied to the affected areas. It can be an expensive solution in times of volatile gas prices (Massee and

[1] The terms concave and convex in this study refer to positions on the landscape. The term concave lower slop position refers to the depression portion of the landscape. The term convex upper slope position refers to the hilltops or knoll portion of the landscape.

Waggoner., 1985; Verity and Anderson., 1990; Larney et al., 1995; Larney et al., 2000a). The use of manure can also be substituted for commercial fertilizers; however, it may be necessary to apply it annually over a long period of time in order to fully restore the eroded organic soil matter (Dormaar et al., 1998; Hamm, 1985; Massee and Waggoner, 1985; Verity and Anderson, 1990; Larney et al., 1995; Larney et al., 2000a). The extent of the erosion attributable to tillage can be minimized by adopting less invasive tillage measures such as converting to minimum tillage, zero tillage or direct seeding. These practices minimize the number of equipment passes on a field while maintaining field cover making soil particles less prone to tillage erosion. While these strategies minimize future topsoil loss in convex upper slope positions, they do not restore the upper slope's production capability, and have, from a producer standpoint, disadvantages. McCarthy et al. (1993) found that reduced tillage systems can cause delays in germination and slow soil microbial breakdown of residue. Cooler soil temperatures, can also delay seeding, especially in poorly drained soils.

An effective, alternative erosion management strategy is the adoption of landscape restoration. Landscape restoration is a process by which organic-rich topsoil is removed from concave lower slope positions, and is moved to the knoll positions where it is incorporated as additional topsoil (Smith, 2008). In field studies, the addition of topsoil on the convex upper slope has resulted in increased crop yield productivity (Lobb et al., 2007; Smith, 2008; Papiernik et al., 2007).

Factors Causing Landscape Erosion

Factors Affecting Topsoil Depth

Natural undisturbed landscapes are exposed to both wind and water erosion. Tillage erosion, however, is the dominant erosion process on undulating landscapes under cultivation (Lindstrom et al., 1990; Govers et al., 1999; Lobb et al., 1999; De Alba, 2003; Van Oost et al., 2003; Heckrath et al., 2005).

Definition of Tillage

In short, tillage includes all field operations where soil is disturbed by tools or field implements. Tillage is a standard agricultural practice which redistributes soil organic matter and incorporates nutrients from manure and crop residues. The practice of tillage has multiple benefits to the soil including the control of weeds, insects, diseases, regulating soil moisture, and soil structure (Smith, 2008). Tillage can also affect the size of the soil aggregates and their stability, which has a large impact on the extent of wind and water erosion that occurs in a field (Lobb et al., 2007).

Tillage Erosion

In sloped landscapes, tillage causes soil disturbance and displacement from the top of the knoll. This results in soil redistribution and soil accumulation in concave lower slope positions. This phenomenon can drastically affect soil structure and structural stability, changing water run-off movement, as well as, the soil's environment (soil organic matter, biomass, microbial) (Lobb et al., 2007). The extent of tillage erosion then becomes a factor of the slope gradient (Papiernik et al., 2007) and; impact soil and air quality both directly and indirectly. Tillage erosion, then, is the dominant soil erosion process responsible for soil displacement (upper slope to lower slope) and is responsible for the redistribution of the same soil in the concave lower slope position of the landscape (Lindstrom et al., 1990; Lobb et al., 1995; Kachanoski and Carter, 1999). Tillage erosion rates are usually highest in the crest and shoulder of the knoll (Papiernik et al., 2007).

Over the course of many years, the use of tillage, as a farming practice, can cause a significant amount of soil organic matter to pool in the concave lower sloped positions, which in turn affects soil productivity and crop yield. As previously explained, the soil displaced from convex upper slope positions accumulates in the concave lower slope positions. Papiernik et al. (2007) found that intensive tillage and cropping showed a 20 cm loss of soil from the convex upper slope positions. Areas affected by tillage erosion have also shown a reduction in yield in the eroded convex upper slope positions (Papiernik et al., 2005). As a result, crop yield decreases in convex upper slope positions. These yield decreases are not offset by an equal increase in crop yield in the concave lower sloped positions because once topsoil depth is over 20 cm, the incremental increase in topsoil depth is slight as the plant already thrives in those topsoil conditions. Also, conditions in concave lower slope positions such as soil salinity, weed presence and excess moisture also have an effect on yield in that portion of the landscape.

Extensive studies on the subject of conservation or zero tillage practices have shown improved long-term productivity of soil and a reduction in the amount of erosion (Hussain et al., 1999; McCarthy et al., 1999). Both of these practices reduce erosion through the reduction the number of tillage passes on the land, thus maintaining crop residue on the land's surface.

Effect of Limited to No Topsoil on the Agricultural Landscape

Soil erosion in agricultural landscapes can result in a significant loss of topsoil in the convex upper slope positions which in turn, results in a reduction in soil quality and crop productivity. Over the same time horizon, the soil found on the knoll becomes severely eroded in the A horizon. The eroded soil contains reduced organic matter which can result in shallow soil profiles, poor water holding capacity and nutrient availability, increased stoniness and carbonates at the soil surface (Smith, 2006). The resulting substandard soil had a direct effect on crop yields, causing a severe decrease in crop yield for convex upper slope positions (Lobb et al., (2007, 1999), Papiernik et al., (2007, 2005).

Problems Associated with Over Fertilization

Production losses, due to the decreased yields, ultimately require producers to offset yield losses by other means. One way to offset the production loss in the upper slope is to apply high levels of fertilizers to the affected areas (Massee and Waggoner, 1985; Mielke and Schepers, 1986; Massee, 1990; Verity and Anderson, 1990; Larney et al., 1995, Larney et al., 2000a). Theoretically, the application of fertilizer should, through increasing the level of nutrients available to the crop, replace the yield lost due to nutrient and topsoil loss. As commercial fertilizers can be expensive to purchase, they may be replaced or supplemented with animal manure, particularly in zones of livestock production.

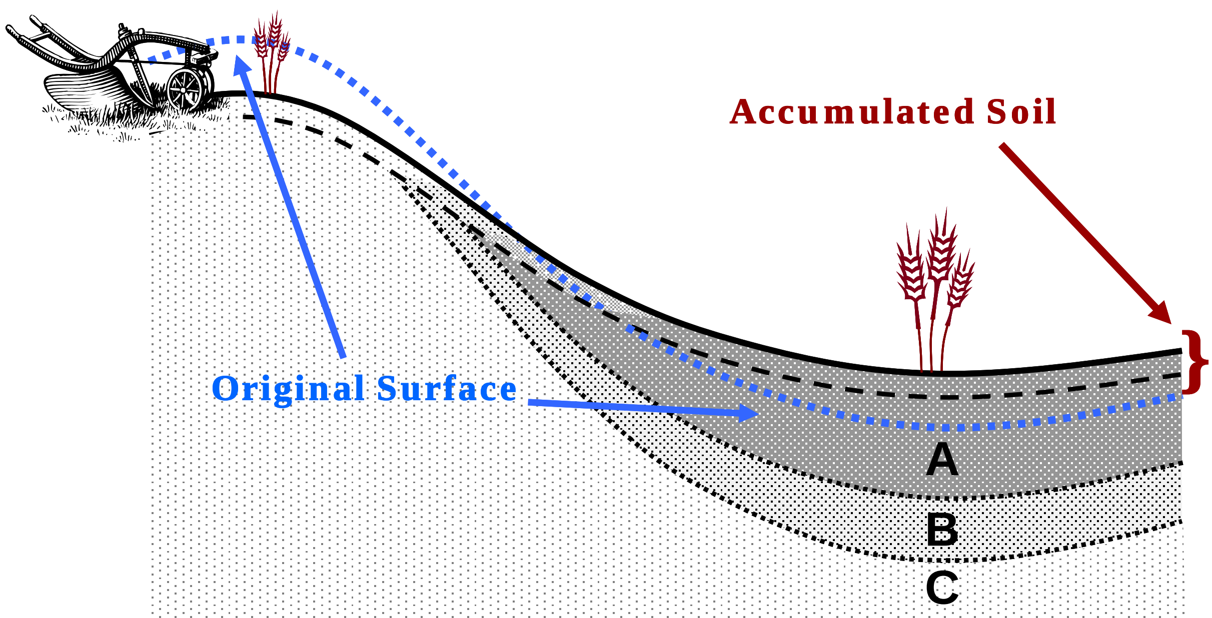
Landscape Restoration

For generations, European farmers in hilly areas have practiced landscape restoration, yet little research has been conducted on its effectiveness. A joint study between the University of Manitoba and the USDA (Lobb et al., 2007) stated the practice was an agronomical benefit. Smith's (2008) field study, exploring the effects of landscape restoration on hilly landscapes in South Western Manitoba demonstrated that 10 cm of topsoil added to severely eroded convex upper slope positions increased crop productivity by as much as 133 per cent, even in years of below normal precipitation during the growing season.

Figure 1 provides a snapshot of a typical hummocky landscape. A healthy hummocky landscape, or the original surface, is outlined by the dashed line. The soil profile in the convex upper slope position is higher, and with a higher A horizon depth. In the concave lower slope position, the soil horizons are present, all with healthy topsoil depths.

The portrait of an eroded hummocky landscape is outlined in black. Notice that, in comparison to the dashed line, the topsoil levels on the convex upper slope positions are lower. Concave lower slope positions also have, in the A horizon, an accumulation of topsoil. Topsoil lost from tillage erosion migrates from the convex upper slope positions to the concave lower slope positions as evidenced by the solid line (Govers et al., 1999). It is at this point that landscape restoration becomes a solution to the problem.

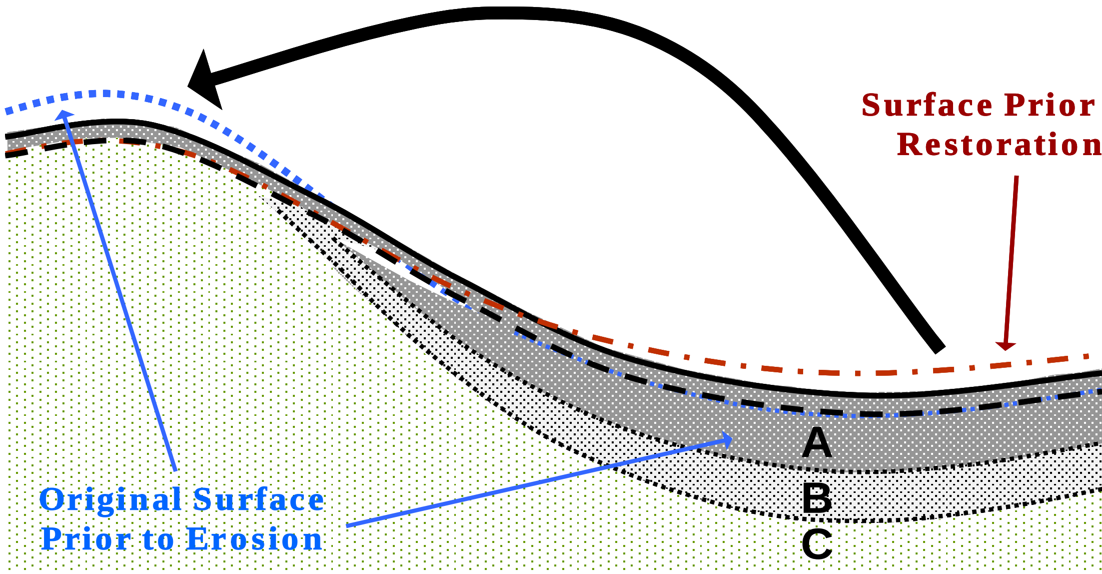
Figure 1: Typical Hummocky Landscape



Definition of Landscape Restoration

In short, landscape restoration redistributes the topsoil within the landscape. Figure 2, illustrates a typical landscape before and after landscape restoration. The thick short dashed line outlines a severely eroded landscape profile prior to landscape restoration. In the process of landscape restoration, organic rich topsoil is removed from the concave lower sloped positions and applied to the convex upper slope positions from where it originated, as illustrated by the arrow. This results in a higher A horizon in the convex upper slope positions, as is illustrated by the thick short dashed line and ultimately restoring the field to its original landscape profile.

Figure 2: Illustration of Landscape Restoration



Summary

Landscape restoration attempts to correct and replace topsoil lost by erosion on convex upper slope positions of a landscape. Field studies have indicated that landscape restoration is a suitable solution for restoring topsoil depths in convex upper slope positions, and increasing yield potential (Lobb et al., 2007; Papiernik et al., 2007; Smith, 2008). While the focus of this study is on the economic feasibility of landscape restoration, a large portion of the model was built to simulate tillage and other types of soil erosion and the restoration of the landscape according to parameters developed in the literature mentioned above.

Chapter 3- Literature on Economic Theory

Scope of the Research

The development of landscape restoration as a research topic also requires an in depth look at cost benefit analysis, the effect of landscape restoration on a farming operation, as well as, a discussion on investment analysis.

Cost Benefit Analysis

In order to objectively determine the success or failure of a particular scenario with LandRec, objective standards must be developed. A cost benefit analysis would be one way of objectively deciding the success of a scenario.

Cost benefit analysis is defined as a technique designed to determine the feasibility of a project or plan by quantifying its costs and benefits (Levin and McEwan, 2001). This technique is a popular method of project valuation (Hummel and Callan (2005), Bonnieux and Le Goffe (1997)). Typically, costs and benefits are expressed in money terms, which are adjusted for the time value of money so that project cost flows, over time, are expressed in present value. The concept of time value of money calculates the value of money given the interest earned over a given period of time. Future values of money are also brought back to their present value so that comparisons of future costs to the present costs can be discounted and reflect the same value of money. In short, the present value of a future stream of cash flow, given a specific rate of return, is used to compare investment options and determine the viability of the options.

The goal of a cost benefit analysis is to predict the cost effectiveness of different alternatives and see whether the benefits of the project outweigh the costs (Kay et al., 2008). In order to determine the value of a project, one must choose an appropriate investment technique method.

Options include: net present worth, internal rate of return, benefit-cost ratio and net benefit investment ratio. There is no one ideal technique for estimating the worth of the project, and all techniques are designed to be decision-making tools.

Economic Assessment of Landscape Restoration

The economic success of a project such as landscape restoration requires not only the increase in soil organic matter in the A horizon, but also an increase in revenues which can be attributed to this practice.

Landscape restoration, is in a sense, an investment decision that a farmer must make. The farmer must know with some degree of certainty that the investment will increase his farming revenues. As with any type of investment, there is no absolute way of knowing if it will be profitable for the investor, but there are ways of calculating the potential of profit and the degree of risk associated with the project in question.

The degree of risk can be minimized through an analysis of the required capital investment and careful consideration of the size of the project, timing and potential revenue stream related to the cash flow. There are two ways to analyze the future returns on an investment: the future value of money and the present value of money. The future value of money method explores the value of investment and its return at some specific point in the future (Kay et al., 2008). The present of value of money on the other hand takes the future earnings of the investment and brings them back to a present value equivalent, so that an individual can know, in today terms, what the return on the investment will be.

The concept of present value refers to the current value of a sum of money to be received or paid in the future. In this case, instead of compounding the interest, the interest is discounted and converted to today's value of the money. The present value of money concept is used more often than the future value of money for an investment analysis, it will, be used in this study to analyze the investment required for landscape restoration.

Investment analysis

Investment analysis is defined as the process of determining the profitability of two or more alternative investments (Kay et al., 2008). In this paper, the profitability of landscape restoration is compared, through a variety of scenarios, to the non-restored equivalent.

This study will examine the initial cost of landscape restoration, the additional revenue received from the additional yield capacity, and the discount rate used.

The additional revenue received from the restoration will be valued as per net present value. The net present value formula is used as it considers the time value of money and takes into account the fluctuation of cash flow over the entire life of landscape restoration. The formula used to calculate net present value is as follows:

NPV *= $(rev^1 – cost^1) + (rev^2 - cost^2)$*discount rate + … + $(rev^n - cost^n)$*discount rate^{n-1}*

Where, revenue is a function of the following factors:

$$rev = f(t_d, y_p, y_h, h_s, p_t)$$

And where revenue as illustrated above as a function of topsoil depth at various positions of the landscape (t_d), yield potential per hectare (y_p), actual yield per hectare (y_h), size hectares seeded in crop production (h_s), and crop prices for the crops in the rotation (p_t). Further, the revenue formula takes the linear form of:

$$Revenue = r_h * h_s$$

Where revenue is calculated by multiplying the revenue per hectare (r_h) and the number of hectares seeded (h_s), providing the revenue for any given year. Therefore, r_h, revenue per hectare is calculated as follows:

$$r_h = (h_d * y_{pd} * r_o) + (h_k * y_{pk} * r_o) + (h_{ne} * r_o)$$

Where revenue per hectare is calculated in three parts: revenue generated by the depression areas, knoll areas and non-eroded areas, or, as it is also referred to, mid slope positions. Both revenues generated by the depression and knoll areas are affected by topsoil levels, which are factored by the yield % index for that portion of the landscape. The variables used in this calculation are as follows:

h_d : % of hectare in depression areas,

h_k : % hectare in knoll areas,

h_{ne}: % hectare in non eroded areas,

y_{pd}: Yield index for depression,

y_{pk}: Yield index for knolls,

r_o: Crop rotation revenue per ha.

With regards to costs, the cost function used to calculate NPV is a function of:

$$Cost \;=\; f(h_s, c_{ph}, t_d\,, d_t, Я_t, s_s, c_r, h_r)$$

Cost is used in the calculation of NPV and is a function of the hectares seeded in crop production (h_s), cost of crop production per hectare (c_{ph}), topsoil depth (t_d), desired topsoil depth(d_t), restoration trigger ($Я_t$), scraper size (s_s), cost of restoration per hectare (c_r), and area restored (h_r).

Further, the formula used to calculate the costs used to calculate NPV in any given year is as follows:

$$Cost = \left(h_s * c_{ph}\right) + (c_{ЯI} + c_{ЯS})$$

Where costs related to cash cropping are the regular expenses per hectare of cash cropping (c_{ph}) and is multiplied by the number of hectares (h_s). Costs relating to restoration are the sum of the cost of the initial restoration ($c_{ЯI}$) and costs of subsequent restorations ($c_{ЯS}$).

Further, Cost of Initial Restoration is defined as follows:

$$c_{Яi} = \;(H_{Ki}/Я_{hdi}) * (Þ_i * ¥_i)$$

Where the days required to complete the initial restoration is calculated by dividing the total area of eroded knolls (H_{Ki}) by the number of hectares restored per day ($Я_{hdi}$). The number of days required to complete the initial restoration is then multiplied by the per day cost of restoration. The per day cost of restoration is the product of cost of running the machinery per hour ($Þ_i$) and total hours of operation per day ($¥_i$).

The Cost of Subsequent Restorations formula is defined as:

$$c_{ЯS} = (H_{Ks}/Я_{hds}) * (Þ_s * ¥_s)$$

Where the days required to complete the initial restoration is calculated by dividing the total area of eroded knolls (H_{Ki}) by the number of hectares restored per day ($Я_{hdi}$). The number of days required to complete the initial restoration is then multiplied by the per day cost of restoration. The per day cost of restoration is the product of cost of running the machinery per hour ($Þ_i$) and total hours of operation per day ($¥_i$).

In the context of the study, the net present value formula is used to calculate the variable titled the *Present Value of Net Revenue*. A standard simulation run in STELLA ® 9.0 runs over a thirty year time period. As such, the concept of NPV is used to bring back costs and revenues to their current day equivalent so that comparisons between scenarios can be done. Net Present Value is used to compare alternatives within a scenario, and helps determine the success of landscape restoration as an investment decision, providing potential investors with an idea of their potential revenue according to today's dollar value.

The underlying model calculates the *Present Value of Net Revenue* differently than the typical net present value formula as described above, for the simple reason that it uses icons such as reservoirs, flows and stocks (as detailed in Chapter 6), rather than the set formula displayed above. Formulas are generated as a result of the relationships outlined in the model and are included in Appendix 1.

The net present value of revenue is as follows:

The underlying model uses a reservoir to sum and accumulate the net revenue at present value

$$Net\ Present\ Value\ =$$

$$= \sum_{t=0}^{n} Net\_Revenue\_at\_Present\_Value(t - dt)$$

$$+ \sum_{t=0}^{n} (Present\_Value\_of\_Annual\_Revenue$$

$$- Present\_Value\_of\_Annual\_Expenses) * dt$$

Where t refers to the length of the run, and dt referring to the actual year in which it is inputted. They are simple indicators of the year in which the calculation is done and are neither multiplied nor subtracted and where the first variable is the previous year's sum plus the current year's information.

Since the underlying model uses a reservoir to accumulate the information, it is assumed that the initial value at the beginning of the simulation run is in year 0 is:

$$Net\_Revenue\_at\_Present\_Value\ =\ 0$$

The present value of annual revenues and expenses feed into the reservoir to calculate the net revenue at present value. To calculate the P*resent Value of Annual Revenues*, the model uses the following formula:

$$Present\_Value\_of\_Annual\_Revenue$$

$$= Total\_Land * Total\_Revenue\_per\_ha * (1/((1 + Discount\_Rate)\hat{}t))$$

Where the P*resent Value of Annual Revenues* is based on the total revenue per hectare times the total land base and discounted accordingly.

To calculate the *Present Value of Annual Expenses*, the model uses the following formula:

$$Present\_Value\_of\_Annual\_Expenses$$
$$= (Frequency\_of\_Restoration\_Costs + Normal\_Expenses\_\_of\_Production)$$
$$* (1/((1 + Discount\_Rate)\hat{}t))$$

Where the *Present Value of Annual Expenses* is the sum of the normal expenses related to production and the restoration costs for that year, the sum is then discounted accordingly.

The model generated net present value should be examined in regards to how much value landscape restoration will bring to a farming operation. If the net return is positive then act of landscape restoration would be beneficial.

If the net present value generated is zero, then it is assumed that the benefit of landscape restoration is negligible, as it is likely not to provide additional net revenue to the operation. In this case, it is also assumed that restoration would not be feasible investment based on the NPV generated. The decision, then, to perform landscape restoration would be based on other criteria such as increasing soil health, increasing yield and enhancing topsoil depth.

Discount rates are used to estimate the opportunity cost of capital, or in other words, the minimum rate of return required to justify the investment. The discount rate can be difficult to estimate, but can provide an indication as to the required return. An investment not requiring financing will also carry a lower discount rate than that where financing is necessary.

In all investments, the payback period is also an important consideration as it provides an indication as to how quickly the investment will pay for itself. The payback period refers to the number of years required for an investment to recoup the original investment cost, through the

NPV of revenue generated over time. As crop yields and prices typically vary through the years, the payback period for landscape restoration sums the year to year annual net cash revenues until the total net revenue equals that of the cost of the initial investment. In general, the shorter the payback period the more desirable the project. Calculating the payback period provides an easy way to identify an investment with a more immediate cash return. It should be noted; however, that the payback period ignores any additional income made after the initial investment is recouped, and is not the best measure of profitability of the investment.

Importance of this research

Landscape restoration is a timely research topic for both producers and industry. There are many applications for the research stemming from this study and the versatility of the computer model allows it to be modified and applied to other landscape types. While the values generated by the model are approximations of actual costs, program users will have a sense of what will work in their own individual operation and, most importantly, how their bottom line is affected by the scenario.

Government departments can use the study findings in the examination of soil and tillage erosion within the province and then determine environmental sustainability of farming practices. The computer model, gives farmers the ability to customize scenarios for their own specific site. It also provides the opportunity for future researchers to build on this research topic and provides an improved base for future computer modeling in landscape restoration. Lastly, the development of this model will provide government extension staff with a user-friendly tool when assisting farmers who wish to restore deteriorating soils.

Chapter 4: Model Background and Development

Model Development:

Origins and Expansion of the Model

Originally developed as part of an undergraduate thesis by Mieke Bosma (2004), the original LandRec model examined the relationship between soil erosion and landscape restoration. The focus of the resulting research paper was the relationship between topsoil depth and crop yield, and the annuity derived from the practice. The original model had its limitations, as it assumed that many of the variables were constant and set in the underlying model. The original model limited the economic cost of landscape restoration in that the cost of production and the crop rotation were pre-selected and the cost of field restoration was assumed. In addition, the model lacked financial outputs. The original model's interface also required additional modification to include the new factors of production such cropping choices, cost of production etc, and to provide a more intuitive format.

For the purposes of this study, variables were expanded and vary according to the scenario selected. The resulting model now includes optimal crop rotations and more specific production costs for the original and additional variables. Major changes to the model on the input section include:

- Expansion of Crop Options

The original model assumed a set crop rotation of canola, flax and barley, and one could only change the crop price and expenses. Yield was also assumed in the underlying model for each crop. The model was subsequently expanded to include crop price, yield, cost of production factors for each possible crop in a rotation, as well as, the number of years a crop is included in the rotation. Crops such as alfalfa or tame hays can be included in a crop rotation for up to 5 years. The model will properly now account for the changes in yield over time, which is different for perennial crops then it is for annual crops.

- Redefinition of Tillage Erosion Rate

  The field characteristics portion of the model, the major addition was the redefinition of the rate of tillage erosion variable. In the original model, the relationship between soil loss and tillage erosion was defined by a graph. Rather than use the graph, the model used a formula which gives similar results to the graph.

- Use of Rented or Owned Equipment

  In terms of restoration specifics, the option to rent the scraper and operator or to perform the restoration with one's own equipment was added. The cost to operate the tractor and scraper were also included, as was the option to change the hourly wage and fuel costs. An on/off switch within the model was added in order to allow the result comparison for the controlled, non-restored field.

- Calculations for Present Value Variable

  The model now calculates all present value variables for a restoration regardless whether it is done with rental equipment and hired operator or if the farming operation uses its own equipment. The rental cost vs. the owned equipment cost can then be compared.

The output generated in the original model was limited it focused on annuity, number of days and the cost of the initial and subsequent restorations. The original model also outlined the effects of restoration with respect to the net present value of the investment in graph format; however, net present value was not its main focus. As a result the model developed for this study contains an expanded output section which was then reorganized into two parts: 1) the effect of restoration on the landscape and 2) the economic impact of restoration.

In the first part of the output section, a graph is generated which displays the varying topsoil depths in a specific field over the length of the simulation. This section also includes a second graph which illustrates the effect of both tillage erosion and subsequent restoration on yield for the knolls and depressions

In the second part of the output section, the original net present value graph was retained and a section outlining the costs of restoration based on rental or owned equipment was added. Finally, for the purposes of analysis, results generated by the model are exported into an Excel spreadsheet.

In summary, the original model was expanded to include: 1) the cost of production elements for crop rotations and equipment ownership, 2) the option use rented or owned machinery, 3) the option to restore the field over the course of one year or two, 4) the option to perform subsequent restorations, 5) a restoration trigger, and 6) the NPV of the investment of landscape restoration using rented or owned equipment.

Several changes were also made to assist users of the program: 1) user-friendly modifications were made to the LandRec model interface, 2) the capability to generate additional graphs was added as well as topsoil level indicators, 3) the expanded economic results output section now provides both the net present value of the investment, revenues and expenses, and, 4) the economic cost of initial and subsequent restorations and the cost relating to renting or owning the equipment were also added.

Developing the Model

LandRec was developed to estimate the costs and benefits of landscape restoration on a given field. Using STELLA ®, LandRec accounts for the following variables; 1) area of land, 2) presence of depressions and hilltops, 3) initial topsoil restoration and successive restorations, 4) the rate of erosion according to different tillage practices, 5) different scraper capacity, and 6) actual market prices as crop prices can be altered to reflect an individual operation's marketing choices. The ability to program these variables, as those not mentioned above, allows us to personalize LandRec according to the needs of a specific farming operation.

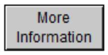
Developing a model in STELLA ® 9.0 is very different that developing a model using typical economic modeling software as STELLA ® 9.0 uses icon-based graphics rather than formulas to build the model. These icon-based graphics use diagrams to visually represent the relationship of the variables and how stocks (used to represent anything that accumulates) and flows (activities that lead to inputs and outputs to stocks) work throughout the system. Using these icon-based graphics to develop the model and mimic the stocks and flows, the equations are generated and stored in the equation layer of the program.

