IRRIGATION, WATER FLOWS AND IMPACTS TO FARM-LEVEL ECONOMICS IN THE ASSINIBOINE DELTA AQUIFER

BY

IAN D. PROVEN

A Thesis Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

Department of Agribusiness & Agricultural Economics
University of Manitoba
Winnipeg, Manitoba

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IRRIGATION, WATER FLOWS AND IMPACTS TO FARM-LEVEL ECONOMICS IN THE ASSINIBOINE DELTA AQUIFER

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ABSTRACT

As populations increase, human, municipal, industrial and agricultural demands on water increase. It is imperative that legislation, management plans and efficient allocation plans be prepared that satisfy the needs of all stakeholders. Manitoba has long been a province with abundant fresh water resources. Only recently have the demands of multiple stakeholder groups put pressure on the available water, particularly in the Assiniboine Delta Aquifer (ADA) area. Potato growers in the ADA rely on the water in the aquifer as a source of irrigation water. Demands of local processors have increased the demand for irrigated potato acres in the area. The current water allocation rules limit the amount of available water to be used for irrigation, despite the large potential economic benefits of irrigated potatoes.

This research examines three types of analyses to study the economic impact of water for irrigated potatoes in the ADA area: a simulation of the water balance in the ADA; a simulation of the water-yield-revenue relationship; and an on-farm capital, financial and economic valuation analysis. The combination of these three analyses provides insight into the possible availability of water for irrigation in the ADA and the economic value of the irrigated potato acres.

Results of the water balance simulation suggest that the ADA has excess water capacity in normal and wet years that could be allocated to irrigators. In dry years, the allocation needs to be carefully managed, but the down-draw of the aquifer is minimal and rebounds quickly. Measured as EBITDA, the economic potential of the existing irrigated acres EBITDA ranges between 10 and 38 million dollars, and on-farm benefit-cost ratios and IRR confirm that potato farming is an excellent agricultural investment.

ACKNOWLEDGEMENTS

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CHAPTER 1. INTRODUCTION

1.1 Introduction

As global, national and provincial populations expand, fresh water becomes an increasingly valuable resource. Governments, populations and stakeholders must work to ensure that the water is appropriately allocated, yet remains clean, sustainable and available. It has been said that "Water is the oil of the 21st century," and is a precious resource that requires careful management, protection and care.

The province of Manitoba benefits from a large volume of fresh water that is available from renewable sources. Southern Manitoba has large areas of fertile farmland that produce high-value crops with irrigation support. There is also a large livestock sector that requires potable fresh water. There are several fresh water bodies that supply southern Manitoba's domestic, agricultural, industrial, environmental and recreational needs. The main sources are:

1. Shoal Lake, Ontario (Supplies the City of Winnipeg)
2. Red River
3. Assiniboine River
4. Winkler Aquifer
5. Assiniboine Delta Aquifer (ADA)
6. Oak Lake Aquifer
7. Souris River

8. Pembina River

Each of these river and aquifer systems is supplied primarily by annual rainfall and snowmelt.

Only within the last ten to twenty years has the value of Manitoba's water supply been recognized. There are fresh water pressures in many areas of the United States and Canada that have not been a problem in Manitoba. As populations increase, there is always a need to examine the effect of the increase on limited resources to ensure that they are properly managed. This is particularly the case with Manitoba's water, as management plans and legislation needs to be kept current to ensure that water remains available and prioritized for all end-users.

As water and population pressures mount in other areas, Manitoba is becoming recognized as a strategic location for industry. This is in part due to the availability of water, fertile land, raw materials, proximity to large U.S. markets, strong transportation infrastructure (highway, rail and air), and the low cost of the Canadian-made goods relative to the U.S. dollar.

J.R. Simplot is taking advantage of opportunities in Manitoba by building a new potato processing plant in Portage La Prairie, Manitoba. The new plant has a potato processing capacity that will initially require 20,000 new acres of potatoes, expanding to 50,000 acres within the next ten years (J.R. Simplot Company website, 2002). As there are currently 33,500 acres (Manitoba Conservation, 2001b) of irrigated potato acres in Manitoba, these additional irrigated potato acres represent an increase of 60% to 150%. Given these increased potato demands, there will be opportunities for existing potato farmers in these areas to increase their potato production to support demand of the new plant and for new farmers to begin growing potatoes. The new plant will require water for the processing of potatoes into french fries. The expanded potato acreage will require new sources of irrigation water to produce potatoes for the plant.

In Manitoba there is sufficient rain to grow potatoes, but not to the size and quality required by processors. Farmers are forced to irrigate potatoes to produce a marketable crop (Manitoba Agriculture and Food, 2001). Based on research by Shaykewich et al (2002), Russet Burbank potatoes require 14 inches of combined precipitation and irrigation to maximize yield. The average annual precipitation ranges between 13 and 15 inches during the growing season (Manitoba Water Stewardship, 2005). Based on averages, Manitoba has sufficient rainfall to grow potatoes. However, due to the variability of the annual rainfall, potatoes may require a large amount of water (potentially 6 inches per acre if the in-season rainfall is reduced to 8 inches, or if the rainfall is not spread appropriately throughout the growing season) to produce a marketable crop. Currently there is sufficient irrigation water to support the potato growers for the existing acres, given "normal" amounts of rainfall, and normal amounts of water in the aquifers and river systems. Research indicates that the additional irrigated acreage required for the new plant is available from several areas (Manitoba Agriculture and Food, 2001), notably:

- Treherne/Glenboro area
- Crystal City area
- Portage la Prairie area
- Carberry area
- Hartney area
- Wet sands area

One important area that will provide increased potato production is area around the Carberry area, specifically the farmland over the ADA. This area has soil in which potatoes grow well and a large availability of fresh water from the Assiniboine River (AR) and from the ADA.

Table 1 shows the relative importance of the AR and ADA to the province in terms of water supply. Together these two bodies of water supply 76% of the water in Manitoba for the area west of the Red River and south of Lake Manitoba and Riding Mountain National Park. The importance of the AR/ADA cannot be overstated.

Table 1 – Sources of Water in South-Western Manitoba

Sources of Water	Annual Sustainable Water Supply (acre-feet)	%
Assiniboine River	110,000	30.3
Assiniboine Delta Aquifer	166,000	45.7
Whitemud River and tributaries	21,000	5.8
Agassiz Irrigation area streams	20,000	5.5
Souris River	17,500	4.8
Oak Lake Aquifer	15,000	4.1
Pembina River and tributaries	14,000	3.9
Total	**363,500**	**100.0**

Source: Bodnaruk, 2001

1.2 Current Water Allocation Policy and Licensing

Water for irrigation is carefully controlled. The Manitoba Water Licensing branch monitors licensed water outflow in the ADA and allocates licenses to ensure that there is adequate downstream flows and local water availability. The levels of the water in the aquifer and river are monitored by Manitoba Department of Conservation.

Licenses to use Manitoba's water are provided by the Department of Conservation Water Branch under the Water Rights Act (Government of Manitoba, 2003). Licenses are issued based on several criteria:

1) Water is available for allocation, based on the Water Branch's rules of allocating only 50% of sustainable flow
2) Water licensing may be subject to other regulatory approvals (Environment)
3) Conservation Districts provide input to the Department of Conservation regarding local priorities of use and allocation of water. The Conservation District boards

examine the impact of all local stakeholders when new water license applications are received

4) The Act sets the order of priority for which water may be used:

    a. Domestic purposes
    b. Municipal purposes;
    c. Agricultural purposes;
    d. Industrial purposes;
    e. Irrigation purposes;
    f. Other purposes.

5) The "First-in-time, first-in-right" rule applies to claims over the same parcel of water

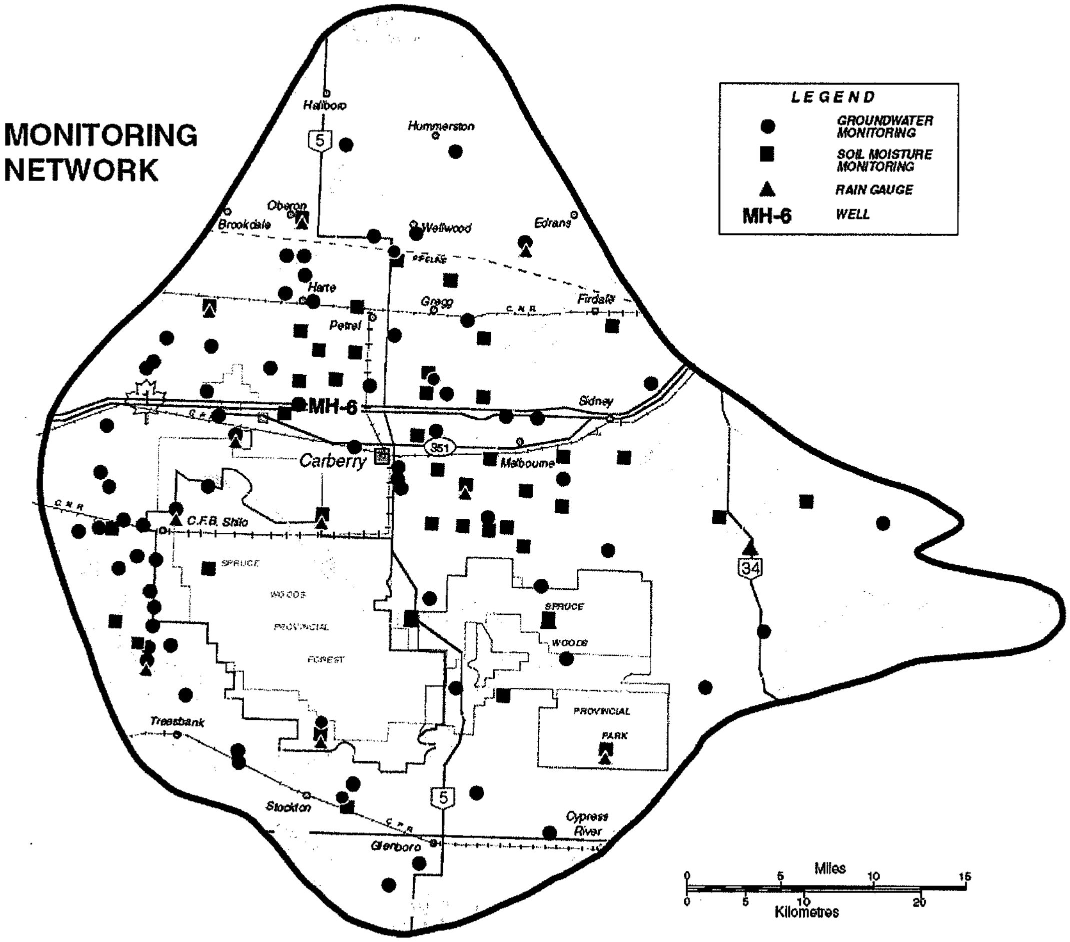
1.3 Research Opportunities

In spite of the licensing and monitoring processes in place, and despite the large volume of research done on the ADA, there still remains a huge number of research areas requiring attention to ensure the long-term viability of southern Manitoba's fresh water supplies. The following sections outline topic areas in which research is required.

1.3.1. Measurement of Flows

As shown in Figure 1 there are several water-level monitoring stations in the ADA (Manitoba Water Stewardship, 2005), however there are relatively few stations monitoring outflows. Kelln (2002) shows outflows from Pine Creek and Oak Creek that are considered "representative" for the region. There is research required to understand whether the existing system of measuring ADA inflows and outflows is adequate, based on the value of the ADA's water. If the current measurement of flows is inadequate, what is the best method of measuring the water flows? What does the model of inflows and outflows from the ADA look like? How does the ADA interact with the fresh water flows from the rest of southern Manitoba? These research opportunities offer a detailed look at the functioning the ADA as a dynamic system.

Figure 1 - Assiniboine Delta Aquifer Monitoring Network



Source: Assiniboine Delta Aquifer Management Plan, May 2005

1.3.2. Management Plan Impact

The literature review in Chapter 2 more fully reviews the Aquifer Management Plan that has been developed by Manitoba Water Stewardship (2005). Despite the time and effort of bringing together all the stakeholders from the ADA area, lingering questions remain. Does the current aquifer management plan address all the issues within the ADA? What is the economic impact of the management plan's alternatives? How are the suggested actions in the management plan going to get enacted, measured and managed? It would be a very interesting exercise to follow-up on the suggestions of the management plan and measure its success a few years in the future, once stakeholders and policy makers can digest and put into action the management plan's recommendations.

1.3.3. Irrigation Impacts

There are many impacts as a result of irrigating potato crops in the ADA. As quantified by Kulthreshtha (1994) and Kulthreshtha and Grant (2002), there are local, regional and provincial economic impacts of using the water to irrigate potatoes. Does increased irrigation make economic sense, relative to other Gross Domestic Product (GDP) opportunities with the water? Local farmers, based on first-in-time, first-in-right have claim to the water, but is irrigation really the most productive use for the water?

There are downstream impacts of using and not using the water for irrigation. What is the downstream impact of increased irrigation in the ADA area? Are the downstream flows in Portage La Prairie, Headingley, Winnipeg and the La Salle River diversion appropriately considered during wet and dry years, based on the irrigation withdrawals from the entire water-flow system?

Is the definition of water risk appropriate? Currently in the ADA it is defined as "1 year in 10 years the crop will require 6-8" or more of water." (Manitoba Agriculture and Food. 2001) What happens in multiple drought years? Will the existing water management and irrigation management plan be sustainable during multiple drought years?

1.3.4. Policy Frameworks

There are research opportunities within the policy structure of the national and provincial water monitoring and legislation authorities. MacMillan et al. (2002) mention several research, planning, policy, pricing and sustainable development issues to be resolved in addition to the list compiled above. Their report demonstrates that there is a lack of policy, management plans and proper economic analysis of many of the water issues in Manitoba. Some of the questions raised by MacMillan et al. (2002) include: is the current method of water licensing the appropriate institutional arrangement to distribute the water in the ADA? Can a market mechanism be established to facilitate exchange for water use rights between license holders? Can water license transfers be decoupled from land ownership? Can pricing/conservation/metering strategies be initiated to recover water investment costs? In order to evaluate these alternatives, what criteria and other information do legislators and policy-makers require to make informed water allocation decisions?

Several bureaucratic agencies are doing preliminary research into planning, policy and legislative issues around Manitoba's fresh water supply. However, the urgency at which the issues are being addressed is of concern. Drought, flooding, environmental disaster or lost economic opportunities might force stakeholders into decisions before adequate planning and research can be completed. Continued research is required to ensure the best results for all stakeholders and the best return for Manitoba's fresh water supplies.

1.4 Objectives of the Study

1.4.1 Specific Areas of Research

The focus of this study is to create simulation model scenarios and calculate on-farm economic values to enable farm-based decision making and policy analysis. Specifically:

A) Create a simulation model of the flows of water in the ADA (i.e. construct the water balance), and research the effects of increased irrigation as a function of variable inflows and outflows

B) Relate those water flows from the ADA as irrigation, converted to potato-based revenue for the farmer

C) Evaluate the economic and financial profile of a potato farm in the ADA, expressed as EBITDA

These analyses will allow different water availability, potato price and yield scenarios to be considered in the context of farm-based irrigation investment decisions that focus on expansion of irrigated acres within the ADA.

1.4.2 General Benefits of the Research

In addition to the specific benefits of the research, there are also several generalized benefits of the research and modeling process. First, the process of building and analyzing models permits researchers and policy makers to understand the impact of decisions before they are applied in the real world. The models can be constructed to devise best-case and worst-case scenarios that are otherwise difficult to encounter in real situations. Second, models are a proactive method of analysis that can help estimate the scope and impact of future problems rather than requiring post-crisis reaction. Understanding the best-case and worst-case scenarios can allow policy makers and stakeholders to make more effective decisions about the aquifer's resources. Third, the models provide constructive, objective action items that will promote the development of the irrigated potato acres with positive economic benefit locally and regionally.

1.5 Limitation of Scope

The irrigation, conservation, prioritization and economic issues with respect to the ADA are enormous in scope. It is not the intention of this study to address all of them, nor is it the purpose of this study to demonstrate expertise in understanding of all the water flow issues within the ADA. This study merely demonstrates a method for tying simulation modeling with economic analysis for the benefit of creating an effective evaluation framework for the ADA's potato acreage.

1.6 Economic Impacts of the Analysis

This research has local, regional, provincial, national and international impact. The economic impact of irrigated acres has been quantified by Kulshreshtha and Grant (2002), Kulshreshtha (1994), and is addressed again in this study.

1.6.1 Local Impact

The impact of increased potato acreage in the Carberry/North Cypress area will increase local revenues for farmers, labourers that the farmers employ and local businesses who supply irrigation implements and crop supplies and inputs.

1.6.2 Regional Impact

The producers provide additional raw materials for potato producers (J.R. Simplot and McCain Foods). The potato plants hire local and regional workers and utilize transportation and infrastructure services within the region.

1.6.3 Provincial Impact

The increased sales of the processed potato products will provide economic opportunities to business that support the potato processors (trucking, bags/boxes, vegetable oils inputs, etc). Also, the research will provide policy and legislative frameworks to allocate water to the "best" economic opportunity within the province.