Simulation runs in this program are done over a period of time. In our case, the standard timeframe is 30 years. Output from the resulting runs are exported into Excel, where they are analysed. The computer also outputs graphs and tables as requested by the model developer.

On the interface front, users choose their variables through the use of knobs, sliders, switches and buttons. Each type of input device serves its own specific purpose. The interface portion also advises the user of problems; for example, it warns the user when topsoil depth on the knolls is very low, and a when subsequent restoration does occur.

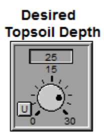
The following section will describe the tools used to develop the interface of the model.

Button



Buttons are used to perform a specific task in the model. These tasks include helping the user navigate the various pages of the models, and to start, stop or pause the simulation run.

Knob



Knobs are used to provide the initial values for stocks or to adjust values of constants within the model. Values are set throughout the length of the simulation and cannot be used for variables requiring equations.

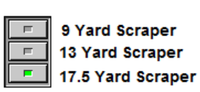
Slider

Sliders adjust constant values for a variable, and can override equation logic. They cannot be connected to many of the tools used to develop the underlying model: such reservoirs, conveyors, types of flows.

Switch

Switches function as an on/off switch within the model. For example, they are used to turn restoration on or off. They are also used for the selection of scraper sizes. When chosen and connected to a converter, the variable it takes on a value of 1, or else it takes a value of zero when off. These types of dummy variables are used many times in this model.

List Input Device



List input devices (LID) are similar to a table in a spreadsheet. In the model they establish the user’s crop rotation parameters, crop cost of production (COP) values and costs related to owning one’s own equipment. LIDs can be used to set values for converters and flows in the model. They can also be used to set initial values for stocks.

Data Collection

The LandRec parameters are based on empirical estimations taking which take into account observed market data (crop prices and average yields), as well as, prior information from field studies related to the soil science experiments (University of Manitoba and USDA). The following is a brief description of the most influential variables, and how their ranges were established: crop yields, cost of production, crop sales, crop rotation, machinery and labour.

Crop Yields

Crop yields are based on a 5-year Olympic average of the five highest yielding varieties for every crop type described in Manitoba. The data for all annual crops originates from Manitoba Seed Guide (2007). For alfalfa, as with any perennial crop it was necessary to build an incremental yield function that would account for yield differences in the establishment year, and following years for up to 5 years.

Cost of Production

Cost of production ranges (COP) were developed using the cost of production budgets from Manitoba Agriculture, Food and Rural Initiatives (2005, 2007). The average value for total COP per crop was used as the default value of the variable, but components of the cost of production for any individual crop can be modified within a given range.

Crop Sales

Market values of crops are based on data from Manitoba Agricultural Services Corporation. The default value is the average price of that specific crop. Historical minimum and maximum values are used to establish the upper and lower limits of that specific crop's market value.

Crop Rotations

Within the context of this study, crop rotation is defined as the practice of growing a series of crops in the same area in sequential seasons. Crop rotation also seeks to balance the fertility demands of the various crops while reducing the risk of depleting the soil of its nutrients. While they can choose the crop rotation that best describes his operation, the crop rotations in our analysis are chosen based on a combination of factors. The selection of crops within a crop rotation will likely be a function of market conditions.

Machinery and Labour

The average cost of running machinery for landscape restoration is set as a default in the model. The program user can choose one of two options for machinery: 1) the rental of land restored machinery and operator or 2) the use of owned equipment on personal time. An average value per hour rate of machinery and operator was then calculated based on these researched values.

For operator owned machinery, a breakdown of the cost elements was developed using estimates developed by Salassi (2001) in order to develop a cost per hour for equipment, gas use and operator’s time.

Model Inputs and Outputs

This model is designed to simulate the many possible outcomes of landscape restoration. This includes but is not limited to: yield levels, topsoil depth, and overall profitability of restoring eroded hilltops and/or the generated net revenue.

As a model, LandRec can be divided with each sub-model focusing on particular aspects of restoration. The first sub-model explores the interaction of soil depth and yield productivity. The second sub-model simulates the economics of cash cropping over time. The third sub-model simulates the cost of restoration for both the initial restoration and secondary restorations. The fourth and last sub-model simulates the effect of erosion on the different slope positions and its relationship to the landscape restoration effort.

It is important to note that each sub-model is inter-related and dependent on the 3 other sub-models for a definitive answer as to the economic benefit of land restoration.

Model Assumptions

As one is unable to quantify all factors of real life into a model, assumptions are made and programmed into the model. For LandRec, the following assumptions were made:

Soil and Crop Model Assumptions

- First, it was assumed that chosen crop rotation will remain, throughout the course of the simulation run, as initially selected. This is based on the fact that the typical farmer prefers to plan his cropping choices and is unlikely to change his tillage practices.
- Secondly it is assumed that yield potential is constant over time. In the real world, yield potential will fluctuate depending on a variety of factors which include climate, seed variety, type of soil etc. The effects of weather and new seed varieties are mitigated in the model by using a 5 year Olympic average for yield for the top 5 varieties in the best producing areas affected by tillage erosion in Manitoba. The mitigations were used based on the assumption is that a farmer is likely to pick his crop rotation based on market conditions as well as his land's production capability.
- Thirdly, in the restoration process, the rate of soil application is constant during the restoration process. Varying speeds are more realistic, but for the model's purpose an average and constant speed provides the model with a reasonable estimate of the time needed to complete a pass.
- Fourthly, the model assumes that only three scraper sizes are available. Scraper capacity is limited to either 6.88 m^3 for a 9 yard, 9.94 m^3 for the 13 yard scraper and 13.35 m^3 for the 17 yard scraper. Regardless of how small the area to be restored, using equipment smaller than 9 yards

would be inefficient for the amount of soil needed to be moved for landscape restoration regardless of how small the area to be restored. Anything larger than 17 yards has the potential to cause compaction problems as the weight of the equipment and frequent machinery passes compact topsoil and, decrease yield. It can also be inefficient due to the size of larger scraper in theory and in practice.

- Fifthly, in regards to soil erosion, it is important to note that some original topsoil loss is expected. While the majority of the topsoil from the convex upper slope positions will deposit in the concave lower slope positions, there will always be a small portion that is lost to other processes like water and wind erosion (Bosma, 2004).
- Finally, the topsoil removed from the concave lower slope position does not lead to a decrease in yield in that position (Battison et al., 1987; Verity & Anderson, 1990). The accumulation of topsoil causes the A horizon to increase in depth over time in the concave lower slope position and creating an overabundance of topsoil. The subsequent removal of the accumulated topsoil from the concave slope position does not hinder productivity as areas prone to flooding and subsequently have a lower yield.

Economic Model Assumptions

- Crop prices will stay constant over time. In real time, the market determines crop prices however for this study; it is assumed that crop prices stay constant. If we assume that crop prices are constant, we can then provide a cautious estimate of the revenue converted back to the present value equivalent.
- Cost of production for crops will stay constant over time. In real time, crop cost of production will vary due to market conditions. In this study, it is assumed that the COP stays constant, in order to provide a better base for comparison.
- The discount rate stays constant throughout the length of the run for the reasons listed above.

- Depending on field and weather conditions, landscape restoration is normally performed in the fall or spring. In the model, it is assumed that the initial restoration is performed in the fall of year 0. The model will generate results from year 0 with the cost of restoration added to the spring of year 1. The model can then generate results for land restoration from year 0 to 30.

Model Interface

The LandRec interface is divided into 4 sections or steps. The model is designed allow the user to progress linearly through the sections and build on previously entered data.

Step 1: Select the Crop Rotation

The first step is to select the crop rotation and modify crop specifics such as yield, costs and prices according to the scenario's needs. This is where the user can customize costs of production according to their own operation and provides an opportunity to either input the individual cost of production for particular crops or calculate the cost of production by itemized categories.

Step 2: Select Field Characteristics

Step 2 is used to set or modify field characteristics. At this point, it is assumed that the chosen field is undulating in nature as the model has been developed for landscape restoration. Once a crop rotation has been chosen, the field, in which that combination of crops will grow, is chosen. In order to simulate individual field landscapes the program includes five landscape characteristics. They include: T*otal Land*, E*ffective Topsoil Depth on Eroded Hilltops*, and Rate *of Soil Loss on Eroding Hilltops*, P*ercentage Application Area* and *Percentage of Removal Area*.

Three tillage settings are also available on this screen: conventional tillage, conservational tillage and zero tillage. It is assumed that a conventionally tilled operation will typically have a soil loss rate between 0.5 mm to 0.8mm of topsoil per year. For conservational tillage, soil loss due to erosion will be closer to 0.2 mm of topsoil per year. Lastly for zero-till the rate of soil loss over a year will be closer to 0.05 mm.

Step 3: Select Restoration Specifics

In Step 3, a landscape restoration method is selected as are S*craper Width*, the *Desired Topsoil Depth* for the newly restored knoll, rental or owned equipment and the R*estoration Trigger*.

Step 4: Run LandRec

Step 4 runs the model and generate its results. This is also where both the agronomic and economic results, over the length of the simulation, can be represented in graph format.

Model Verification

The process of model verification examined whether the original question was properly transposed into its model equivalent. In this case, does the model accurately represent the process of landscape restoration and does it estimate the benefits and costs? Model verification was performed by hand calculation of the formulas and the subsequent comparison of these results with the model's results. Throughout the development process of the model, simulation runs were performed for each sub-model both in isolation and in relation to the other sub-models in order to test whether or not the formulas had generated accurate results. The purpose of these simulations was also to eliminate errors and correct issues as they arose. While analyzing the sub-models separately and together did significantly reduce the errors present in the model, it does not mean that the model is error free.

Research suggests that a useable model should not exclude the essential elements of the system in question, and on the other hand it should not include unnecessary details (Balci, 1989). For example, full inclusion of weather effects would have increased the model's accuracy. These effects were only partially captured with the inclusion of crop yield in the model as one cannot predict weather with any degree of accuracy. It was therefore determined that the use of average yield values would suffice for the purposes of this study.

Model Validation

The developed model was then validated. The process of model validation refers to whether the model produces results that are sufficiently accurate. The model results were compared to the results of the field trial results for the physiological model. In general, results generated by the model were considered accurate when compared to field trial results for the years available.

For comparison purposes, the following section is a brief summary of the results that were compared to verify that the model was generating results similar to those by Smith's results (2008).

The following table (Table 1) provides a description of the soil information relating to the site locations and the type of crop produced in the first year following restoration.

Table 1: Study Sites used in Smith's Study

Site	Location	Crop Type	Soil Group
MZTRA 1	Brookdale, Manitoba	Flax	Black Chernozem
MZTRA 2	Brookdale, Manitoba	Flax	Black Chernozem
MZTRA 3	Brookdale, Manitoba	Peas	Black Chernozem
BRX	Bruxelles, Manitoba	Wheat	Dark Grey Chernozem
SWL	Swan Lake, Manitoba	Flax	Dark Grey Chernozem
TRE	Treherne, Manitoba	Peas	Dark Grey Chernozem

When comparing the yield results from the field study and model, the following table (Table 2) outlines the yield differences following initial restoration. While results generated from the model are not identical to those experienced in the field, they fall within an acceptable range.

Table 2: Yield Results Comparison

Yield Difference (%) in year 1			
Site	Crop	Field Study	Model Results
MZTRA 1	Flax	41%	45%
MZTRA 2	Flax	39%	37%
MZTRA 3	Peas	25%	31%
BRX	Wheat	128%	110%
SWL	Flax	94%	90%
TRE	Peas	64%	71%

Summary

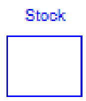
The original model provided a good starting point for this study. The model was expanded by adding more crop choices, cost of production calculators, adding the option to outsource the restoration or perform it using one's own equipment and through elaboration of the financial output sector. These additions to the model were tested to ensure that they were properly added and that acceptable results were generated. Errors were found and corrected and, model outputs were compared to verify they were within the acceptable range.

Formulas

The model used to run the simulation is organized in 17 over arching sections. Developing models in the STELLA ® 9.0 program uses icon-based graphics to develop the underlying model and graphically mimics the relationships between the variables and their interaction. In one of the underlying interfaces, it translates the icons and their relationships into formulas. As there are many formulas due to the numerous variables, only the most important variables are discussed and presented in this section. As well, both the graphical relationships and the underlying formulas are presented in this section. The complete formula list for the model is included in the Appendix 1.

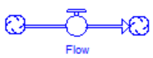
Using Stella ® 9.0 the sub-models used the following four tools to develop the relationships between variables: stocks, flows, converters and connectors.

Stocks



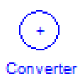
The stock icons purpose is to accumulate information over time. They collect whatever flows into them, and net whatever flows out of them.

Flows



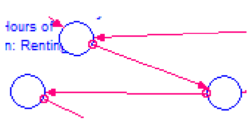
The flow icon is used to either fill or drain accumulations (or stocks). They can either be uniflow (either only filling or draining) or be biflow.

Converters



The most used icon of this model, a converter can be used to describe a constant, define external inputs into the model, calculate algebraic relationships and or be used as a repository for graphical functions. It is referred to as a converter as it converts inputs into outputs.

Connectors



Lastly, connectors are used to link the other various icons and elements of the model. Two types of converters exist: the action connector or the information connector. Those made of dashed lines refer to information connectors, and solid lines refer to action connectors.

Crop rotation

This section explores the effects of landscape restoration on yield and, subsequently, the costs and revenues from the cropping rotation. For example, the yield sector calculates the annual yield of three different parts of the landscape: the eroded knolls, the non eroded landscape, and the depressions. Each part of the landscape will generate different yields based on the E*ffective Topsoil Depth;* however, the eroded knolls' yield will fluctuate the most due to the amount of soil added to the knolls, the type of tillage practice used, and subsequent restoration triggers. (It is important to note at this point that the maximum topsoil level depth which is considered effective for maximum yield production of 20 cm (Mielke and Schepers, 1986; Verity and Anderson, 1990) The portion of the field that is not eroded will see consistent yields, year after year, as tillage erosion has had little effect on its topsoil depth. The yield in depressions will vary little as its yield potential is already limited due to moisture levels, salinity and weed presence.

For each crop, one can manually input all factors of production (Ex*pected Yield, Expected Revenue, and the Costs of Production per Hectare*). All factors related to the cost of production or a gross number per hectare can also be entered.

The model assumes that the crop rotation chosen is seeded and harvested each year. The field is divided into equal portions, based on the crops selected in the first part of the model and assumes that all chosen crops chosen are seeded and harvested each year throughout the length of the simulation.

The annual yield section of the model is illustrated in the following Figure 3 below.

igure 3: Annual Yield Illustration

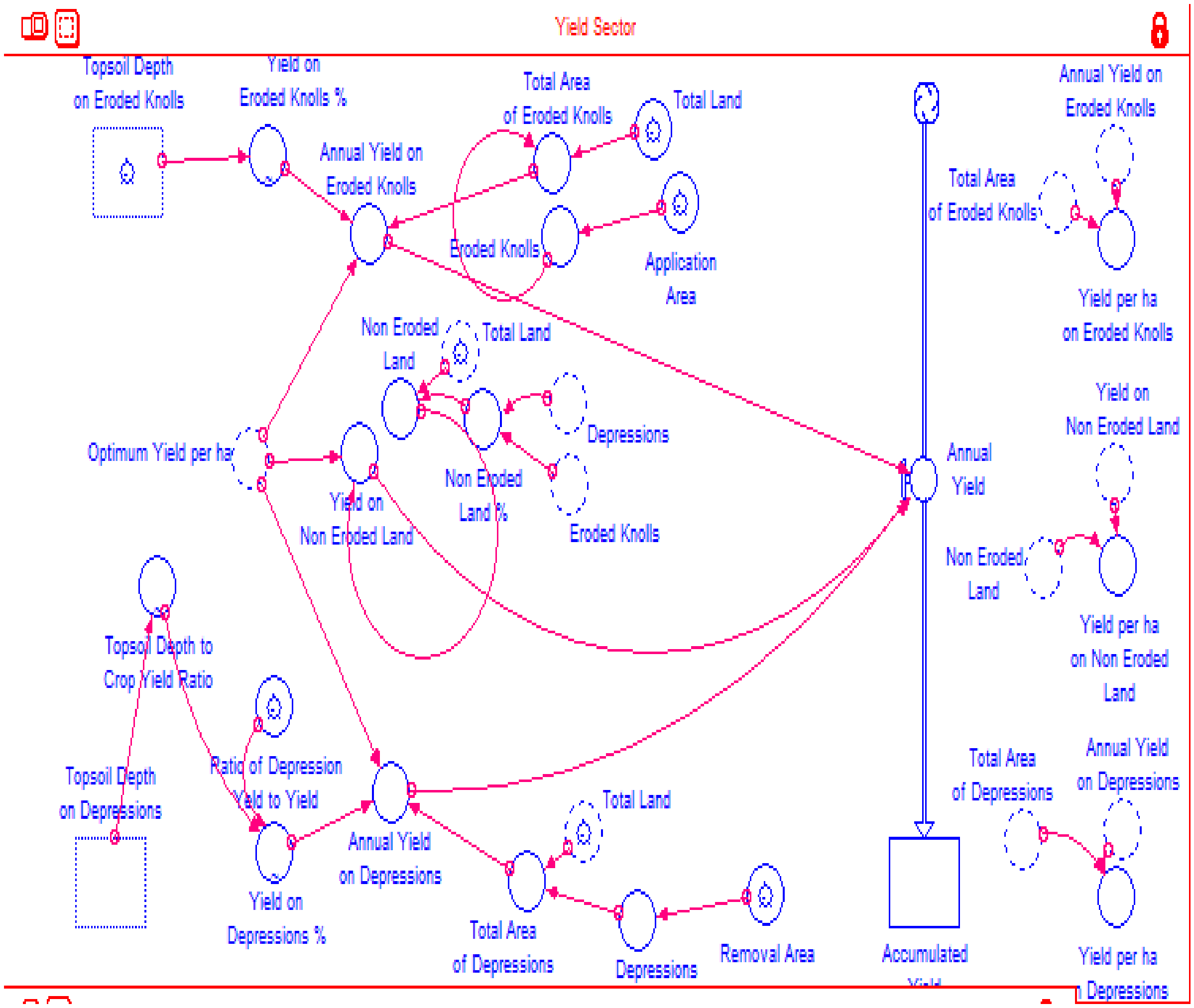


Figure 3 visually represents the annual yield sub-model where yield is calculated for the various portions of the landscape, and then is used to calculate the annual yield of the field. To run this portion of the model one must input the following factors: total land, removal area, application area, and ratio of depression yield to yield, crop rotation yield/ha, topsoil depth on eroded knolls. Stocks such as topsoil depth on eroded knolls and topsoil depth in depressions are used to establish the starting topsoil depth. All of the factors illustrated in Figure 3 are then used to calculate the annual yield on the three portions of the landscape: eroded knolls, non eroded land

and depressions. This sub-model estimates the approximate yield of the various positions of the landscape over the course of a simulation run.

(a) Total Area of Depression

For the portion of the landscape considered as depressions, the total area considered as depression is a factor of total land and the portion of which is considered as depressions (based on the value selected from the Removal Area knob as a percentage of total land) multiplied by the total land.

$$= \left(\frac{RemovalArea}{100}\right) * total\ land$$

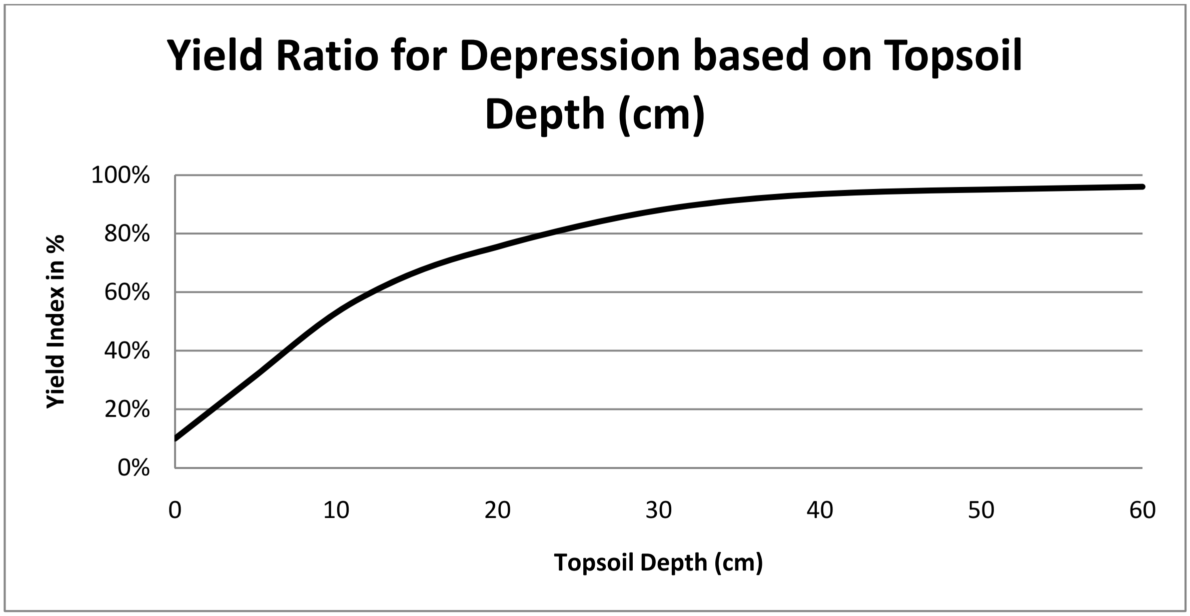
(b) Yield on Depression %

The Yield on Depression % is a graphical function that uses information provided by the ratio of depression yield to yield and the topsoil depth to crop yield ratio to determine the appropriate yield % for the depression.

$$= Ratio\ of\ Depression\ Yield\ to\ Yield * Topsoil\ Depth\ to\ Crop\ Yield\ Ratio$$

The resulting value is a percentage that is then cross-referenced to the yield potential based on the yield productivity of that portion of the landscape and the topsoil depth for the depressions. The relationship between topsoil depth in depressions and the yield is visually represented in the following graph (Bosma, 2004).

Figure 4 : % Yield Ratio for Depression based on Topsoil Depth



(c) Annual Yield on Depressions

Yield in depression areas is reflective of both the topsoil depth and the moisture content of the area. Typically, potential yield in the depressions is very low due to the moisture accumulation which accumulates due to run-off, or rain, during the growing season. Annual yield in depressions is calculated by taking the yield index in the depression areas, multiplying it by the total area considered to be depression areas and multiplying it by the crop rotation's *Yield/ha*. As such, the annual yield on depression is defined below:

$$= Total\ Area\ of\ Depression * Yield\ \ Index\ on\ Depressions\% * Yield/ha$$

(d) Total Area of Eroded Knolls

For the knoll portion of the landscape, the relationship between variables is quite similar to that of the depressions. The total area of eroded knolls is a function of eroded knolls (application area divided by 100) multiplied by the total land of the area.

$$= \left(\frac{ApplicationArea}{100}\right) * Total\ Land$$

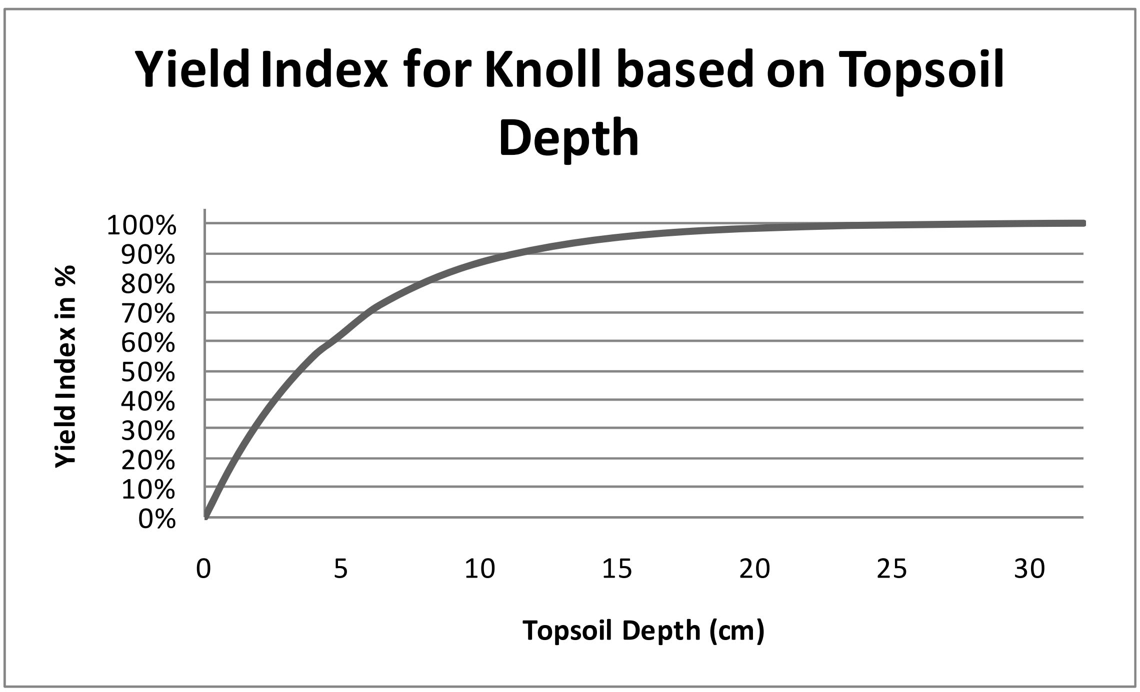
(e) Annual Yield on Eroded Knolls

Yield from eroded knoll fluctuates according to the topsoil depth of the area. Topsoil depth is a function included in the *Yield Index for Eroded Knolls*. *Yield Index for Eroded Knolls* is multiplied by the total area of the eroded knolls and the *Yield/ha*. This calculation is illustrated below:

*=Total Area of Eroded Knolls * Yield Index for Eroded Knolls * Yield/ha*

Where the relationship between topsoil depth and yield determines the yield index for eroded knolls based on the following graph (Bosma, 2004).

Figure 5: Yield Index for Knolls by Varying Desired Topsoil Depth



(f) Non-Eroded Land

The non-eroded portion of the landscape is calculated as the difference between the total area and the portions deemed to be eroded knolls and depressions:

$$= Non\ Eroded\ Land\ \% * Total\ Land$$

Where Non Eroded Land % can be further described as:

$$= 1 - \left(\frac{RemovedArea}{100}\right) - (\frac{ApplicationArea}{100})$$

(g) Yield on Non-Eroded Land

Yield in the non-eroded portion of the landscape is assumed to have sufficient topsoil depth to consistently reach yield potential from year to year. As its yield is not a function of the yield index on the non-eroded land, the calculation for yield on non-eroded land is as illustrated below:

*=Total Non Eroded Land * Yield/ha*

(h) Annual Yield

Annual Yield is defined as the annual yield for all three slope positions (depressions, non-eroded soil and eroded knolls). It is defined by the following formula:

=Annual Yield on Depressions + Annual Yield on Eroded Knolls + Yield on Non-Eroded Land

The yearly values for *Annual Yield* are calculated and are accumulated in the *Accumulated Yield Reservoir*. Simply put, the *Accumulated Yield* Reservoir is the sum of the annual yields over the course of the run.

$$= \sum_{t=0}^{n} Annual\ Yield$$

Lastly the annual yield sub-model calculates the yield per ha for the three portions of the landscapes. The principle is the same for all three calculations and is defined as follows:

$$Yield\ per\ Hectare\ on\ Depressions\ = \frac{AnnualYieldonDepressions}{TotalAreaofDepressions}$$

$$Yield\ per\ Hectare\ on\ Non\ Eroded\ Land\ = \frac{YieldonNonErodedLand}{NonErodedLand}$$

$$Yield\ per\ Hectare\ on\ Eroded\ Knolls\ = \frac{AnnualYieldonErodedKnolls}{TotalAreaofErodedKnolls}$$

Landscape Physical Characteristics

Topsoil depth is a function of current topsoil levels in the various portions of the landscape, the rate of erosion lost due to the tillage practice, and the accumulation of topsoil lost from the convex upper slope positions to the concave lower sloped areas of the field. It is also a factor of the initial and subsequent restorations done on the field. Subsequent restorations, in this model are automatically triggered once the topsoil threshold has reached a set value and, as a result, is performed to return the topsoil depth to the desired level set at the beginning of the simulation. The

Figure 6 below graphically explains the various relationships between the variables and how the sources, sinks and triggers interact with one another.