1.6.4 National & International Impact

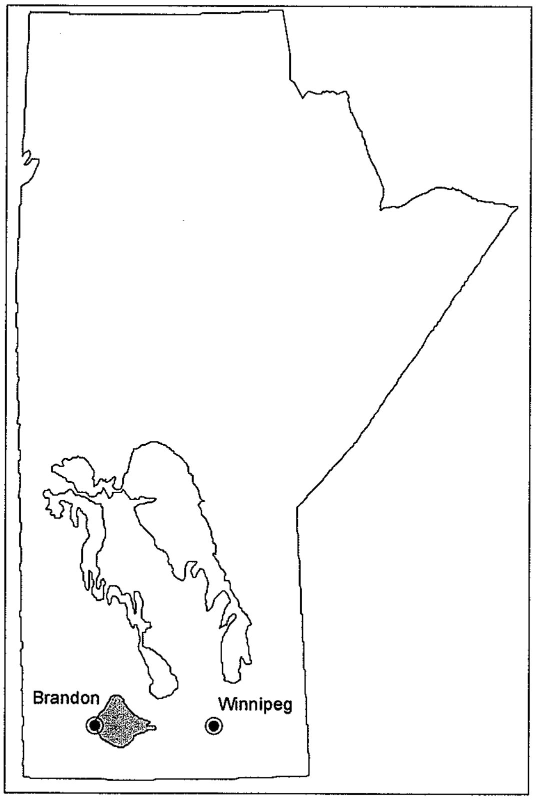
National and International impact analysis provides building blocks to understand the value of managing fresh water in a nation and world that is beginning to see that fresh water management is becoming an increasingly serious issue. This research framework helps legislators, researchers, industry, conservation and farmers understand the relative positioning of their needs and wants within a "big picture" context.

CHAPTER 2. ASSINIBOINE DELTA AQUIFER – BACKGROUND INFORMATION

2.1 Physical Location of the Assiniboine Delta Aquifer

As shown in Figure 2, the ADA is located in the south-western corner of the province of Manitoba, Canada between Brandon and Winnipeg. The ADA is a sand and gravel unconfined aquifer that is 1500 mi^2 in area centered around Carberry, Manitoba. The aquifer is roughly pear shaped, and includes within its boundaries Carberry, Shilo, Wellwood, Sidney, Spruce Woods Provincial Park and Spruce Woods Provincial Forest.

Figure 2 – Location of the Assiniboine Delta Aquifer

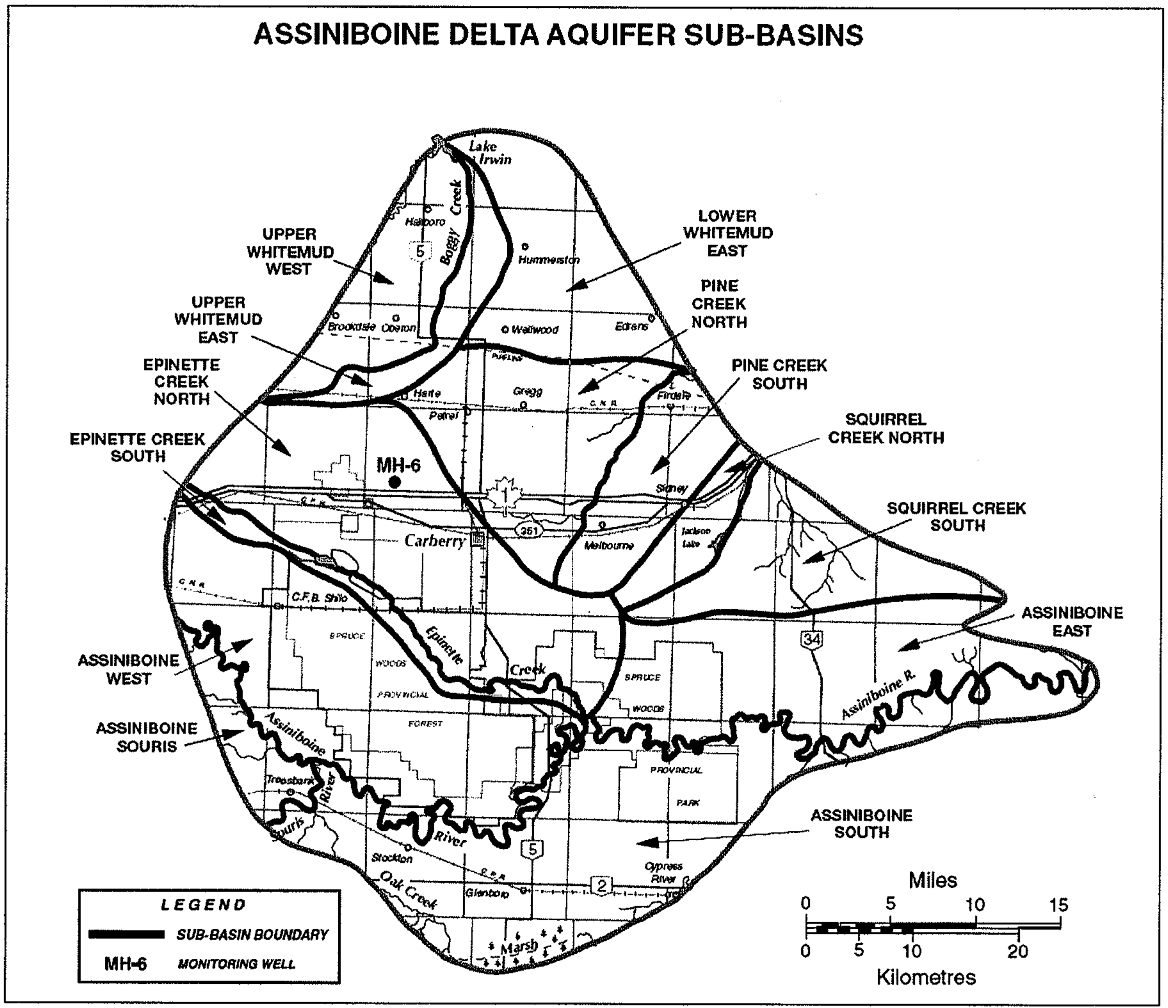


Source: Created by Author

2.2 Physical Characteristics of the ADA

Figure 3 shows the location and size of the ADA and its sub-basins. There are 13 sub-basins that make up the aquifer. Two regional waterways are within the boundaries of the ADA: the Assiniboine River and the termination of the Souris River, where it joins with the Assiniboine River near the village of Treesbank. Also within the aquifer are local waterways: Boggy Creek, Squirrel Creek, Pine Creek, Epinette Creek and Oak Creek.

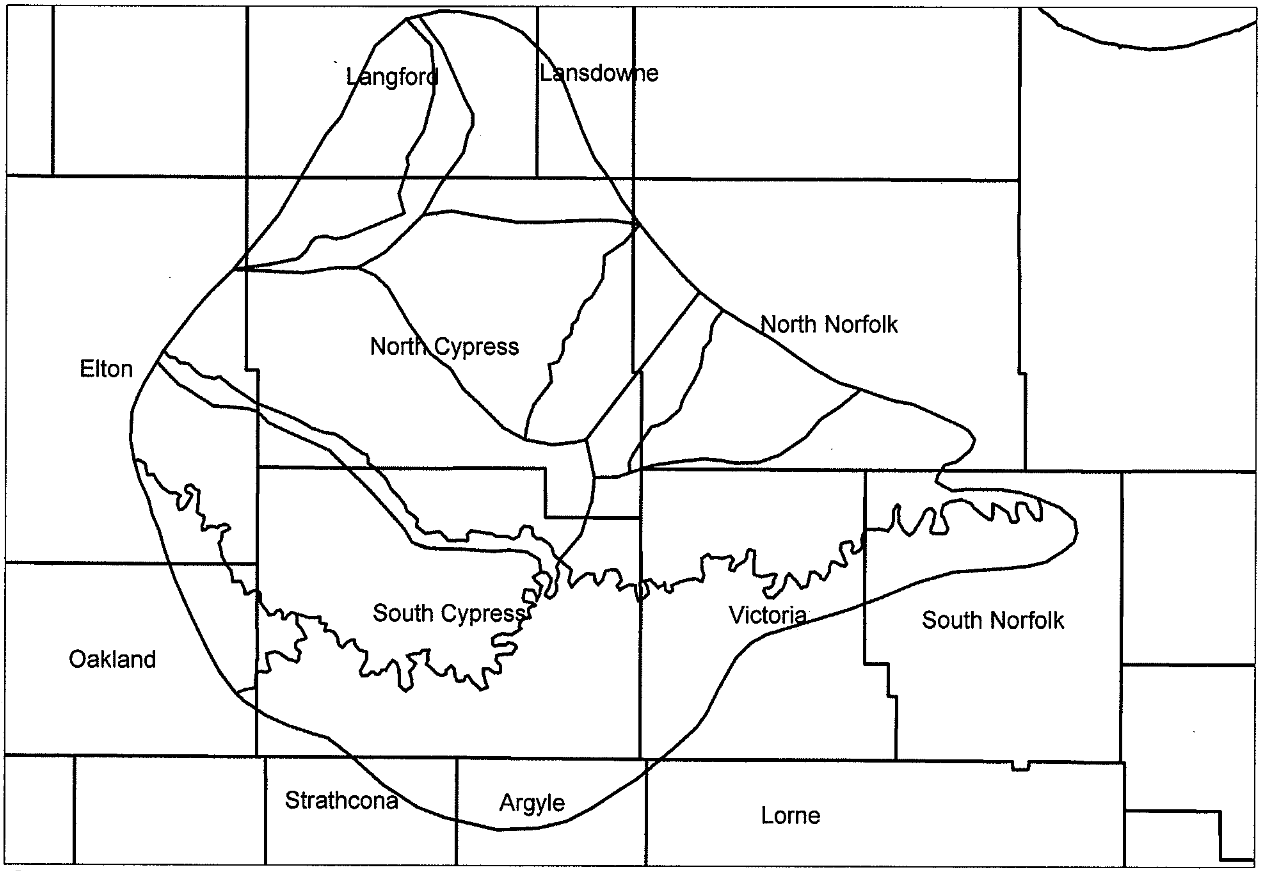
Figure 3 - Assiniboine Delta Aquifer and Sub-Basins



Source: Manitoba Water Stewardship, 2005

Figure 3 shows the ADA and the Rural Municipalities that span it. The municipalities of North Cypress and South Cypress are both nearly wholly contained within the ADA, and lesser parts of the municipalities of Langford, Lansdowne, Elton, North Norfolk, South Norfolk, Oakland, Victoria and Argyle are within the ADA boundaries.

Figure 4 - Assiniboine Delta Aquifer and Associated Rural Municipalities



Source: Created by Author

2.3 Water Characteristics of the ADA

Table 2 summarizes the water volume profile of the aquifer. The ADA's capacity is 12 million acre-feet of water. Total average annual recharge of the aquifer is 166,000 acre-feet. Of that 114,000 acre-feet is either located in unavailable areas (under Spruce Woods Provincial Park, or CFB Shilo), or is allocated for domestic and environmental usage. The remainder, 52,000 acre-feet is available for allocation through the Water Licensing section of Manitoba Conservation. Currently 29,000 acre-feet has been allocated via license. There is currently about of 23,000 acre-feet of water available remaining for allocation (Manitoba Water Stewardship, 2005).

Table 2 – Assiniboine Delta Aquifer Water Supply and Demand

Supply	**Volume** (acre-ft/year)
Groundwater Storage	12,000,000
Sustained Yield	166,000
Reserved for non-licensed use, environmental use and inaccessible	114,000
Water for available for allocation	52,000
Demand	
Irrigation	23,500
Industrial	3,800
Municipal	1,500
Domestic/Agr Projects	200
Total current demand	29,000
Remaining for allocation	23,000

Source: Manitoba Water Stewardship, 2005

Table 3 breaks out the sustained yield and allocation limit by sub-basin. For some sub basins (e.g. Pine Creek North, Upper Whitemud West, Epinette Creek North), the water allocation is at 100% of the available limit. Other sub basins (Lower Whitemud East, Pine Creek South, and Assiniboine East) have 50% or more of their allocation limit available. However since there is a regulation that does not permit inter-basin transfers of the water, much of the water in those sub-basins is unavailable for allocation since it is below Spruce Woods Provincial Park. Additionally, Table 3 relates water allocation to the number of irrigation projects and the number of irrigated acres, by sub basin.

Table 3 shows that the water used for irrigation in 2001 for the ADA averages 9.8 inches per acre. This value exceeds the lower bound of the 10% risk of water deficit, even though 2000 was not a drought year. (The 10% risk level for the Carberry/North Cypress area is 6" to 8", meaning that 1 in 10 years the crops will require 6-8 inches or more of water (Manitoba Agriculture and Food, 2001).

Table 3 is misleading in that it shows all licensed water projects, not just irrigation. Every sub-basin that exceeds 8 inches of irrigation is due to a "non-irrigation" related license. For purposes of this study, 8 inches per acre will be the limit of irrigation per acre. Also, 8 inches is the current maximum availability of water for irrigators. Often irrigators use less water than the amount allocated.

Note that the column "Total Developable Yield" in Table 3 represents the amount of the aquifer area that can be developed, resulting in 109,000 acre-feet of available water. As previously stated the area of the ADA is 1500 square miles, but only 1000 square miles of the aquifer are available for irrigated crop production, so not all of the 166,000 sustained yield of the aquifer are available for irrigation purposes.

Table 3 - Assiniboine Delta Aquifer: Water Supply and Allocation

Sub Basin	Total Developable Yield (acre-ft/year)	Allocation Limit (acre-ft/year)	Actual Allocation (acre-ft/year)	Remaining Allocation Potential (acre-ft/year)	Total Number of Projects	Licensed Irrigation Projects	Annual Irrigated Acres	Water Allocation Per Irrigation Project (acre-ft per irrigation project)	Water Used (ft/acre)	Water Used (inches/acre)
Whitemud Sub Basins										
Upper Whitemud West	6,519	1,951	979	972	9	8	1,490	122	0.657	7.9
Upper Whitemud East	4,236	636	613	23	7	7	943	88	0.650	7.8
Lower Whitemud East	8,521	4,260	2,054	2,206	20	20	3,160	103	0.650	7.8
Pine Creek North	11,000	5,500	5,508	0	49	48	6,935	115	0.794	9.5
Pine Creek South	5,692	2,846	1,257	1,589	15	15	1,935	84	0.650	7.8
Squirrel Creek North	3,015	1,507	350	1,157	5	5	538	70	0.651	7.8
Squirrel Creek South	7,126	3,563	129	3,434	2	2	260	65	0.496	6.0
Sub Total	**46,109**	**20,263**	**10,890**	**9,381**	**107**	**105**	**15,261**	**104**	**0.714**	**8.6**
Assiniboine Sub Basins										
Epinette Creek North	18,000	9,000	9,765	0	57	51	9,521	191	1.026	12.3
Epinette Creek South	335	167	128	39	1	1	160	128	0.800	9.6
Assiniboine East	15,900	7,950	205	7,745	4	2	240	103	0.854	10.3
Assiniboine South	17,754	8,877	2,079	6,798	15	13	3,104	160	0.670	8.0
Assiniboine West	8,256	4,128	4,148	0	32	32	5,185	130	0.800	9.6
Assiniboine Souris	2,866	1,433	0	1,433	0	0	0	0	0.000	0.0
Sub Total	**63,111**	**31,555**	**16,325**	**16,015**	**109**	**99**	**18,210**	**165**	**0.896**	**10.8**
Total	**109,220**	**51,818**	**27,215**	**25,396**	**216**	**204**	**33,471**	**133**	**0.813**	**9.8**

Source: Manitoba Conservation, Water Branch, Water Licensing Section, 2001 (Current as of November 20, 2001)
(Upper Whitemud East Allocation Limit adjusted based on Manitoba Water Stewardship's Assiniboine Delta Management Plan, 2005)

CHAPTER 3. LITERATURE RESEARCH AND INTERVIEWS

3.1 Introduction

There is a significant amount of literature available regarding the ADA from academic, consulting and governmental sources, including a several popular sources of detailed research regarding the physical makeup, waterflow properties and irrigation within the ADA: Render (1988), Burton and Ryan (2000), Kulthreshtha (1994).

The literature review of this study concentrates on reference material that provides both the academic and policy rationale for the research, and provides insight into farm-based decisions and economic impacts to irrigators in the ADA. This is in keeping with the objectives of the study 1.4.1 (B) and (C), where on-farm impacts of irrigation are the key areas of focus.

The literature review conducted for this study was conducted with the following goals in mind:

1. To obtain government- and stakeholder-sponsored information and background relevant to the issues around water and irrigation in the ADA;
2. To review other similar academic research related to the objectives of this study;
3. To provide a framework and rationale for the basis of this research;

4. To provide appropriate coefficients and equations to the models prepared as part of this research.

3.2 Review of Manitoba's Water Resource Plans & Policies

Manitoba's geographical position has ensured that it is blessed with abundant fresh water resources in all areas of the province. In the past, the abundance of fresh water meant that there was little concern for the efficient allocation of the resource. Complex legislation and regulatory bodies were not required to manage the allocation of water to interested parties.

In the last 20 years there has been a dramatic increase in demand for water from domestic, municipal, industrial, agricultural and federal sectors (Manitoba Conservation, 2001a). Coupled with concerns over quality, sustainability and management, the Government of Manitoba has found itself unprepared to manage water resource allocation. Water usage license applications are backlogged. There is insufficient usage metering and usage data on licensed water projects. Despite the lack of appropriate plans, data and administration, the Government has prepared several strategic planning documents. Sustainable development and management plans as guiding documents for the new realities of water management in Manitoba.

(MacMillan et al, 2002) provided an academic review of the history and current water policies and reports that have been instrumental in the structure of Manitoba's water management plans. This review discussed and recommended changes to policies, watershed planning, institutional structure, sustainable development and water jurisdiction, due to the new pressures on managing the provinces precious water resource.

In 1980's, Manitoba developed a Provincial Sustainable Development Strategy, from which water became the first public resource to be addressed. The Water Branch began with public consultation around the issues of water use and allocation (Manitoba Conservation, 2000a). One of the recommendations of these consultations was to prepare aquifer management plans. The first of these was completed in 1997 for the Winkler Aquifer (Manitoba Conservation, 1997), followed by the Oak Lake management plan (Manitoba Conservation, 2001b), and in 2005 a management plan was finalized for the Assiniboine Delta Aquifer (Manitoba Water Stewardship, 2005).

The aquifer management plans were developed with the purpose of bringing together stakeholders from various interest groups, ensured that every stakeholder's interests were brought forth and understood, and that the aquifers were managed in a sustainable manner. These management plans played an important political role in terms of putting all the issues on the table, and gaining consensus on the major issues to be addressed. Major inflows and outflows to and from the aquifer were examined, and discussions of the physical environment were also presented. The development of a concise, mutually-agreed upon list of issues formed the conclusion of the management plans. A major weakness of the Winkler and Oak Lake management plans was that there was no mechanism for follow-through. Once the issues were identified, there was no committee from the stakeholder team that managed the issues through to resolution. In May 2005, the final version of the Assiniboine Delta Aquifer Management Plan was released after feedback was received from aquifer-area residents and stakeholders (Manitoba Water Stewardship, 2005). The plan recommends the following actions:

- Monitoring and data analysis of the aquifer
- Water quantity and quality protection
- Irrigation co-management between government and local irrigators
- Awareness education for key users of the aquifer's water

Action plans and reports to provincial authorities are part of the future work of the ADA Management Plan. Stakeholders from the planning process will participate in fulfilling the recommendations. Through the examination of these management plans, it was evident that the range of issues among aquifers is fairly consistent, and focus mainly on monitoring, licensing and sustainability of the water resource.

Various departments of the Federal and Manitoba Provincial government have prepared research and documentation around the sustainability of and strategies for irrigation development. (Coote and Gregorich, 2000, Manitoba Conservation, 2001a). These types of planning and policy framework documents demonstrate the infancy of such policy frameworks within the federal and provincial governments.

Manitoba Conservation (2001a) outlined Manitoba's provincial water strategy. This paper provided an umbrella document to support more detailed strategies that are currently under development and outlined possible future initiatives. The focus of the document was a regulatory framework that will ensure sustainable water management for Manitoba. Manitoba Agriculture and Food (2001) provides a detailed examination of the possible sustainable irrigation development strategies for Manitoba. This study included irrigation project benefits and costs involved in irrigating various areas of Manitoba, coupled with the availability of suitable soil to support potato production. Additionally, the cost of irrigation infrastructure from the producer, regional and provincial perspective was summarized.

3.3 Review of Research Literature

There are several academic and interest-group funded studies available to assist and support this research, particularly from past work done to quantify the economic value of water in the ADA, and through the development of water flow modeling techniques.

(Cai et al, 2001) discussed the use of efficient allocation of water and water resources management, using both physical and economic efficiency measures. These measures were calculated using a one-year water model that incorporated irrigation, domestic use and industrial usage, using inflow and outflow measurements and calculation of water levels in various water storage systems. The use of this modeling technique provided an effective method for analyzing water flow scenarios and the impact of the water flow scenarios on the efficiency measures. The basic techniques of modeling in Cai et al. (2001) were applied to the ADA inflow and outflows to measure the availability of irrigation water under various weather scenarios.

Several detailed studies have been performed to determine the economic impact of irrigation in Manitoba and in the ADA. McNair (1981), analyzed the water resource allocation problem from an efficiency perspective and as a scarce resource. Through the examination of various institutional alternatives for managing water, McNair concluded that revenues due to irrigation increase greatly once regulation and controls are enforced. Kulthreshtha and Grant (2002) quantified the economic impacts of irrigation in Manitoba, measuring impacts based on the benefits to farm, region, province and nation of existing and future irrigation. The study used the Manitoba Input-Output and Employment Model to generate economic impact coefficients and overall returns to GDP. The conclusion of Kulthreshtha and Grant's (2002) analysis was that irrigated potatoes contribute significantly to all levels of the economy, both during the investment phase and ongoing production phases. They concluded that the expansion of irrigated acres in Manitoba has considerable positive impact to provincial GDP, and increased the stability of on-farm incomes. The addition of value-add production facilities, like the new potato processing facility in Portage La Prairie resulted in over $500 million annually to the local economy, of which nearly $120 million stays in the irrigation region.

Kulthreshtha and Grant (2002) extended the work previously done by Kulthreshtha (1994) to quantify the economic value of groundwater in the ADA. Kulthreshtha (1994) calculated the value of water in the ADA from an economic efficiency perspective and a regional development perspective. Using annualized use-related value of the ADA, in 1990 dollars the ADA has value ranging from $4.65 million (based on economic efficiency – the total contribution of the aquifer to Canadian society), to $43.55 million based on a regional development accounting perspective.

Sustainable development of irrigation water within the ADA has long been a concern for stakeholders and government. The Oak Lake and Winkler Management plans produced by Manitoba Conservation Water Branch (1997 and 2000b) and the Assiniboine Delta Aquifer Management Plan (Manitoba Water Stewardship, 2005) highlighted sustainability as a key issue to be resolved. Simonovic (2001) examined sustainability of the water resource within the ADA using three separate policy alternatives, and assessed the development of practical measurement tools. Simonovic (2001) used three criteria for measurement of sustainability were reversibility, risk and equity, in addition to benefit cost analysis and environmental assessment. The results of this analysis were inclusive, which leads to further questions as to how sustainability can be accurately measured and assessed.

A final source of information that was obtained during the research was through personal interviews with three people with in-depth knowledge and areas of expertise within the ADA. The notes of these interviews are found in Appendix 5. A phone call with Frank Render (personal communication) confirmed that measurements of outflows are based on a few measurement stations on Pine Creek, and that the bulk of the ADA analysis looks at all the basins combined, rather than examining basins individually. Ted Poyser (personal communication), retired agrologist (previously employed by the Manitoba Soil Survey and as a Soils Specialist with the Manitoba Department of Agriculture) had several questions and concerns about whether irrigated potatoes really provided the optimal use of the ADA's water. He hypothesized that if the water was used downstream for higher value-add activities that GDP would be more positively impacted. Randy Baron (personal communication), potato farmer within the ADA echoed the concern of lack of any actionable research being done in the ADA, and confirmed that there is a definite lack of government support in the region, particularly in the areas of licensing and monitoring of wells. Farmers are frustrated by the lack of coordination and research that supports their needs.

The literature review clearly shows that there is a significant level of governmental, academic and stakeholder interest in the ADA, irrigation and appropriate allocation of the water resources. In most cases research contained recommendations and findings rather than action steps to solve the needs of all stakeholders. Issues of economic value of water and sustainability have been well-researched by several academic authors. Modeling methods and economic valuations have been created. Past cost-benefit analyses have been done. However the research turned up little, in terms of developing the practical models and tools that can benefit the farmers and stakeholders within the ADA. It is hoped that the methods and results of this paper can begin to bridge the theory and models with the day-to-day modeling and policy issues in the ADA.

CHAPTER 4. ANALYTICAL METHODS

4.1 Introduction

Chapter 4 discusses the methodology for preparing the water-balance simulation models and economic on-farm value profiles that will be measured to fulfill the objectives of this study.

4.2 Construction of the Water Balance

This section outlines the construction of the water balance, or water budget for the ADA, and methods for approximating the budget.

4.2.1 Understanding the Water Balance

A preliminary requirement for the study of the ADA is to understand the inflows and outflows of water from the area. The "water balance" is the equilibrium condition that exists when volume of inflows equal the volume of outflows (assuming the main reservoir of water is not in a prior deficit condition). As there is only a finite amount of water that can be held by any holding system (natural or man-made), outflows of water occur when the capacity of the system can no longer support more water. In completely natural environments outflows are surface drainage (rivers, creeks, streams, lakes and sloughs) and evapotranspiration. When irrigation or other man-made withdrawals are made from the main body, less is available for the natural outflow, and/or there is depletion of the main body of water, known as "draw-down."

Inflows into the system must "recharge" the withdrawals of water. If inflows do not equal or exceed outflows, there is a reduction in volume of water in the reservoir component of the system. The main inflows for Manitoba's water reserves are snowmelt and spring rainfall.

In the ADA, there are few lakes or wetlands due to the sandy soil. There are 2 regional waterways: The Assiniboine River and the Souris River, and several local waterways (Pine Creek, Rat Creek, Boggy Creek, Squirrel Creek & Epinette Creek). The ADA supplies these local and regional waterways with streamflow, through springs. These rivers do not feed the aquifer, as their riverbeds have eroded beneath the aquifer water table. Total aquifer discharge to the waterways is 145 cfs (106,000 acre-feet per year). It is estimated that only 10% of precipitation enters the aquifer. 85% of precipitation exits through evapotranspiration, and the remaining through surface runoff to waterways (Manitoba Water Stewardship, 2005).

Environmental and conservation policies that protect habitats for fish, waterfowl and recreation areas require minimum flows in the rivers and streams. This limits the amount of water that can be withdrawn for agricultural, domestic or industrial use. One other unlegislated but necessary requirement of the water from the Assiniboine River is dilution of effluent. It is necessary to have a flow of 200 cfs at Headlingley. In an average year, 6% of the Assiniboine River flow comes from the ADA. In dry years, this percentage of flow rises to 30% (Harrison, 2003).

4.2.2 Formulation of Inflows and Outflows

This section formulates the inflows and outflows. There are two main types of inflows into the ADA water system:

Natural: α_n, where n=1 to x_1. Natural inflows are rainfall and snowmelt. There are x_1 natural inflows into the ADA water system. The natural inflows can be quantified as simple as total inflow for the entire aquifer, or measured as regional inflows on a sub-basin by sub-basin basis. For the purposes of this study, inflows are examined over the entire aquifer.

Recycled: β_r, where r=1 to x_2. Recycled inflows are lagoon returns, water treatment facilities and excess run-off from irrigation and heavy rains. These flows are the result of human intervention on the natural inflow structure. There are x_1 recycled inflows into the ADA water system. In the ADA the recycled inflows represent a very small portion of the inflows. For this purposes of this study, they will be considered negligible.

Total inflows: are simply the sum of natural inflows and recycled inflows.

$$IF = \sum_{1}^{x_1} \alpha_n + \sum_{1}^{x_2} \beta_r \qquad \text{(Equation 1)}$$

There are four main types of outflows:

Natural: $\gamma_{n,}$ where n=1 to y_1. Natural outflows are river, creek and groundwater flow and evapotranspiration. Natural outflows may have a minimum acceptable limit that takes priority over other outflows, for example a river or creek may require a minimum flow rate that is provided by the aquifer.

Domestic: $\delta_{d,}$ where d=1 to y_2. Domestic usage is the amount used by human populations for household use. There are y_2 domestic outflows in the system. These outflows represent the usage by towns and village in the aquifer, and usage by rural individuals with wells in the aquifer.

Agricultural: $\varepsilon_{a,}$ where a=1 to y_3. Agricultural usage is amount of water used for irrigation and livestock watering. There are y_3 domestic outflows in the system. This represents livestock watering at the farms &, feedlots, and crop irrigation.

Industrial: $\zeta_{p,}$ where p=1 to y_4. Industrial usage is the amount used by manufacturing and food processing plants in the ADA region. In the ADA region, this includes the McCain plant in Carberry, and other smaller local industries.

Total outflows: are simply the sum of all outflows.

$$OF = \sum_{1}^{y_1} \gamma_n + \sum_{1}^{y_2} \delta_d + \sum_{1}^{y_3} \varepsilon_a + \sum_{1}^{y_4} \zeta_p \qquad \text{(Equation 2)}$$

Water balance is achieved when total inflows equal total outflows:

$$\mathrm{IF} = \mathrm{OF} \qquad \text{(Equation 3)}$$

Or

$$\sum_{1}^{x_1} \alpha_n + \sum_{1}^{x_2} \beta_r = \sum_{1}^{y_1} \gamma_n + \sum_{1}^{y_2} \delta_d + \sum_{1}^{y_3} \varepsilon_a + \sum_{1}^{y_4} \zeta_p \qquad \text{(Equation 4)}$$

4.3 Simulation Modeling using STELLA

The simulation models prepared for this research were programmed in STELLA version 7.0.3. This tool was chosen for it's ability to model natural systems, and for the inclusion of other variables, such as economic, yield, policy values into the simulation. The software and modeling process is described in this section.

4.3.1 Introduction to STELLA Software

STELLA Software is simulation programming language that utilizes "Systems Thinking". Systems Thinking involves three main skills: operational, closed-loop and non-linear thinking. These skills, implemented with this software, allow for construction of simulations about all kinds of dynamic systems from natural environments to team dynamics to economic markets (Richmond, 2001). This software has some great advantages for modeling dynamic environments. First, the modeling software allows approximations to be applied when actual values aren't known. These approximations can be graphical relationships, tabular data or constants, which provides a range of methods for populating the variables when developing a model. Models can be developed using simple constants or complex interactive variables. Secondly, the models permit non-linear relationships, which allows complex quadratic, recursive, time-series or branching relationships to be applied to the model. Finally, the closed-loop functionality ensures that whatever inputs enter into the model either stay in it, or come out as an output. This ensures that there is no leakage, or unexplained results from the model.

With these advantages, it is an ideal tool for modeling the natural environment of aquifer inflows and outflows. Additionally, it provides scalability, starting with the simplicity of getting a model running, to the complex sub-models that allow for the minutest variations in the environment.

Much like today's "open-source" technology environment, these models can be shared, adjusted and refined to meet the needs of ongoing research.

4.3.2 Calculation of the Aquifer Water Balance

The research model includes the development of a simulation model that combines the inflows and outflows of water in the ADA and incorporates agricultural, domestic, industrial and natural outflows. The model will provide a time-series based forecast that incorporates aquifer inflow and outflow data, as detailed in Section 4.2. Where data is unknown or unavailable, best-guess graphs and constants (that are adjustable by the researcher) are used to examine different recharge, irrigation amounts, water allocation limits and outflow scenarios. Simulations of wet years, dry years and drought conditions, and varying economic conditions were modeled. The models were run through 10 year simulations for three reasons: the 10 year period represents a long enough weather cycle to allow for changing cycles of flood and drought; the 10 years represents a significant portion of the lifespan of most of the capital items purchased by the farmer; and finally it represents an adequate window for return on investment.

4.3.3 Weather Extremes Applied to the Water Balance Model

The water balance model allows for an infinite variety of weather simulations to be applied. In an effort the provide the logical boundaries for drought and extreme wet conditions, 3 years of 30% reduction in aquifer recharge was chosen (i.e. rainfall or snowmelt), indicating persistent drought conditions. This is not based on any "standard" definition of drought, but was merely based on a best guess of what would be considered a significant reduction of inflow water into the aquifer. Three consecutive years of 30% reduced inflow but is meant to represent a severe drought. Based on these minimum aquifer recharge conditions, the opposite effects are also examined, meaning that 3 consecutive years of 30% higher than average recharge is experienced. Measuring the response of the aquifer to these modeled conditions allows us to understand the aquifer's rebound and the availability of water for irrigation purposes. The specifics of the scenarios modeled are discussed in Chapter 5.

4.3.4 Calculation of Water – Yield - Revenue Simulation Model Using STELLA

This section involves the development of a simulation model that converts water inputs (rain water and irrigation) through a yield function developed by Shaykewich et al (2002) to produce potatoes, and potato revenue for the potato farmer. The Water-Yield-Revenue model provided various forecasts that demonstrated the change in farm revenues as a result different water availability scenarios.

This model assumed that yield was a function of water availability and did not consider the effects of other "standard" potato farming practices, such as fertilization, in-crop chemical application, hilling of the potatoes. Also the effects of potato plant diseases and pests were not considered.

4.4 On-Farm Economic Valuation Methods

This part of the study examines whether the producer benefits of irrigated potato acreage outweigh the costs. The economic valuation was provided using standard cost-benefit analysis, Net Present Value (NPV) and Internal Rate of Return (IRR) calculations. Several stages of calculation were analyzed for the on-farm economic valuation:

Capital Investment

This analysis summarizes the capital investment required to grow potatoes. The costs were expressed in terms of total cost and per acre costs. Capital investment was broken into 4 main categories: land, storage facilities, irrigation system and machinery & equipment. Storage, irrigation, machinery & equipment have salvage value; land has no salvage value as it remains useful indefinitely.

Financial Analysis

The per-acre financial viability of potato acreage is summarized in the financial analysis. This analysis summarizes a typical "accounting view", showing revenues, expenses, fixed costs, and ultimately EBITDA (Earnings before interest, taxes, depreciation and amortization), over a fixed time period. For purposes of this analysis, time was evaluated over 20 years, in annual increments.