Figure 6: Topsoil Depth Sub-Model

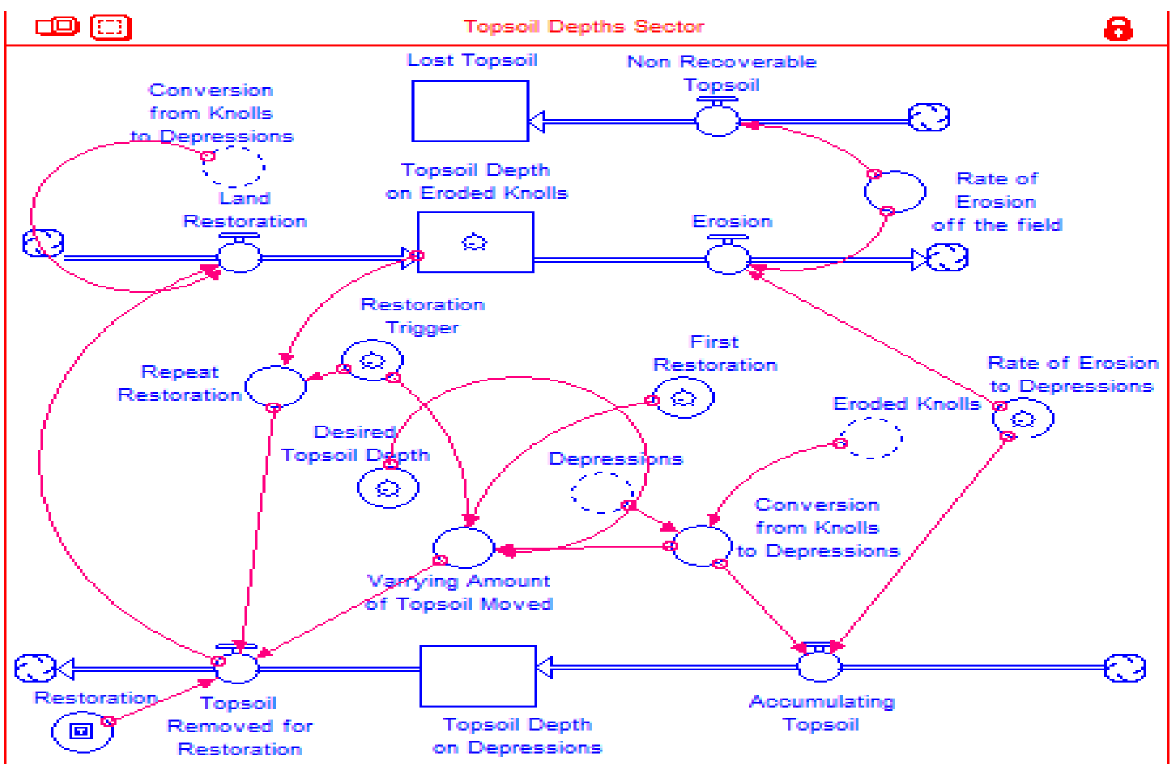


Figure 6 illustrates that the topsoil depth sub-model monitors topsoil depth for the knoll and depression portions of the landscape. *Topsoil Depth* will vary over time due to the tillage practice used and the level to which the topsoil is restored. A portion of the topsoil will be lost due to other erosion practices and is captured in the *Lost Topsoil* reservoir.

The level of tillage erosion on the convex upper slope positions can vary in the simulation depending on the value chosen for the *Rate of Erosion to Depression* converter. This value tells the model the average E*rosion off the Field* feed the erosion flow, which then estimates the *Total Topsoil* Loss per Year. The resulting value is then deducted from the *Topsoil Depth on Eroded Knolls* reservoir. The *Topsoil Depth on Eroded Knolls* reservoir calculates the topsoil depth over time based on the *Initial Topsoil Depth*, adding any additional topsoil that may have been incorporated through restoration and deducting the topsoil loss (both the recoverable and non recoverable loss).

For the depression portion of the sub-model, similar relationships are established. Based on the value chosen for the *Rate of Erosion to Depression* Knob and the converter for the *Conversion from Knoll to Depression* the yearly *Accumulating Topsoil* flow for the depression is populated. The yearly value generated by the *Accumulating Topsoil* flow is then sent to the *Topsoil Depth on Depressions* which sums the yearly accumulation of topsoil over and above the initial topsoil level for the depression and subtracts the topsoil removed for restoration. The portion of topsoil which is redistributed to the convex upper slope positions following a restoration is calculated based on the *Desired Topsoil Depth* knob, the *First Restoration* knob and the *Restoration Trigger* knob used to trigger additional restorations. These three knobs are used to calculate the yearly *Varying Amount of Topsoil Moved*. *The Yearly Varying Amount of Topsoil Moved*, the *Repeat Restoration* and the *Restoration on/off* switch are then used to calculate the yearly amount of topsoil removed from the depressions for the purposes of restoration. The information generated by the *Topsoil Removed for Restoration* Flow is also sent to the *Topsoil Depth on Depression* Reservoir to provide information regarding the portion of topsoil lost due to restoration over time.

Expressing the above relationships in equation form, the simulation of soil erosion and the physical aspects of landscape restoration is covered by the following formulas:

1. Topsoil Depth on Depression

   Topsoil Depth on Depressions refers to the topsoil depth in the concave slope positions. The formula assumes that concave slope positions have at a minimum of 30 cm of topsoil at the start of the simulation run. Based on the tillage practice in use the formula will add the topsoil lost from the convex slope positions to the concave slope positions through the *Conversion from Knolls to Depression* variable. This in turn determines the topsoil depth for all hectares considered depressions/ or concave.

   *=30 + (30*Conversion from Knolls to Depression)*

2. Topsoil Removed for Restoration

   The topsoil removed for restoration refers to the amount of topsoil removed from the concave lower slope areas, which is then used for the landscape restoration process. This formula is triggered both in the initial restoration, as well as, subsequent restorations. The amount of soil required for restoration is chosen and is then calculation for the simulation run.

   *=Pulse (Varying Amount of Topsoil Moved, 0, Repeat Restoration)*Restoration*

3. Accumulating Topsoil

   This formula simulates the topsoil lost by natural erosion processes such as wind, water and the tillage practice. The accumulation of topsoil is calculated by using a conversion process which takes into account the rate of soil erosion as specified in the model.

   *=Conversion from Knolls to Depression * Rate of Erosion to Depression*

4. Varying Amount of Topsoil Moved

   The formula for varying the amount of topsoil moved is dependent on the *Conversion from Knolls to Depression* as well as, the *Restoration Trigger*, *Desired Topsoil Depth* and the amount topsoil needed in the initial restoration. The formula reads as follows:

   *=If (time=0) then (First Restoration*Conversion from Knolls to Depressions) else (Desired Topsoil Depth- Restoration Trigger*Conversion from Knolls to Depression)*

5. Repeat Restoration

   This formula is used to trigger subsequent restoration. An minimum topsoil level must be selected and maintained throughout the simulation; however, should the level of topsoil in a field fall to its lowest threshold level, a subsequent restoration is automatically triggered for the desired topsoil depth.

   =If (Topsoil Depth on Eroded Field <= Restoration Trigger) then (time) else (0)

6. Land Restoration

   Over the length of the simulation run, this variable informs the sub-model how many times the act of land restoration has been done based on the other parameters and their interaction within the yield sub-model. The number of restorations during a run is also a function of the topsoil removed for restoration, and its eventual erosion and accumulation from the knoll positions to the concave lower slope positions.

   =Topsoil Removed for Restoration/Conversion from Knolls to Depression

7. Erosion

   This formula sums up the erosion lost on the various parts of the field, and the accumulation of topsoil in the depressions of the field.

   =Rate of Erosion off the Field + Rate of Erosion to Depression

Act of Landscape Restoration

As for the act of landscape restoration, the time and cost required to move the required amount of topsoil is defined in the section entitled Days to Restore. Figure 7 graphically displays the relationship between the variables in this section and the flow of information through this sub-model.

Figure 7: Days to restore Field for Initial Restoration

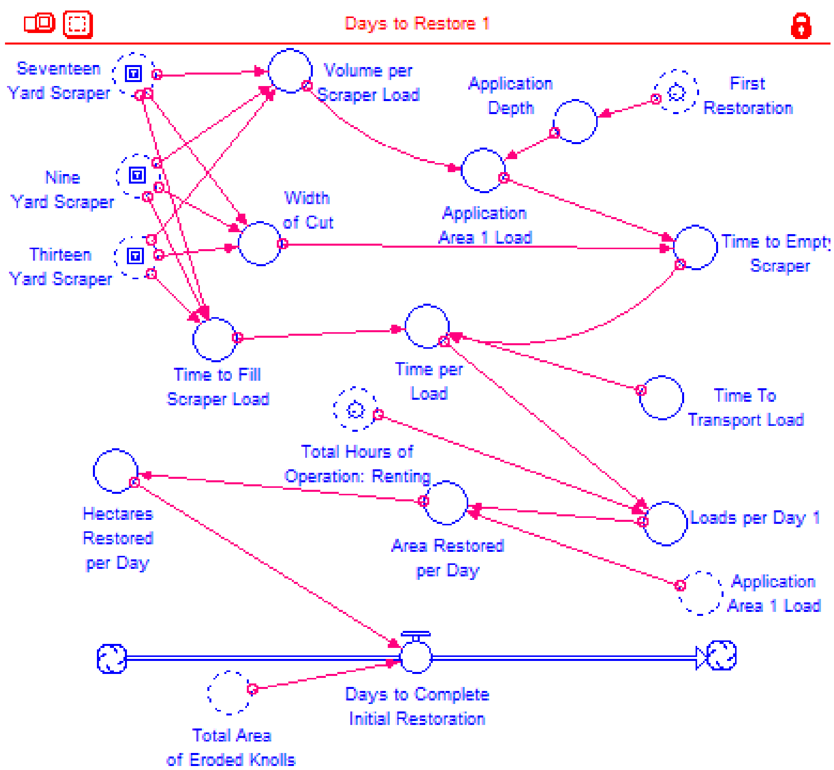


Figure 7 visually displays the relationship between variables in order to recreate the number of days initially required to restore a field. The sub-model performs three important functions. First, it determines the time, cost and volume moved in one equipment pass. Second, based on the restoration specifics it calculates the number of passes required to meet the restoration target. Lastly, based on the time required to perform the target number of passes, it calculates the number of days required to restore the field for the initial restoration of the field.

The size of the scraper is chosen and this is entered into the *Volume per Scraper Load* converter, the W*idth of Cut* converter and the T*ime to Fill Scraper Load* converter.

The *Volume per Scraper Load* converter will then calculate the *Application Area 1 Load* based on the requirements of the first restoration and application depth. The application area 1 load converter and the width of cut converter are used to calculate the time to empty scraper converter. The T*ime to Fill Scraper Load* converter, the *Time to* Em*pty Scraper* converter and the T*ime to Transport Load* converter are used to estimate the T*ime per Load* converter.

Based on the estimated volume moved and time to complete a pass, the number of loads per day 1 is calculated. If the equipment and labour are rented, then that information is included in order to factor in the number of passes to be completed over set hours of work.

The area restored per day converter uses date generated by the *Loads per Day 1* converter and the *Application Area 1 load*, converter, in order to estimate the *Total Restored Area for a Day*. The area restored per day converter then converts the area restored to a hectare equivalent.

Finally the flow days to complete initial restoration generates the number of days required to complete the initial restoration based on the *Hectares Restored per Day* converter and the T*otal Area of Eroded Knolls*.

The following section provides an overview of the important formulas contained in this sub-model.

Depending on the size and extent of soil erosion, different amounts of soil may be moved, using different sizes of equipment. In order to restore a field, a producer must have or have access to a scraper, a tractor and some method of carting soil from the lower sloped areas to the knoll areas. The proper equipment must also be chosen to do this task. It is important to select the proper size of scraper (9 yard, 13 yard or 17 yard) that is best suited for restoration, recognizing that the selected size of scraper depends on the extent of soil erosion and the depth of topsoil accumulation in the depression areas. The size of equipment selected will also determine the amount of soil moved, the number of hectares restored per day, as well as, the number of days required to perform the restoration.

1. Volume per Scraper Load

   Depending on the size of scraper chosen, a dummy variable is used to determine the volume per scraper load. The set values refer to the volume of soil moved in one load.

   *= (9 Yard Scraper * 6.881) + (13 Yard Scraper * 9.939) + (17 Yard Scraper * 13.379)*

2. Width of Cut

   Depending on the chosen size of the scraper, a dummy variable is used to determine the width of the cut per load. The set values refer to the width or cut being removed in one load.

   *= (9 Yard Scraper * 2.172) + (13 Yard Scraper * 2.477) + (17 Yard Scraper * 2.756)*

3. Time to Fill Scraper

   Depending on the size of the scraper chosen, a dummy variable is used to determine the time required to fill a scraper with a load of soil based on the respective sized scraper chosen. The set values refer to the portion of time required to complete the task and is represented in the fraction of the hour it takes.

   *= (9 Yard Scraper * 0.0104) + (13 Yard Scraper * 0.0132) + (17 Yard Scraper * 0.0127)*

4. Time to Empty Scraper

   The time required to empty a scraper will is dependent on chosen equipment, as well as, the volume of soil it can transport. This formula calculates the time required to empty a scraper based on the A*pplication Area per Load* and the *Width of the Cut*. The constant 4000 represents the application speed of (metre/hr) which will be used as the typical scraper size.

= (Application Area per Load / Width of Cut / 4000)

5. Time per Load

   This formula estimates the time required to fill an empty scraper, transport the load up the hill and empty and spread the load at the top of the hill, and then return to the bottom of the hill.

   = (Time to Empty the Scraper + Time to Fill the Scraper + Load to Transport + Time to Transport Load)

6. Area Restored per Day

   To obtain an accurate picture of how much area can be restored over the course of a day, the following formula is used. It takes into account the *Application Area Load* and multiplies it by the number of loads completed in a day.

   *= (Application Area Load * Load per Day)*

7. Days to Complete Restoration

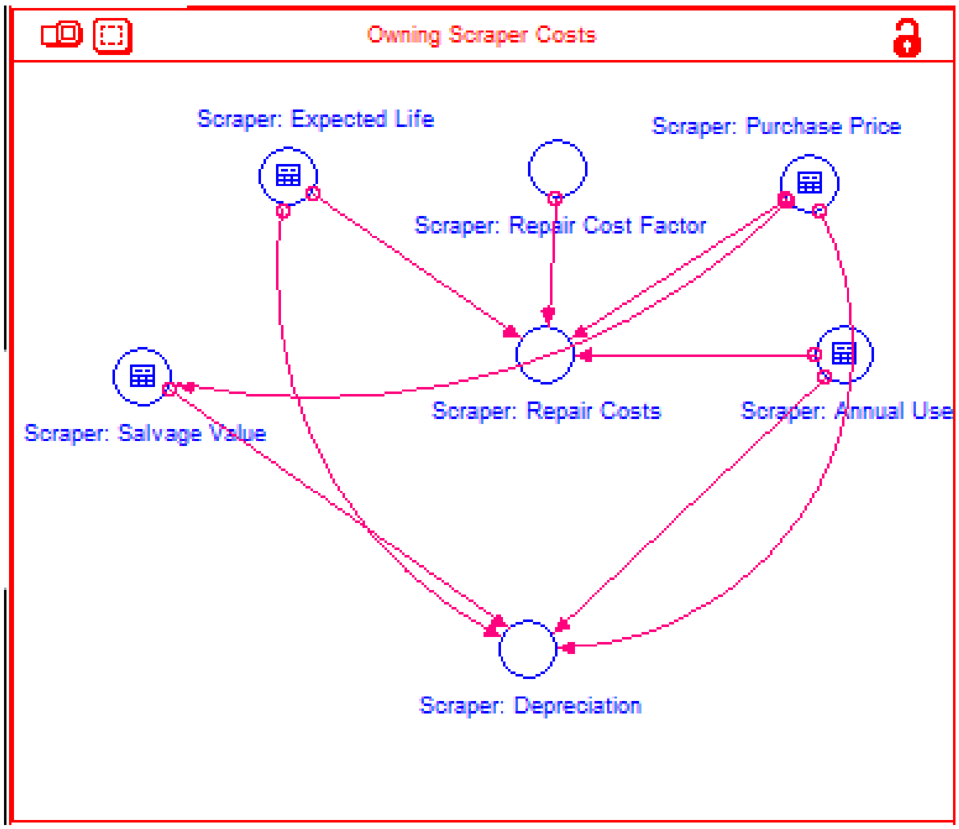
   To estimate the number of days required to restore the field in question, the formula calculates the number of hectares restored per day and the total area to be restored.

   = (Total Area of Eroded Knolls / Hectares Restored per Day)

Owning Scraper Costs

To perform restoration of a field, a farmer must have access to the proper equipment either through ownership or through rental equipment and retaining an operator to move the soil. In this section the cost to run and operate one's own equipment is calculated.

Figure 8: Wear and Tear Calculations on Own Equipment



This sub-model of owning scraper costs is illustrated in Figure 8 above. Equipment used to perform a task such as landscape restoration is subject to wear and tear costs. As a result, repair costs, salvage value and depreciation must be known in order to calculate the wear and tear for a scraper.

One must enter the scraper: *Purchase Price*, the *Scraper: Annual Use* and the *Scraper: Expected Life*. These converters as well as the *Scraper: Repair Cost Factor* are used to calculate the value for the *Scraper Repair Cost* converter. The *Scraper: Purchase Price* converter is then used to calculate the *Scraper: Salvage Value* converter. The following three converters are then used to calculate the *Scraper: Depreciation*, *Scraper: Annual Use*, *Scraper: Purchase Price* and *Scraper: Salvage Value*.

Most of the factors in this sub-section are entered based on the scenario specifics (purchase price of scraper, and its salvage value) while other factors in this sub-section are dependent on the inputted numbers used to calculate variables such as scraper depreciation and repair costs.

1. Scraper Depreciation

   The scraper value will decrease with use and over time. This concept is called depreciation. To calculate the depreciation of the scraper many factors such as the purchase price of the scraper, the expected life of the scraper and its salvage value come in to play.

   = ((Scraper Purchase Price –Scraper Salvage Value) / Scraper Expected Life) / Scraper Annual Use

2. Scraper Repair Costs

   When calculating the cost of using owned equipment, one must take into account any potential repairs.

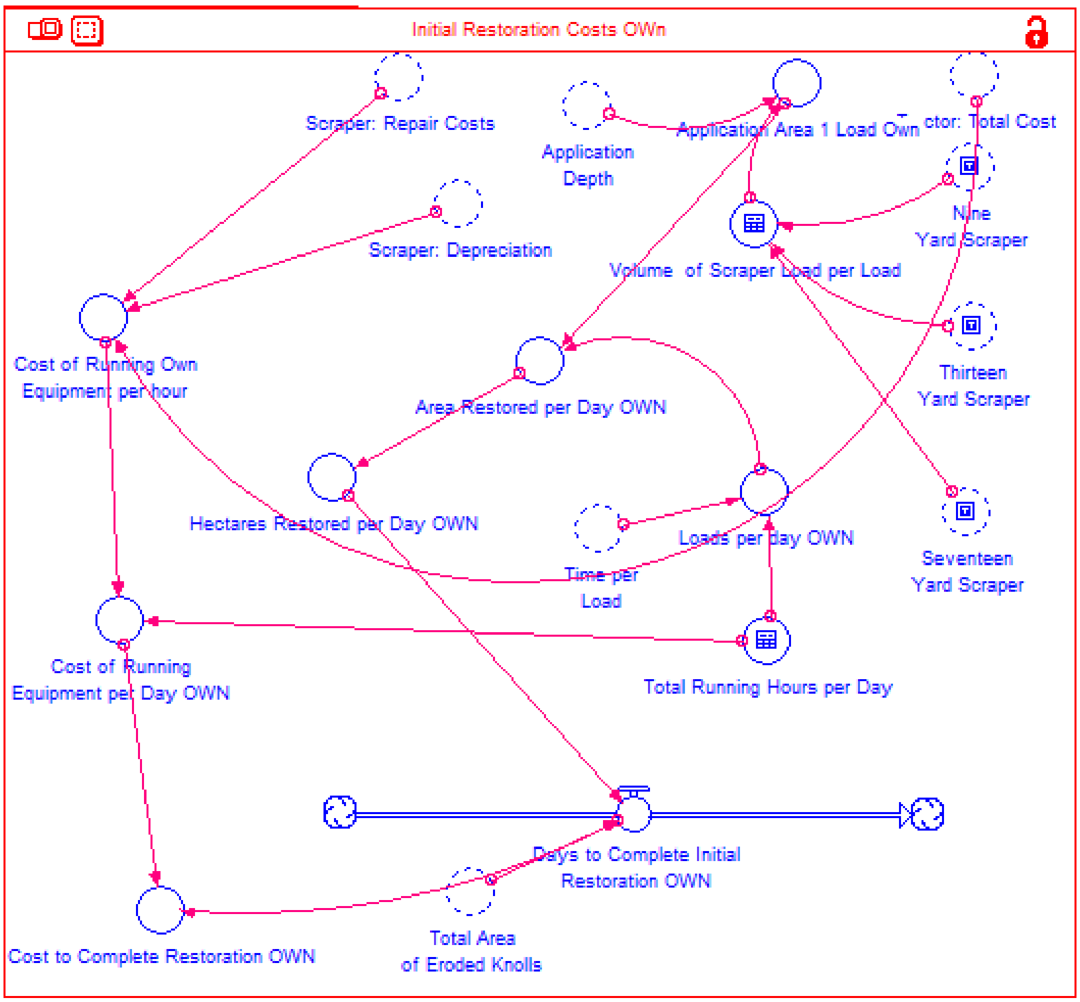
   *= ((Scraper Purchase Price * Scraper Repair Cost Factor) / Scraper Expected Life) / Scraper Annual Use*

   The *Scraper Repair Costs* estimates the portion of scraper costs related to repairs based on the purchase price, expected value and annual use. The first part of the formula estimates the portion of the scraper's value used to estimate the repair costs for the scraper. It is determined by multiplying the *Scraper Purchase Price and the Scraper Repair Cost Factor* (currently set at 66 per cent). From there the hourly estimated cost of *Scraper Repair Costs* are calculated. Scraper specific costs are calculated, they are included in the section of the model that estimates the cost of the initial restoration using an owned scraper.

Initial Restoration Costs for Owning Equipment

Figure 9 is very similar to the one used to determine the number of days required for field restoration. The main difference between these two sub-models is the addition of financial variables that are used to estimate the cost of restoration.

Figure 9: Restoration Costs When Owning Equipment



To estimate the *Cost of* Running *Own Equipment per Hectare,* the following converters are use: tractor: T*otal Cost, Scraper: Repair Costs and Scraper: Depreciation*. The resulting figure is an hourly rate for the cost of running the equipment. This figure does not include labour.

The model then calculates the costs of restoration per day based on what is considered the length of a working day and the hourly cost of running one's own equipment. Lastly, total restoration costs are based on the *Cost to Complete Restoration Own* converter.

The following section highlights the important formulas used in the *Initial Restoration Costs Own* sub-model:

1. Volume of Scraper Load per Load

   This is the same formula that was used in the Days to Restore section.

2. Cost of Running Own Equipment per Hour

   The cost of running the equipment per hour takes into account the *Scraper Depreciation* and *Repair Costs* as well as the cost of running the tractor, referred to in the formula below as *Tractor Total Cost*.

   = (Scraper Depreciation + Scraper Repair Costs + Tractor Total Cost)

   It is assumed that a scraper's main use is to redistribute topsoil on the landscape as per dictated by landscape restoration and so its depreciation and repair costs are included in this formula. A tractor on the other hand is used to perform many different tasks around the farm, making it difficult to calculate the portion of the depreciation specifically related to landscape restoration activities. However, *Tractor Total Cost* variable can be further broken down into:

   $$= \text{Tractor Fixed Costs} + \text{Tractor Operating Costs}$$

   This includes fuel, repairs and labour for the operating of the tractor when restoring the field.

3. Cost of Running Equipment per Day (own)

   From an hourly total, one can then calculate the cost of running the equipment and restoring the area as selected.

   *=(Cost of running own equipment per hour * total running hours per day)*

4. Days to Complete Initial Restoration

As was done with the days to restore section this formula is brought back again and is used to estimate the cost of restoration.

In estimating the cost of restoration, the user may choose the option to rent the equipment and operator or use owned equipment and restore the field themselves. The next section of the model estimates the costs associated with running one's own equipment.

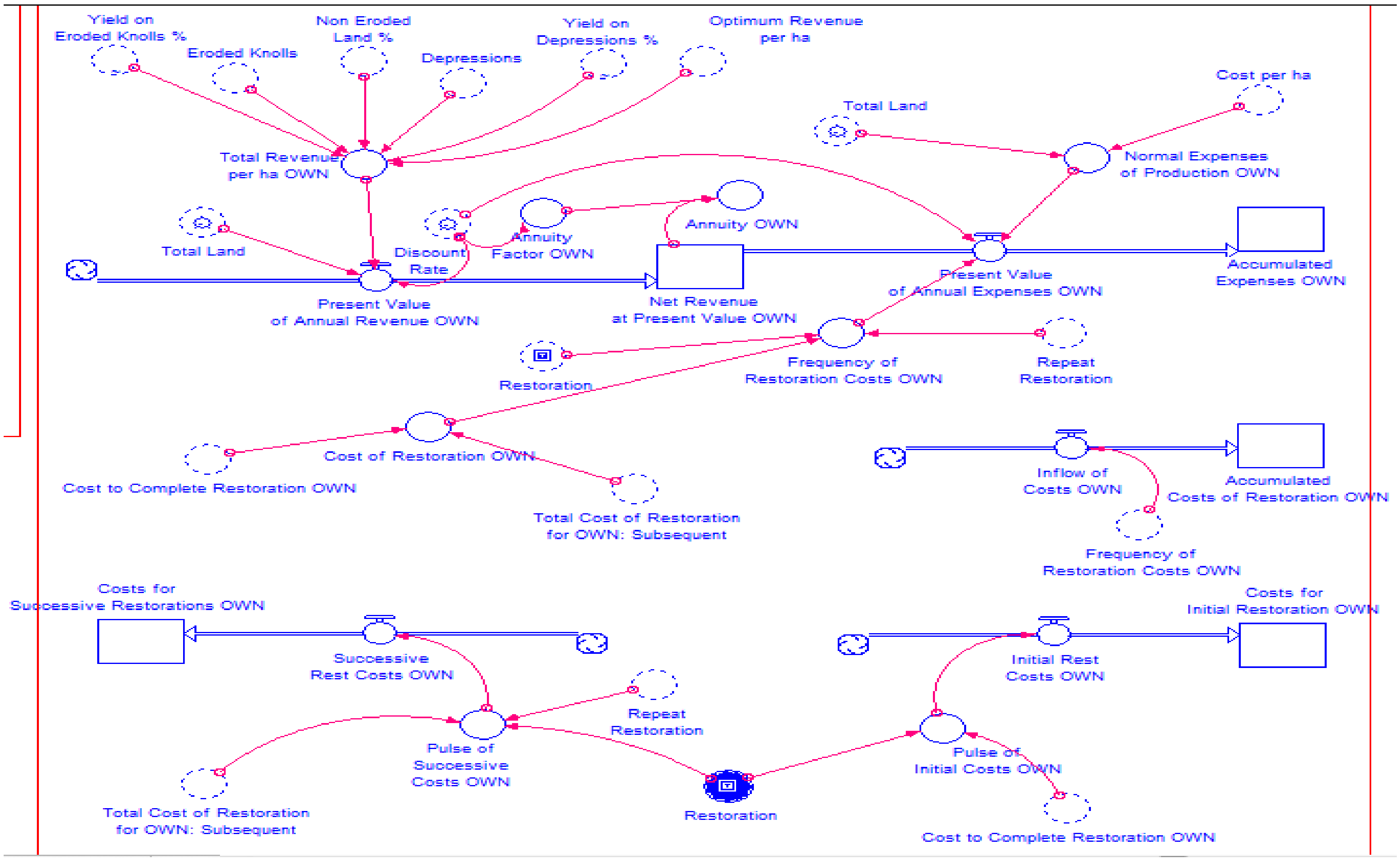
Economic Sub-Model

The previous sub-model outlined the way in which the costs of restoration are calculated. In the economic sub-model, crop revenues, the regular cost of production, and costs of initial and subsequent restoration are used to calculate the net present value of the investment.

Figure 10 shows the relationships between the variables used in the economic sub-model. To run this sub-model, one must input *Total Land*, *Discount Rate* and have the *Restoration Switch* turned on. This sub-model also uses converters used in other sub-models, such as the Initial Restoration Cost and Subsequent Restoration Cost sub-model. They are used to populate some of the converters used in this sub-model. These include: *Cost to Complete Restoration Own*, *Frequency of Restoration Costs Own*, *Repeat Restoration*, *Total Cost of Restoration for Own: Subsequent*, *Cost per ha*, *Yield index for Eroded Knolls*, *Eroded Knolls*, *Non Eroded Land %, Depression*, *Yield Index for Depressions*, and *Crop Rotation Revenue per ha*.

The costs for initial restoration is based on the total initial restoration costs, which are either generated by performing restoration with one's own equipment or generated through hiring an equipment operator. This is also done to calculate the costs of successive restoration.

Figure 10: Economic Sub-Model



The economic sub-model can be broken down into four sections: Costs of Initial Restoration, Cost of Successive Restorations, Annual Revenue and Annual Expenses. These portions of the sub-model are used to ultimately estimate the NPV of the investment decision.

1. Costs of Initial Restoration

   a. Pulse of Initial Costs OWN

      Pulses are used to generate a set value at a specific time. In this case it is used to add the costs of initial restoration for owning to the initial cost flow. This is done by multiplying the restoration switch (it takes a value of 1 if on and a value of 0 if not) and the cost to complete restoration OWN for year zero.

      $$= \left(PULSE(Cost\ of\ Restoration\ Own, 0,0)\right) * Restoration$$

   b. Initial Rest. Costs Own

      The value calculated by *Pulse of Initial Costs OWN* is then inputted into the *Initial Res. Costs OWN* so that it can flow into the *Costs for Initial Restoration* OWN Reservoir.

      $$= Pulse\ of\ Initial\ Costs\ OWN$$

   c. Costs for Initial Restoration OWN

      The *Costs for Initial Restoration OWN* formula is used to calculate the costs of initial restoration over time. This is done in part so that if the restoration were to occur over 2 years, then both portions of the restoration costs could be summed here.

      $$= Costs\ for\ Initial\ Restoration\ OWN\ (t - dt) + (Initial\ Rest\ Costs\ OWN) * dt$$

      Please note that t refers to the length of the run, and that dt refers to the actual year in which it is inputted. They are simple indicators of the year in which the calculation is done and are neither multiplied nor subtracted. This simply indicates the previous year's sum plus the current year's cost of successive restoration.

2. Costs of Subsequent Restorations

As in the previous section, this portion of the sub-model calculates the cost of subsequent or successive restorations as they are referred to in the formula section of the model.

a. Pulse of Successive Costs OWN

The P*ulse of Successive Costs OWN* variable indicates the number of times that successive restorations are performed providing the restoration on/off switch is on.

$$= if\,(Time\ 0)\ Then\ (0)\ Else\ \left(Pulse\begin{pmatrix} Total\ Cost\ of\ Restoration\ for\ OWN{:}\,Subsequent, \\ Repeat\ Restoration, Repeat\ Restoration \end{pmatrix}\right)$$

$$*\ Restoration))$$

For year 0, the formula takes on the value of 0, in order to keep the initial and subsequent restoration costs separate. For any other year of the simulation, other than 0, if a subsequent restoration is performed, the costs will be calculated using this formula.

b. Successive Rest. Costs OWN

This variable is set as a flow in this portion of the sub-model. Simply put, every year that a subsequent restoration is performed a value is populated and then accumulates in the Costs for Successive Restoration OWN reservoir.

c. Costs for Successive Restoration OWN

This reservoir's purpose is to sum the costs of successive restorations over the course of the simulation run. It makes the distinction between the initial and subsequent restoration costs.

$$= Costs\ for\ successive\ restorations\ OWN(t - dt)$$
$$+ (Successive\ Restoration\ Costs\ OWN) * dt$$

Note that in this case, t refers to the length of the run, and dt refers to the actual year in which it is performed and inputted. They are simple indicators of the year in which the calculation is done and are neither multiplied nor subtracted. Where the first variable is the previous year's sum, if any, plus the current year's cost of successive restoration.

3. Annual Revenue

In Annual Revenue, the following sub-section explores the formulas used to derive the annual revenue generated by the sub-model.

a. Total Revenue per ha OWN

Total Revenue per ha OWN refers to the per hectare revenue generated by the various portions of the field each year. It uses the yield indexes for the various portions of the landscape and multiplies it by the portion of the landscape in production. Total revenue per hectare calculates the per hectare revenue for all crops in the crop rotation for the knolls, as well as, the non-eroded and depression portions of the landscape.

$$= (Depression * Yield\ Index\ for\ Depression * Crop\ Rotation\ Yield) + (Eroded\ Knolls * Yield\ Index\ for\ Eroded\ Knolls * Crop\ Rotation\ Yield) + (non\ eroded\ land * Crop\ Rotation\ Yield)$$

Where *Yield Index for Depression* and *Eroded Knolls* are a percentage (based on yield possible with respect to topsoil depth), it is multiplied by the *Crop Rotation Yield* set out in the interface portion of the model. The portion of the landscape considered non-eroded is a simple multiplication of crop rotation yield and the portion of the hectares which are considered non-eroded.

b. Present Value of Annual Revenue OWN (NPV Revenue)

This formula is responsible for determining the yearly revenue generated by crop in a particular field. Over the years, the value generated is discounted to bring it back to today's value of money. The yearly values generated in this portion of the model are fed into the NPV of the investment in order to calculate the total net revenue generated by the model.

$$= Total\ Land * Total\ Revenue\ per\ ha\ OWN * \left(\frac{1}{1 + Discount\ Rate}\right)^{t}$$

4. Annual Expenses

The following sub-section explores the formulas used to derive the annual expenses generated by the sub-model.

a. Frequency of Restoration Costs OWN

This formula works as a pulse in that it is calculated every time a subsequent restoration is performed based on the information that it is fed by other variables.

$$= (Pulse(Cost\ of\ Restoration\ OWN, 0.5, Repeat\ Restoration) * Restoration$$

Please note that the 0.5 indicates that a subsequent restoration can occur midway through year 0, differentiating the model's initial and subsequent restorations. This formula will calculate the costs of the initial restoration and subsequent restorations. The formula will only generate a value providing that the *Restoration Switch* is turned on.

b. Normal Expenses of Production OWN

This formula calculates the normal expenses related to crop production for every any given year. It multiplies the cost of production per hectare, based on the crop rotation chosen, by the total land area under question.

$$= Cost\ per\ ha * Total\ Land$$

c. Present Value of Annual Expenses OWN (NPV Expenses)

This final formula estimates the yearly expenses for the scenario and brings the values back to a present value equivalent.

$$= (frequency\ of\ Restoration\ Costs\ OWN + Normal\ Expenses\ of\ Production\ OWN) * \ (1/((+Discount\ Rate)^{t}$$

Normal production expenses and the frequency of restoration costs are calculated for each year. The resulting value is also stored in the Accumulated Expenses OWN Reservoir to in order to calculate the total expenses for each scenario.

This formula is also used to calculate the NPV of the investment.

5. Net Present Value

Lastly, this sub-model is used to calculate the NPV of the investment.

$$= Net\ Revenue\ at\ Present\ Value(t - dt)$$
$$+ (Present\ Value\ of\ Annual\ Revenue\ OWN$$
$$- Present\ Value\ of\ Annual\ Expenses\ OWN) * dt$$

As this formula is a reservoir, its goal is to sum the NPV of revenue over time. The yearly formula used to calculate that sum is described as above, where the previous year's sum of NPV is added to the current years'. Where t refers to the length of the run, and dt referring to the actual year in which it is inputted.

Summary of formulas

In summary, the main sub-models, important economic and financial formulas of LandRec were described in this chapter. Screenshots of the sub-models and variables and their interactions were described. Important formulas were described and their contributions to the model were explained. As a large portion of the model describes the soil science aspect of the model and, as a result, some of these aspects were described in the chapter. All formulas used in the development of this model, including those not described in this chapter, are included in

Appendix 1.

Chapter 5: Sensitivity Analysis

Once the verification and validation have occurred, and the model has been thoroughly been tested a comprehensive sensitivity analysis is performed. For a model of this nature, the sensitivity analysis is a time consuming process, and cannot be easily performed using statistical programs. By fixing all of the variables except one, and running the model at various increments, a sensitivity analysis was performed on the variables to determine the relationships between the variables and their sensitivity to change. The following table outlines the starting inputs used for the sensitivity analysis run.

Table 3: Starting Inputs Used in Sensitivity Analysis Model

Size of field (ha)	100	Scraper size used (ft)	9
Depression yield potential (%)	100%	Equipment used for restoration	rent
Effective topsoil depth hilltop (cm)	2	Desired topsoil depth (cm)	15
Rate of soil loss hilltop (mm)	0.8	Initial restoration (cm)	20
Type of tillage used	Conventional Tillage	Subsequent restoration trigger (cm)	10
% application area hilltop	30	Discount rate (%)	0.05
% removal area depression	20		

Hourly rental cost	$ 150.00	Working hours per day	10
Tractor purchase price	$ 115,000.00	Scraper purchase price	$ 35,000.00
Tractor expected life (yr)	30	Scraper expected life (yr)	30
Tractor annual use (hr)	1,000	Scraper annual use (hr)	440
Fuel consumption (km/l)	54	Hourly wage ($/hr)	$ 10.00
Fuel Price ($/l)	$ 0.94		

The model run for the sensitivity analysis assumed a field of 100 hectares, with a productive depression. The field is conventionally tilled and has an effective topsoil depth on the hilltop prior to restoration of 2 centimetres. Approximately 30 per cent of the field requires restoration, while the area where topsoil is to be removed in the depressions is 20 per cent. The restoration is performed using a rented 9 yard scraper. The desired topsoil depth after restoration is 15 centimetres, requiring an initial restoration of 20 centimetres. Subsequent restorations are performed when topsoil has diminished to 10 centimetres. The discount rate used is of 5 per cent.

The initial crop rotation used for the sensitivity analysis is wheat and canola. The following table outlines the revenue, cost and yield for these specific crops.

Table 4: Crop Rotation Used as Starting Inputs for Sensitivity Analysis

Cropping Rotation	Year 1	Year 2
	Wheat	Canola
Yield (t/ha)	2.7100	1.7595
Price ($/t)	$ 340.00	$ 299.55
Prod. Costs ($/ha)	$ 209.93	$ 500.00

An overview of the sensitivity analysis of the model and the influential variables sensitivity analysis is provided in the section below.

Influential Variables

Rate of Soil Loss on Eroding Hilltops

The Rate of Soil Loss on Eroding Hilltops variable represents the rate of soil loss due to tillage, wind and water erosion during a given year. The type of tillage practice used will either accelerate or minimize erosion that occurs. For example, a farming operation, which practices conventional tillage on a hummocky landscape, will see more tillage erosion when compared to other, more conservative tillage practices. Therefore it is assumed that these high disturbance tillage practices will also require restoration that is more frequent.

Typically a farmer can adopt one of three tillage practices: no-tillage (zero tillage, direct seeding), conservation (minimum) tillage or conventional tillage. Average topsoil loss per year will varying on the type of tillage used, based on the number of passes on the field, and on type of implement used.

No-tillage, zero tillage and direct seeding fall into a category of tillage practices which leave the soil and crop residue relatively undisturbed except where seed and fertilizer are placed in the ground. In these low disturbance tillage practices, more than 60 per cent, on average, of the previous crop's residue remains on the surface after planting. As a result, the rate of soil loss over a year will be closer to 0.05 mm of topsoil. Following the initial restoration, a field currently using zero tillage practices, will not require additional restorations nor incur additional restoration costs.

Table 5: Effect of varying Rates of Soil Loss on Eroding Hilltops on Restoration Costs

Soil Loss on Eroding Hilltops and Restoration Costs	Zero Tillage	Minimum Tillage	Conservation Tillage	Conventional Tillage
mm of Topsoil Lost per Year	0.05	0.20	0.50	0.80
Cost of Initial Restoration	$ 59,067.10	$ 59,067.10	$ 59,067.10	$ 59,067.10
Number of Subsequent Restorations	-	-	1	3
Additional Restoration Costs	-	-	$ 18,651.40	$ 55,954.20
NPV	$ 261,075.00	$ 258,783.00	$ 244,609.00	$ 224,185.00

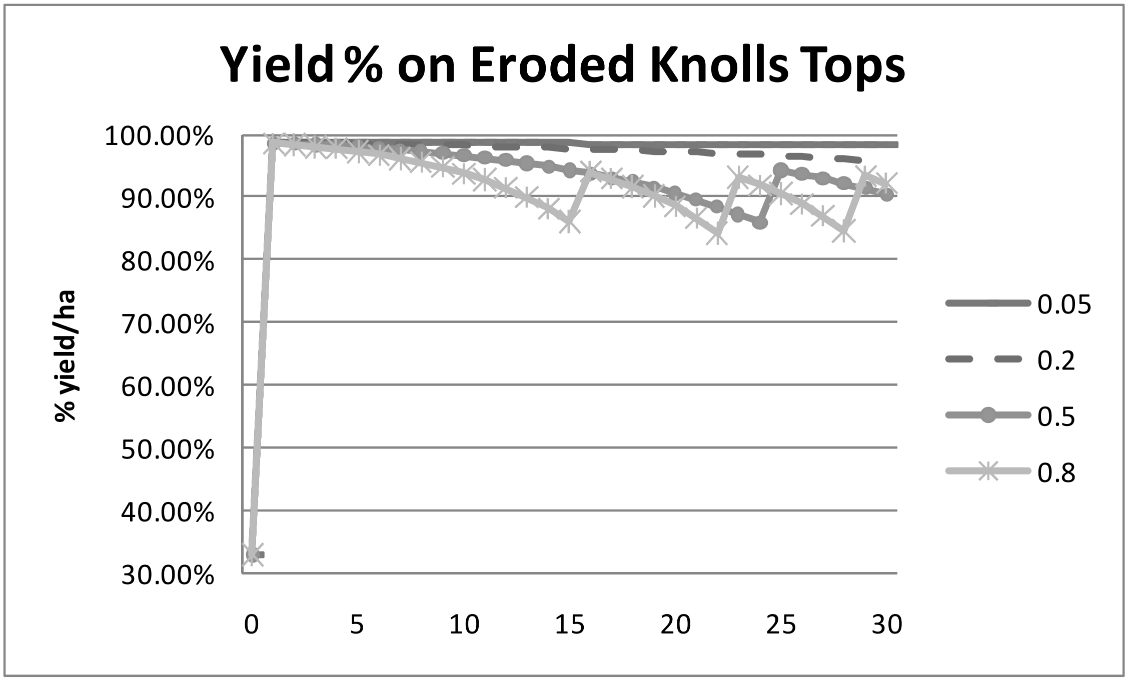
Conservation or minimum tillage is defined as tillage that retains most of the crop residue on the surface prior to planting (Lobb et al., 2007). Typically, 30-60 per cent of the previous crop's residue remains on the surface after planting. For conservation tillage, topsoil lost due to tillage erosion will range from 0.2 to 0.5 mm of topsoil lost per year. For the same farming operation using conservation tillage practices, two possible alternatives involving different implements were examined.

If the farming operation uses implements that cause minimal soil disturbances. The operation has also made a conscious effort to reduce the number of equipment passes on the field. Due to this, the field will typically lose 0.2 mm of topsoil per year and will incur no additional restorations and subsequent restoration costs. If the farming operation uses implements which cause higher soil disturbance and has increased passes on field, it will lose closer to 0.5 mm of topsoil per year due to tillage erosion. In this case, the operation losing 0.5 mm of topsoil per year will incur subsequent restoration in year 24. This additional restoration will increase restoration costs by $18,651.40.

Conventional tillage is defined as tillage that incorporates most (70 per cent or more) of the crop residue prior to planting (Lobb et al., 2007). With this type of tillage practice, the average topsoil lost due to tillage erosion ranges from 0.5 mm to 0.8 mm of topsoil per year. If the operation loses 0.5 mm of topsoil per year, it will require an additional restoration in year 24 and subsequent restoration costs of $18,651.40. If the same operation loses 0.8 mm of topsoil lost per year, it will require 3 subsequent restorations (year 15, 22 and 28), of 7.5 cm of topsoil on eroded areas. The increased restoration costs, for all restorations performed will then total $55,954.20.

The impact of the subsequent restorations on yield are described in the figure below.

Figure 11: Relationship between yield percentage and tillage practices over the years



In a zero tillage operation, as illustrated by the continuous line in Figure 11, yield has flat lined over a thirty year time period. In fact, yield in zero tillage, will only decrease 0.017 per cent each year demonstrating that the minimal soil loss caused by tillage erosion has had little effect on yield over time. In a minimum tillage operation, illustrated by the dashed line, the yield wanes over time, beginning at 98.55 per cent and subsequently decreasing by 0.102 per cent each year. For conservation tillage, at a loss of 0.5 mm per year (circle marker line), yield peaks at 98.65 per cent in year 1, and then decreases to 85.92 per cent in year 24, just prior to subsequent restoration. The average annual yield loss observed with conventional tillage with 0.5 mm of soil loss a year is approximately 0.583 per cent. For conventional tillage, with a topsoil loss of 0.8 mm per year (star marker line), yield peaks at 98.56 per cent in year 1 and then drops by 1.15 per cent per year. This type of tillage practice also requires three additional restorations which greatly affect overall yield. Yield peaks in years 16, 23 and 29 due to the addition of topsoil in the previous year.

Present value of net revenue is as follows: $261,075 (zero tillage), $258,783 (minimum tillage), $244,609 (conservation tillage) and $224,185 (conventional tillage).

Table 6: Difference in Net Revenue when Rate of Soil Loss on Eroding Hilltop is varied

Difference in Net Revenue Depending on Tillage Used	Zero Tillage	Minimum Tillage	Conservation Tillage	Conventional Tillage
Zero Tillage		$ 2,292.00	$ 16,466.00	$ 36,890.00
Minimum Tillage			$ 14,174.00	$ 34,598.00
Conservation Tillage				$ 20,424.00
Conventional Tillage				

Table 6 outlines the present value of net revenue based on the chosen tillage practice used. The difference in the NPV increases as the tillage practice goes from zero tillage to conventional tillage. This can be attributed to the fact that the higher the level of disturbance in a field, the greater the soil loss. The higher soil loss ultimately results in a lower yield potential and requires additional restoration, as indicated by the restoration trigger threshold.

Restoration Trigger

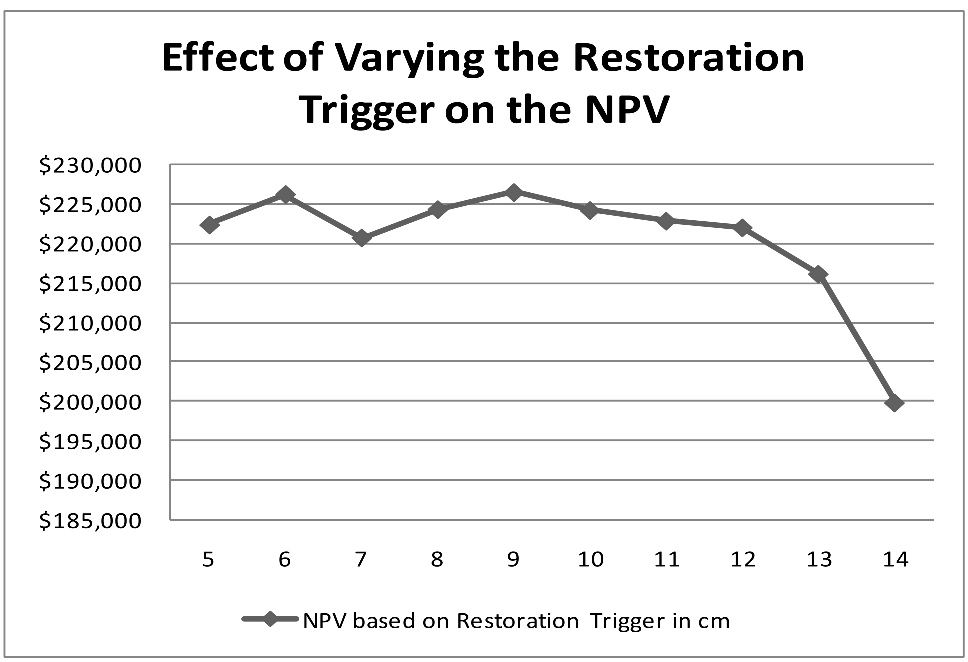
The Restoration Trigger represents the remaining amount of topsoil on the eroded knolls and signals that a subsequent restoration should occur when the lower threshold is reached. For this test, values for the restoration trigger ranged from 5 cm to 14 cm of topsoil on the eroded knoll.

Table 7: Effect of Varying the Restoration Trigger on Restoration Costs (Initial and Subsequent)

Restoration Trigger (cm)	# of Sub. Rest.	Cm Added	Total cm Added	$/Sub. Rest.	Total Cost of Sub. Res.	NPV
5	1	15	15	$ 32,123	$ 32,123	$ 222,351
6	1	13.5	13.5	$ 29,429	$ 29,429	$ 226,210
7	2	12	24	$ 26,735	$ 53,469	$ 220,720
8	2	10.5	21	$ 24,040	$ 48,080	$ 224,300
9	2	9	18	$ 21,346	$ 42,692	$ 226,451
10	3	7.5	22.5	$ 18,651	$ 55,954	$ 224,185
11	4	6	24	$ 15,957	$ 63,828	$ 222,837
12	5	4.5	22.5	$ 13,263	$ 66,314	$ 221,995
13	8	3	24	$ 10,568	$ 84,546	$ 216,130
14	17	1.5	25.5	$ 7,874	$ 133,857	$ 199,856

In Table 7, the effect of varying the *Restoration Trigger* is presented. In general, a higher required base of soil (cm) triggers more frequent restoration which, in turn, increases the cumulative cost of restorations and has a larger effect on the NPV. For each additional cm required by the restoration trigger, the amount of topsoil added per restoration decreases by 1.5 cm.

Figure 12: Effect of Varying the Restoration Trigger on the NPV at Present Value Over Time



The NPV varies with respect to the restoration trigger as demonstrated by Figure 12. For this particular operation, the best restoration trigger is either 6 or 9 cm. The 6 cm restoration trigger will only requires the initial restoration, while the 9 cm restoration trigger will require both the initial and subsequent restoration. While there will be a greater yield loss for the restoration trigger of 6 cm, it does not incur the costs of subsequent restorations. The second restoration for the 9 cm restoration trigger happens late in the simulation and consequently, takes full advantage of the increased topsoil depth and subsequent increased yields over the course of the run. The increased yields of the 9 cm restoration are attributed to the additional topsoil from the subsequent restorations and the additional cost is offset by additional revenue.

Figures 13-15 illustrates the incremental income derived from improved topsoil after restoration. The Restoration Trigger varies from 5 cm to 14 cm. The incremental income that can be attributed to landscape restoration decreases over time, as calculated by the NPV formula and is affected by the discount rate. Please note that in Figures 13-15 that the Restoration Trigger varies from 5 cm to 14 cm.

Figure 13:Yearly Net Revenue Based on Varying Restoration Trigger Variable (5 to 7 cm)

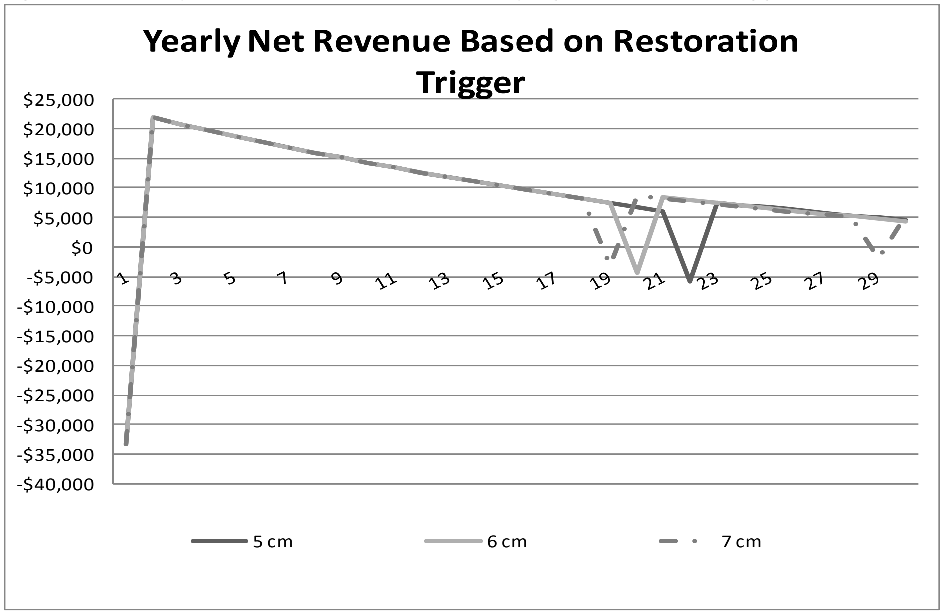


Figure 14: Yearly Net Revenue Based on Varying Restoration Trigger Variable (8 to 11 cm)

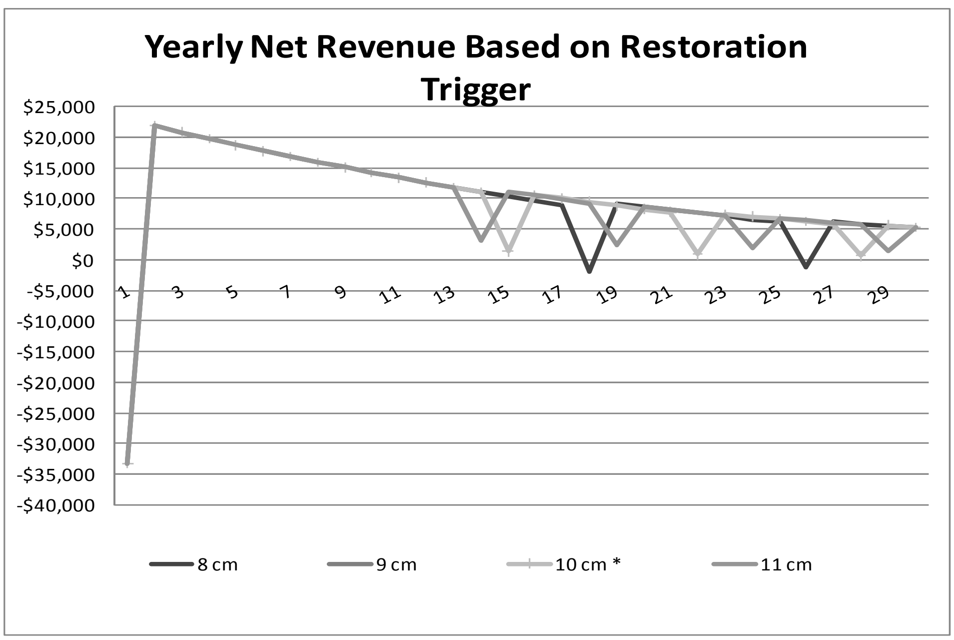
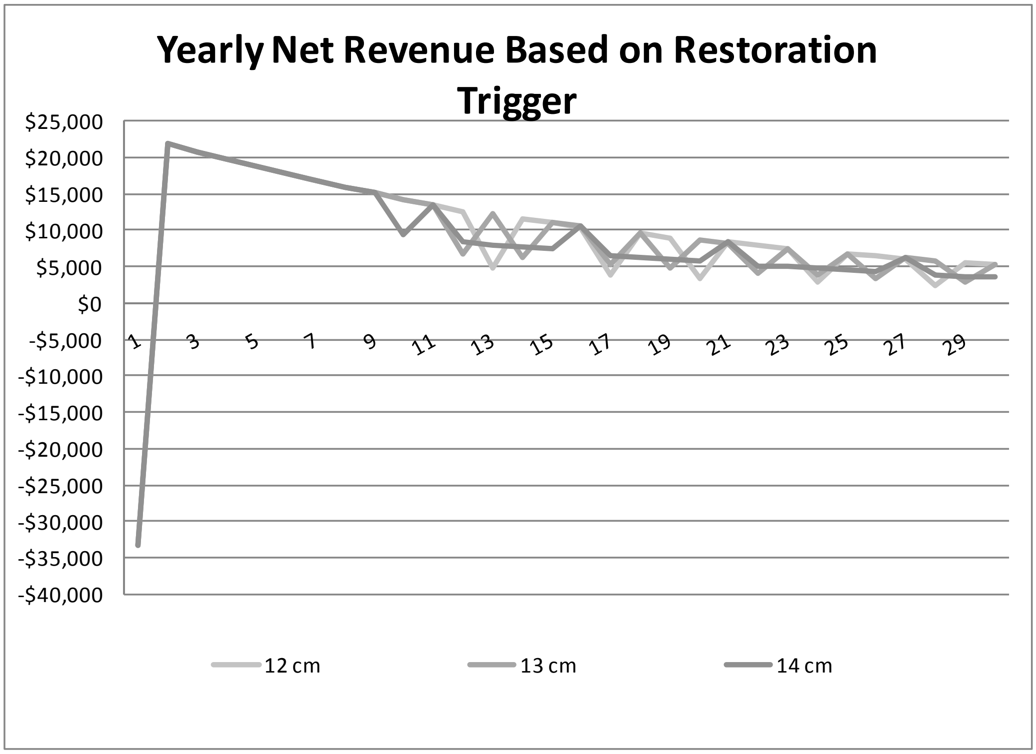


Figure 15 : Yearly Net Revenue Based on Varying Restoration Trigger Variable (12 to 14 cm)



The dips outlined in the figures above illustrate the subsequent restorations which are triggered by the value of the restoration trigger variable. The number of subsequent restorations will increase as the restoration trigger variable increases.