Calculation of EBITDA is achieved by calculating the revenues at time t (R_t), less operating expenses (OE_t). EBITDA is expressed as the benefit at time t.

$$\text{EBITDA} = R_t - OE_t \qquad \text{(Equation 5)}$$

Farm operation costs at time t, C_t, was the initial cost of land and equipment, less the salvage costs at the end of the time period. For the purposes of this analysis, costs were defined in terms of land and equipment.

The cost of land, over the time period t:

$C_{Land} = C_{0, Land} - C_{t, Land}$

The cost of equipment

$C_{Equip} = C_{0, Equip} - C_{t, Equip}$

Economic Analysis

Using values from the Capital Investment and Financial Analysis worksheets, it is possible to derive the economic metrics Cost-Benefit ratio and internal rate of return (IRR). A Cost-Benefit ratio of 1 indicates no net gain or loss, less than 1 indicates a net cost, and greater than one indicates a beneficial project. Due to the nature of IRR, it will not derive a value for negative cash flows. The basis of the economic analysis is the Net Farm Return, which is calculated by subtracting all farm expenses (AE_t) from revenues (R_t).

$$\text{Net Farm Return} = B_t = R_t - AE_t \qquad \text{(Equation 6)}$$

The data used to calculate the on-farm economic analyses were obtained from Manitoba Agriculture (Manitoba Agriculture and Food, 1997) and through personal interviews with Randy Baron, Carberry area potato farmer.

CHAPTER 5. RESULTS OF WATER BALANCE ANALYSIS

5.1 Construction of the Water Balance Simulation Model

The water balance was constructed using the STELLA simulation software. For simplicity, the model was constructed using a 10-year simulation window, showing the values of aquifer and various flows once per year. A semi-annual checkpoint was added to permit the calculation of excess water throughout the annual cycle. The model was constructed to permit variance of several key variables. The first variable was the inflows (as acre-feet) into the aquifer through recharge, to simulate years of insufficient and excess snowmelt and spring rainfall. The second variable was the amount of water (as acre-feet) removed from the ADA to be used as irrigation. The third main variable was the percentage-based annual adjustment to the amount of the irrigation acres allocated (known as the "50% rule", as currently 50% of average annual inflow can be allocated to licensed water projects). The percentage adjustment could be varied to alter the amount of acre-feet available to non-licensed and environmental flows (currently set at 114,000 acre-feet)

As a simplifying assumption, several outflows were set as static throughout the 20 year simulation, including domestic, livestock and industrial withdrawals. There are modest increases forecast in the population of the aquifer area (Manitoba Water Stewardship, 2005), but those were assumed static for the purposes of this study.

The model was designed so that the maximum capacity of the aquifer was set at 12 million acre-feet. If recharge plus water in storage exceeded 12 million acre-feet, that water passed to an outflow called "Excess Water," which tabulated the flow of licensed water not used when volumes exceeded 12 million acre-feet.

Tabular output of the model simulation included the annual volume of water in the aquifer, the amount by outflow type (including irrigation), and the inflows. Through the use of scenarios showing multiple year droughts, multiple year rainy seasons, etc., the tabular reporting simulated aquifer response to various annual inflow and outflow conditions and how quickly it returned to the steady state of 12 million acre-feet. Details of the water balance simulation model are located in APPENDIX 1.

5.2 Aquifer Water Balance Scenarios

The following water balance scenarios were modeled:

5.2.1 Steady-state, matching the documented average inflow and outflow levels. The values for the Steady-State water balance model are found in Table 4.

Table 4 –Water Balance Model Scenarios

Scenario	**1: Steady-State**	**2**	**3**	**4**	**5**	**6**
	Acre-Feet					
ADA Capacity	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000
Inflows:	166,000	116,200[1]	215,800[2]	166,000	166,000	116,200[3]
Annual Increment:	0	0	0	2,000	2,000	0
Water Allocation Rule:	50%	50%	50%	50%	60%	50%
Outflows:						
Unavailable Outflow	114,401	Annual outflows vary in response to simulation behaviour				
Irrigation	23,500					
Non-Irrigation Licensed	5,500					
Excess Water	22,600					
Total Outflows	166,000					

[1] Acre-feet inflows are 116,200 for Years 1 to 3 and 166,000 for years 4 through 10

[2] Acre-feet inflows are 215,800 for Years 1 to 3 and 166,000 for years 4 through 10

[3] Acre-feet inflows are 116,200 for Years 1 to 3, 215,800 for Years 4 & 5, and 166,000 for years 6 through 10

5.2.2 Three consecutive years of insufficient recharge inflow (30% less than usual). All remaining variables at steady-state.

5.2.3 Three consecutive years of excess recharge (30% more than usual). All remaining variables at steady-state

5.2.4 Constant annual increase of irrigation demand over 10 years (an additional 2000 acre-feet per year), which consumes 20,000 of the 23,000 remaining acre-feet to be allocated (at the 50% allocation-rule level). All remaining variables at steady state.

5.2.5 Constant annual increase of irrigation demand over 10 years (an additional 2000 acre-feet per year), at 60% allocation. All remaining variables at steady-state.

5.2.6 Three consecutive years of insufficient recharge inflow (30% less than usual), followed by 2 years of excess recharge (30% more than usual). All remaining variables at steady state.

As it is a dynamic simulation scenario, infinite variations of these scenarios are possible.

5.3 Interpretation of results of scenarios

Scenario 1 merely demonstrated that the simulation model remains at steady-state with the inflows and outflows measures. Without properly baselining the model in this way, it would not be possible to use the model for testing of scenarios with inflows or outflows adjusted.

Scenario 2 showed the effect of three consecutive years of 30% reduction in inflow water through snowmelt or spring rainfall. All outflows remained at "normal" levels. In this case, a 30% reduction meant that the recharge of the aquifer was reduced to 116,200 acre-feet from 166,000 acre-feet. After the 3 year period, the aquifer requires 5 years to return to full capacity, assuming normal inflows in every year following the 3 year reduced inflow period. During this time the maximum draw-down of the aquifer was approximately 11,900,000 acre-feet (a loss of 100,000 acre-feet). Put differently, if the 100,000 acre-feet were distributed across the 1500 square miles of the aquifer, the water level would drop approximately 1.25 inches. During the 8 years of reduced water level in the aquifer, the "Excess Water" outflow dropped to 0, indicating that there was no excess water being routed out of the aquifer to rivers or streams.

Scenario 3 showed the impact of the three consecutive years of 30% increase in inflow water through snowmelt or spring rainfall. All outflows remained at "normal" levels. A 30% increase meant that the recharge of the aquifer was increased to 215,800 acre-feet from 116,200 acre-feet. In these years 72,400 acre-feet of water of excess water exited the aquifer as outflow through streams and rivers, as the aquifer had no capacity to hold water beyond 12 million acre-feet.

Scenario 4 showed that an increase in demand due to irrigation through 10 years, the aquifer remains at 12 million acre-feet of capacity. The excess capacity amount fell linearly with the increase in irrigation demand. As seen from Scenario 2, this excess outflow dropped sharply when there was insufficient inflow, so the usage of the extra allocation amount led to diminishing of reserves of the aquifer.

Scenario 5 increased the demand similar to Scenario 4 on the aquifer but increases the allocation of water to 60%. This resulted in basically the same type of result as Scenario 4, with a less rapid reduction in excess capacity, as more is available for irrigation

Scenario 6 demonstrated the ability of the aquifer to rebound from a period of reduced inflow through a subsequent period of excess inflows. The aquifer was able to rebound to beyond steady-state capacity within 2 years of excess flow, producing excess outflows in the second year of the excess recharge.

Detailed tabular output of the scenario output from the water balance simulation is found in APPENDIX 2.

5.4 Construction of the Water-Yield-Revenue Simulation Model

The Water-Yield-Revenue model was constructed using the STELLA simulation modeling software. The model tracked the passage of water inflows on one acre of potatoes. A water-yield relationship developed by Shaykewich et al (2002) was applied that converts the available water into a marketable potato yield. Shaykewich's model was developed for Russet Burbank potatoes (the predominant variety grown in the ADA), from a regression equation using yield and water data from 1994 to 1998.

Y = Total Yield (cwt/acre)

x = Precipitation + Irrigation (mm)

$$Y = -0.0026x^2 + 2.1226x - 92.319 \qquad \text{(Equation 6)}$$

While Shaykewich's equation is a quadratic formula, the simulation model is essentially a linear model, with no feedback loops. This model simply converted incoming water to yield. Sample prices ($ per cwt) were then applied to the yield to obtain revenue generated from the potato crop and ultimately the water. In Shaykewich's equation, the distribution of yields varied between 250 and 400 cwt per acre, based on water inputs (precipitation+irrigation) between 250 and 450 millimetres per acre. Simply formulated, revenue is a function of yield and price:

Revenue = f(yield, price)

Yield is a function of water availability (irrigation + rainfall):

Yield = f(water availability)

Revenue=f(price, rainfall, irrigation)

Three scenarios were considered to establish the sensitivity of revenue to price and sensitivity due to water availability.

5.4.1 Potato Revenue sensitivity to Available Water. Irrigation limit: 8" (203.2 mm). This assumes that if there is a rainfall water shortage that the farmer will irrigate to achieve 400 mm total.

5.4.2 Potato Revenue sensitivity to Potato Price. Irrigation Limit: 8" (203.2 mm). Potato price was the amount paid to growers by the processor, expressed as a price per hundred-weight of potatoes (cwt).

5.4.3 Total Potato Revenue sensitivity to Increased Potato Acres. Irrigation Limit: 8" (203.2 mm). This showed a revenue-based value of an additional acre of irrigated potatoes to the ADA region.

In the ADA, there is little information on the total acreage of irrigated potatoes. Kulshreshtha & Grant (2002) used a report from Gaia Consulting (2000) that cited 1999 irrigated acres within the ADA was 33,594 (Kulshreshtha, S., C. Grant. 2002). For purposes of the simulation model, the number of irrigated potato acres was variable. However the Gaia Consulting (2000) suggested that the maximum irrigated acreage for the ADA was 42,812 acres, and Manitoba Agriculture and Food (2001) set the potential irrigable land base at 130,839 acres. Based on a 3 year rotation, this is equal to 43,613 annual irrigated acres, so both sources agree that the region's maximum irrigated area is about 43,000 acres. However Hay (2003) stated that Class 1 through Class 3 soil types are suitable for irrigation. Table 5 shows the acreage suitable for irrigation by rural municipality and over 550,000 acres are suitable for irrigation in the ADA. Based on a 3 year rotation this means that 184,000 acres would be the maximum irrigated potato acreage. For sensitivity analysis purposes, the irrigated potato acreage in the ADA was set at 35,000 acres. The market price of potatoes was set at $8.00 per cwt.

Table 5 - Suitability of Land for Irrigated Potato Production (Acres)

Rural Municipality	Class 1	Class 2	Class 3	Class 4	Class 5	Water	Unclassified	Total
Argyle	3,136	5,278	41,602	78,200	65,842	7,798	0	**201,856**
Cornwallis	-	-	-	-	-	-	-	**0**
Elton	-	-	-	-	-	-	-	**0**
Langford	-	-	-	-	-	-	-	**0**
Landsdowne	-	-	-	-	-	-	-	**0**
North Cypress	29,642	97,765	39,548	41,251	89,472	1,263	321	**299,262**
North Norfolk	18,184	11,913	150,946	30,549	75,262	366	37	**287,257**
Oakland	-	-	-	-	-	-	-	**0**
South Cypress	-	-	-	-	-	-	-	**0**
South Norfolk	8,863	19,182	65,358	32,513	56,331	1,616	405	**184,268**
Strathcona	250	526	2,903	88,761	30,576	9,167	126	**132,309**
Victoria	15,763	24,478	17,154	28,720	87,194	1,601	395	**175,305**
Total	**75,838**	**159,142**	**317,511**	**299,994**	**404,677**	**21,811**	**1,284**	**1,280,257**

Source: Hay, 2003

(Classes 1, 2, 3 are considered suitable for Irrigation)

Economic impact is maximized when revenue is maximized. Rainfall is not controllable. Price is set by the market. Irrigation amounts can be controlled through management plans.

Details of the Water-Yield-Revenue simulation model are located in APPENDIX 1.

5.5 Interpretation of Water-Yield-Revenue Output

Tabular output of the three scenarios described in the previous section are found in APPENDIX 3.

5.5.1 Results of Scenario 5.4.1 – Potato Revenue Sensitivity to Available Water

Maximum revenue per acre of $2,726 occurred when total water availability through irrigation and rainfall was 400mm. Since the Shawkewich yield equation (Equation 6) is an inverse quadratic equation, the results of Scenario 5.4.1 demonstrate the diminishing returns of increasing amount of water for potato acres. Shaykewich's equation resulted in a maximum at approximately 400mm of available water, after which yields and revenues no longer increase. These results are shown in Table 6. Every millimeter of water in the first 203 mm (8 inches) season is worth $8 per acre. As 400mm of water is approached, this revenue diminished to 0. Using the model (and using the simplifying assumption that the water is "free"), the farmer would maximize his water application such that total water applied is 400mm, as allowed by the 8-inch irrigation limit and available in-season rainfall. The sum of the diminishing returns (up to the 400mm limit), results in incremental revenues of $35 per acre

Table 6 - Sensitivity of Revenue to Amount of Water Available for Potatoes

				ΔR	ΔW	
Irrigation (mm)	**Rainfall (mm)**	**Water for Potatoes (mm)**	**Revenue per Acre ($)**	**Change in Revenue per acre ($)**	**Change in Water for Potatoes (mm)**	**Ratio of Changes (ΔR/ΔW)**
203	0	203.2	1,853	0	0	0.00
203	25	228.2	2,053	200.16	25	8.01
203	50	253.2	2,228	174.24	25	6.97
203	75	278.2	2,376	148.16	25	5.93
203	100	303.2	2,498	122.16	25	4.89
203	125	328.2	2,594	96.24	25	3.85
203	150	353.2	2,664	70.16	25	2.81
203	175	378.2	2,708	44.24	25	1.77
200	200	400	2,726	17.28	25	0.69
175	225	400	2,726	0	25	0.00
150	250	400	2,726	0	25	0.00
125	275	400	2,726	0	25	0.00
100	300	400	2,726	0	25	0.00
75	325	400	2,726	0	25	0.00
50	350	400	2,726	0	25	0.00
25	375	400	2,726	0	25	0.00
0	400	400	2,726	0	25	0.00
0	425	425	2,721	-4.48	25	-0.18
0	450	450	2,691	-30.48	25	-1.22
0	475	475	2,634	-56.48	25	-2.26

5.5.2 Results of Scenario 5.4.2 – Potato Revenue Sensitivity to Potato Price

Table 7 shows the results of this scenario. Since revenue is linearly proportional to yield and acres, only one test was required here. For this example it was assumed that total water availability is 400mm (in this case it is through utilizing all irrigation water, but the source of the water is not important to the results) Revenue per acre increased by $340.72 for every $0.01 increase in price.

Table 7 - Sensitivity of Revenue to Potato Price

				ΔR	ΔP	
Irrigation (mm)	**Rainfall (mm)**	**Water for Potatoes (mm)**	**Revenue per Acre ($)**	**Change in Revenue per acre ($)**	**Change in Price for Potatoes ($)**	**Ratio of Changes (ΔR/ΔP)**
203	197	400	2,589	34.07	0.10	340.72

5.5.3 Results of Scenario 5.4.3 Total Potato Revenue sensitivity to Increased Potato Acres

Table 8 shows the results of this scenario. With explanation similar to 5.5.2, there was an increase in farm-based potato revenue for the entire ADA region of $2,726 for every additional irrigated potato acre.

Table 8 - Sensitivity of Total Revenue to Potato Acres

				ΔT	ΔA	
Irrigation (mm)	**Rainfall (mm)**	**Water for Potatoes (mm)**	**Revenue per Acre ($)**	**Change in Total Revenue ($)**	**Change in Potato Acres**	**Ratio of Changes (ΔT/ΔA)**
203	197	400	2,726	2,725,760	1,000	2,725.76

CHAPTER 6. RESULTS OF ON-FARM ECONOMIC AND CAPITAL ANALYSIS

6.1 Introduction

This analysis was undertaken to provide an understanding of the capital, financial and economic situations facing a farmer with potato acreage, ultimately determining if potato farming is a worthwhile economic endeavour.

6.2 Discussion of data assumptions and estimations

1. The analysis assumed that the potato operation was being undertaken by a typical grain farmer, who has the equipment required for that type of operation, but not necessarily the land required to effectively grow potatoes. As such, this analysis assumed that the farmer purchased land and additional equipment to plant, cultivate, harvest and store potatoes.

2. Per acre production and labour costs were based on Manitoba Agriculture and Food's "Irrigated Processing Potato Production Costs" (Manitoba Agriculture and Food, 1997). Debt and depreciation costs were supplied by Randy Baron, Carberry area potato farmer.

3. The equipment suggested is a blend of new and used. This assumed that the farmer does not have the resources to purchase "all new" equipment, which is realistic.