In general, a restoration trigger falling between 5 and 12 cm, is considered feasible; however, do subsequent restorations will be required. For this reason, it would be economically advisable to limit the occurrence of subsequent restorations to once or twice during a 30 year time frame. Thus, if this operation were only to commit to one subsequent restoration every 30 years, a 6 cm restoration trigger would be most beneficial. If the operation is willing to restore twice more after the initial restoration, a restoration trigger of 9 cm would be optimal.

Desired Topsoil Depth

Desired Topsoil Depth refers to the effective topsoil depth in the convex upper slope positions following the completion of the first restoration.

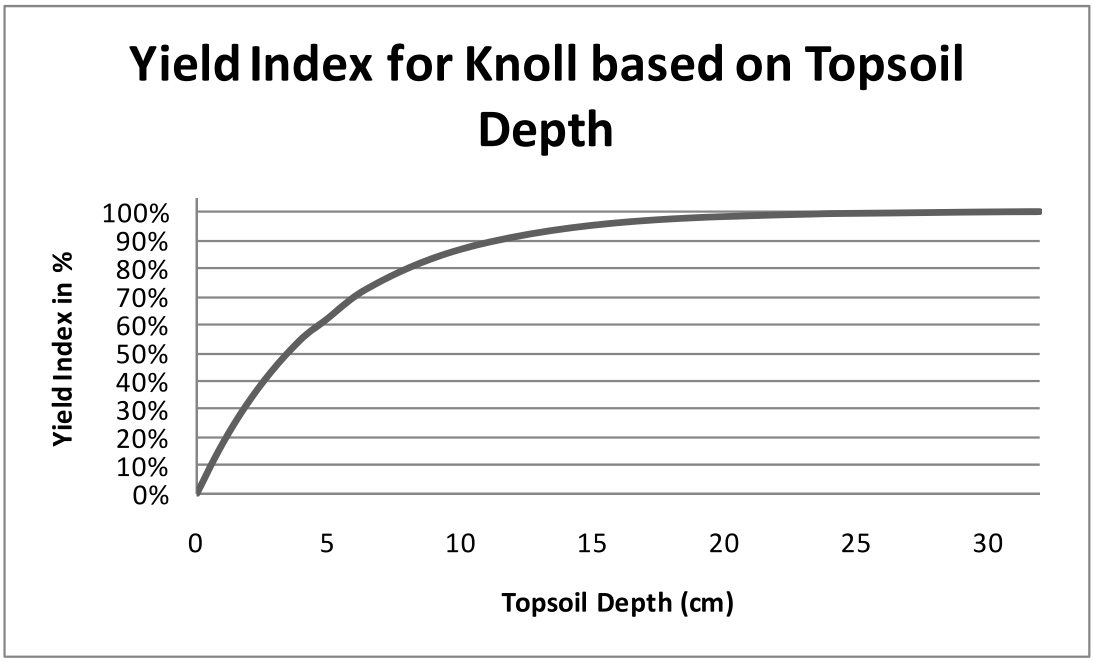
Keeping all variables constant, the desired topsoil depth, the model examined the sensitivity of desired topsoil depth variable and the effects of the model on the upper and lower limits of the desired topsoil. Table 8 demonstrates that the desired topsoil depth varied from 12 to 40 cm. While the average ideal topsoil depth, from a soil science perspective, is between 15 and 40 cm, the effect of the model on upper and lower limits of the desired topsoil depths had to be explored.

Table 8: Effect of Varying the Desired Topsoil Depth on Restoration Costs (Initial and Subsequent)

Desired Topsoil Depth	# Subsequent Rest.	cm added	total cm added	Cost of Subsequent Rest.	Total of Rest. Cost	NPV Revenue
12	7	3	21	$ 10,568.30	$ 133,045.20	$ 270,671.28
14	4	6	24	$ 15,957.10	$ 122,895.50	$ 276,655.43
15	3	8	24	$ 18,651.40	$ 115,021.30	$ 279,140.65
17	2	11	22	$ 24,040.20	$ 107,147.50	$ 282,788.70
18	2	12	24	$ 26,734.60	$ 112,536.30	$ 282,138.50
20	2	15	30	$ 32,123.30	$ 123,313.70	$ 279,888.25
22	2	18	36	$ 37,512.10	$ 134,091.30	$ 277,754.63
24	1	21	21	$ 42,900.80	$ 101,967.90	$ 285,648.80
26	1	24	24	$ 48,289.60	$ 107,356.70	$ 284,265.60
28	1	27	27	$ 53,678.30	$ 112,745.40	$ 282,474.60
30	1	30	30	$ 59,067.10	$ 118,134.20	$ 280,422.20
32	1	33	33	$ 64,455.80	$ 123,522.90	$ 278,195.10
34	1	36	36	$ 69,844.60	$ 128,911.70	$ 275,845.00
36	1	39	39	$ 75,233.30	$ 134,300.40	$ 273,411.20
38	1	42	42	$ 80,622.10	$ 139,689.20	$ 270,916.80
40	1	45	45	$ 86,010.80	$ 145,077.90	$ 268,393.60

If the farmer solely examined the NPV at the end of the 30 years, the choices for the desired topsoil depth, in declining order would be: 24, 26, 17, 28, 18, 30, 20, 15, 32, 22, 14, 34, 36, 38, and 12 centimetres. The desired topsoil depth of 24 cm has the highest present value of net revenue; however, the amount of topsoil required to restore it is significant. After the 24 cm mark, a deeper topsoil depth does result in higher yields and the NPV revenue decreases for every additional cm of topsoil depth added. The yield index for the knoll is displayed in

Figure 16: Yield Index for Knolls by Varying Desired Topsoil Depth

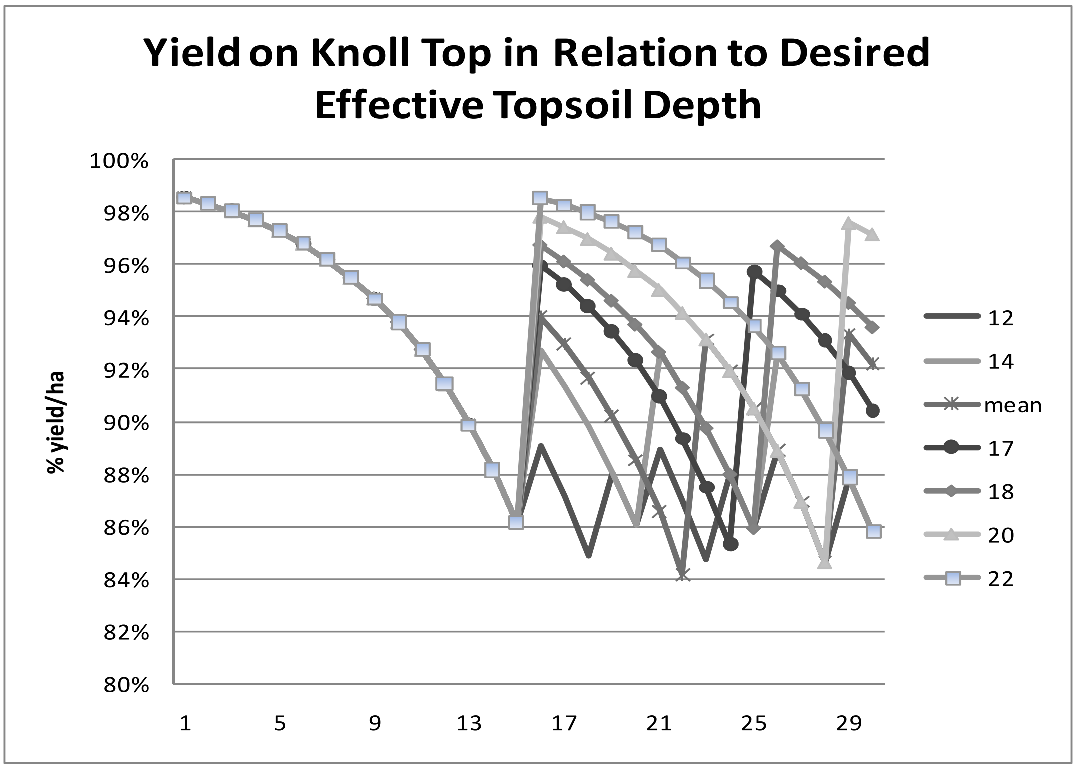


The yield index, explores the relationship between topsoil depth for the knolls and their yield potential. Severely eroded fields, with initial topsoil depths of 0 to 12 cm prior to restoration, will demonstrate the largest increase in yield when restored to a desired topsoil depth of 13 cm or more. Fields with higher topsoil depths at knolls.

The largest increase in yield, with respect to topsoil depth occurs by choosing a desired topsoil depth of 1 to 12 cm. However, yield increases are incrementally smaller with each additional cm of topsoil desired past 13 cm. Around the 22 cm mark, the incremental increase in yield for each additional desired cm is less that 0.01 per cent as a plant has all of the nutrients required to reach its potential.

The impact of varying the desired effective topsoil depth has an effect on the present value of net revenue. Depending on the desired topsoil depth chosen, and the restoration trigger, the additional cost for subsequent restorations will impact the NPV of the investment. It is for that reason that NPV varies so much in this sensitivity analysis.

Figure 17: Relationship Between Yield Percentage and Tillage Practices by Varying Desired Effective Topsoil Depth Over Time



In Figure 17, it is important to note that topsoil depth is restored according to the requirements set out at the beginning of the model. Depending on the desired effective topsoil depth chosen, yield increases will vary proportionally to the desired effective topsoil depth. In general, the increase in topsoil depth required for restoration will result in higher yields.

Scraper Size

The size of the chosen scraper ultimately affects both of time required to perform the restoration and the cost of restoration. When the model ran the same operation, the scraper size was varied to calculate the area that is restored per day. The results stemming from the restoration of the same field with three different scraper sizes is predictable.

Assuming that the cost of renting or owning the scraper would be the same regardless of the size, the best choice would be the larger scraper size due to the amount of restoration that could occur in one day. If all other variables are held constant the present value of net revenue for the larger scraper is higher. However, this may not be a plausible solution depending on the size and landscape of the field to be restored. Table 9 reflects the area restored by different scraper sizes over the course of a 10 hour work day.

Table 9: Effect of Varying the Scraper Size on Area Restored per Day

Scraper size (yrds)	Area Rest./load (sq.f)	Number of Loads/ day	Area Rest/day (ha)	Number of Days to Restore (10 hr)	Cost of Initial Restoration	NPV
9	34	221	0.7618	39.3780	$ 59,067.40	$ 224,185
13	50	204	1.0139	29.5899	$ 44,384.84	$ 257,323
17.50	67	201	1.3496	22.2295	$ 33,442.50	$ 282,225

Other Variables

Other variables present in the model have demonstrated proportional increases or decreases depending on the scenario selected. When examining cropping variables, it is assumed that a farmer will be able to, at the very least, cover the costs of production. If a producer cannot cover the cost of production, they will be less inclined to invest in landscape restoration. Thus, investment in landscape restoration ultimately depends on the cost of restoration and whether or not the net revenue is positive.

Break Even Analysis

While no single variable seemed to create a negative NPV for landscape restoration, a negative NPV can be achieved. The following section examines the effect of restoration on an operation that is currently breaking even in terms of its regular costs of production, yield and market price for the crops. The crop rotation used for this example is of Barley and Canola. The following sources are used to estimate values used in this example for yield (MAFRI, 2007a), crop prices (MASC, 2007) and production costs (MAFRI, 2007b).

This analysis is done for a 1 hectare field. The equipment used to restore the field is rented at the standard market rate. The current topsoil depth is 4 cm, and the desired topsoil depth is set at 10 cm, which is at the lower end of the accepted range for topsoil depth. The operation also uses conventional tillage practices that also increases topsoil loss to 0.8 mm per year.

The restoration trigger is set at 0 centimetres, meaning that subsequent restorations will only be triggered if topsoil depth at knolls is non-existent.

Based on the assumptions made about this 1 hectare field, it is evident that landscape restoration could have a positive impact on revenue generated by a break even farm if the soil was restored to an acceptable level. In this case; however, variables were specifically chosen to be below the optimal levels to demonstrate that the model could generate negative NPV if multiple variables were in the lower acceptable range.

Table 10: Restoration Specifics for Break Even Operation

Size of field (ha)		1	Scraper size used (ft)		9
Depression yield potential (%)		50	Equipment used for restoration	Rented	
Effective topsoil depth hilltop (cm)		4	Desired topsoil depth (cm)		10
Rate of soil loss hilltop (mm)		0.8	Initial restoration (cm)		6
Type of tillage used	Conventional till		Subsequent restoration trigger (cm)		0
% application area hilltop		25	Discount rate (%)	5	
% removal area depression		15			

Assuming the farm was breaking even, the cost of the initial and subsequent restorations would actually cost the operation more than it would generate as it was not able to increase yield in the convex upper slope positions enough to offset the costs of restoration. In this simulation, the net revenue generate from landscape restoration is -$1,063.37/ha.

Chapter 6: Landscape Restoration Model, Scenarios, Results and Discussion

LandRec was developed as a way to estimate how much effort, time and money could be generated after investing in land restoration. The LandRec model simulates terrain characteristics, elevation and erosion rates; all of which are factors affecting crop yield.

This study used LandRec to simulate the landscape restoration process and the subsequent benefit and cost of this method for set farming operations. As every operation is unique in its setup, the appropriate solution, for each particular farming operation, is also likely to be unique based on individual production factors. These production factors (farm size, operation type, machinery and initial capital investment) will then determine how likely the producer is to accept landscape restoration as a plausible solution.

Scenarios to Explore

There were three objectives for this study. The first objective was to establish the net revenue increase over time of restoring a field. The results generated for the restored field were then compared to its non-restored equivalent in order to provide a comparison which established the net monetary benefit of landscape restoration.

The second objective of this study was to explore the relationship between cropping practices and landscape restoration, as well as, its effect on the frequency of restoration. It will determine the reduced yield potential that is related to the lost opportunity income when landscape restoration is not performed. Cropping practices, which have a direct impact on the maintenance of target topsoil levels, are also explored.

Finally, the last objective of this study was to examine the effect of topsoil loss and landscape restoration on a scale larger than a field or a farming operation. As a result, this study explored the economic effect of landscape restoration on a municipality.

Scenario 1: Establishing Net Revenue Increases

The intent of the first scenario is to establish the net revenue increase of a restored field. This is accomplished through a comparison of a field that is fully restored with its non restored state. Using information collected from various sources (farmer interviews, provincial publications, and landscape profiles for affected regions), the following profile on which the standard field in this study is based, is used in this scenario.

The standard field is represented by a typical farming operation near Treherne, Manitoba. This area is known for its hummocky landscape, presence of soil erosion, and had been used by Smith (2008) for landscape restoration field trials in her Master's research. For our purposes, the area under examination is 145 hectares, with approximately 10 per cent of its total landscape classified as hilltops. These hilltops range in slope from 5 to 9 per cent. It is assumed that the upper slope positions on the knolls have an effective topsoil depth of 10 cm and are still productive. Using 10 cm as the effective field topsoil depth, mimics, over time, a productive field experiencing a decrease in yield potential in the convex upper sloped positions. It is assumed that this farming operation has adopted minimum tillage in order to reduce any future soil loss due to tillage erosion and that the convex upper slope positions have been restored to the 10 cm depth. The soil for this restoration has been redistributed from the lower concave positions to the upper convex position.

Table 11: Crop Rotation Chosen for Scenario 1

Cropping Rotation	Year 1	Year 2	Year 3	Year 4
	Wheat	Flax	Barley	Canola
Yield (t/ha)	1.9051	0.7348	4.722	2.938
Price ($/t)	$ 178.00	$ 358.00	$ 147.00	$ 421.00
Prod. Costs ($/ha)	$ 575.42	$ 457.38	$ 576.93	$ 572.16

The cropping rotation (wheat, flax, barley, canola) is illustrated in Table 11 above.

Table 12: Additional Parameters for Scenario 1

Size of field (ha)	145	Scraper size used (ft)	17.5
Depression yield potential (%)	50	Equipment used for restoration	Rent
Effective topsoil depth hilltop (cm)	10	Desired topsoil depth (cm)	20
Rate of soil loss hilltop (mm)	0.2	Initial restoration (cm)	10
Type of tillage used	Minimum Tillage	Subsequent restoration trigger (cm)	10
% application area hilltop	10.741	Discount rate (%)	5
% removal area depression	6.296		

Subsequent restorations for this field will only be performed if the effective topsoil depth at knolls hits a restoration trigger of 10 cm.

Results

Control Field (Non-restored Field)

For this scenario, the non-restored field is used as a control against which the effects of landscape restoration can be measured. The control simulation is done for a 30-year run. Table 13, below, outlines the effect that topsoil depth has on the yield in the non-restored field. Over a 30 year time frame, a decrease of 0.8703 tonnes/ha for yield per hectare on the hilltop and see no change for yield per acre on depressions was observed. There was no change in the yield per hectare in depressions as, typically, an accumulation of additional topsoil in these areas does not correspond to an increase in yield.

Table 13: Scenario 1- Non-restored Field Results for Topsoil Depth & Loss

	First year	Last year	Absolute Change
Yield/ha hilltop	2.2273	1.3570	0.8703
Yield/ha depression	0.1215	0.1215	0.0000
Topsoil depth hilltop (cm)	10.0000	3.7600	6.2400
Topsoil depth depression (cm)	81.1765	91.4118	10.2353
NPV Revenue	$		1,297,439.80

Tillage erosion soil loss depends on the type of tillage methods and implements that are used. In this study minimum or conservation tillage was used because it is the tillage method which produces an “average” amount of soil loss. (Note that soil loss directly attributed to conservation tillage is less than that of conventional tillage but more than zero tillage.) Conservation tillage, over a thirty year time frame, will reduce topsoil depth on hilltops by 6.24 cm. The lost soil accumulates in the depressions with a total accumulation of 10.2353 cm over thirty years. This increase in the soil depth in the concave lower slopes positions is somewhat proportional to the loss from the convex upper slope positions (minus the loss from the hilltops due to wind erosion).

Restored Field

In a restored field, there will be a yield in these convex slope positions areas, after the addition of 10 cm. The increase in yield will continue will be sustained for approximately thirty years and will. almost match the yield per hectare in the depressions.

Despite restoration, topsoil depth begins to decrease, in year 1, due to the ever-present water and tillage erosion. Table 14 also demonstrates the topsoil loss on the convex upper slope positions after the initial restoration.

Table 14: Scenario 1- Results for Restored Field Topsoil Depth & Loss

	Restored Field				
	First year	**After Restoration**	**Last year**	**Absolute Change yr 0-30**	**Absolute Change yr 1-30**
Yield t/ha hilltop	2.2273	2.5264	2.4098	0.1825	0.1166
Yield t/ha depression	2.5749	2.5749	2.5749	0.0000	0.0000
Topsoil depth hilltop (cm)	10.0000	19.7920	13.7600	3.7600	6.0320
Topsoil depth depression (cm)	81.1765	64.4588	74.3529	6.8236	9.8941
Year 30					
NPV Revenue					$ 1,328,595.20

In the depressions, the decrease in topsoil depth has no effect on the yield per hectare and the amount of topsoil, in these areas, continues to be worn away due to erosion factors. With respect to the payback period on this scenario, the costs associated with the initial restoration are recovered by year 10.

Control Field vs. Restored Field

A comparison of the control and restored field highlights several differences between the fields. An increased yield potential in the restored field is observed. This increased yield, in turn, increases the potential revenue per hectare. The grey line, in Figure 18 below, outlines that, in the non-restored field, yield decreases more than 30 per cent over a 30-year span. In comparison, the restored field's yield potential is quite flat and decreases from approximately 97 per cent to approximately 93 per cent during the same time span.

Figure 18: Scenario 1 - Yield on Eroded Knolls

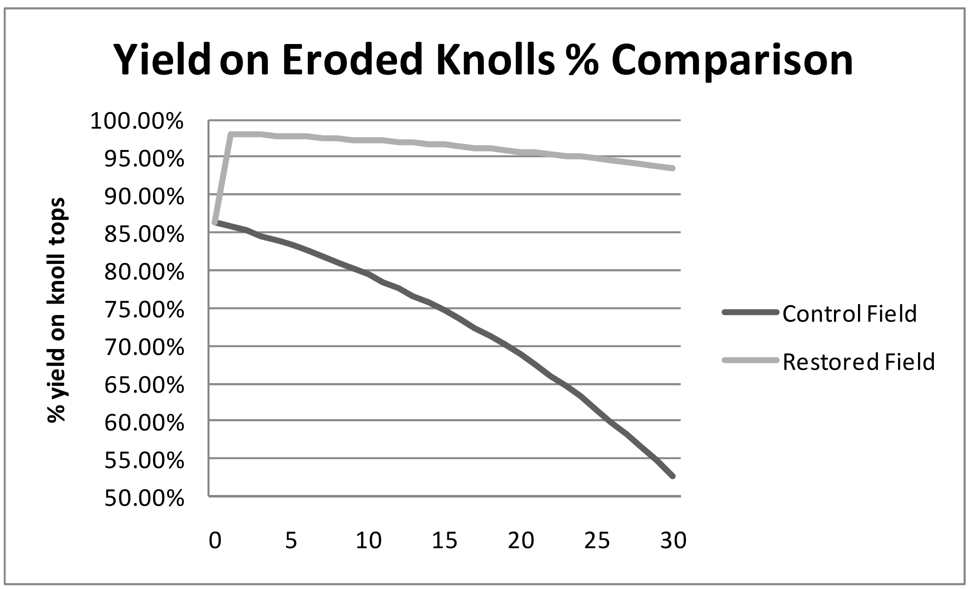


Table 15 outlines the results from both the control and restored field as well as displays the additional revenue attributed to the increased topsoil depth. Net revenue attributed to landscape restoration is equal to $21,903.70 over the thirty years when brought back to today's value. This displays a positive increase in NPV.

Table 15: Scenario 1 Summary Table

	Control Field			Restored Field				
	First year	**Last year**	**Absolute Change**	**First year**	**After Restoration**	**Last year**	**Absolute Change yr 0-30**	**Absolute Change yr 1-30**
Yield t/ha hilltop	2.2273	1.3570	0.8703	2.2273	2.5264	2.4098	0.1825	0.1166
Yield t/ha depression	0.1215	0.1215	0.0000	2.5749	2.5749	2.5749	0.0000	0.0000
Topsoil depth hilltop (cm)	10.0000	3.7600	6.2400	10.0000	19.7920	13.7600	3.7600	6.0320
Topsoil depth depression (cm)	81.1765	91.4118	10.2353	81.1765	64.4588	74.3529	6.8236	9.8941
Year 30								
NPV Revenue			$ 1,297,439.80					$ 1,328,595.20
NPV Expenses			$ 1,215,861.10					$ 1,225,113.30
NPV			$ 81,578.70					$ 103,481.90
NPV attributed to Land Restoration								$ 21,903.20

Summary of results for Scenario 1

Scenario 1 established that NPV Revenue will increase over time for a restored field, in comparison to its non-restored equivalent. Increases in yield can be attributed to landscape restoration and increased the NPV attributed to landscape restoration.

Scenario 2: Exploring the Relationship Between Tillage Practices and Landscape Restoration

The second scenario examines the relationship between cropping practices and landscape restoration. More specifically, it explores the direct effect that cropping practices have on landscape restoration when target topsoil levels are made a farming priority. The results generated for this scenario determine the effect of reduced topsoil levels on yield and revenue loss.

The standard field is represented by a typical farming operation in the RM of Lorne. For the purpose of this scenario, the field question is 203 hectares, with approximately 15 per cent of its total landscape as hilltops. These hilltops range in slope from 5 to 9 per cent. This field is assumed to still be productive in the convex upper slope positions, with an effective topsoil depth of 10 cm prior to restoration. In order to perform the restoration, soil is relocated from the depressions to the hilltop for the desired topsoil depth of 20 cm. Since the depressions have limited yield potential, there is little effect on yield for the lower sloped positions once the extra topsoil is removed. The crop mix for scenario two is illustrated in Table 16.

Table 16: Crop Rotation for Scenario 2

Cropping Rotation	Year 1	Year 2	Year 3	Year 4
	Wheat	Soybeans	Corn	Canola
Yield (t/ha)	1.6601	1.007	2.4638	3.1875
Price ($/t)	$ 162.00	$ 358.00	$ 73.00	$ 483.00
Prod. Costs ($/ha)	$ 580.10	$ 311.90	$ 373.38	$ 583.16

Table 17 outlines the characteristics of the operation as well as the additional parameters related to landscape restoration for scenario two.

Table 17: Additional Parameters for Scenario 2

Size of field (ha)	203	Scraper size used (yd)	13
Depression yield potential (%)	10	Equipment used for restoration	Rent
Effective topsoil depth hilltop (cm)	10	Desired topsoil depth (cm)	20
Rate of soil loss hilltop (mm)	0.5	Initial restoration (cm)	10
Type of tillage used	Conventional Tillage	restoration trigger (cm)	12
% application area hilltop	15	Discount rate (%)	5
% removal area depression	10		

Through this scenario field characteristics remain constant while tillage practices are varied in order to demonstrate the effect that tillage practices have on soil erosion and potential yield. This second scenario also examines the relationship between soil loss and the initial and subsequent restorations.