4. The annual potato acreage considered was 450 acres. 450 acres of potatoes is adequately serviced by 3 irrigation pivots, each of which irrigates 135 acres in a circular radius. Thus there were roughly 15 acres in each 150 acre field that was not irrigated. As there is a 3 year rotation of potatoes in a field, this requires that a producer have 1350 total farm acres available. The producer typically selects a well-site that is central to 3 fields and moves the pivot to that year's potato acreage. The pivot is connected to the well using moveable surface pipeline. In this method, with 3 wells and 3 pivots, a potato producer can irrigate 450 acres of potatoes and maintain a 3 year rotation.

5. A 20 year useful life was assumed for all capital investments in the analysis. This differs from CCRA's Capital Cost allowance guidelines (Government of Canada, 2002), but simplifies the analysis.

6.3 Economic and capital analysis scenarios

Four scenarios were developed that varied yield and revenue to compare EBITDA (Earnings before interest, taxes, depreciation and amortization) under constant cost assumptions of $1,724 per acre. The four scenarios are summarized in Table 9 below:

Table 9 - Net Farm and EBITDA Scenarios

	Baseline	Scenario 1	Scenario 2	Scenario 3
Yield (cwt/acre)	250	200	250	300
Price ($/acre)	8.00	8.00	7.00	8.00
Total Revenue	2,000	1,600	1,750	2,400
Total Costs	1,724	1,724	1,724	1,724
Net Farm Return	276	-124	26	676
EBITDA	691.50	291.50	441.50	1091.50

Note that the scenarios in the on-farm economic analysis are not related to the scenarios developed for the analysis of the Water Balance model.

Combinations of yield and price resulted in per acre revenues between $1,600 to $2,400. Between these revenues, Net Farm Return ranged between -$124 per acre and $676 per acre, and EBITDA ranged between $291.50 and $1,091.50 per acre. As seen with these scenarios it is possible to have negative per-acre net farm returns, yet have positive EBITDA results. Full tabular spreadsheets of the scenarios are found in APPENDIX 4.

6.4 Interpretation of results of scenarios

Using capital cost analysis and EBITDA from the four scenarios in Section 5.3, Capital Investment, Financial Investment and Economic Analysis. Each is summarized below.

6.4.1 Capital Investment

Total capital cost was $2.1 million, of which $675,000 was land. For each category of capital, there was a calculation of the 20-year salvage value of the equipment. The present value of the salvage was calculated at approximately $30,000. Land has no salvage value, as it remains useful infinitely.

6.4.2 Financial Analysis

The financial analysis was summarized in Table 9 in Section 6.3. As stated previously, all scenarios had positive EBITDA, while not necessarily having positive Net Farm Returns. Scenario 1 had the interesting result of negative net farm return and positive

EBITDA. This occurred because depreciation and debt are offset by capital salvage value and annual tax benefits.

6.4.3 Economic Analysis

The baseline scenario B/C ratio is 1.12, indicating that potato farming provides positive economic activity. The two worst-case scenarios (Scenarios 1 and 2) showed a negative B/C ratio. Scenario 3's calculated IRR showed positive returns after 8 years, with sustained returns over 10% for the last 8 years of the 20 year window.

6.4.4 Results of Scenarios

Table 10 summarizes the gross revenue results, sorted by gross revenue. Scenario 1 provided the smallest gross revenue at $1,600 per acre, the smallest EBITDA at -$124, yet maintained a B/C ratio of 0.42 (which is less than 1, indicating a project with negative benefit). IRR will not provide a result due to negative net farm returns.

On the other end of the spectrum, Scenario 3 showed a 50% increase in revenue from Scenario 1, and had an extremely positive B/C ratio at 1.82 and 10- and 20-year Internal Rate of Returns of 7% and 13% respectively. Under this revenue situation, this is a positive investment.

Table 10 - Economic Analysis Scenarios – Per Acre Metrics

Scenario	Gross Revenue per acre	Net Farm Returns per acre	EBITDA per acre	B/C Ratio per acre	IRR Year 10 per acre	IRR Year 20 per acre
Scenario 1	1,600	-124	291.50	0.42	-	-
Scenario 2	1,750	26	441.50	0.68	-	-
Baseline	2,000	276	691.50	1.12	-4%	1%
Scenario 3	2,400	676	1091.50	1.82	7%	13%

Table 11 and 12 show the total regional return of these revenue scenarios on an entire ADA basis. Table 11 shows the Net Farm Returns and EBITDA based on the current amount of irrigated acres in the aquifer (34,500 acres), and Table 12 shows the Net Farm Returns and EBITDA based on the maximum potential irrigated acres (184,000 acres) in the ADA.

These on-farm economics demonstrated that given sufficient revenues (through price and/or yield combinations), positive economic impact potato farming achieves, both on-farm and for the ADA region. Increases in potato price, available water and increased irrigated acreage showed tremendous positive impact to the economic profile of the area. However under conditions where price and/or yield is not sufficient, irrigated potato farming has negative benefit-cost ratios, and is a poor economic investment.

For the existing acreage the ADA EBITDA ranged between 10 and 38 million dollars. For the maximum potential acreage in the ADA, EBITDA ranged between 53 and 200 million dollars.

Table 11 - Economic Analysis Scenarios - 34,500 Irrigated Acres

TOTAL ADA - For all Irrigated Acres (34,500 acres). Values ($000's)

Scenario	Gross Revenue	Net Farm Returns	EBITDA
Scenario 1	55,200	-4,278	10,057
Scenario 2	60,375	897	15,232
Baseline	69,000	9,522	23,857
Scenario 3	82,800	23,322	37,657

Table 12 - Economic Analysis Scenarios – 184,000 Irrigated Acres

TOTAL ADA - For all Potential Irrigated Potato Acres (184,000 acres)
Values ($000's)

Scenario	Gross Revenue	Net Farm Returns	EBITDA
Scenario 1	294,400	-22,816	53,636
Scenario 2	322,000	4,784	81,236
Baseline	368,000	50,784	127,236
Scenario 3	441,600	124,384	200,836

CHAPTER 7. LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

7.1 Limitations of Water Balance Model

The water balance model has the following limitations:

7.1.1 The model is for the aquifer as a whole. There is no detail by sub-basin. As each sub-basin is basically managed as a separate entity of water, it would be beneficial to model each separately.

7.1.2 The model uses annualized inflows and outflows of water. Rainfall and irrigation occurs throughout the spring and summer seasons. Seasonality is not represented in the model. It would be very beneficial to add real weather data to the model, and validate the model against past annual rainfall and snowmelt events.

7.1.3 From a hydrology and waterflow perspective, this is a very simplified model. The model assumes immediate flow from inflows through to outflows. There is no delay due to soil transmissivity and hydrology variables.

7.1.4 There is no variance of many of the outflows (domestic, municipal, etc), or consideration that these outflows may increase as time passes due to increase in demand due to increase in population or other water demands.

7.1.5 Water outflows were not priorized, using the order of priorization of water projects as mandated by the Water Branch, as discussed in Section 1.2.

7.1.6 All outflows were considered to flow at full capacity, regardless of drought or excess water conditions. In a natural environment, droughts or excess water conditions would limit the outflow in the stream and rivers.

7.1.7 Ideally inflow and outflows would have a direct connection to the Water-Yield-Revenue model, so that the model would demonstrate immediate revenue impact based on the water flow scenario.

7.1.8 The simulation scenarios analyzed in this study were a small subset of the possible scenarios. More complex, "real-world" scenarios should be developed, with input from appropriate experts, to fully analyze the effects of adjusting inflows and outflows from a policy perspective.

7.2 Limitations of Water-Yield-Revenue Model

The following are recognized limitations of the Water-Yield-Revenue model:

7.2.1 The model was constructed using a water-yield relationship for the Russet-Burbank variety of potatoes. Models exist for the Shepody variety and could be incorporated based on the seasonal seeded acres of both varieties.

7.2.2 Farmer revenues vary based on contract, processor and grading of potatoes. The model assumed a generalized revenue level for the entire ADA.

7.2.3 Potato yields vary from field-to-field based on weather, rainfall, disease, agronomic and harvest conditions. The model assumed a generalized marketable yield for the entire ADA.

7.3 Limitations of On-Farm Economic Analysis

The following are recognized limitations of the On-Farm economic analysis:

7.3.1 In the model, production and labour costs were fixed, rather than providing variable cost scenarios.

7.3.2 Many of the costs were based on one farmer's experiences with capital costs, labour costs, and revenues. A more comprehensive survey of balance sheet items may assist the analysis.

7.3.2 Ideally the on-farm economic analysis would be linked into the Water Balance model and the Water-Revenue-Yield models to provide a comprehensive simulation model that considered all aspects of the impacts of irrigated potato acres in the ADA.

7.4 Extending the Research

There is a significant body of discussion papers from Federal Government; from the provincial departments of Conservation, Agriculture and Intergovernment Affairs; from academia and from stakeholder groups. It is time to use the body of knowledge as a framework for further analysis and to start working on applied analysis that provides meaningful, actionable feedback to all stakeholder groups and that enables and informs legislators and policy makers.

The analysis introduced as the research component of this paper will form part of that applied body of knowledge on the ADA. Additionally the calculation of economic benefits that the water provides for irrigators and processors will help quantify and refine regional/province/national impact analyses.

This study examined three analytic research problems within the ADA. Further work is required to generate actionable results. The next steps to achieve the results include:

1. Where possible, eliminate estimations from the analysis. Gather data from primary and secondary sources and compile meaningful coefficients.
2. Complete the analysis for the entire ADA region sub-basins
3. Assemble an analytical team to add academic rigor to entire process; obtain funding; and divide the project to leverage technical expertise, in coordination with Manitoba Conservation, Manitoba Water Stewardship and Manitoba Crop Diversification Centre
4. Obtain primary research data about the ADA's farmers. This information will assist the models by providing "real" values for many of the assumed constants in the analyses.

CHAPTER 8. CONCLUSIONS

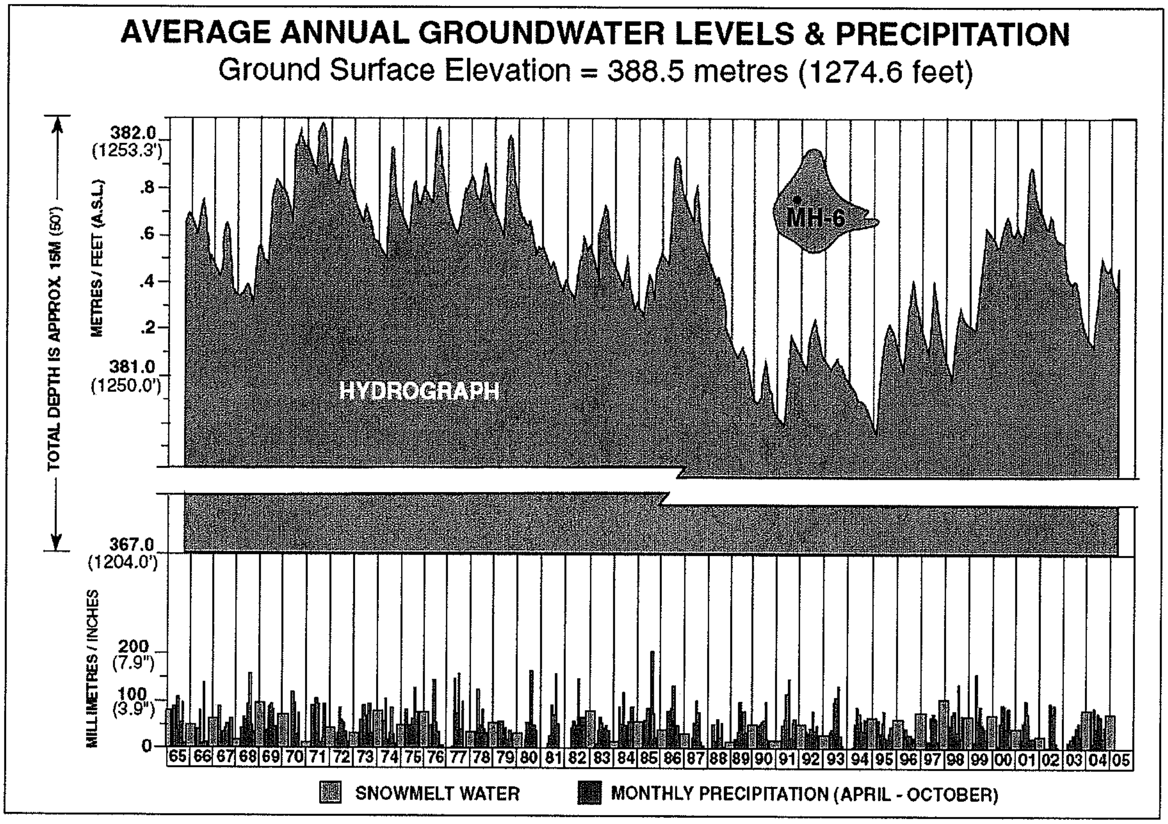
This research has encompassed three different analyses to examine the effects of water availability on potato-farm revenue. This section summarizes each of the analyses individually, then considers the three analyses collectively.

8.1 Conclusions from Water Balance Modeling

The water balance model demonstrated that a realistic simulation model can be constructed to examine inflow and outflow scenarios in the ADA.

The model demonstrated that the aquifer shows relatively quick rebound from insufficient recharge seasons. Full recharge can occur within 1-2 years of a significant period of deficient recharge. During the period of insufficient recharge, when draw-down does occur, it is relatively insignificant relative to the volume of water in the aquifer. As mentioned in the study, the maximum draw-down was equivalent to a 1.25 inch decrease across the entire area of the aquifer. The ADA water balance model's response to rebound from drought is consistent with comments made during the ADA Roundtable sessions ("Round Table Meeting #12." 2003), where it was noted that the ADA by both Laurie Frost and Rob Matthews that the aquifer has a relatively quick rebound after both pumping and seasonal discharge. This conclusion is also substantiated by the groundwater measurements at the test well MH-6 in the ADA. Figure 5 shows how the ADA has annual discharge and recharge effects based on snowmelt and rainfall. In a single year, the discharge and recharge can each be 12 to 18 inches.

Figure 5: Average Annual Groundwater Levels and Precipitation



Source: Manitoba Water Stewardship, 2005

In years of excess flow, a significant volume of water goes downstream. There is no method or policy to leverage this temporarily during the season of excess water flow. Since storage reservoirs within the aquifer are difficult due to the coarse soils, it may be difficult to utilize the excess flow efficiently. However there may be seasonal or yearly opportunities for downstream users to obtain permission to utilize the excess flows.

Clearly a method of predicting an upcoming season of excess inflow (by measuring snow pack in spring?) means that on a year-by-year basis an extra allocation of water could be granted to irrigators or other interested stakeholders. It is not clear whether this is physically possible, since the downstream flow may occur too quickly in the spring. Irrigation demands occur later in the summer, during the drier months of July and August.

Despite the model's demonstrated ability to recharge, and the corroboration with other research, the water balance model's construction is very simple and lacks the dynamics of hydrology. Until the model's responses can be validated by research hydrologists, it merely demonstrates a technique for water balance modeling. The conclusions mentioned with respect to this research require additional testing and verification.

8.2 Conclusions from Water-Yield-Revenue model

From this model it was clear that allocation of water to the growth of potatoes increased yields and revenues to the farmer and the entire ADA region. On-farm and regional economic benefit was realized from increased water flow, from increased potato prices and from increasing the amount of irrigated acres in the ADA. This translates into more farms that are more prosperous, economically stable, and provides a positive economic impact to the ADA region.

8.3 Conclusions from On-Farm Economic Analysis

Despite the high capital cost and land costs required to engage in irrigated potato farming, it appeared that irrigated potato farming provides an acceptable level of return, under conditions where gross revenue exceeded $2000 per acre. At that level and above, B/C ratios were positive despite the entry risk. For $2000+ gross revenue per acre, IRR percentages indicated generally positive returns. Multiplied over the entire ADA region, there was significant economic impact from the irrigated potato acreage. By examining the potential irrigated acreage in the ADA, there is a possibility of achieving $124 million of Net Farm Returns.

8.4 Big picture – What do all the results mean for farmers? For policy makers? Other Stakeholders?

The economics of potato farming make irrigation a big lever for local, regional, provincial and national impact. By allocating more water to irrigation, these economic impacts can be realized. This is consistent with research previously done by Kulthreshtha (2000), Kulthreshtha and Grant (2002), and Manitoba Agriculture and Food (2001), where it was demonstrated that irrigated potato farming provides positive economic impact.

The simulation model demonstrated that the aquifer, through management, can support increased outflow of water, particularly in years where excess inflow is predicted. The rest of the stakeholders for the water remain satisfied, while the excess flow is utilized to maximize the benefit for ADA-area potato farmers.

A different issue for policy makers is the efficient allocation of the excess water. Certainly allocating to irrigation makes regional economic sense for the ADA area. However if the excess water was used for a higher value economic benefit downstream (i.e. for an industrial application), it may have a higher payoff from a provincial and national GDP perspective.

This paper has advocated an increase in irrigation, and demonstrated the positive economic impact of increased irrigation. However it is recognized that the decision to increase irrigation may have effects on other stakeholder groups that have not been considered as part of this research. It is necessary to ensure that if irrigation is increased in the ADA that environmental concerns are considered, that ADA farmers remain mindful of good agronomic practices including farm management, soil testing, precision farming, etc. Water resource management, sustainability and strong agronomic practices continue to be important considerations as the irrigation policies are adjusted to meet the needs of the ADA potato growers.

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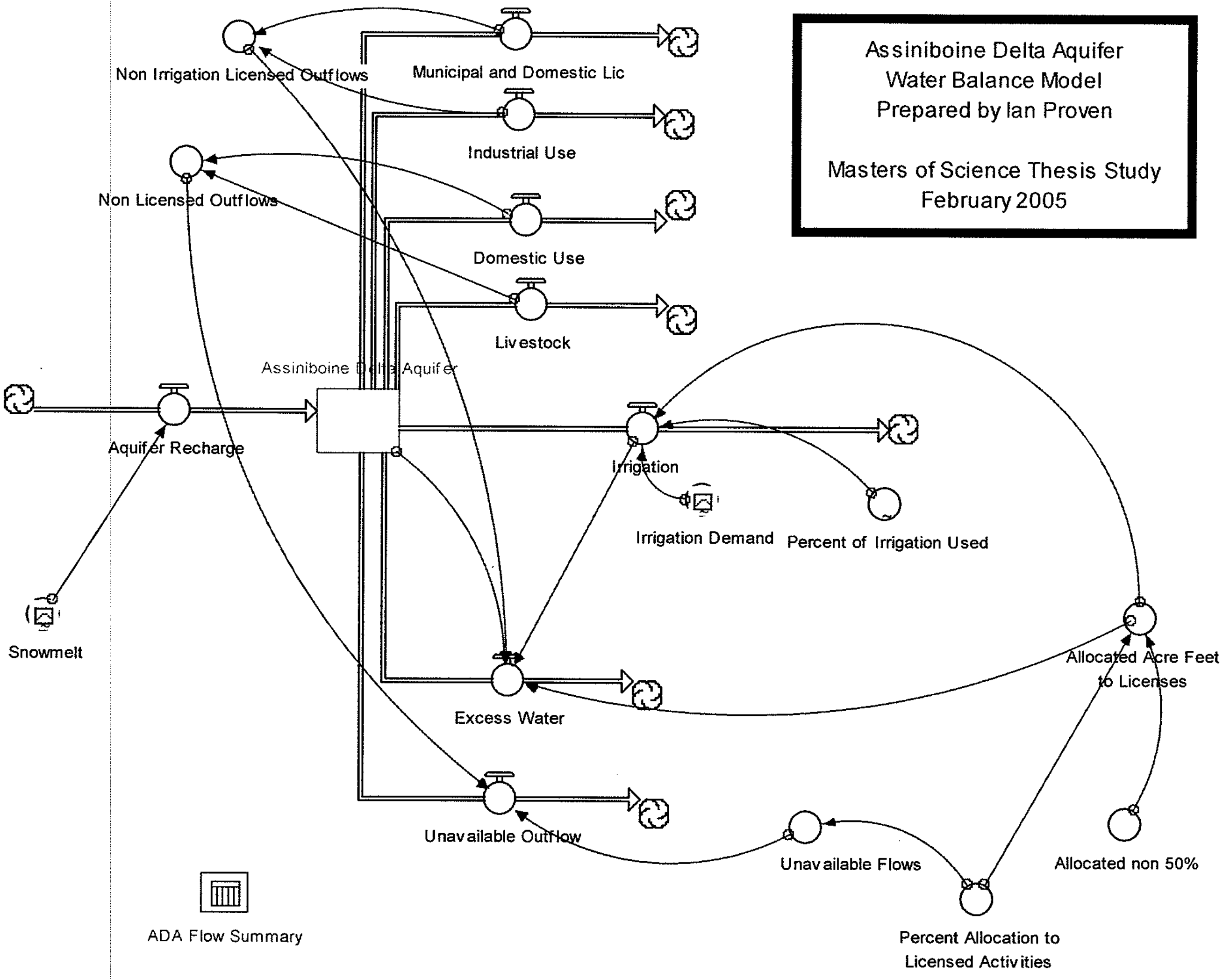
APPENDIX 1 – SIMULATION MODELS

STELLA 7.0.3: Assiniboine Delta Water Balance Simulation Model



STELLA 7.0.3: Assiniboine Delta Water Balance Simulation Model – Equations in the model

```
Assiniboine_Delta_Aquifer(t) = Assiniboine_Delta_Aquifer(t - dt) + (Aquifer_Recharge - Industrial_Use - Livestock - Domestic_Use -
Municipal_and_Domestic_Lic - Irrigation - Unavailable_Outflow - Excess_Water) * dt
INIT Assiniboine_Delta_Aquifer = 12000000

INFLOWS:
Aquifer_Recharge = Snowmelt
OUTFLOWS:
Industrial_Use = if mod(time,2)=0 then 3800 else 0
Livestock = if mod(time,2)=0 then 1200
else 0
Domestic_Use = if mod(time,2)=0 then 2276 else 0
Municipal_and_Domestic_Lic = if mod(time,2)=0 then 1500+200 else 0
Irrigation = if mod(time,2)>0 then 0 else

min(Allocated_Acre_Feet__to_Licenses, Irrigation_Demand*Percent_of_Irrigation_Used)
Unavailable_Outflow = if mod(time,2)=0 then
Unavailable_Flows-Non_Licensed_Outflows
else 0
Excess_Water = if mod(time,2)=0>0 then

(Allocated_Acre_Feet__to_Licenses-Irrigation-Non_Irrigation_Licensed_Outflows)-220
-max((12000000-Assiniboine_Delta_Aquifer),0)

else

max((Assiniboine_Delta_Aquifer-12000000),0)
Allocated_Acre_Feet__to_Licenses = Percent_Allocation_to_Licensed_Activities*98465+Allocated_non_50%
Allocated_non_50% = 2587
Non_Irrigation_Licensed_Outflows = Industrial_Use+Municipal_and_Domestic_Lic
Non_Licensed_Outflows = Livestock+Domestic_Use
Percent_Allocation_to_Licensed_Activities = .5
Unavailable_Flows = 57000 + ((1-Percent_Allocation_to_Licensed_Activities)*98465)+8168
Irrigation_Demand = GRAPH(TIME)
(0.00, 23500), (1.00, 23500), (2.00, 23500), (3.00, 23500), (4.00, 23500), (5.00, 23500), (6.00, 23500), (7.00, 23500), (8.00, 23500), (9.00, 23500),
(10.0, 23500), (11.0, 23500), (12.0, 23500), (13.0, 23500), (14.0, 23500), (15.0, 23500), (16.0, 23500), (17.0, 23500), (18.0, 23500), (19.0, 23500),
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(30.0, 23500), (31.0, 23500), (32.0, 23500), (33.0, 23500), (34.0, 23500), (35.0, 23500), (36.0, 23500), (37.0, 23500), (38.0, 23500), (39.0, 23500),
(40.0, 23500)
```
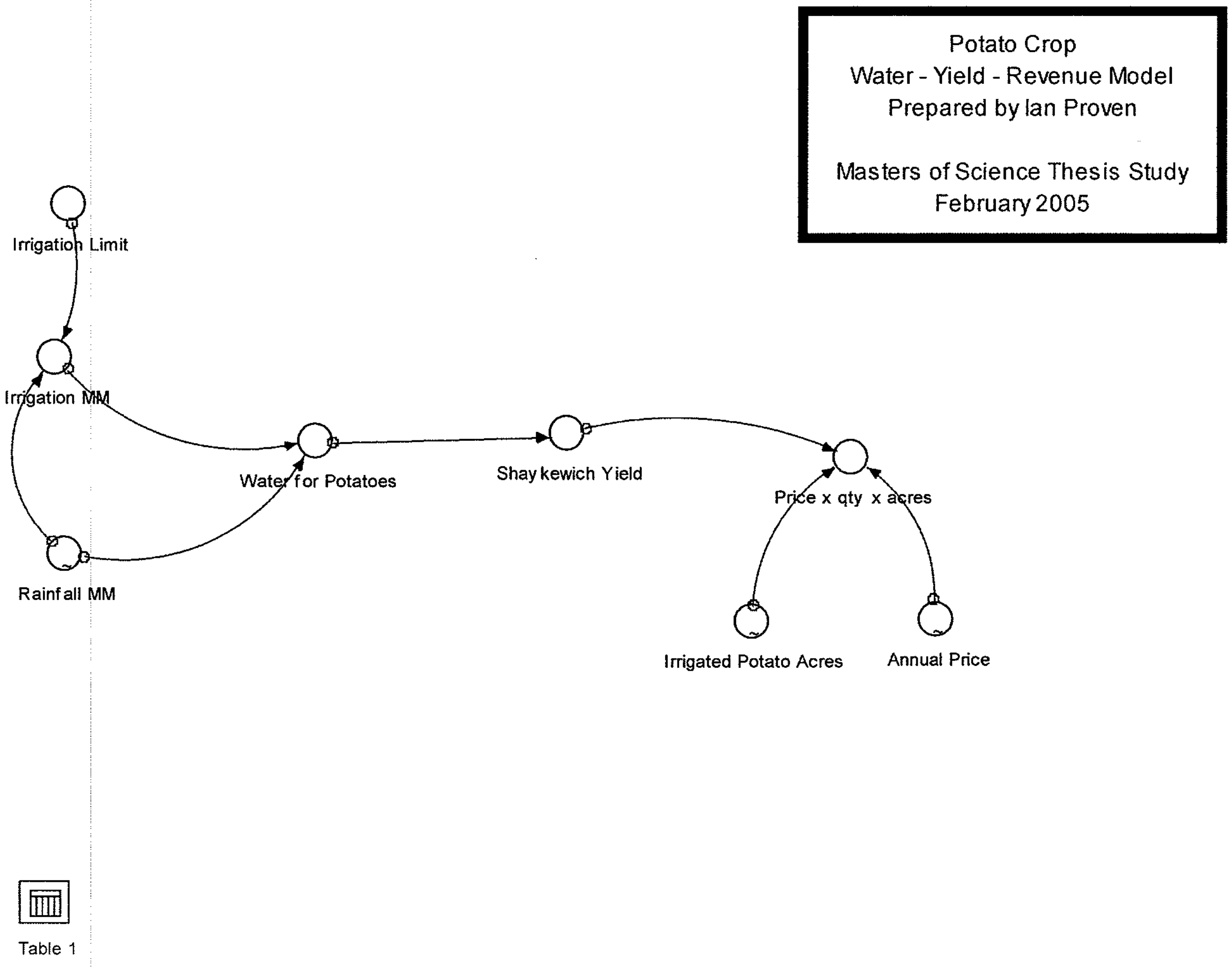

Percent_of_Irrigation_Used = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00), (26.0, 1.00), (27.0, 1.00), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 1.00), (40.0, 1.00)
Snowmelt = GRAPH(TIME)
(0.00, 166000), (1.00, 0.00), (2.00, 166000), (3.00, 0.00), (4.00, 166000), (5.00, 0.00), (6.00, 166000), (7.00, 0.00), (8.00, 166000), (9.00, 0.00), (10.0, 166000), (11.0, 0.00), (12.0, 166000), (13.0, 0.00), (14.0, 166000), (15.0, 0.00), (16.0, 166000), (17.0, 0.00), (18.0, 166000), (19.0, 0.00), (20.0, 166000), (21.0, 0.00), (22.0, 166000), (23.0, 0.00), (24.0, 166000), (25.0, 0.00), (26.0, 166000), (27.0, 0.00), (28.0, 166000), (29.0, 0.00), (30.0, 166000), (31.0, 0.00), (32.0, 166000), (33.0, 0.00), (34.0, 166000), (35.0, 0.00), (36.0, 166000), (37.0, 0.00), (38.0, 166000), (39.0, 0.00), (40.0, 0.00)

STELLA 7.0.3: Water – Yield - Revenue Simulation Model



STELLA 7.0.3: Irrigation – Yield – Revenue Simulation Model – Equations in the Model

```
Irrigation_Limit = 8*25.4
Irrigation_MM = min(max(400-Rainfall_MM,0),Irrigation_Limit)
Price_x_qty_x_acres = Annual_Price*Shaykewich_Yield*Irrigated_Potato_Acres
Shaykewich_Yield = -0.0026*Water_for_Potatoes^2+(2.1226*Water_for_Potatoes)-92.319
Water_for_Potatoes = Irrigation_MM+Rainfall_MM
Annual_Price = GRAPH(TIME)
(0.00, 8.00), (1.00, 8.00), (2.00, 8.00), (3.00, 8.00), (4.00, 8.00), (5.00, 8.00), (6.00, 8.00), (7.00, 8.00),
(8.00, 8.00), (9.00, 8.00), (10.0, 8.00), (11.0, 8.00), (12.0, 8.00), (13.0, 8.00), (14.0, 8.00), (15.0, 8.00),
(16.0, 8.00), (17.0, 8.00), (18.0, 8.00), (19.0, 8.00), (20.0, 8.00)
Irrigated_Potato_Acres = GRAPH(TIME)
(0.00, 35000), (1.00, 35000), (2.00, 35000), (3.00, 35000), (4.00, 35000), (5.00, 35000), (6.00, 35000),
(7.00, 35000), (8.00, 35000), (9.00, 35000), (10.0, 35000), (11.0, 35000), (12.0, 35000), (13.0, 35000),
(14.0, 35000), (15.0, 35000), (16.0, 35000), (17.0, 35000), (18.0, 35000), (19.0, 35000), (20.0, 35000)
Rainfall_MM = GRAPH(TIME)
(0.00, 0.00), (1.00, 25.0), (2.00, 50.0), (3.00, 75.0), (4.00, 100), (5.00, 125), (6.00, 150), (7.00, 175), (8.00,
200), (9.00, 225), (10.0, 250), (11.0, 275), (12.0, 300), (13.0, 325), (14.0, 350), (15.0, 375), (16.0, 400),
(17.0, 425), (18.0, 450), (19.0, 475), (20.0, 475)
```

APPENDIX 2 – WATER BALANCE SCENARIO OUTPUT

Scenario 1 - Steady State

Half-Year	Assiniboine Delta Aquifer	Aquifer Recharge	Unavailable Outflow	Irrigation	Excess Water	Non Irrigation Licensed Outflow	Non Licensed Outflows	Allocated to Licenses	Percent Allocation to Licenses	Percent of Irrigation Used
0	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
1	12,000,000	0	0	0	0	0	0	51,820	50%	100%
2	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
3	12,000,000	0	0	0	0	0	0	51,820	50%	100%
4	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
5	12,000,000	0	0	0	0	0	0	51,820	50%	100%
6	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
7	12,000,000	0	0	0	0	0	0	51,820	50%	100%
8	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
9	12,000,000	0	0	0	0	0	0	51,820	50%	100%
10	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
11	12,000,000	0	0	0	0	0	0	51,820	50%	100%
12	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
13	12,000,000	0	0	0	0	0	0	51,820	50%	100%
14	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
15	12,000,000	0	0	0	0	0	0	51,820	50%	100%
16	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
17	12,000,000	0	0	0	0	0	0	51,820	50%	100%
18	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
19	12,000,000	0	0	0	0	0	0	51,820	50%	100%
20	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
Final	12,000,000							51,820	50%	100%

Scenario 2 - 3 Years of 30% Reduction in Recharge Inflow

Half-Year	Assiniboine Delta Aquifer	Aquifer Recharge	Unavailable Outflow	Irrigation	Excess Water	Non Irrigation Licensed Outflow	Non Licensed Outflows	Allocated to Licenses	Percent Allocation to Licenses	Percent of Irrigation Used
0	12,000,000	116,200	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
1	11,950,200	0	0	0	0	0	0	51,820	50%	100%
2	11,950,200	116,200	110,925	23,500	0	5,500	3,476	51,820	50%	100%
3	11,923,000	0	0	0	0	0	0	51,820	50%	100%
4	11,923,000	116,200	110,925	23,500	0	5,500	3,476	51,820	50%	100%
5	11,895,799	0	0	0	0	0	0	51,820	50%	100%
6	11,895,799	166,000	110,925	23,500	0	5,500	3,476	51,820	50%	100%
7	11,918,399	0	0	0	0	0	0	51,820	50%	100%
8	11,918,399	166,000	110,925	23,500	0	5,500	3,476	51,820	50%	100%
9	11,940,998	0	0	0	0	0	0	51,820	50%	100%
10	11,940,998	166,000	110,925	23,500	0	5,500	3,476	51,820	50%	100%
11	11,963,598	0	0	0	0	0	0	51,820	50%	100%
12	11,963,598	166,000	110,925	23,500	0	5,500	3,476	51,820	50%	100%
13	11,986,197	0	0	0	0	0	0	51,820	50%	100%
14	11,986,197	166,000	110,925	23,500	8,797	5,500	3,476	51,820	50%	100%
15	12,000,000	0	0	0	0	0	0	51,820	50%	100%
16	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
17	12,000,000	0	0	0	0	0	0	51,820	50%	100%
18	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
19	12,000,000	0	0	0	0	0	0	51,820	50%	100%
20	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
Final	12,000,000							51,820	50%	100%