Land restoration is executed with a rented 13 yard scraper. The goal of this farming operation is to maintain higher topsoil depth than the level prior to restoration. As a result, any subsequent restoration will be performed when the topsoil depth on hilltops is 12 cm. Subsequent restorations depend on tillage practices in use and will therefore be triggered at various times within the 30-year time frame.

The computer model simulation will run four times, one time for each of the following tillage practices: zero tillage (0.05 mm loss per year), minimum tillage (0.2 mm), conservation tillage (0.5 mm), and conventional tillage (0.8 mm). The results from each of the four tillage practices will then be analyzed separately and compared with each other.

Results for Scenario 2

Zero tillage

Table 18 outlines the effect that adopting zero tillage has on both yield and topsoil depth on hilltops and in depressions. Five columns of data (First Year, After Restoration, Last Year, Absolute Change (0-30) and Absolute Change (1-30) are presented in this table. The column labelled "First Year" refers to the field prior to restoration. The column "After Restoration" refers to the field following the initial restoration and the "Last Year" column refers to the field situation in year 30.

The last two columns outline the absolute change for the variables prior to restoration until year 30, as well as the first year after the restoration until year 30.

Table 18: Scenario 2: Using Zero Tillage - Results for Restored Field Topsoil Depth & Loss

Zero Tillage	First year	After Restoration	Last year	Absolute Change yr 0-30	Absolute Change yr 1-30
Yield t/ha hilltop	1.7989	2.0417	2.0262	0.2273	0.0155
Yield t/ha depression	0.2169	0.2169	0.2169	0.0000	0.0000
Topsoil depth hilltop (cm)	10.0000	19.9420	18.2600	8.2600	1.6820
Topsoil depth depression (cm)	75	60.075	62.25	12.75	2.175
				Control	Restored
NPV Revenue				$ 1,625,322.20	$ 1,662,598.40
NPV Expenses				$ 1,421,241.10	$ 1,465,790.00
NPV				$ 204,081.10	$ 196,808.40
NPV attributed to Land Restoration					-$ 7,272.70

If this farming operation adopts zero tillage practices, both yield and topsoil loss quite small following the restoration. Yield loss on the hilltop, over the 30 year run, is approximately 0.0155 tonnes/ha while hilltop topsoil loss is approximately 1.6820 cm over the same time frame.

The payback period for the zero tillage example was of 18 years.

Minimum tillage (0.2 mm loss per year)

The following table outlines the effect that minimum tillage has on the field over the same 30 year time period. The term minimum tillage is used to reflect the loss of 0.2 mm of topsoil per year due to this practice.

Table 19: Scenario 2: Using Minimum Tillage - Results for Restored Field Topsoil Depth & Loss

Minimum Tillage	First year	After Restoration	Last year	Absolute Change yr 0-30	Absolute Change yr 1-30
Yield t/ha hilltop	1.7989	2.0404	1.9463	0.1474	0.0942
Yield t/ha depression	0.2169	0.2169	0.2169	0.0000	0.0000
Topsoil depth hilltop (cm)	10.0000	19.7920	13.7600	3.7600	6.0320
Topsoil depth depression (cm)	75	60.3	69	6	8.7
				Control	**Restored**
NPV Revenue				$ 1,603,066.30	$ 1,659,551.50
NPV Expenses				$ 1,442,142.10	$ 1,465,790.00
NPV				$ 160,924.20	$ 193,761.50
NPV attributed to Land Restoration					$ 32,837.30

The yield decrease for the hilltop position due to minimum tillage, is 0.0942 tonnes per hectare, for the length of the simulation. Topsoil depth decreased by 6.0320 mm over the 30-year period. While the topsoil loss is greater than the zero tillage scenario, minimum tillage only requires one restoration during the thirty year simulation. The cost of the initial restoration is paid back in year 14 for the minimum tillage field.

Conservation Tillage (0.5 mm loss)

The next tillage method examined in this hypothetical operation is conservation tillage. Conservation tillage normally experiences a 0.5 mm loss in topsoil per year in the convex upper slope positions. Table 20 (below) demonstrates that this type of tillage requires two restorations: one in year 0 and one in year 15. The subsequent restoration (year 15) was triggered when topsoil depth on the hilltop reached the 12 cm threshold. Total yield loss over the 30-year time frame, for the hilltop, is 0.2726 tonnes per hectare and total topsoil lost on the same portion is 25.0668 cm. Total soil accumulation in the concave lower slope positions areas is 21 cm. The cost of the initial restoration was paid back in year 10 for this operation.

Table 20: Scenario 2: Using Conservation Tillage - Results for Restored Field Topsoil Depth & Loss

Conservation Tillage	First year	After Restoration	Year 16, Sub. Rest.	Last year	Absolute Change yr 1-15	Absolute Change yr 16-30	Total Loss or Gain yr 1-30
Yield t/ha hilltop	1.7989	2.0379	2.0369	1.9172	0.1529	0.1197	0.2726
Yield t/ha depression	0.2169	0.2169	0.2169	0.2169	0.0000	0.0000	0.0000
Topsoil depth hilltop (cm)	10.000	19.492	19.3640	1.917	7.6200	17.4468	25.0668
Topsoil depth depression (cm)	75.000	60.750	60.750	70.500	11.250	9.750	21.000
						Control	Restored
NPV Revenue						$ 1,528,027.30	$ 1,656,597.00
NPV Expenses						$ 1,442,142.10	$ 1,475,312.40
NPV						$ 85,885.20	$ 181,284.60
NPV attributed to Land Restoration							$ 95,399.40

Conventional Tillage (0.8 mm loss)

Conventional tillage is the last simulation run in this scenario. Topsoil lost due to conventional tillage is approximately 0.8 mm per year. The following table outlines the effect that conventional tillage would have on this hypothetical operation, if all other factors are held constant.

Table 21: Scenario 2: Using Conventional Tillage - Results for Restored Field Topsoil Depth & Loss

Conventional Tillage	First year	After Restoration	Year 11, Sub. Rest.	Year 21, Sub. Rest.	Last year	Absolute Change yr 1-10	Absolute Change yr 11-20	Absolute Change yr 21-30	Total Loss or Gain yr 1-30
Yield t/ha hilltop	1.7989	2.0355	2.0348	2.0341	1.8804	0.1484	0.1511	0.1537	0.4532
Yield t/ha depression	0.2169	0.2169	0.2169	0.2169	0.2169	0.0000	0.0000	0.0000	0.0000
Topsoil depth hilltop (cm)	10.000	19.192	19.1120	19.0320	11.760	7.2720	7.2720	7.2720	21.8160
Topsoil depth depression (cm)	75.000	61.200	61.200	61.200	72.000	10.8000	10.800	10.800	32.400
								Control	Restored
NPV Revenue								$ 1,486,590.40	$ 1,655,396.30
NPV Expenses								$ 1,442,142.10	$ 1,491,194.50
NPV								$ 44,448.30	$ 164,201.80
NPV attributed to Land Restoration									$ 119,753.50

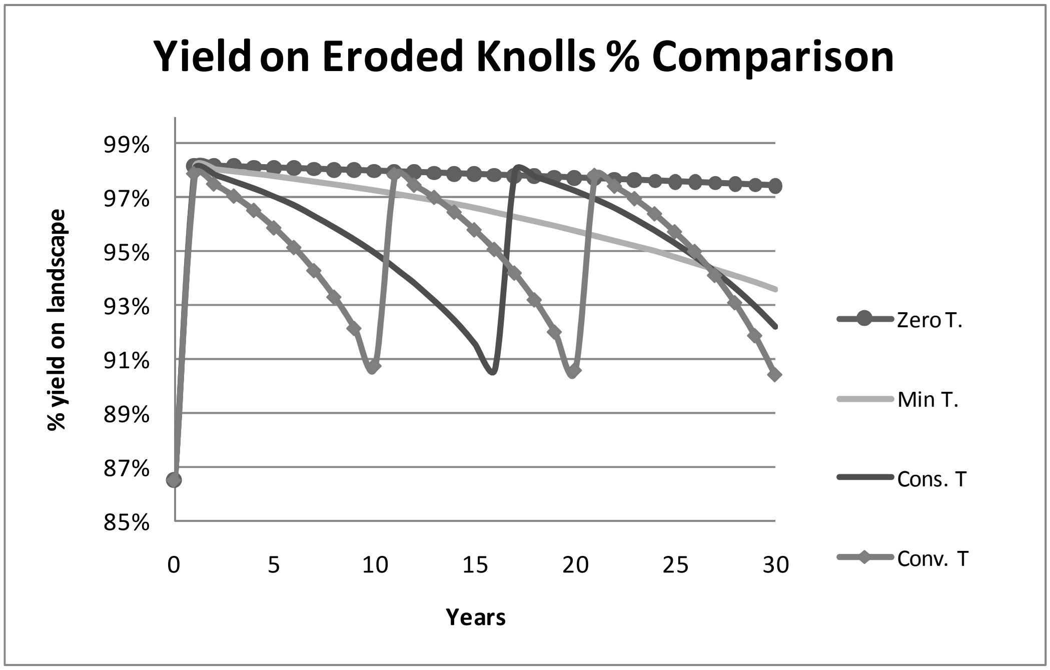
Total yield loss in the hilltops, over the 30 year period, is 0.4532 tonnes/hectare while topsoil loss totals 21.816 mm. Two additional restorations are prompted within the 30 year period: one in year 10 and another in year 20.

Total yield loss in the hilltops, over the 30 year period, is 0.4532 tonnes/hectare while topsoil loss totals 21.816 mm. Two additional restorations are prompted within the 30 year period: one in year 10 and another in year 20. The initial restoration costs were recovered by year 8 for the conventional tilled operation.

Overall Comparison

Four different types of tillage practices were used to demonstrate the effect that tillage practices have on yield, revenue and the cost of crop production in a specific operation. Keeping all other variables constant four tillage practices (zero tillage, minimum tillage, conservation tillage and conventional tillage) were separately applied to the hypothetical field. Figure 19 illustrates the effect that these four tillage practices have on yield, specifically on the portion of the field considered as the knolls.

Figure 19: Comparison of Yield % on Eroded Knolls Based on Tillage Practices Used



The circle marker line represents zero tillage. The yield % slope for zero tillage is quite flat, with a slight decrease in yield potential over time. Minimum tillage, with a loss of 0.2 mm per year, is illustrated by the light grey line. The graph illustrates that yield percentage for minimum tillage at a decreases greater rate than zero tillage in the same period.

Conservation tillage (the dark grey line), with an average loss of 0.5 mm per year, shows greater yield percentage losses than both zero and minimum tillage over the course of the 30-year time frame. A subsequent restoration is triggered at the end of year 15.

Lastly, conventional tillage, represented by the diamond marker line, displays more frequent dips than all conservation dips, which indicates the need for two subsequent restorations; one in year 10 and 20. Restoration was triggered for both conservation and conventional tillage, ensuring that yield percentage for the knoll positions does not fall below 90 per cent.

The following table (Table 22) outlines the difference in accumulated yield based on the tillage practice. In general, the higher rate of topsoil loss, the lower the accumulated yield will be. For example, zero tillage has the lowest topsoil loss of all tillage practices studied. In terms of accumulated yield, the zero tillage practice outperforms both types of all other types of tillage.

Table 22: Scenario 2 - Difference in Accumulated Yield in Year 30 Depending on Tillage Practice Used

Difference in Accumulated Yields Depending on Tillage Used (tonnes/ha)	Zero Till 0.05 mm	Cons. Till 0.2 mm	Cons. Till 0.5 mm	Conv. Till 0.8 mm
Zero Till 0.05 mm		26.9	43.2	50
Cons. Till 0.2 mm			16.3	23.1
Cons. Till 0.5 mm				6.8

If accumulated yields are higher upon adoption of zero tillage then the increased yield converts not only to additional revenue, but also to lower restoration costs, as restoration will only be triggered once during the 30-year time frame. With an assumed constant field and crop rotation, assuming the same field and crop rotation and the same time frame, the net revenue difference between zero and conventional tillage amounts to $32,607. The differences in net revenue, for the four tillage practices, are outlined in the table below.

Table 23: Scenario 2 - Difference in Net Revenue in Year 30 Depending on Tillage Practice Used

Difference in Net Revenue Depending on Tillage Used	Zero Till 0.05 mm	Cons. Till 0.2 mm	Cons. Till 0.5 mm	Conv. Till 0.8 mm
Zero Till 0.05 mm		$ 3,047	$ 15,524	$ 32,607
Cons. Till 0.2 mm			$ 12,477	$ 29,560
Cons. Till 0.5 mm				$ 17,083

Table 23 demonstrates that when the amount of topsoil lost due to tillage practice increases, there is a corresponding loss of potential revenue. For example, minimum tillage (0.2 mm soil loss), nets $3,047 less than zero tillage (0.05 mm loss), but approximately $29,560 more than conventional tillage (0.8 mm loss). The payback period for the other tillage practices in increasing order are: conservation tillage (10 years), minimum tillage (14 years), and zero tillage (18 years). The following table (Table 24) summarizes the effect of the four tillage practice on yield, revenue and topsoil depth and, ultimately, on the net present value (NPV) at the end of the simulation run. With respect to the payback period on the initial restoration, the conventionally tilled operation was the quickest to recoup the costs of restoration, doing so by year 8.

Table 24: Summary of Effect of Tillage Practices on Yield, Revenue and Topsoil Depth

	Zero Till	**Min. Till**	**Cons. Till**	**Conv. Till**
Topsoil lost per year (mm)	0.05	0.2	0.5	0.8
Intial Restoration				
Topsoil removed from depression for Initial Restoration (cm)	10			
Desired Topsoil Depth at Knolltops (cm)	20			
Cost of Initial Restoration	$ 24,830.30			
Subsequent Restoration				
Number of Subsequent Restorations Performed			1	2
Amount of topsoil removed by a Subsequent Restoration (cm)			12	
Amount of topsoil added to Knolltops by a subsequent Restoration (cm)			8	
Cost for Each Subsequent Restoration			$ 20,786.20	$ 20,786.20
Total Restoration Costs			$ 20,786.20	$ 41,572.40
Effect on Revenue at the End of Year 30				
NPV Revenue	$ 1,662,598.40	$ 1,659,551.50	$ 1,656,597.00	$ 1,655,396.30
NPV Expenses	$ 1,465,790.00	$ 1,465,790.00	$ 1,475,312.40	$ 1,491,194.50
NPV	$ 196,808.40	$ 193,761.50	$ 181,284.60	$ 164,201.80
NPV attributed to Land Restoration	-$ 7,272.70	$ 32,837.30	$ 95,399.40	$ 119,753.50

The NPV revenue for the four tillage practices, in declining order are: $1,662,598.40 (zero tillage), $1,659,551.50 (minimum tillage), $1,656,597.00 (conservation tillage) and $1,655,396.30 (conventional tillage). For the NPV after expenses keeps the same order.

The last line of Table 24 compares the same field in both its non-restored and restored state. It clearly demonstrates that the increase in yield can be attributed to landscape restoration, and subsequently, that increased revenues is a factor of topsoil depth. Essentially, the more disruptive the tillage practice employed, the more beneficial the landscape restoration can be. The net present value for three tillage practices is positive; however, the fourth tillage practice, zero tillage, is an exception (-$7272.70). The NPV increase, for all four tillage options, which can be solely attributed to landscape restoration is as follows: $119,753.80 (conventional tillage), $95,399.40 (conservation tillage), $32,837.40 (minimum tillage) and -$7272.70 (zero tillage). It is important to note that land restoration where zero tillage is practiced is not advised, despite the fact that, when restored, has the highest NPV Revenue ($1,662,598.40), one of the lowest NPV's after expenses ($1,465,790.00). Land restoration is not advised in this case as the adoption of zero tillage already mitigates the risk of tillage erosion.

Scenario 3: Effects of Landscape Restoration on a Municipality

Scenario 3 explores the effect of topsoil loss and landscape restoration on a larger scale. Within Manitoba, the rural municipalities (RM) of Lorne, Louise and South Norfolk are all prone to soil erosion due to hummocky landscape. Smith's soil science study (2008), associated with this study, had the majority of its field experiments located in the RM of Lorne. Of the three municipalities, the RM of Lorne, is the municipality most affected by soil loss, due to its undulating landscape. Therefore, scenario 3 will explore the benefits, the costs of landscape restoration for the RM of

Lorne and result in a gross estimate of the additional revenue generated by land restoration on the agricultural land portion of the municipality.

Background on the Rural Municipality of Lorne

Located in south central Manitoba, the Rural Municipality (RM) of Lorne covers 976,000 hectares of land and ten townships. Larger urban areas include Notre Dame de Lourdes, Somerset and Swan Lake. The majority of the land in this RM is used for agricultural purposes including but not limited to intensive livestock production, supply management commodities, and crop production ranging from grains, to oilseeds and to forage production. The landscape of the RM is dominated by hummocky land and rolling land. Interspersed within the rolling land are areas of near level terrain having slopes of 0% to 2%. The area also contains portions of slight, moderate and severe sloped areas, as is illustrated in the table below (Table 25). Topographical areas, with slopes of 15% or greater, are normally used for grazing or wood lots and are generally not cropped.

Table 25: Slope Classes based on the Information Bulletin for the RM of Lorne

Slope Class	Area (ha)	% of RM
0 to 2 %	35748	36.6
2 to 5 %	29328	30
5 to 9%	11468	11.7
9 to 15%	10870	11.1
15 to 30%	2983	3.1
30% or greater	4430	4.5
Water	2805	2.9
Total	97631	100

Based on the Canada Land Inventory system (CLI, 1965),
Table 26 shows the agricultural capability of the RM of Lorne. This is corroborated by information from Soils and Terrain information (MAFRI, 1998), which suggests that approximately 89.30% of the total land in the Rural Municipality of Lorne can sustain some sort of agriculture (Classes 1 through 5). Classes 1 to 3 represent prime agricultural land; Class 4 agricultural land is considered

marginal for sustained cultivation, while Class 5 land is capable of producing perennial forages. This study is limited to land which is considered dry land agriculture capable, more specifically, Classes 1 to 3.

Table 26: Agricultural Capability of the RM of Lorne

Agricultural Capability	Area (ha)	% of RM
Class 1	8342	8.59%
Class 2	38774	39.91%
Class 3	17021	17.52%
Class 4	11063	11.39%
Class 5	11552	11.89%
Total Arable Land	86752	89.30%
Class 6	6978	7.18%
Water	2367	2.44%
Organic	1052	1.08%
Total Landbase	**97149**	**100.00%**

Of the available hectares, only 72,823 are actually for crop and forage production. Of the available hectares, approximately 7,675.32 used for continual forage production, leaving 65,147.68 hectares for crop production. Using this information and the slope information provided in Table 25 and Table 26, the proportion of agricultural land available for crop production, based on its slope, is extrapolated (Table 27).

Table 27: Agricultural Land Distribution According to Slope Categories

Ag Land Distribution According to Slope	in ha
0 to 2% slope	26,653.22
2 to 5% slope	21,846.90
5 to 9% slope	8,520.29
9 to 15% slope	8,083.35
Total arable ha	**72,823.00**

Table 28, below, provides an overview of the top ten cropping choices in the RM of Lorne (Canadian Agriculture Census, 2006). This information was subsequently used to determine the crop rotations for this study.

Table 28: Top 10 Crops in Production in the RM of Lorne

Top 10 Crops in Lorne According to 2006 Ag Census	in ha	%
Wheat	23,581	38.10%
Canola	21,407	34.59%
Alfalfa	866	1.40%
Barley	6,853	11.07%
Flaxseed	3,771	6.09%
Oats	3,019	4.88%
Sunflowers	722	1.17%
Corn	711	1.15%
Rye	643	1.04%
Buckwheat	314	0.51%
Total	61,887	100

Within the computer model, the RM of Lorne is broken into 4 distinct sub-scenarios based on the slope categories found in Table 27. The computer model was then run to determine the cost of initial and subsequent restoration, as well as, the additional revenue generated from landscape restoration due to increased crop yield. Each sub-scenario had, prior to restoration, its own specific crop rotation, tillage practice and initial topsoil depth at knoll. In all sub-scenarios, the land has the same restoration trigger. This information is presented in the figure below (Table 29).

Table 29: Field Specifics for Scenario 3

	Scenario 3.1	Scenario 3.2	Scenario 3.3	Scenario 3.4
Total Land (ha)	26,653.22	21,846.90	8,520.29	8,083.35
Slope of Area	0 to 2%	2 to 5%	5 to 9%	9 to 15%
Type of Tillage Used	Conventional Tillage	Conventional Tillage	Conservation Tillage	Zero Tillage
Crop Rotation				
Year 1	Wheat	Wheat	Barley	Corn
Year 2	Canola	Canola	Flax	Oats
Year 3	Barley	Barley	Wheat	Wheat
Year 4	Oats		Canola	
Years 4 through 8		Alfalfa		Alfalfa

Results of simulations

Scenario 3 simulates the effect of soil loss due to tillage, the effect of landscape restoration on topsoil levels, and the additional revenues provided by landscape restoration. Four individual sub-scenarios were run based on the parameters set out in the previous tables. They were then compared to their non-restored alternative to quantify the increase in revenue, and net revenue for that area. The following section examines the individual results for the four sub-scenarios.

Scenario 3.1: 0-2% slope land base

Scenario 3.1 examines the economic benefit of landscape restoration on an area of land deemed of having a slope of 0 to 2 per cent in the RM of Lorne (Table 30). As the general slope of the area is minimal, it was assumed that the area would be managed by conventional tillage practices, with an average topsoil loss of 0.5 mm per year. Topsoil depth at hilltop is at 15 cm, and is to be restored to a topsoil depth of 25 cm. Table 31 outlines the cropping rotation and includes the yield, price and production costs for this particular crop rotation. For this sub-scenario, a typical rotation of Wheat - Canola - Barley - Oats is used.

Table 30: Scenario 3.1 - Restoration Specifics

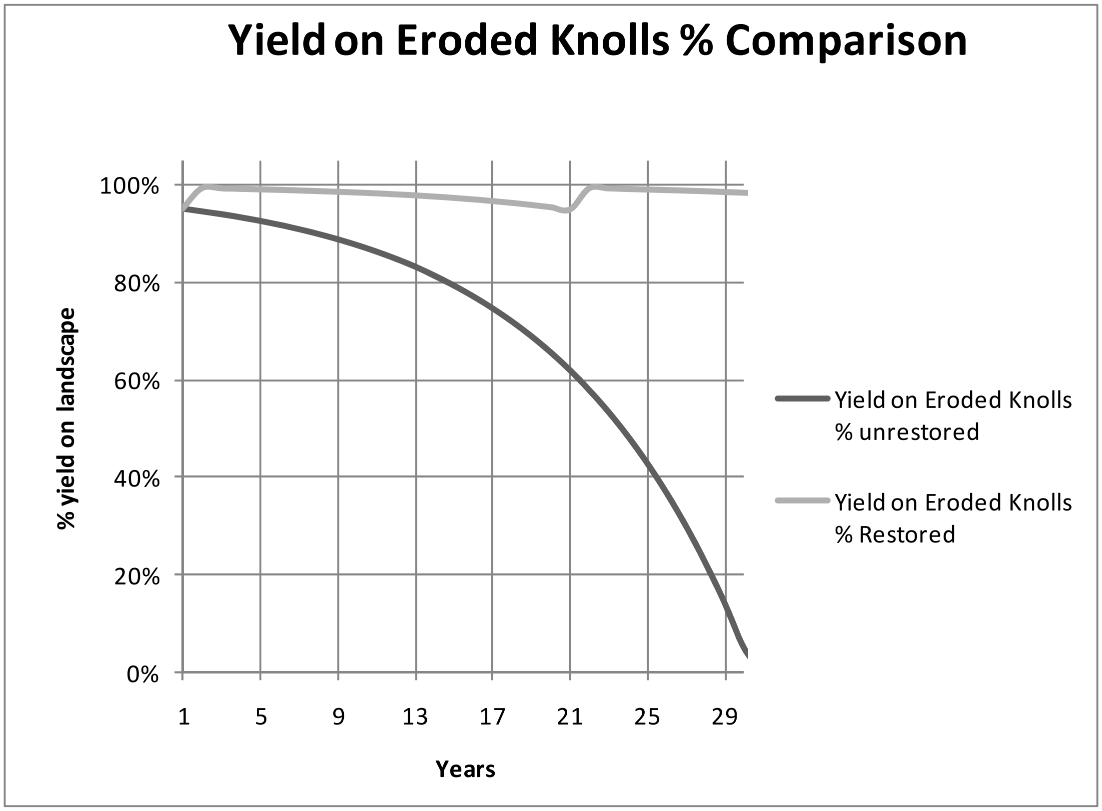
Size of field (ha)	26653.22	Scraper size used (ft)	17.5
Depression yield potential (%)	100	Equipment used for restoration	Rented
Effective topsoil depth hilltop (cm)	15	Desired topsoil depth (cm)	25
Rate of soil loss hilltop (mm)	0.5	Initial restoration (cm)	10
Type of tillage used	Conventional till	Subsequent restoration trigger (cm)	15
% application area hilltop	10	Discount rate (%)	0.05
% removal area depression	10		

Table 31: Scenario 3.1 - Crop Rotation

Cropping Rotation	Year 1	Year 2	Year 3	Year 4
	Wheat	Canola	Barley	Oats
Yield (t/ha)	1.5241	2.8765	4.5560	1.5966
Price (t/ha)	$ 186.00	$ 480.00	$ 149.00	$ 158.00
Prod. Costs ($/ha)	$ 209.32	$ 542.00	$ 420.00	$ 206.40

The following chart (Table 32) outlines the effect of landscape restoration on the percentage yield on the eroded knolls from the restored and non-restored land. With the addition of topsoil, the potential yield significantly increases due to both the initial and subsequent restoration. When compared to its non-restored state, the high yield potential in restored land is maintained, throughout the thirty-year time frame. In non-restored knolls, the sharply decreasing black line is indicative of the tillage type used; in this case, conventional tillage, which has an average topsoil loss of 0.5 mm per year.

Figure 20: Scenario 3.1 Yield Comparison for Eroded Knolls



The cost related to the initial restoration of the 26,653.22 hectares is approximately $1.66 million dollars. Each subsequent restoration would also cost the same amount, if the desired topsoil depth of 25 cm on the hilltops is maintained.

Based on the field and yield characteristics outlined in the previous two tables (Table 30 & Table 31), Table 32 compares the same field in its restored state to its non-restored state. This comparison highlights the cost of restoration for the area and the net revenue increase attributed to landscape restoration due as well as the resulting increase in crop yield.

Table 32: Scenario 3.1: Restoration Cost Comparison

	No Restoration	Restoration Performed
Topsoil lost per year (cm)	0.5	
Cost of Initial Restoration		$ 1,662,550.00
Cost for Each Subsequent Restoration		$ 1,662,550.00
Total Restoration Costs		$ 3,325,100.00
Effect on Revenue at the End of Year 30		
NPV Revenue	$ 237,535,250.00	$ 243,575,460.00
NPV Expenses	$ 141,791,740.00	$ 144,011,480.00
NPV	$ 95,743,510.00	$ 99,563,980.00
NPV attributed to Land Restoration		$ 3,820,470.00

Present value of net revenue for the non-restored field is $95.7 million. When restored, the present value of net revenue for the field is estimated at $99.7 million. The net difference in NPV , therefore, is $3.8 million for the restored field indicating a positive NPV.

Scenario 3.2: 2-5% slope land base

Scenario 3.2 examines the economic benefit of landscape restoration of land, in the RM of Lorne, with a slope of 2 to 5 per cent.

As the general slope of the area is in the minimal to moderate category (2-5%), it was assumed that the area would be managed by conventional tillage practices which have an average topsoil loss of 0.5 mm per year. Topsoil depth on the hilltop is 10 cm and will be restored to a topsoil depth of 20 cm.

Table 33: Scenario 3.2 - Restoration Specifics for 5 to 9% Slope

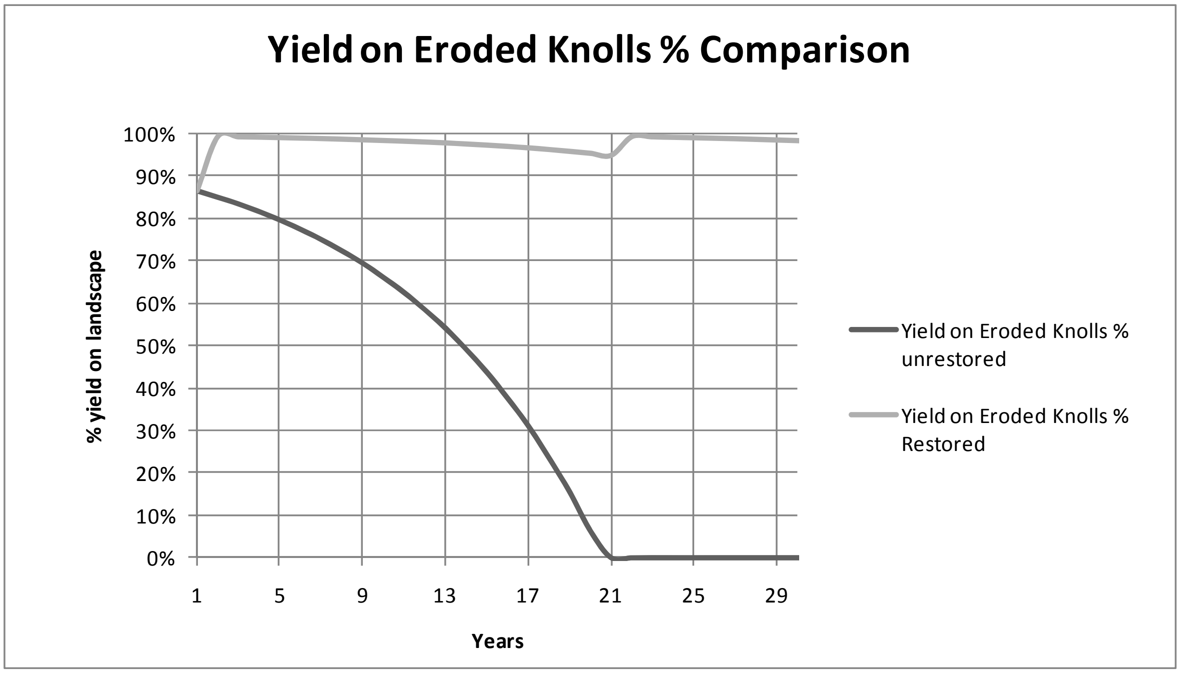
Size of field (ha)		21943.62	Scraper size used (ft)		17.5
Depression yield potential (%)		0.8	Equipment used for restoration	Rented	
Effective topsoil depth hilltop (cm)		10	Desired topsoil depth (cm)		20
Rate of soil loss hilltop (mm)		0.5	Initial restoration (cm)		10
Type of tillage used	Conventional Tillage		Subsequent restoration trigger (cm)		15
% application area hilltop		20	Discount rate (%)		5
% removal area depression		10			

Table 34: Scenario 3.2 - Crop Rotation

Cropping Rotation	Year 1		Year 2		Year 3		Years 4 to 8	
	Wheat		Canola		Barley		Alfalfa	
Yield (t/ha)		5.6400		3.8277		7.0526		2.7830
Price (t/ha)	$	164.00	$	415.00	$	150.00	$	150.00
Prod. Costs ($/ha)	$	209.32	$	520.42	$	475.87	$	96.91

The above table (Table 34) outlines the cropping rotation and includes yield, price and production costs for this particular crop rotation. For this sub-scenario, a typical rotation of Wheat – Canola – Barley- Alfalfa is used. Alfalfa, a perennial crop, is seeded in year 4, and is kept in the field for an additional 3 years. During that period of time soil erosion loss decreases as the area is not tilled.

Figure 21: Scenario 3.2 Yield Potential on Eroded Knolls



In Figure 21 above, yield potential is outlined in both the restored and the non-restored field equivalent. Yield remains relatively stable in the restored field with only one restoration triggered in year 21 as per the above figure. Yield potential incrementally decreases over time, until it flat lines at 0% in year 21.

Table 35: Scenario 3.2 Restoration Cost Comparison

	No Restoration	Restoration Performed
Topsoil lost per year (mm)	0.8	
Cost of Initial Restoration		$ 3,790,980.00
Cost for Each Subsequent Restoration		$ 2,725,490.00
Total Restoration Costs		$ 6,516,470.00
Effect on Revenue at the End of Year 30		
NPV Revenue	$ 188,302,850.00	$ 211,151,930.00
NPV Expenses	$ 79,977,430.00	$ 84,615,100.00
NPV	$ 108,325,420.00	$ 126,536,830.00
NPV attributed to Land Restoration		$ 18,211,410.00

Initial restoration costs for an area this size is approximately $3.79 million dollars. Each additional subsequent restoration will then cost an additional $2.72 million dollars if the desired topsoil depth is 20 cm on the hilltops. The cost of the initial restoration is recovered in year 9.

When comparing the effect of landscape restoration on the restored area to its non-restored equivalent, NPV Revenue is approximately $22.8 million dollars. However, after regular expenses and the cost of restoration, the NPV attributed solely from land restoration for this area is approximately $18.2 million dollars over a thirty years period.

Scenario 3.3: 5-9% slope land base

Scenario 3.3 examines the economic benefit of landscape restoration on the area of land in the RM of Lorne which has a slope of 5 to 9 percent. It is assumed conservation tillage practices have been adopted which have an average topsoil loss of 0.2 mm per year. Topsoil depth at hilltop is 7 cm and will be restored to 25 cm.

Table 36: Scenario 3.3 - Restoration Specifics

Size of field (ha)	8520.29	Scraper size used (ft)	13
Depression yield potential (%)	0.5	Equipment used for restoration	Rent
Effective topsoil depth hilltop (cm)	7	Desired topsoil depth (cm)	25
Rate of soil loss hilltop (mm)	0.2	Initial restoration (cm)	18
Type of tillage used	Conservation Tillage	Subsequent restoration trigger (cm)	15
% application area hilltop	25	Discount rate (%)	5
% removal area depression	15		

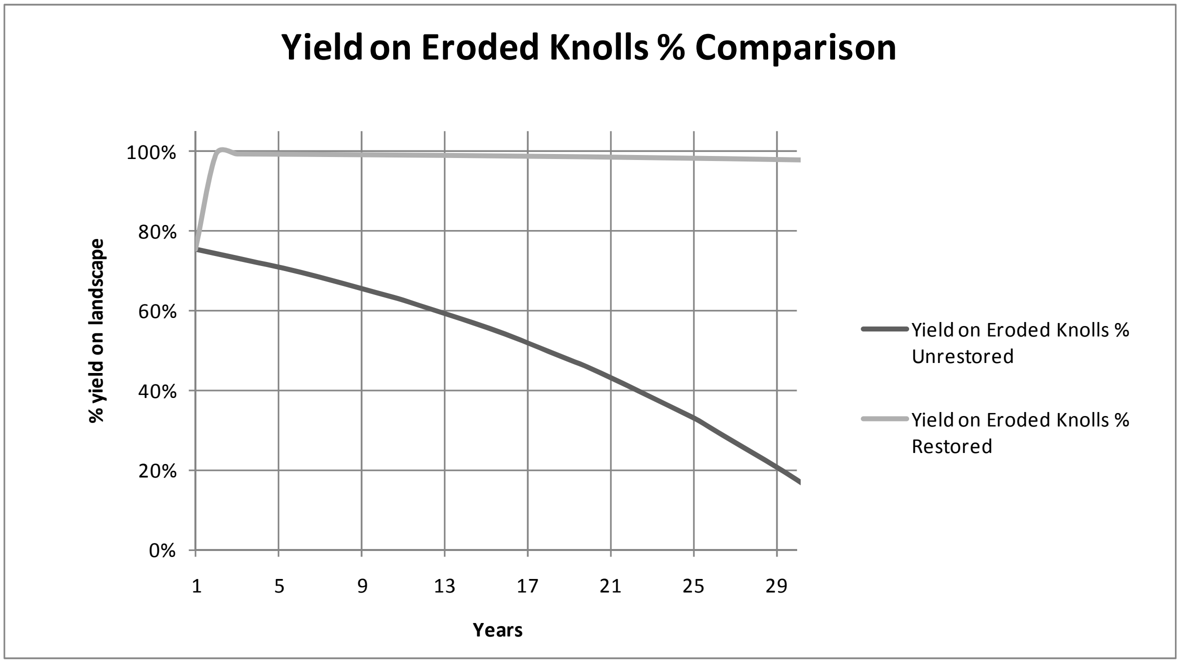
Table 38, below, outlines the cropping rotation, yields, prices as well as the cost of production for this particular crop rotation. For this sub-scenario, a typical rotation of Wheat – Canola – Barley-Flax is used.

Table 37: Scenario 3.3 Crop Rotation Specifics

Cropping Rotation	Year 1	Year 2	Year 3	Year 4
	Wheat	Canola	Barley	Flax
Yield (t/ha)	1.3300	2.8125	4.8889	0.8437
Price (t/ha)	$ 161.00	$ 441.00	$ 146.00	$ 370.00
Prod. Costs ($/ha)	$ 209.32	$ 490.07	$ 490.32	$ 431.58

The following figure (Figure 22) outlines the effect of landscape restoration on the restored area, in terms of the percentage yield on the eroded knolls in both the restored and non-restored areas. With the additional topsoil, the yield potential increases significantly in the restored field, reaching almost 100% in the first year. The high yield potential is then maintained throughout the thirty year time frame. The increase in yield can be directly attributed to the additional soil and to the adoption of conservation tillage. In the non-restored field, yield potential decreases over time, dropping to less than 20 % in year 30.

Figure 22: on Eroded Knolls Comparison for Scenario 3



Based on the field and yield characteristics outlined in the previous two tables, Table 38 , below, outlines the cost of restoration and its effect on the NPV for both the restored and non-restored field. This comparison highlight the costs of restoration for the area, the increase in yield to the affected areas, and the overall net revenue increase attributed to landscape restoration.

Table 38: Scenario 3.3 - Crop Rotation

	No Restoration	Restoration
Topsoil lost per year (mm)	0.2	
Cost of Initial Restoration		$ 2,868,530.00
Cost for Each Subsequent Restoration		$ -
Total Restoration Costs		$ 2,868,530.00
Effect on Revenue at the End of Year 30		
NPV Revenue	$ 61,743,851.00	$ 70,295,400.00
NPV Expenses	$ 53,088,208.00	$ 55,820,148.00
NPV	$ 8,655,643.00	$ 14,475,252.00
NPV Attributed to Land Restoration		$ 5,819,609.00

The initial cost to restore an area of this size (how many hectares) to a desired topsoil depth of 20 cm is approximately $2.87 million dollars. When comparing the effect of landscape restoration to it none restored equivalent, the NPV revenue difference is approximately $8.56 million dollars; however, after the deduction of crop expenses and the cost of restoration, the additional NPV for the restored area is approximately $5.8 million dollars over the thirty year period.

Scenario 3.4: 9-15% slope land base

The last sub-scenario in this example explores the effects of restoration and its economic benefit for the area defined in this example. The area to be restored is 8030.35 hectares. The effective topsoil depth prior to restoration was 5 cm, with an additional yearly topsoil loss of 0.050 mm due to zero tillage practices. Twenty centimetres of topsoil is applied to eroded knolls in order to achieve a desired topsoil depth of 25 cm.

Table 39: Scenario 3.4 - Restoration Specifics

Size of field (ha)	8030.35	Scraper size used (ft)	13
Depression yield potential (%)	30	Equipment used for restoration	Rent
Effective topsoil depth hilltop (cm)	5	Desired topsoil depth (cm)	25
Rate of soil loss hilltop (mm)	0.05	Initial restoration (cm)	20
Type of tillage used	Zero Tillage	Subsequent restoration trigger (cm)	15
% application area hilltop	30	Discount rate (%)	5
% removal area depression	20		

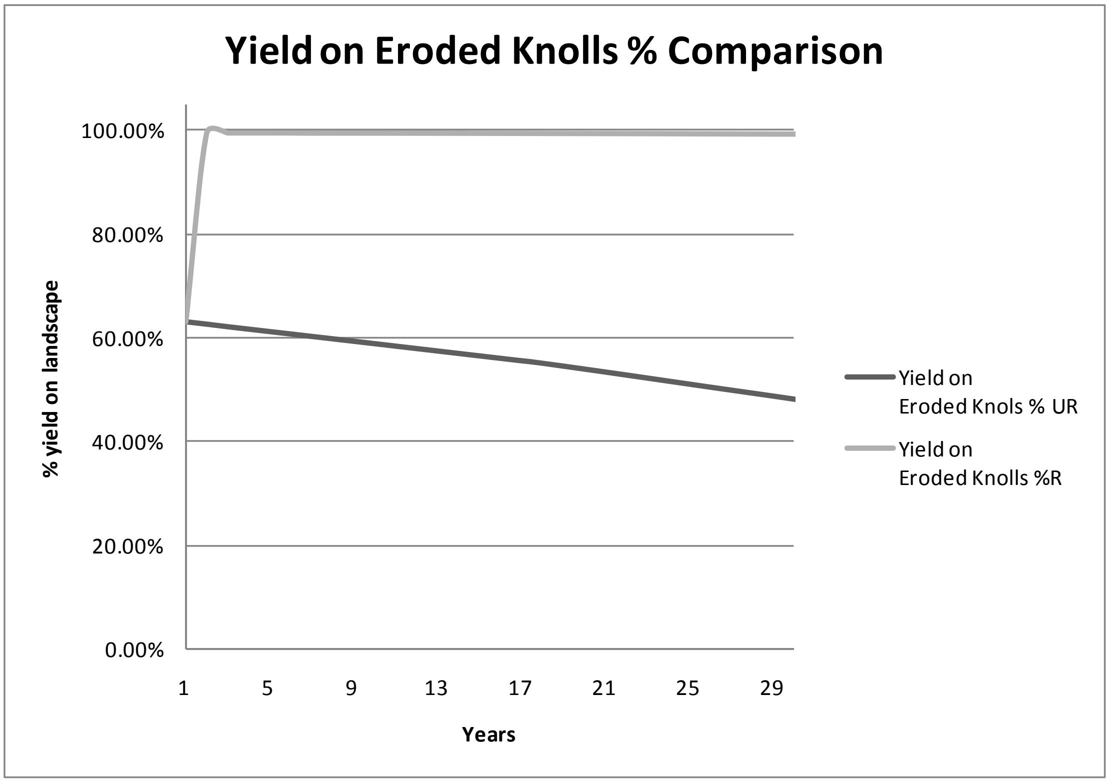
Table 40, below demonstrates the yield, price and production cost for the following rotation: Corn – Oats – Wheat – Alfalfa. After restoration, this area will continue to use zero tillage to minimize reduce future topsoil loss.

Table 40: Scenario 3.4 - Crop Rotation

Cropping Rotation	Year 1	Year 2	Year 3	Year 4-8
	Corn	Oats	Wheat	Alfalfa
Yield (t/ha)	6.3654	1.7437	3.4672	5.0712
Price (t/ha)	$ 195.00	$ 205.00	$ 176.00	$ 160.00
Prod. Costs ($/ha)	$ 373.38	$ 206.84	$ 209.32	$ 96.91

Following the initial restoration, yield quickly rises to and remains near 100% while yield for the non-restored land slowly decreases from just above 60% in year 0 to approximately 50% in year 30.

Figure 23: Yield on Eroded Knolls Comparison for Scenario 3.4



With regards to restoration, the cost of initially restoring the 8030.35 hectares is estimated at $3.59 million dollars. With respect to effect of restoration on the present value of net revenue, the NPV increased to $8.7 million dollars.

Table 41: Scenario 3.4 - Restoration Cost

	No Restoration	Restoration Performed
Topsoil lost per year (mm)		0.05
Cost of Initial Restoration		$ 3,587,780.00
Cost for Each Subsequent Restoration		$ -
Total Restoration Costs		$ 3,587,780.00
Effect on Revenue at the End of Year 30		
NPV Revenue	$ 67,272,242.00	$ 79,420,890.00
NPV Expenses	$ 20,896,770.00	$ 24,313,710.00
NPV	$ 46,375,472.00	$ 55,107,180.00
NPV Attributed to Land Restoration		$ 8,731,708.00

Overall Comparison: Results for the RM of Lorne

The previous scenario, using the agricultural land in the RM of Lorne, assumed that the RM of Lorne restored all of its arable agricultural land (65,147.48 ha) within a one-year period. This assumption is important as it illustrates the total potential for increased agricultural revenue. Agricultural land within the RM was split into four sub-models based on their varying slope categories (0-2%, 2-5%, 5-9%, 9-15%). Based on various tillage practices, slope of the land and initial topsoil depths, a thirty-year simulation was generated from the model for both the restored land and its non-restored alternative. For accurate comparison, the restored land was also compared to its non-restored equivalent in order to quantify the effect of landscape restoration on income and net revenue. The table below (Table 42) outlines the costs of restoration for the RM and compares it to its non restored equivalent.

Table 42: Overall Comparison of Scenario 3

Restoration	Non Restored	0 to 2% Slope	2 to 5% Slope	5 to 9% Slope	9 to 15% Slope	Restored Total	Rest. Vs. Non Rest.
Hectares	65,147.48	26,653.22	21,943.62	8,520.29	8,030.35	65,147.48	
Accumulated Yield (t)	598,804.96	213,472.94	471,289.70	159,638.65	335,432.57	1,179,833.86	581,028.90
Increase in yield (t)		68,492.85	290,993.31	77,178.02	144,364.72	581,028.90	
Cost of initial Restoration		$ 1,662,550.00	$ 3,790,980.00	$ 2,868,530.00	$ 3,587,780.00	$ 11,909,840.00	
Cost/ ha		$ 62.38	$ 172.76	$ 336.67	$ 446.78	$ 182.81	
Cost of Subsequent Restoration		$ 1,662,550.00	$ 2,725,490.00	$ -	$ -	$ 4,388,040.00	
Cost/ha		$ 62.38	$ 124.20	$ -	$ -	$ 186.58	
Total Cost of Restoration		$ 3,325,100.00	$ 6,516,470.00	$ 2,868,530.00	$ 3,587,780.00	$ 16,297,880.00	
Cost/ha		$ 124.75	$ 296.96	$ 336.67	$ 446.78	$ 250.17	
NPV Revenue	$ 554,864,193.00	$ 243,575,460.00	$ 211,151,930.00	$ 70,295,400.00	$ 79,420,890.00	$ 604,443,680.00	$ 49,579,487.00
NPV Expenses	$ 295,754,148.00	$ 144,011,480.00	$ 84,615,100.00	$ 55,820,148.00	$ 24,313,710.00	$ 308,760,438.00	$ 13,006,290.00
NPV	$ 259,103,045.00	$ 99,563,980.00	$ 126,536,830.00	$ 14,475,252.00	$ 55,107,180.00	$ 295,683,242.00	$ 36,580,197.00

Yield comparison

When comparing the restored and non-restored yield potential, the difference in the accumulated yield of the area reaches 581,028.90 tonnes over the thirty-year period.

Cost of restoration

The total cost related to the initial restoration of the landscape is $11.91 million and has a rough estimate cost of $182.81/ha. For the 0 to 2 per cent and 2 to 5 per cent slope sub-scenarios, subsequent restorations were performed when the topsoil depth at knolls reached the restoration trigger. The total cost for the subsequent restorations was $4.39 million, with an average cost per hectare for subsequent restoration of $186.58/ha.

The total cost of restoration for the total area restored (includes both the initial and triggered restorations) was $16.3 million or $250.17/ha. This figure represents two things: 1) the cost of restoration as well as 2) the additional work and investment in the agricultural landscape. This means that the implementation of landscape restoration in the RM of Lorne would be a direct investment into its land base.

Net Present Value (NPV)

For the net present value section, the non-restored column (Table 42) is used for comparison against the restored area. For example, NPV Revenue for the non-restored area is $553.8 million, whereas, the restored equivalent is $616.8 million. The increase in NPV revenue is of $62.9 million. The increase in revenue solely attributed to landscape restoration is an estimated $40.9 million in today's value.

Total expenses, including restoration costs and the cost of production for the cropping mix, in today's dollar is $324 million. When compared to its non-restored alternative, the restored field had increased costs of $22,000,290.00, related to initial and subsequent restorations.

The objective of this scenario was to estimate the net revenue generated by landscape restoration on a larger scale. For the RM of Lorne, the restoration process has created an additional $62,935,867 which, ideally, would be reinvested in the municipality. This investment translated to an additional return of $40,935,577 to the farmers of the RM after the initial investment is paid off over a thirty year time frame. This translates to an approximate additional return $561.50/ha over the length of the investment and can be solely attributed to the landscape restoration process.

Chapter Summary

Three scenarios were explored in this chapter. The first scenario established that net revenues will increase over time for a restored field, when compared to its non-restored equivalent. The first scenario showed both an increased yield and increased revenue over the course of the simulation. As its present value of net revenue was positive, landscape restoration was considered beneficial, and should be carried out.

The second scenario examined the relationship between cropping practices and landscape restoration. The assumption was that the more disruptive the tillage practice, the lower the generated NPV. Using the same field as a base for comparison, the only variable changed was the tillage practice used. Zero tillage and minimum tillage only required one restoration, while conservational tillage and conventional tillage required subsequent restorations to maintain the desired topsoil depth. With respect to its effect on present value of net revenue, the scenario showed that zero tillage (followed by minimum tillage, conservation tillage and conventional tillage) had the highest NPV Revenue. With respect to the portion of NPV solely generated by land restoration, the scenario showed a negative NPV for zero tillage. While the initial restoration increased yields for the zero tillage operation, the additional revenues generated by the additional topsoil did not cover costs of restoration, and tillage erosion had a lesser effect on the topsoil depth. All other types of tillage showed increased NPV attributed to land restoration.

Lastly, the third scenario explored the effect of topsoil loss and landscape restoration for the RM of Lorne. The same assumptions held true, the more conservative the tillage practice used, the lower the restoration costs and the higher the NPV at the end of the 30-year period. If the entire land base used for cropping was restored, this last scenario indicates an increase in NPV per hectare of $561.498, or an additional return of $40,935,577 to farms in the RM of Lorne due to the land restoration. The present value of net revenue is positive and the return is significant for the area. The decision to invest in landscape restoration as an RM should be considered.

Chapter 7: Conclusions and Limitations

In general, net revenue, following landscape restoration, will increase over time. Maintaining a minimum topsoil depth (25 cm) at knoll positions was shown to increase yield potential over time. The increased yields resulted in higher gross revenues than their non-restored equivalent, as well as, higher net revenue.

Maintaining the optimal yield potential is closely linked to the tillage practice in use. Tillage practices, while used for a variety of reasons, greatly affected the topsoil level on the knolls. Higher disturbance tillage practices such as conventional (0.8 mm loss/year) and conservation (0.5 mm loss/year) tillage required additional restorations to maintain a minimum topsoil level on the knolls. The tillage practices of moderate conservation, or minimum till, (0.2 mm loss/year) and zero tillage (0.05 mm loss/year) were maintain the minimum topsoil level set for knolls. This demonstrates that, if an operation is able to adopt lower disturbance tillage practices, the increase in yield and net revenue over time will be higher than that when higher disturbance tillage practices are used.

Selecting the right scraper size will also help the farm's bottom line. Selecting a scraper too small for the field being restored increases the number of passes needed to restore the area as well as time required to restore it. This translates to higher restoration costs. Selecting a scraper that is too big for the field being restored can also be inefficient and lead to its own set of problems.

On a larger scale, landscape restoration can be applied to rural municipalities experiencing topsoil loss on knolls. While it would be considered a significant investment due to the scale of land requiring restoration, scenario 3 has shown that it can lead to significantly increased yields and net revenue over the long term.

Farming operations in hummocky landscapes, experience topsoil loss at knolls and can benefit from landscape restoration. This study has demonstrated that land restoration led to positive net returns in all three of the scenarios explored. At the municipal level, landscape restoration has shown that additional revenues can be created, and that positive net returns indicate that farmers in the Rural Municipality of Lorne should consider performing landscape restoration.

While the computer model and the scenarios indicated a positive relationship between topsoil depth, yields and net revenue, this study is not without its limitations. Programming the model in STELLA ® required thinking outside of the box to in order to best describe the relationships between the variables. Many assumptions were made throughout the development of the model which while facilitated its development, had they been included would have increased the accuracy of the output. Now that the computer model simulations have proven accurate for landscape restoration and compared the results generated with non-restored equivalent, it would be suggested to expand on certain aspects of the model. Possible model expansions could include the effect of weather on yield in order to provide a more accurate representation of yield over time. In addition, allowing the variables of discount rate, crop market price, cost related to crop production and the price of fuel, to fluctuate between two set boundaries would better describe the effect of landscape restoration over time.