Scenario 3 - 3 Years of 30% Excess Inflow

Half-Year	Assiniboine Delta Aquifer	Aquifer Recharge	Unavailable Outflow	Irrigation	Excess Water	Non Irrigation Licensed Outflow	Non Licensed Outflows	Allocated to Licenses	Percent Allocation to Licenses	Percent of Irrigation Used
0	12,000,000	215,800	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
1	12,049,800	0	0	0	49,800	0	0	51,820	50%	100%
2	12,000,000	215,800	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
3	12,049,800	0	0	0	49,800	0	0	51,820	50%	100%
4	12,000,000	215,800	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
5	12,049,800	0	0	0	49,800	0	0	51,820	50%	100%
6	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
7	12,000,000	0	0	0	0	0	0	51,820	50%	100%
8	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
9	12,000,000	0	0	0	0	0	0	51,820	50%	100%
10	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
11	12,000,000	0	0	0	0	0	0	51,820	50%	100%
12	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
13	12,000,000	0	0	0	0	0	0	51,820	50%	100%
14	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
15	12,000,000	0	0	0	0	0	0	51,820	50%	100%
16	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
17	12,000,000	0	0	0	0	0	0	51,820	50%	100%
18	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
19	12,000,000	0	0	0	0	0	0	51,820	50%	100%
20	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
Final	12,000,000							51,820	50%	100%

Scenario 4 - 2000 acre-feet increase in Irrigation Outflow per year

Half-Year	Assiniboine Delta Aquifer	Aquifer Recharge	Unavailable Outflow	Irrigation	Excess Water	Non Irrigation Licensed Outflow	Non Licensed Outflows	Allocated to Licenses	Percent Allocation to Licenses	Percent of Irrigation Used
0	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
1	12,000,000	0	0	0	0	0	0	51,820	50%	100%
2	12,000,000	166,000	110,925	25,500	20,600	5,500	3,476	51,820	50%	100%
3	12,000,000	0	0	0	0	0	0	51,820	50%	100%
4	12,000,000	166,000	110,925	27,500	18,600	5,500	3,476	51,820	50%	100%
5	12,000,000	0	0	0	0	0	0	51,820	50%	100%
6	12,000,000	166,000	110,925	29,500	16,600	5,500	3,476	51,820	50%	100%
7	12,000,000	0	0	0	0	0	0	51,820	50%	100%
8	12,000,000	166,000	110,925	31,500	14,600	5,500	3,476	51,820	50%	100%
9	12,000,000	0	0	0	0	0	0	51,820	50%	100%
10	12,000,000	166,000	110,925	33,500	12,600	5,500	3,476	51,820	50%	100%
11	12,000,000	0	0	0	0	0	0	51,820	50%	100%
12	12,000,000	166,000	110,925	35,500	10,600	5,500	3,476	51,820	50%	100%
13	12,000,000	0	0	0	0	0	0	51,820	50%	100%
14	12,000,000	166,000	110,925	37,500	8,600	5,500	3,476	51,820	50%	100%
15	12,000,000	0	0	0	0	0	0	51,820	50%	100%
16	12,000,000	166,000	110,925	39,500	6,600	5,500	3,476	51,820	50%	100%
17	12,000,000	0	0	0	0	0	0	51,820	50%	100%
18	12,000,000	166,000	110,925	41,599	4,501	5,500	3,476	51,820	50%	100%
19	12,000,000	0	0	0	0	0	0	51,820	50%	100%
20	12,000,000	166,000	110,925	43,500	2,600	5,500	3,476	51,820	50%	100%
Final	12,000,000							51,820	50%	100%

Scenario 5 - 2000 acre-feet increase in Irrigation Outflow per year, at 60% Allocation

Half-Year	Assiniboine Delta Aquifer	Aquifer Recharge	Unavailable Outflow	Irrigation	Excess Water	Non Irrigation Licensed Outflow	Non Licensed Outflows	Allocated to Licenses	Percent Allocation to Licenses	Percent of Irrigation Used
0	12,000,000	166,000	101,078	23,500	32,446	5,500	3,476	61,666	60%	100%
1	12,000,000	0	0	0	0	0	0	61,666	60%	100%
2	12,000,000	166,000	101,078	25,500	30,446	5,500	3,476	61,666	60%	100%
3	12,000,000	0	0	0	0	0	0	61,666	60%	100%
4	12,000,000	166,000	101,078	27,500	28,446	5,500	3,476	61,666	60%	100%
5	12,000,000	0	0	0	0	0	0	61,666	60%	100%
6	12,000,000	166,000	101,078	29,500	26,446	5,500	3,476	61,666	60%	100%
7	12,000,000	0	0	0	0	0	0	61,666	60%	100%
8	12,000,000	166,000	101,078	31,500	24,446	5,500	3,476	61,666	60%	100%
9	12,000,000	0	0	0	0	0	0	61,666	60%	100%
10	12,000,000	166,000	101,078	33,500	22,446	5,500	3,476	61,666	60%	100%
11	12,000,000	0	0	0	0	0	0	61,666	60%	100%
12	12,000,000	166,000	101,078	35,500	20,446	5,500	3,476	61,666	60%	100%
13	12,000,000	0	0	0	0	0	0	61,666	60%	100%
14	12,000,000	166,000	101,078	37,500	18,446	5,500	3,476	61,666	60%	100%
15	12,000,000	0	0	0	0	0	0	61,666	60%	100%
16	12,000,000	166,000	101,078	39,500	16,446	5,500	3,476	61,666	60%	100%
17	12,000,000	0	0	0	0	0	0	61,666	60%	100%
18	12,000,000	166,000	101,078	41,599	14,347	5,500	3,476	61,666	60%	100%
19	12,000,000	0	0	0	0	0	0	61,666	60%	100%
20	12,000,000	166,000	101,078	43,500	12,446	5,500	3,476	61,666	60%	100%
Final	12,000,000							61,666	60%	100%

Scenario 6 - 3 Years of 30% Reduction in Recharge Inflow followed by 2 Years of 30% Excessive Inflow

Half-Year	Assiniboine Delta Aquifer	Aquifer Recharge	Unavailable Outflow	Irrigation	Excess Water	Non Irrigation Licensed Outflow	Non Licensed Outflows	Allocated to Licenses	Percent Allocation to Licenses	Percent of Irrigation Used
0	12,000,000	116,200	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
1	11,950,200	0	0	0	0	0	0	51,820	50%	100%
2	11,950,200	116,200	110,925	23,500	0	5,500	3,476	51,820	50%	100%
3	11,923,000	0	0	0	0	0	0	51,820	50%	100%
4	11,923,000	116,200	110,925	23,500	0	5,500	3,476	51,820	50%	100%
5	11,895,799	0	0	0	0	0	0	51,820	50%	100%
6	11,895,799	215,800	110,925	23,500	0	5,500	3,476	51,820	50%	100%
7	11,968,199	0	0	0	0	0	0	51,820	50%	100%
8	11,968,199	215,800	110,925	23,500	0	5,500	3,476	51,820	50%	100%
9	12,040,598	0	0	0	40,598	0	0	51,820	50%	100%
10	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
11	12,000,000	0	0	0	0	0	0	51,820	50%	100%
12	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
13	12,000,000	0	0	0	0	0	0	51,820	50%	100%
14	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
15	12,000,000	0	0	0	0	0	0	51,820	50%	100%
16	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
17	12,000,000	0	0	0	0	0	0	51,820	50%	100%
18	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
19	12,000,000	0	0	0	0	0	0	51,820	50%	100%
20	12,000,000	166,000	110,925	23,500	22,600	5,500	3,476	51,820	50%	100%
Final	12,000,000							51,820	50%	100%

APPENDIX 3 – WATER-YIELD-REVENUE SCENARIO OUTPUT

Scenario 1 - Potato Revenue sensitivity to Rainfall. Irrigation limit: 8" (203.2 mm)

											ΔR	ΔW	
Test	**Irrigation (mm)**	**Rainfall (mm)**	**Revenue $**	**Yield (cwt/acre)**	**Irrigation Limit (mm)**	**Water for Potatoes (mm)**	**Price ($/cwt)**	**Irrigated Potato Acres**	**Revenue per Acre ($)**	**Revenue per mm ($)**	**Change in Revenue per acre ($)**	**Change in Water for Potatoes (mm)**	**Ratio of Changes (ΔR/ΔW)**
0	203.2	0	64,859,200	231.64	203.2	203.2	8	35,000	1,853	319,189			
1	203.2	25	71,864,800	256.66	203.2	228.2	8	35,000	2,053	314,920	200.16	25	8.01
2	203.2	50	77,963,200	278.44	203.2	253.2	8	35,000	2,228	307,912	174.24	25	6.97
3	203.2	75	83,148,800	296.96	203.2	278.2	8	35,000	2,376	298,881	148.16	25	5.93
4	203.2	100	87,424,400	312.23	203.2	303.2	8	35,000	2,498	288,339	122.16	25	4.89
5	203.2	125	90,792,800	324.26	203.2	328.2	8	35,000	2,594	276,639	96.24	25	3.85
6	203.2	150	93,248,400	333.03	203.2	353.2	8	35,000	2,664	264,010	70.16	25	2.81
7	203.2	175	94,796,800	338.56	203.2	378.2	8	35,000	2,708	250,653	44.24	25	1.77
8	200	200	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	17.28	25	0.69
9	175	225	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
10	150	250	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
11	125	275	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
12	100	300	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
13	75	325	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
14	50	350	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
15	25	375	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
16	0	400	95,401,600	340.72	203.2	400	8	35,000	2,726	238,504	0.00	25	0.00
17	0	425	95,244,800	340.16	203.2	425	8	35,000	2,721	224,105	-4.48	25	-0.18
18	0	450	94,178,000	336.35	203.2	450	8	35,000	2,691	209,284	-30.48	25	-1.22
19	0	475	92,201,200	329.29	203.2	475	8	35,000	2,634	194,108	-56.48	25	-2.26
Final	0	475	92,201,200	329.29	203.2	475	8	35,000	2,634	194,108			

Scenario 2 - Potato Revenue sensitivity to Price. Irrigation Limit: 8" (203.2 mm)

											ΔR	ΔP	
Test	**Irrigation (mm)**	**Rainfall (mm)**	**Revenue $**	**Yield (cwt/acre)**	**Irrigation Limit (mm)**	**Water for Potatoes (mm)**	**Price ($/cwt)**	**Irrigated Potato Acres**	**Revenue per Acre ($)**	**Revenue per mm ($)**	**Change in Revenue per acre ($)**	**Change in Price for Potatoes ($)**	**Ratio of Changes (ΔR/ΔP)**
0	203.2	196.8	89,439,000	340.72	203.2	400	7.50	35,000	2,555	223,598			
1	203.2	196.8	90,631,520	340.72	203.2	400	7.60	35,000	2,589	226,579	34.07	0.10	340.72
2	203.2	196.8	91,824,040	340.72	203.2	400	7.70	35,000	2,624	229,560	34.07	0.10	340.72
3	203.2	196.8	93,016,560	340.72	203.2	400	7.80	35,000	2,658	232,541	34.07	0.10	340.72
4	203.2	196.8	94,209,080	340.72	203.2	400	7.90	35,000	2,692	235,523	34.07	0.10	340.72
5	203.2	196.8	95,401,600	340.72	203.2	400	8.00	35,000	2,726	238,504	34.07	0.10	340.72
6	203.2	196.8	96,594,120	340.72	203.2	400	8.10	35,000	2,760	241,485	34.07	0.10	340.72
7	203.2	196.8	97,786,640	340.72	203.2	400	8.20	35,000	2,794	244,467	34.07	0.10	340.72
8	203.2	196.8	98,979,160	340.72	203.2	400	8.30	35,000	2,828	247,448	34.07	0.10	340.72
9	203.2	196.8	100,171,680	340.72	203.2	400	8.40	35,000	2,862	250,429	34.07	0.10	340.72
10	203.2	196.8	101,364,200	340.72	203.2	400	8.50	35,000	2,896	253,411	34.07	0.10	340.72
11	203.2	196.8	102,556,720	340.72	203.2	400	8.60	35,000	2,930	256,392	34.07	0.10	340.72
12	203.2	196.8	103,749,240	340.72	203.2	400	8.70	35,000	2,964	259,373	34.07	0.10	340.72
13	203.2	196.8	104,941,760	340.72	203.2	400	8.80	35,000	2,998	262,354	34.07	0.10	340.72
14	203.2	196.8	106,134,280	340.72	203.2	400	8.90	35,000	3,032	265,336	34.07	0.10	340.72
15	203.2	196.8	107,326,800	340.72	203.2	400	9.00	35,000	3,066	268,317	34.07	0.10	340.72
16	203.2	196.8	108,519,320	340.72	203.2	400	9.10	35,000	3,101	271,298	34.07	0.10	340.72
17	203.2	196.8	109,711,840	340.72	203.2	400	9.20	35,000	3,135	274,280	34.07	0.10	340.72
18	203.2	196.8	110,904,360	340.72	203.2	400	9.30	35,000	3,169	277,261	34.07	0.10	340.72
19	203.2	196.8	112,096,880	340.72	203.2	400	9.40	35,000	3,203	280,242	34.07	0.10	340.72
Final	203.2	196.8	113,289,400	340.72	203.2	400	9.50	35,000	3,237	283,224			

Scenario 3 - Potato Revenue sensitivity to Increased Potato Acres. Irrigation Limit: 8" (203.2 mm)

											ΔT	ΔA	
Test	Irrigation (mm)	Rainfall (mm)	Revenue $	Yield (cwt/acre)	Irrigation Limit (mm)	Water for Potatoes (mm)	Price ($/cwt)	Irrigated Potato Acres	Revenue per Acre ($)	Revenue per mm ($)	Change in Total Revenue ($)	Change in Potato Acres	Ratio of Changes (ΔT/ΔA)
0	203.2	196.8	81,772,800	341	203.2	400	8.00	30,000	2,726	204,432			
1	203.2	196.8	84,498,560	341	203.2	400	8.00	31,000	2,726	211,246	2,725,760	1,000	2,726
2	203.2	196.8	87,224,320	341	203.2	400	8.00	32,000	2,726	218,061	2,725,760	1,000	2,726
3	203.2	196.8	89,950,080	341	203.2	400	8.00	33,000	2,726	224,875	2,725,760	1,000	2,726
4	203.2	196.8	92,675,840	341	203.2	400	8.00	34,000	2,726	231,690	2,725,760	1,000	2,726
5	203.2	196.8	95,401,600	341	203.2	400	8.00	35,000	2,726	238,504	2,725,760	1,000	2,726
6	203.2	196.8	98,127,360	341	203.2	400	8.00	36,000	2,726	245,318	2,725,760	1,000	2,726
7	203.2	196.8	100,853,120	341	203.2	400	8.00	37,000	2,726	252,133	2,725,760	1,000	2,726
8	203.2	196.8	103,578,880	341	203.2	400	8.00	38,000	2,726	258,947	2,725,760	1,000	2,726
9	203.2	196.8	106,304,640	341	203.2	400	8.00	39,000	2,726	265,762	2,725,760	1,000	2,726
10	203.2	196.8	109,030,400	341	203.2	400	8.00	40,000	2,726	272,576	2,725,760	1,000	2,726
11	203.2	196.8	111,756,160	341	203.2	400	8.00	41,000	2,726	279,390	2,725,760	1,000	2,726
12	203.2	196.8	114,481,920	341	203.2	400	8.00	42,000	2,726	286,205	2,725,760	1,000	2,726
13	203.2	196.8	117,207,680	341	203.2	400	8.00	43,000	2,726	293,019	2,725,760	1,000	2,726
14	203.2	196.8	119,933,440	341	203.2	400	8.00	44,000	2,726	299,834	2,725,760	1,000	2,726
15	203.2	196.8	122,659,200	341	203.2	400	8.00	45,000	2,726	306,648	2,725,760	1,000	2,726
16	203.2	196.8	125,384,960	341	203.2	400	8.00	46,000	2,726	313,462	2,725,760	1,000	2,726
17	203.2	196.8	128,110,720	341	203.2	400	8.00	47,000	2,726	320,277	2,725,760	1,000	2,726
18	203.2	196.8	130,836,480	341	203.2	400	8.00	48,000	2,726	327,091	2,725,760	1,000	2,726
19	203.2	196.8	133,562,240	341	203.2	400	8.00	49,000	2,726	333,906	2,725,760	1,000	2,726
Final	203.2	196.8	136,288,000	341	203.2	400	8.00	50,000	2,726	340,720			

APPENDIX 4 – ON-FARM WORKSHEETS AND DATA

Capital Investment
(Assuming 450 acres of potatoes)

	Capital Investment		Salvage Value		
	Total Cost	Per Acre Cost		Total Value	Per Acre Value
Land Value					
($1500 per acre)	675,000	1,500.00			
Storage Facilities (100,000 CWT)					
Building and climate control ($6 per cwt)	600,000	1,333.33			
Bin Piler	50,000	111.11	Useful Life (years)	20	
Grading Table	70,000	155.56	Salvage Value %	5	
Total Storage Facilities	**720,000**	**1,600.00**	**Salvage Value**	**36,000**	**80**
Irrigation System					
Pivot, need 3: 1 pivot per 135 acres ($60,000 each)	180,000	400.00			
Well (3 req'd, $50,000 each)	150,000	333.33	Useful Life (years)	15	
Pipeline	10,000	22.22	Salvage Value %	10	
Total Irrigation	**340,000**	**755.56**	**Salvage Value**	**34,000**	**76**
Machinery & Equipment*					
Digger	120,000	266.67			
Windrower	90,000	200.00			
Tractors (used)	30,000	66.67			
Extra Trucks (3 @ $20,000) used	60,000	133.33			
Live Bottom Boxes (3 @ $30,000) used	90,000	200.00			
Deep Tiller	30,000	66.67	Useful Life (years)	20	
Cultivators (2 @ $15,000)	30,000	66.67	Salvage Value %	10	
Total Machinery & Equipment	**450,000**	**1,000.00**	**Salvage Value**	**45,000**	**100**
Total Capital Investment	**2,185,000**	**4,855.56**	**Total Salvage Value**	**115,000**	**256**
Total Equipment Cost	**1,510,000**	**3,355.56**	**Present Value of Salvage**	**29,718**	**66**
Equipment Cost per year	75,500	168	(assume after tax opportunity cost of 7%)		

* Machinery & Equipment is assuming some Used equipment to cut costs

Source:
Personal Interview - Randy Baron, 2002

Net Farm Returns for Irrigated Potato Acreage Per Acre

Net Farm Return and EBITDA per Acre

	Baseline	**Scenario 1**	**Scenario 2**	**Scenario 3**
Yield (cwt/acre)	250	200	250	300
Price ($/cwt)	8.00	8.00	7.00	8.00
Gross Revenues	**2,000**	**1,600**	**1,750**	**2,400**
Production Costs[3]	1,221.00	1,221.00	1,221.00	1,221.00
Fixed Costs				
Debt[2]	95.5	95.5	95.5	95.5
Depreciation[2]	320	320	320	320
Total Fixed Costs	415.5	415.5	415.5	415.5
Labour (own)[3]	87.5	87.5	87.5	87.5
Total Costs	**1,724.00**	**1,724.00**	**1,724.00**	**1,724.00**
Net Farm Return	**276.00**	**-124.00**	**26.00**	**676.00**
EBITDA	**691.50**	**291.50**	**441.50**	**1,091.50**

Sources:

[1] Manitoba Conservation, 2001

[2] Randy Baron - Personal Interview, 2003

[3] Manitoba Agriculture and Food, 1997

[4] Source: David Hay, Manitoba Agriculture and Food, 2003 [Excellent and Good acres within ADA]

Net Farm Returns for Irrigated Potato Acreage

Total ADA

	Baseline Scenario Total ADA		Scenario 1 Total ADA		Scenario 2 Total ADA		Scenario 3 Total ADA	
	Irrigated Acres[1]	**Potential Irrigated* Potato Acres**[4]	**Irrigated Acres**[1]	**Potential Irrigated* Potato Acres**[4]	**Irrigated Acres**[1]	**Potential Irrigated* Potato Acres**[4]	**Irrigated Acres**[1]	**Potential Irrigated* Potato Acres**[4]
Acres	34,500	184,000	34,500	184,000	34,500	184,000	34,500	184,000
Gross Revenues	69,000,000	368,000,000	55,200,000	322,000,000	60,375,000	322,000,000	82,800,000	441,600,000
Production Costs[3]	42,124,500	224,664,000	42,124,500	224,664,000	42,124,500	224,664,000	42,124,500	224,664,000
Fixed Costs								
Debt[2]	3,294,750	17,572,000	3,294,750	17,572,000	3,294,750	17,572,000	3,294,750	17,572,000
Depreciation[2]	11,040,000	58,880,000	11,040,000	58,880,000	11,040,000	58,880,000	11,040,000	58,880,000
Total Fixed Costs	14,334,750	76,452,000	14,334,750	76,452,000	14,334,750	76,452,000	14,334,750	76,452,000
Labour (own)[3]	3,018,750	16,100,000	3,018,750	16,100,000	3,018,750	16,100,000	3,018,750	16,100,000
Total Costs	**59,478,000**	**317,216,000**	**59,478,000**	**317,216,000**	**59,478,000**	**317,216,000**	**59,478,000**	**317,216,000**
Net Farm Return	**9,522,000**	**50,784,000**	**-4,278,000**	**4,784,000**	**897,000**	**4,784,000**	**23,322,000**	**124,384,000**
EBITDA	**23,856,750**	**127,236,000**	**10,056,750**	**81,236,000**	**15,231,750**	**81,236,000**	**37,656,750**	**200,836,000**

*Potential Acres for Suitable for Irrigated Potato Production = 552,491

Based on 3 Year Rotation of Acres, approximately 184,000 acres are the maximum potential

Sources:

[1] Manitoba Conservation, 2001

[2] Randy Baron - Personal Interview, 2002

[3] Manitoba Agriculture and Food, 2001a

[4] Source: David Hay, Manitoba Agriculture and Food, 2003 [Class 1, 2, 3 acres within ADA]

Economic Analysis - Summary

Scenario	Gross Revenue per acre	Net Farm Returns per acre	EBITDA per acre	B/C Ratio per acre	IRR Year 10 per acre	IRR Year 20 per acre
Scenario 1	1,600	-124	291.50	0.42	-	-
Scenario 2	1,750	26	441.50	0.68	-	-
Baseline	2,000	276	691.50	1.12	-4%	1%
Scenario 3	2,400	676	1091.50	1.82	7%	13%

($ 000's)

TOTAL ADA - For all Irrigated Acres (34,500 acres). Values ($000's)

Scenario	Gross Revenue	Net Farm Returns	EBITDA
Scenario 1	55,200	-4,278	10,057
Scenario 2	60,375	897	15,232
Baseline	69,000	9,522	23,857
Scenario 3	82,800	23,322	37,657

($ 000's)

TOTAL ADA - For all Potential Irrigated Potato Acres (184,000 acres)
Values ($000's)

Scenario	Gross Revenue	Net Farm Returns	EBITDA
Scenario 1	294,400	-22,816	53,636
Scenario 2	322,000	4,784	81,236
Baseline	368,000	50,784	127,236
Scenario 3	441,600	124,384	200,836

Economic Analysis - Baseline

Variable	Description	Per Acre Value	NPV
	Discount Rate	10%	
Variable	**Description**	**Per Acre Value**	**NPV**
B(t)	= NPV(Net Farm Return) = NPV(R(t) - AE(t))	276.00	$2,349.74
Land Cost	=Current Cost	1500	
	+ PV($2000 at year 20)	297.29	
Equipment Cost	=Current Cost	3,355.56	
	-PV(Salvage Value)	66.04	
Equipment Tax Benefit	=NPV(320 per acre)	320	$2,724.34
B(t) - Land Cost - Equipment Cost + Equipment Tax Benefit			$581.86

Cost - Benefit Ratio		
Benefits	B(t)	2,350
	Land (20)	297
	Salvage (20)	66
	Tax Benefits	2,724
	Total Benefits	**5,437**
Costs	Land Cost	1,500
	Equipment Cost	3,356
	Total Costs	**4,856**
	B/C Ratio	1.12

Internal Rate of Return			
	Year	**Cash Flow**	**IRR**
Initial Cost	**0**	**-4855.556**	
Net Income	1	276.00	
Net Income	2	276.00	
Net Income	3	276.00	
Net Income	4	276.00	#NUM!
Net Income	5	276.00	#NUM!
Net Income	6	276.00	#NUM!
Net Income	7	276.00	-19%
Net Income	8	276.00	-15%
Net Income	9	276.00	-12%
Net Income	10	276.00	-9%
Net Income	11	276.00	-7%
Net Income	12	276.00	-5%
Net Income	13	276.00	-4%
Net Income	14	276.00	-3%
Net Income	15	276.00	-2%
Net Income	16	276.00	-1%
Net Income	17	276.00	0%
Net Income	18	276.00	0%
Net Income	19	276.00	1%
Net Income	20	276.00	1%

Economic Analysis - Scenario 1

Variable	Description	Per Acre Value	NPV
	Discount Rate	10%	
Variable	**Description**	**Per Acre Value**	**NPV**
B(t)	= NPV(Net Farm Return) = NPV(R(t) - AE(t))	-124.00	($1,055.68)
Land Cost	=Current Cost	1500	
	+ PV($2000 at year 20)	297.29	
Equipment Cost	=Current Cost	3,355.56	
	-PV(Salvage Value)	66.04	
Equipment Tax Benefit	=NPV(320 per acre)	320	$2,724.34
B(t) - Land Cost - Equipment Cost + Equipment Tax Benefit			($2,823.57)

Cost - Benefit Ratio		
Benefits	B(t)	-1,056
	Land (20)	297
	Salvage (20)	66
	Tax Benefits	2,724
	Total Benefits	**2,032**
Costs	Land Cost	1,500
	Equipment Cost	3,356
	Total Costs	**4,856**
	B/C Ratio	0.42

Internal Rate of Return			
	Year	**Cash Flow**	**IRR**
Initial Cost	**0**	**-4855.556**	
Net Income	1	-124.00	
Net Income	2	-124.00	
Net Income	3	-124.00	
Net Income	4	-124.00	
Net Income	5	-124.00	
Net Income	6	-124.00	#NUM!
Net Income	7	-124.00	#NUM!
Net Income	8	-124.00	#NUM!
Net Income	9	-124.00	#NUM!
Net Income	10	-124.00	#NUM!
Net Income	11	-124.00	#DIV/0!
Net Income	12	-124.00	#DIV/0!
Net Income	13	-124.00	#DIV/0!
Net Income	14	-124.00	#DIV/0!
Net Income	15	-124.00	#DIV/0!
Net Income	16	-124.00	#DIV/0!
Net Income	17	-124.00	#DIV/0!
Net Income	18	-124.00	#DIV/0!
Net Income	19	-124.00	#DIV/0!
Net Income	20	-124.00	#DIV/0!

Economic Analysis - Scenario 2

Discount Rate 10%

Variable	Description	Per Acre Value	NPV
B(t)	= NPV(Net Farm Return) = NPV(R(t) - AE(t))	26.00	$221.35
Land Cost	=Current Cost	1500	
	+ PV($2000 at year 20)	297.29	
Equipment Cost	=Current Cost	3,355.56	
	-PV(Salvage Value)	66.04	
Equipment Tax Benefit	=NPV(320 per acre)	320	$2,724.34
B(t) - Land Cost - Equipment Cost + Equipment Tax Benefit			($1,546.53)

Cost - Benefit Ratio		
Benefits	B(t)	221
	Land (20)	297
	Salvage (20)	66
	Tax Benefits	2,724
	Total Benefits	**3,309**
Costs	Land Cost	1,500
	Equipment Cost	3,356
	Total Costs	**4,856**
	B/C Ratio	0.68

Internal Rate of Return			
	Year	**Cash Flow**	**IRR**
Initial Cost	**0**	**-4855.556**	
Net Income	1	26.00	
Net Income	2	26.00	
Net Income	3	26.00	
Net Income	4	26.00	
Net Income	5	26.00	#NUM!
Net Income	6	26.00	#NUM!
Net Income	7	26.00	#NUM!
Net Income	8	26.00	#NUM!
Net Income	9	26.00	#NUM!
Net Income	10	26.00	#NUM!
Net Income	11	26.00	#DIV/0!
Net Income	12	26.00	#DIV/0!
Net Income	13	26.00	#DIV/0!
Net Income	14	26.00	#DIV/0!
Net Income	15	26.00	#DIV/0!
Net Income	16	26.00	#DIV/0!
Net Income	17	26.00	#DIV/0!
Net Income	18	26.00	#DIV/0!
Net Income	19	26.00	#DIV/0!
Net Income	20	26.00	#DIV/0!

Economic Analysis - Scenario 3

Discount Rate 10%

Variable	Description	Per Acre Value	NPV
B(t)	= NPV(Net Farm Return) = NPV(R(t) - AE(t))	676.00	$5,755.17
Land Cost	=Current Cost	1500	
	+ PV($2000 at year 20)	297.29	
Equipment Cost	=Current Cost	3,355.56	
	-PV(Salvage Value)	66.04	
Equipment Tax Benefit	=NPV(320 per acre)	320	$2,724.34
B(t) - Land Cost - Equipment Cost + Equipment Tax Benefit			$3,987.28

Cost - Benefit Ratio		
Benefits	B(t)	5,755
	Land (20)	297
	Salvage (20)	66
	Tax Benefits	2,724
	Total Benefits	**8,843**
Costs	Land Cost	1,500
	Equipment Cost	3,356
	Total Costs	**4,856**
	B/C Ratio	1.82

Internal Rate of Return			
	Year	**Cash Flow**	**IRR**
Initial Cost	**0**	**-4855.556**	
Net Income	1	676.00	
Net Income	2	676.00	
Net Income	3	676.00	
Net Income	4	676.00	-20%
Net Income	5	676.00	-11%
Net Income	6	676.00	-5%
Net Income	7	676.00	-1%
Net Income	8	676.00	2%
Net Income	9	676.00	5%
Net Income	10	676.00	7%
Net Income	11	676.00	8%
Net Income	12	676.00	9%
Net Income	13	676.00	10%
Net Income	14	676.00	10%
Net Income	15	676.00	11%
Net Income	16	676.00	11%
Net Income	17	676.00	12%
Net Income	18	676.00	12%
Net Income	19	676.00	12%
Net Income	20	676.00	13%

Economic Cost-Benefit Analysis of Irrigated Potatoes
Interview with Randy Baron, Carberry Area Potato Farmer

1) Does a well feed more than one pivot? I.e. can you move a pivot year-after-year, or do you only use it once every 3 years?

mostly one pivot per well, used once every 3 years

2) What is the cost of new/used potato harvesting & seeding implements?

Implement	Price (new)	Price (Used)	Salvage Price	Useful Life (years)
digger	120,000	15,000	20%	15
wind-rower	90,000		20%	15
pivot	60,000		10%	25
shed (100,000 CWT @ $5/CWT)	500,000		10%	50
well	50,000		10%	20
pipes	10,000		0%	20
piler	50,000			20
grading table	70,000			20
extra truck (3 @ $180,000 each)	540,000	20,000		15
extra tractors	170,000	30,000		10
live bottom boxes	70,000	30,000		15
deep tiller	30,000			10
cultivator (2 @ $15,000 each)	30,000			
	940,000			

3) What are estimated operating costs of potato implements?

Randy's operating cost per acre: $1200

4) How many acres does a pivot supply water for?

135

5) What is an average yield per acre (CWT)

260 - 290 CWT per acre gross, 220 - 245 CWT per acre marketable

6) What is an average price (range) CWT for potatoes?

Min	Mid	Max
$7.75/CWT	$8/CWT	$8.5/CWT

7) Tax benefit (%) of equipment 160,000 (depreciation)
(320/acre)

8) Interest cost on equipment

Buildings	30,000	
Total	43,000	95.55555556
	$90 / acres on capital less land	

Land prices: 1500/acre - 25 years
land interest cost

APPENDIX 5 – TELEPHONE CONVERSATIONS AND PERSONAL INTERVIEWS

Additional information gathering was done through some informal conversations with individuals who have experience or involvement with the water management issues in Southern Manitoba and the ADA. Those conversations are summarized below.

A5.1 Telephone Conversation with Frank Render, Manitoba Conservation. Interview conducted on March 28, 2002

- Pine Creek is measured to approximate outflows from ADA using "gross assumptions"
- 0.2 ft of water penetrates to aquifer, times the number of square feet of exposed sand = rough estimate of water outflowing the aquifer
- By policy, 50% of water in developable areas is allocated to irrigators, the rest is allocated to sustainable flows for rivers and swamps
- For outflows, use the following estimates:
  - General human use: 50 Gal/day x population
  - Find out flow rate of pivots for irrigation x # days irrigating x # pivots
  - Contact Ray Bodnaruk for licensing and outflow estimates (like Kroeker Farms in Winkler Aquifer plan)
- Mr. Render estimates the economic value of MidWest foods at $200 million
- Concerns about recycling of water from MidWest's lagoon into the aquifer system. ("recirculating sewage")
- Convinced that the irrigators have had "no impact" on ADA basin water levels through ongoing groundwater measurement tests

- Current focus on ADA is "whole basin" approach, and not to single out sub-basins or individuals and their impacts

A5.2 Personal Interview with Ted Poyser, Manitoba Soils Specialist (retired). Interview conducted March 22, 2002.

- Concerned that no one understands the aquifer and its importance to supplying a great deal of southern Manitoba's fresh water
- AR flow is 50 cubic-feet per second (cfs) from Shellmouth Dam, and is 100 cfs in Portage, so some flow must come from ADA into AR. Not sure what flows from AR into ADA, and what ADA returns to AR.
- Concerned about local till plains in the aquifer that divide basins. Thinks that localized irrigation can cause localized water shortages
- Thinks that current governmental bodies do not have the "big picture" in mind when allocating water licenses. Licensing is done based on local concerns, not using true economic decision variables.
- Convinced that there is a measurable hierarchy of GDP uses for water and that research should quantify the relative return to GDP of irrigation, livestock watering and dry industry from the use of 1 acre-foot of water. He hypothesizes that the approximate magnitude is as follows:
    - 1 acre-foot of water adds $4,000 to GDP when used for irrigation
    - 1 acre-foot of water adds $40,000 to GDP when used for livestock watering
    - 1 acre-foot of water adds $400,000 to GDP when used for dry industry

- This opinion is that water allocation planning should be province-wide and water transfers should not be confined to intra-watershed per current legislation

A5.3 Personal Interview with Randy Baron, Carberry-area potato farmer and irrigator. Interview Conducted on April 23, 2002

- Frustrated with lack of resources being applied to irrigation issues. Lots of studies have been done, but nothing has changed
- Frustrated with the lack of availability of irrigation licenses and the backlog of information to process
- Not seeing the value of all the information they track for the water branch
- Concerned about unlicensed irrigators
- Provided facts and figures used in the on-farm economic analysis (see APPENDIX 4)