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Appendix 1: Model formulas

Alfalfa Establishing Costs

Alfalfa:_Establishment_Year= *Alfalfa_Est:__Labour_Costs + Alfalfa_Est:__Moving_Costs + Alfalfa_Est:_Crop_Insurance + Alfalfa_Est:_Fertilizer + Alfalfa_Est:_Herbicide + Alfalfa_Est:_Interest_on_Operating + Alfalfa_Est:_Land + Alfalfa_Est:_Land_Taxes + Alfalfa_Est:_Machinery_Depreciation + Alfalfa_Est:_Machinery_Investment + Alfalfa_Est:_Other_Costs + Alfalfa_Est:_Repair_and_Maintenance + Alfalfa_Est:_Seed_&_Treatment + Alfalfa_Est:_Storage_Depreciation + Alfalfa_Est:_Storage_Investment + Alfalfa_Est:Fuel*

Cost of Restoration Initial RENT

Total_Cost_of_restoration_for_RENTAL:_Initial = Days_to_Complete_Initial_Restoration * (Cost_per_Hour:_Renting * Total_Hours_of_Operation:_Renting)

Cost of Restoration Successive OWN

Costs_of_Subsequent_REst_OWN(t) = Costs_of_Subsequent_REst_OWN(t - dt)

Where t refers to the sum of this calculation, and (t-dt) refer to the current year's calculation

COSTS_end = *Total_Cost_of_Restoration_for_OWN:_Subsequent * Days_to_Complete_Successive_Restorations*

Pulse_of_Successive_Costs_OWN = *IF(t=0)THEN(0) ELSE ((PULSE (Total_Cost_of_Restoration_for_OWN:_Subsequent, Repeat_Restoration, Repeat_Restoration)) *Restoration)*

Total_Cost_of_Restoration_for_OWN:_Subsequent = *(Days_to_Complete_Successive_Restorations_OWN_2 * (Cost_of_Running_Own_Equipment_per_hour * Total_Running_Hours_per_Day))*

Cost of Restoring Susccessive RENT

Total_Cost_of_Restoration_for_Rental:_Subsequent = *Days_to_Complete_Successive_Restorations * (Cost_per_Hour:_Renting *Total_Hours_of_Operation:_Renting)*

Days to Restore 1

Days_to_Complete_Initial_Restoration = *Total_Area_of_Eroded_Knolls/Hectares_Restored__per_Day*

Application_Area_1_Load = *Volume_per_Scraper_Load/Application_Depth*

Application_Depth = *First_Restoration/100*

Area_Restored_per_Day = Application*_Area_1_Load*Loads_per_Day_1*

Hectares_Restored__per_Day = *Area_Restored_per_Day/10000*

Loads_per_Day_1 = *Total_Hours_of_Operation:_Renting/Time_per_Load*

Time_per_Load = *Time_to_Empty_Scraper + Time_to_Fill_Scraper_Load + Time_To__Transport_Load + Time_To__Transport_Load*

Time_To__Transport_Load *= 0.0154*

Time_to_Empty_Scraper *= (Application_Area_1_Load/Width_of_Cut)/4000*
Time_to_Fill_Scraper_Load *= (Nine_Yard_Scraper*0.0104) + (Thirteen_Yard_Scraper*0.0132) + (Seventeen_Yard_Scraper*0.0127)*

Volume_per_Scraper_Load *= (Nine_Yard_Scraper*6.881) + (Thirteen_Yard_Scraper*9.939) + (Seventeen_Yard_Scraper*13.379)*

Width_of_Cut = *(Nine_Yard_Scraper*2.172) + (Thirteen_Yard_Scraper*2.477) + (Seventeen_Yard_Scraper*2.756)*

Days to Restore 2

Days_to_Complete_Successive_Restorations *= Total_Area_of_Eroded_Knolls / Hectares_Restored__per_Day_2*

Application_Area_2 *= Volume_per_Scraper_Load_2/Application_Depth_2*

Application_Depth_2 = *(Desired_Topsoil_Depth-Restoration_Trigger)/100*

Area_Restored_per_Day_2 *= Loads_per_Day_2*Application_Area_2*

Hectares_Restored__per_Day_2 *= Area_Restored_per_Day_2/10000*

Loads_per_Day_2 = *Total_Hours_of_Operation:_Renting/Time_per_Load_2*

Time_per_Load_2 *= Time_to_Empty_Scraper_2 + Time_to_Fill_Scraper_Load_2 + Time_To__Transport_Load_2 + Time_To__Transport_Load_2*

Time_To__Transport_Load_2 *= 0.0154*

Time_to_Empty_Scraper_2 *= ((Application_Area_2/Width_of_Cut_2)/4000)*

Time_to_Fill_Scraper_Load_2 *= (Nine_Yard_Scraper*0.0104) + (Thirteen_Yard_Scraper*0.0132) + (Seventeen_Yard_Scraper*0.0127)*

Volume_per_Scraper_Load_2 *= (Nine_Yard_Scraper*6.881) + (Thirteen_Yard_Scraper*9.939) + (Seventeen_Yard_Scraper*13.379)*

Width_of_Cut_2 = *(Nine_Yard_Scraper*2.172)+(Thirteen_Yard_Scraper*2.477)+(Seventeen_Yard_Scraper*2.756)*

Days to Restore 2 OWN

Days_to_Complete_Successive_Restorations_OWN_2 = *Total_Area_of_Eroded_Knolls / Hectares_Restored_per_Day_2_OWN*

Application_Area_2_OWN = *volume_of_Scraper_Load_2_OWN/Application_Depth_OWN*

Application_Depth_OWN = (*Desired_Topsoil_Depth-Restoration_Trigger)/100*

Area_REsotred_per_day_2_own = *Application_Area_2_OWN*Loads_per_day_2_OWN*

Hectares_Restored_per_Day_2_OWN = *Area_REsotred_per_day_2_own/1000*

Loads_per_day_2_OWN *= Total_Running_Hours_per_Day/Time_per_load_2_OWN*

Time_per_load_2_OWN *= Time_to_fill_Scraper_load_2_OWN + Time_to_transport_Load_2_Own + Time_to_Empty_Scraper_2_OWN + Time_to_transport_Load_2_Own*

Time_to_Empty_Scraper_2_OWN *= (Application_Area_2_OWN/Width_of_Cut_2_OWN)/4000*

Time_to_fill_Scraper_load_2_OWN = *(Nine_Yard_Scraper*.0104) + (Thirteen_Yard_Scraper*.0132) + (Seventeen_Yard_Scraper*0.0127)*

Time_to_transport_Load_2_Own = 0.0154

volume_of_Scraper_Load_2_OWN = *(Nine_Yard_Scraper*6.88) + (Thirteen_Yard_Scraper*9.939) + (Seventeen_Yard_Scraper*13.379)*

Width_of_Cut_2_OWN = *(Nine_Yard_Scraper*2.172) + (Thirteen_Yard_Scraper*2.477) + (Seventeen_Yard_Scraper*2.756)*

Economic Sector Own

Accumulated_Costs_of_Restoration_OWN(t) *= Accumulated_Costs_of_Restoration_OWN(t - dt) + (Inflow_of_Costs_OWN) * dt*

INIT Accumulated_Costs_of_Restoration_OWN *= Inflow_of_Costs_OWN*

Inflow_of_Costs_OWN = *Frequency_of_Restoration_Costs_OWN*

Accumulated_Expenses_OWN(t) = *Accumulated_Expenses_OWN(t - dt) + (Present_Value_of_Annual_Expenses_OWN) * dt*

INIT Accumulated_Expenses_OWN = *Present_Value_of_Annual_Expenses_OWN*

Present_Value_of_Annual_Expenses_OWN = (Frequency_of_Restoration_Costs_OWN + Normal_Expenses__of_Production_OWN) * (1/((1+Discount_Rate)^t)

Costs_for_Initial_Restoration_OWN(t) = Costs_for_Initial_Restoration_OWN(t - dt) + (Initial_Rest_Costs_OWN) * dt

INIT Costs_for_Initial_Restoration_OWN = 0

Initial_Rest_Costs_OWN = Pulse_of_Initial_Costs_OWN

Costs_for_Successive_Restorations_OWN(t) = Costs_for_Successive_Restorations_OWN(t - dt) + (Successive__Rest_Costs_OWN) * dt

INIT Costs_for_Successive_Restorations_OWN = 0

Successive__Rest_Costs_OWN = Pulse_of_Successive__Costs_OWN

NPV OWN(t) = NPV OWN(t - dt) + (Present_Value_of_Annual_Revenue_OWN - Present_Value_of_Annual_Expenses_OWN) * dt

INIT NPV OWN = 0

Present_Value_of_Annual_Revenue_OWN = Total_Land * Total_Revenue_per_ha_OWN * (1/((1+Discount_Rate)^t))

Present_Value_of_Annual_Expenses_OWN = (Frequency_of_Restoration_Costs_OWN + Normal_Expenses__of_Production_OWN) * (1/((1+Discount_Rate)^t))

Annuity_Factor_OWN = IF(Discount_Rate=0) THEN(t) ELSE ((1-(1 / ((1+Discount_Rate) ^ t))) /Discount_Rate)

Annuity_OWN=IF(t=STOPTIME) THEN(Net_Revenue_at_Present_Value_OWN/Annuity_Factor_OWN) ELSE(0)

Cost_of_Restoration_OWN = IF(t<=1) THEN(Cost_to_Complete_Restoration_OWN) ELSE (Total_Cost_of_Restoration_for_OWN:_Subsequent)

Frequency_of_Restoration_Costs_OWN = (PULSE (Cost_of_Restoration_OWN, 0.5, Repeat_Restoration)) *Restoration

Normal_Expenses__of_Production_OWN = Cost_per_ha*Total_Land

Pulse_of_Initial_Costs_OWN = (PULSE(Cost_to_Complete_Restoration_OWN,0,0))*Restoration

Pulse_of_Successive__Costs_OWN = IF (TIME=0) THEN(0) ELSE((PULSE (Total_Cost_of_Restoration_for_OWN:_Subsequent,Repeat_Restoration,Repeat_Restoration))*Restoration)

Total_Revenue_per_ha_OWN *= (Depressions * Yield Index for Depressions * Crop Rotation Revenue_per_ha) + (Eroded_Knolls * Yield Index For Eroded_Knolls * Crop Rotation Revenue Revenue_per_ha) + (Non_Eroded_Land_% * Crop Rotation Revenue_per_ha)*

Economic Sector Rental

Accumulated_Costs_of_Restoration(t) *= Accumulated_Costs_of_Restoration(t - dt) + (Inflow_of_Costs) * dt*

INIT Accumulated_Costs_of_Restoration = *Inflow_of_Costs*

INFLOWS:

Inflow_of_Costs = *Frequency_of_Restoration_Costs*

Accumulated_Expenses(t) = *Accumulated_Expenses(t - dt) + (Present_Value_of_Annual_Expenses) * dt*

INIT Accumulated_Expenses = *Present_Value_of_Annual_Expenses*

INFLOWS:
Present_Value_of_Annual_Expenses *= (Frequency_of_Restoration_Costs + Normal_Expenses__of_Production) * (1/((1+Discount_Rate)^t))*

Costs_for_Initial_Restoration(t) *= Costs_for_Initial_Restoration(t - dt) + (Initial_Rest_Costs) * dt*

INIT Costs_for_Initial_Restoration = 0

INFLOWS:
Initial_Rest_Costs *= Pulse_of_Initial_Costs*

Costs_for_Successive_Restorations(t)= *Costs_for_Successive_Restorations(t - dt) + (Successive__Rest_Costs) * dt*

INIT Costs_for_Successive_Restorations = 0

INFLOWS:

Successive__Rest_Costs *= Pulse_of_Successive__Costs*

NPV RENT(t) = *NPV RENT(t - dt) + (Present_Value_of_Annual_Revenue - Present_Value_of_Annual_Expenses) * dt*

INIT Net_Revenue_at_Present_Value = 0

INFLOWS:

Present_Value_of_Annual_Revenue *= Total_Land*Total_Revenue_per_ha*(1/((1+Discount_Rate)^t))*

OUTFLOWS:

Present_Value_of_Annual_Expenses = *(Frequency_of_Restoration_Costs + Normal_Expenses__of_Production) * (1/((1+Discount_Rate)^t))*

Annuity = *IF(TIME=STOPTIME) THEN(Net_Revenue_at_Present_Value/Annuity_Factor) ELSE(0)*

Annuity_Factor *= IF(Discount_Rate=0) THEN(TIME) ELSE((1-(1/((1+Discount_Rate)^t)))/Discount_Rate)*

Cost_of_Restoration *= IF(t<=1) THEN(Total_Cost_of_restoration_for_RENTAL:_Initial) ELSE (Total_Cost_of_Restoration_for_Rental:_Subsequent)*

Frequency_of_Restoration_Costs = *(PULSE(Cost_of_Restoration,0.5,Repeat_Restoration))*Restoration*

Normal_Expenses__of_Production = *Cost_per_ha*Total_Land*

Pulse_of_Initial_Costs *= (PULSE(Total_Cost_of_restoration_for_RENTAL:_Initial,0,0))*Restoration*

Pulse_of_Successive__Costs *= IF (t=0) THEN(0) ELSE ((PULSE (Total_Cost_of_Restoration_for_Rental:_Subsequent ,Repeat_Restoration, Repeat_Restoration))*Restoration)*

Total_Revenue_per_ha *= (Depressions * Yield Index for Depression * Crop Rotation_Revenue_per_ha) + (Eroded_Knolls * Yield_Index_for__Eroded_Knoll * Crop Rotation_Revenue_per_ha) + (Non_Eroded_Land_%*Crop Rotation_Revenue_per_ha)*

Fixed Costs $ per Hectare

Alfalfa:_Fixed_Costs *= Alfalfa:_Land_Investment_Costs + Alfalfa:_Machinery_Depreciation + Alfalfa:_Machinery_Investment + Alfalfa:_Storage_Costs*

Barley:*_Land_Investment_Costs+Barley:_Machinery_Depreciation+Barley:_Machinery_Investment+Barley:_ Storage_Costs*

Canola:_Fixed_Costs = *Canola:_Land_Investment_Costs + Canola:_Machinery_Depreciation + Canola:_Machinery_Investment + Canola:_Storage_Costs*

Corn:__Fixed_Costs *= Corn:_Land_Investment_Costs + Corn:_Machinery_Depreciation + Corn:_Machinery_Investment + Corn:_Storage_Costs*

Flax:_Fixed_Costs *= Flax:_Land_Investment_Costs + Flax:_Machinery_Depreciation + Flax:_Machinery_Investment + Flax:_Storage_Costs*

Legume:_Fixed_Costs = *Legume:_Land_Investment_Costs + Legume:_Machinery_Depreciation + Legume:_Machinery_Investment + Legume:_Storage_Costs*

Other:_Fixed_Costs *= Other:_Land_Investment_Costs + Other:_Machinery_Depreciation + Other:_Machinery_Investment + Other:_Storage_Costs*

Pea:_Fixed_Costs = *Pea:_Land_Investment_Costs + Pea:_Machinery_Depreciation + Pea:_Machinery_Investment + Pea:_Storage_Costs*

Potato:_Fixed_Costs = *Potato:_Land_Investment_Costs + Potato:_Machinery_Depreciation + Potato:_Machinery_Investment + Potato:_Storage_Costs*

Soybean:Fixed_Costs = *Soybean:_Land_Investment_Costs + Soybean:_Machinery_Depreciation + Soybean:_Machinery_Investment + Soybean:_Storage_Costs*

Wheat:_Fixed_Costs = *Wheat:_Land_Investment_Costs + Wheat:_Machinery_Depreciation + Wheat:_Machinery_Investment + Wheat:_Storage_Costs*

Initial Restoration Costs Own

UNATTACHED:
Days_to_Complete_Initial_Restoration_OWN = *Total_Area_of_Eroded_Knolls / Hectares_Restored_per_Day_OWN*

Application_Area_1_Load_Own = *Volume__of_Scraper_Load_per_Load/Application_Depth*

Area_Restored_per_Day_OWN = *Application_Area_1_Load_Own*Loads_per_day_OWN*

Cost_of_Running_Equipment_per_Day_OWN = *Cost_of_Running_Own_Equipment_per_hour * Total_Running_Hours_per_Day*

Cost_of_Running_Own_Equipment_per_hour = *Scraper:_Depreciation + Scraper:_Repair_Costs + Tractor:_Total_Cost*

Cost_to_Complete_Restoration_OWN = *Days_to_Complete_Initial_Restoration_OWN * Cost_of_Running_Equipment_per_Day_OWN*

Hectares_Restored_per_Day_OWN = *Area_Restored_per_Day_OWN/10000*

Loads_per_day_OWN = *Total_Running_Hours_per_Day/Time_per_Load*

Volume__of_Scraper_Load_per_Load = *(Nine_Yard_Scraper*6.881) + (Seventeen_Yard_Scraper*13.379) + (Thirteen_Yard_Scraper*9.939)*

Num Crops

Num_Crops = *Alfalfa_Rotation + Barley_Rotation + Canola_Rotation + Corn_Rotation + Flax_Rotation + Legume_Rotation + Other_Rotation + Pea_Rotation + Potato_Rotation + Wheat_Rotation + Soybean_Rotation*

Operating Costs

Alfalfa:_Operating_Costs = *Alfalfa:_Crop_Insurance + Alfalfa:_Fertilizer + Alfalfa:_Fuel + Alfalfa:_Interest_on_Operating + Alfalfa:_Land_Taxes + Alfalfa:_Machinery_Operating + Alfalfa:_Moving_Costs + Alfalfa:_Other_Costs*

Barley:_Operating_Costs = *Barley:_Crop_Insurance + Barley:_Drying_Costs + Barley:_Fertilizer + Barley:_Fuel + Barley:_Fungicide + Barley:_Herbicide + Barley:_Insecticide + Barley:_Interest_on_Operating + Barley:_Land_Taxes + Barley:_Machinery_Operating + Barley:_Other_Costs + Barley:_Seed_&_Treatment*

Canola:_Operating_Costs = *Canola:_Crop_Insurance + Canola:_Drying_Costs + Canola:_Fertilizer + Canola:_Fuel + Canola:_Fungicide + Canola:_Insecticide + Canola:_Interest_on_Operating + Canola:_Land_Taxes + Canola:_Machinery_Operating + Canola:_Other_Costs + Canola:_Seed_&_Treatment + Canola:Herbicide*

Corn:_Operating_Costs = *Corn:_Crop_Insurance + Corn:_Fertilizer + Corn:_Fuel+Corn:_Fungicide + Corn:_Herbicide + Corn:_Insecticide + Corn:_Interest_on_Operating + Corn:_Land_Taxes + Corn:_Machinery_Operating + Corn:_Other_Costs + Corn:_Seed_&_Treatment + Corn:_Drying_costs*

Flax:_Operating_Costs = *Flax:_Crop_Insurance + Flax:_Drying_Costs + Flax:_Fertilizer + Flax:_Fuel + Flax:_Fungicide + Flax:_Herbicide + Flax:_Insecticide + Flax:_Interest_on_Operating + Flax:_Land_Taxes + Flax:_Machinery_Operating + Flax:_Other_Costs + Flax:_Seed_&_Treatment*

Legume:_Operating_Costs = *Legume:_Other_Costs + Legume:_Machinery_Operating + Legume:_Interest_on_Operating + Legume:_Insecticide + Legume:_Fungicide + Legume:_Herbicide + Legume:_Fuel + Legume:_Fertilizer + Legume:_Drying_Costs + Legume:_Crop_Insurance + Legume:_Land_Taxes + Legume:_Seed_&_Treatment*

Other:_Operating_Costs = *Other:_Crop_Insurance + Other:_Drying_Costs + Other:_Fertilizer + Other:_Fuel + Other:_Fungicide + Other:_Herbicide + Other:_Insecticide + Other:_Interest_on_Operating + Other:_Land_Taxes + Other:_Machinery_Operating + Other:_Other_Costs + Other:_Seed_&_Treatment*

Pea:_Operating_Costs = *Pea:_Crop_Insurance + Pea:_Drying_Costs + Pea:_Fertilizer + Pea:_Fuel + Pea:_Fungicide + Pea:_Herbicide + Pea:_Insecticide + Pea:_Interest_on_Operating + Pea:_Land_Taxes + Pea:_Machinery_Operating + Pea:_Seed_&_Treatment + Pea:_Other_Costs*

Potato:_Operating_Costs = *Potato:_Crop_Insurance + Potato:_Fertilizer + Potato:_Fuel + Potato:_Fungicide + Potato:_Herbicide + Potato:_Insecticide + Potato:_Interest_on_Operating + Potato:_Irrigation_Costs + Potato:_Land_Taxes + Potato:_Machinery_Operating + Potato:_Other_Costs + Potato:_Seed_&_Treatment*

Soybean:_Operating_Costs = *Soybean:_Crop_Insurance + Soybean:_Drying_Costs + Soybean:_Fertilizer + Soybean:_Fuel + Soybean:_Fungicide + Soybean:_Herbicide + Soybean:_Insecticide + Soybean:_Interest_on_Operating + Soybean:_Land_Taxes + Soybean:_Machinery_Operating + Soybean:_Other_Costs + Soybean:_Seed_&_Treatment*

Wheat:_Operating_Costs = *Wheat:_Crop_Insurance + Wheat:_Drying_costs + Wheat:_Fertilizer + Wheat:_Fuel + Wheat:_Fungicide + Wheat:_Herbicide + Wheat:_Insecticide + Wheat:_Interest_on_Operating + Wheat:_Land_Taxes + Wheat:_Machinery_Operating + Wheat:_Other_Costs + Wheat:_Seed_&_Treatment*

Revenue per crop

Alfalfa_Revenue/%ha *= (Alfalfa_Rotation/Num_Crops)*Alfalfa_Yield*Price_of_Alfalfa*

Barley__Revenue/%ha *= (Barley_Rotation/Num_Crops)*Barley_Yield*Price_of_Barley*

Canola_Revenue/%ha *= (Canola_Rotation/Num_Crops)*Canola_Yield*Price_of_Canola*

Corn_Revenue/%ha *= (Corn_Rotation/Num_Crops)*Corn_Yield*Price_of_Corn*

Flax_Revenue/%ha*= (Flax_Rotation/Num_Crops)*Flax_Yield*Price_of_Flax*

Legume_Revenue/%ha *= (Legume_Rotation/Num_Crops)*Legume_Yield*Price_of_Legume*

Other_Revenue/%ha*= (Other_Rotation/Num_Crops)*Other_Yield*Price_of_Other*

Pea_Revenue/%ha *= (Pea_Rotation/Num_Crops)*Pea_Yield*Price_of_Pea*

Potato_Revenue/%ha *= (Potato_Rotation/Num_Crops)*Potato_Yield*Price_of_Potato*

Crop Revenue_per_ha *= (Alfalfa_Revenue/%ha + Barley__Revenue/%ha + Canola_Revenue/%ha + Corn_Revenue/%ha + Flax_Revenue/%ha + Legume_Revenue/%ha + Other_Revenue/%ha + Pea_Revenue/%ha + Potato_Revenue/%ha + Wheat_Revenue/%ha + Soybean__Revenue/%ha)*

Soybean__Revenue*/%ha = (Soybean_Rotation/Num_Crops)*Soybean_Yield*Price_of_Soybean*

Wheat_Revenue*/%ha* = *(Wheat_Rotation/Num_Crops)*Wheat_Yield*Price_of_Wheat*

Yield Index per ha

Yield Index per ha *= ((Alfalfa_Yield * Alfalfa_Rotation) + (Barley_Yield * Barley_Rotation) + (Canola_Yield * Canola_Rotation) + (Corn_Yield * Corn_Rotation) + (Flax_Yield * Flax_Rotation) + (Legume_Yield * Legume_Rotation) + (Other_Yield * Other_Rotation) + (Pea_Yield * Pea_Rotation) + (Potato_Yield * Potato_Rotation) + (Wheat_Yield * Wheat_Rotation) + (Soybean_Yield * Soybean_Rotation)) /Num_Crops*

Owning Scraper Costs

Scraper:_Depreciation *= ((Scraper:_Purchase_Price -Scraper:_Salvage_Value) / Scraper:_Expected_Life) / Scraper:_Annual_Use*

Scraper:_Repair_Costs *= (((Scraper:_Purchase_Price * Scraper:_Repair_Cost_Factor) / Scraper:_Expected_Life) / Scraper:_Annual_Use)*

Scraper:_Salvage_Value *= Scraper:_Purchase_Price*.10*

Tractor:_Depreciation *= ((Tractor:_Purchase_Price - Tractor:_Salvage_Value) / Tractor:_Expected_Life) / Tractor:_Annual_Use*

Tractor:_Fixed_Costs *= Tractor:_Depreciation*

Tractor:_Fuel_Cost *= Price_of_Gas_per_Litre*Tractor:_Gas_Consumption_per_Hour*

Tractor:_Operating_Costs *= Tractor:_Fuel_Cost + Tractor_Repair_Costs + Labour_Cost*

Tractor:_Salvage_Value *= Tractor:_Purchase_Price*0.10*

Tractor:_Total_Cost *= Tractor:_Fixed_Costs+Tractor:_Operating_Costs*

Tractor_Repair_Costs *= ((Tractor:_Purchase_Price * Tractor:_Repair_Cost_Factor) / Tractor:_Expected_Life) / Tractor:_Annual_Use*

Cost per ha

Cost_per_ha *= ((Alfalfa_Costs * Alfalfa_Rotation) + (Barley_Costs * Barley_Rotation) + (Canola_Costs * Canola_Rotation) + (Corn_Costs * Corn_Rotation) + (Flax_Costs * Flax_Rotation) + (Legume_Costs * Legume_Rotation) + (Other_Costs * Other_Rotation) + (Pea_Costs * Pea_Rotation) + (Potato_Costs * Potato_Rotation) + (Wheat_Costs * Wheat_Rotation) + (Soybean_Costs * Soybean_Rotation)) /Num_Crops*

Topsoil Depths Sector

Lost_Topsoil(t) = *Lost_Topsoil(t - dt) + (Non_Recoverable_Topsoil) * dt*

INIT Lost_Topsoil *= Rate_of__Erosion_off_the_field*

INFLOWS:

Non_Recoverable_Topsoil *= Rate_of__Erosion_off_the_field*

Topsoil_Depth_on_Depressions(t) *= Topsoil_Depth_on_Depressions(t - dt) + (Accumulating__Topsoil - Topsoil_Removed_for_Restoration) * dt*

INFLOWS:

Accumulating__Topsoil *= Conversion___from_Knolls__to_Depressions*Rate_of_Erosion_to_Depressions*

OUTFLOWS:

Topsoil_Removed_for_Restoration *= PULSE (Varrying_Amount_of_Topsoil_Moved, 0 , Repeat_Restoration) * Restoration*

Topsoil_Depth_on_Eroded_Knolls(t) *= Topsoil_Depth_on_Eroded_Knolls (t - dt) + (Land_Restoration - Erosion) * dt*

INFLOWS:

Land_Restoration *= Topsoil_Removed_for_Restoration/Conversion___from_Knolls__to_Depressions*

OUTFLOWS:

Erosion = *Rate_of__Erosion_off_the_field+Rate_of_Erosion_to_Depressions*

Conversion___from_Knolls__to_Depressions = *Eroded_Knolls / Depressions*

Repeat_Restoration = *IF(Topsoil_Depth_on_Eroded_Knolls <= Restoration_Trigger) THEN(t) ELSE(0)*

Varrying_Amount_of_Topsoil_Moved = *IF (t=0) THEN (First_Restoration * Conversion___from_Knolls__to_Depressions) ELSE ((Desired_Topsoil_Depth -Restoration_Trigger) * Conversion___from_Knolls__to_Depressions)*

Total Costs $ per hectare

Alfalfa_Costs = *Alfalfa:_Establishment_Year + ((Alfalfa_Rotation -1) * (Alfalfa:_Fixed_Costs + Alfalfa:_Labour_Costs + Alfalfa:_Operating_Costs))*

Barley_Costs = *Barley:_Fixed_Costs+Barley:_Labour_Costs+Barley:_Operating_Costs*

Canola_Costs = *Canola:_Fixed_Costs + Canola:_Operating_Costs + Canola:Labour_Costs*

Corn_Costs = *Corn:__Fixed_Costs + Corn:_Labour_Costs + Corn:_Operating_Costs*

Flax_Costs = *Flax:_Fixed_Costs + Flax:_Labour_Costs + Flax:_Operating_Costs*

Legume_Costs = *Legume:_Fixed_Costs + Legume:_Labour_Costs + Legume:_Operating_Costs*

Other_Costs = *Other:_Fixed_Costs + Other:_Labour_Costs + Other:_Operating_Costs*

Pea_Costs = *Pea:_Fixed_Costs + Pea:_Labour_Costs + Pea:_Operating_Costs*

Potato_Costs = *Potato:_Fixed_Costs + Potato:_Labour_Costs + Potato:_Operating_Costs*

Soybean_Costs = *Soybean:Labour_Costs + Soybean:_Operating_Costs + Soybean:Fixed_Costs*

Wheat_Costs = *Wheat:_Fixed_Costs + Wheat:_Labour_Costs + Wheat:_Operating_Costs*

Yield Sector

Accumulated_Yield(t) = *Accumulated_Yield(t - dt) + (Annual_Yield) * dt*

INIT Accumulated_Yield = 0

INFLOWS:

Annual_Yield = *Annual_Yield_on_Depressions + Annual_Yield_on_Eroded_Knolls + Yield_on_Non_Eroded_Land*

Annual_Yield_on_Depressions *= Yield Index forDepression* Total_Area_of_Depressions * Crop Rotation_Yield_per_ha*

Annual_Yield_on_Eroded_Knolls *= Total_Area_of_Eroded_Knolls * Yield Index for Eroded_Knolls_% * Crop Rotation Yield per ha*

Depressions *= Removal_Area / 100*

Eroded_Knolls *= Application_Area / 100*

Non_Eroded_Land *= Total_Land * Non_Eroded_Land_%*

Non_Eroded_Land_% *= 1 - (Depressions + Eroded_Knolls)*

Total_Area_of_Depressions *= Depressions * Total_Land*

Total_Area_of_Eroded_Knolls *= Eroded_Knolls * Total_Land*

Yield_on_Non_Eroded_Land = *Non_Eroded_Land * Optimum_Yield_per_ha*

Yield_per_ha_on_Depressions *= Annual_Yield_on_Depressions / Total_Area_of_Depressions*

Yield_per_ha_on_Eroded_Knolls *= Annual_Yield_on_Eroded_Knolls / Total_Area_of_Eroded_Knolls*

Yield_per_ha_on_Non_Eroded_Land *= Yield_on_Non_Eroded_Land / Non_Eroded_Land*

Removed_Soil_Productivity = 7