MODEL COMPARISON OF THREE IRRIGATION SYSTEMS FOR POTATO PRODUCTION IN QUEBEC

by

Henri Tichoux

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Department of Agricultural and Biosystems Engineering
Macdonald Campus, McGill University
Montreal, Quebec

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ABSTRACT

M.Sc Agricultural and Biosystems Engineering

Henri Tichoux

Model Comparison of Three Irrigation Systems for Potato Production in Quebec

The purpose of this thesis is to design a computer model which compares three sprinkler irrigation systems – portable pipe with volume gun, traveller with volume gun and towable/non-towable centre pivot – for potato production. The model user is required to enter a set of basic data: crop and field conditions, irrigation technical parameters and basic economic data, following which the model establishes the preliminary irrigation system and a comparative investment analysis. The model was applied and tested on a potato farm situated in Notre-Dame-de-la-Paix (southwestern Quebec). Based on a 14-year climatic analysis, supplemental irrigation for a normal rainfall growing period (368 mm) was estimated at 250 mm. The application of the model indicates that for a normal rainfall period with an assumed yield increase of 25% over non-irrigated production, all three systems provide net profits (increases of 11% to 50%). However, when determining the Internal Rate of Return (IRR) on a 10-year period, the maximum rate attained by the more profitable systems – portable pipe and non-towable centre pivot (both with an electric pump) – was 14%, a rate inferior to the IRR for non-irrigated production (17%). The Net Present Value (NPV) analysis for the two most profitable irrigation systems provided a slightly higher NPV value for irrigated than for non-irrigated production ($10,942 - irrigated vs $10,522 - non-irrigated production). The payback period for those two irrigation systems was 7 years. Greater gains of irrigated over non-irrigated yields would be expected for a dry period because of low and unpredictable yields in non-irrigated conditions. A farmer planning to invest in an irrigation system must carefully investigate all technical and socio-economic aspects. The model presented gives the farmer a useful tool with which to do this.

RÉSUMÉ

M.Sc **Génie rural et Biosystèmes**

Henri Tichoux

Comparaison par modèle de trois systèmes d'irrigation par aspersion pour la production de la pomme de terre au Québec

L'objet de la recherche vise la conception d'un modèle informatique qui se veut être un outil d'aide à la décision. Il permet de comparer trois systèmes d'irrigation par aspersion pour la culture de pomme de terre. Les systèmes étudiés sont : les tuyaux portatifs avec canon arroseur, l'enrouleur à canon arroseur et le système à pivot central fixe et mobile. Le modèle requiert l'entrée de données de base relatives à : la plante, l'état du champs, les paramètres du système d'irrigation et des données économiques. En fonction de ces données, le modèle dimensionne le système d'irrigation en plus fait une analyse économique comparative. Une exploitation agricole de pomme de terre à Notre-Dame-de-la-Paix (sud ouest du Québec) a été choisie pour appliquer et tester le modèle. Sur 14 années de données climatiques, la pluviométrie moyenne de la période culturale est de 368 mm et l'apport total d'eau d'irrigation : 250 mm. Ainsi, sur la base d'une pluviométrie moyenne et en supposant un rendement supérieure de 25% par rapport au rendement moyen non-irrigué, le modèle indique que les trois systèmes d'irrigation augmentent le profit net d'environ 11% - 50%. Toutefois, le taux de rentabilité interne (TRI) calculé sur 10 ans indique un taux maximal de 14% pour les systèmes les plus rentables (tuyaux portatifs avec canon arroseur et pivot central fixe avec pompe électrique) alors que pour la production non-irriguée le TRI est de 17%. Quant à la valeur actuelle nette (VAN), les deux systèmes d'irrigation les plus rentables ont donné de meilleurs résultats par rapport à la situation non-irriguée, soit $10 942 et $10 522 respectivement. La période de remboursement est estimé à 7 ans pour ces deux derniers équipements. Cependant en année sèche, l'irrigation donne de plus grands bénéfices que la situation non-irriguée. Le producteur doit donc choisir son système d'irrigation en fonction de critères technique et socio-économique et ce modèle s'avère être un outil de travail qui peut l'aider à faire son choix.

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NOMENCLATURE

ASRA:	Assurances Stabilisation des Revenus Agricoles
ASW:	Available Soil Water
AW:	Available Water
BMP:	Best Management Practices
CEC:	Cation Exchange Capacity
CP:	Centre Pivot
CPVQ:	Conseil de Production Végétale du Québec
DSS:	Decision Support Systems
ES:	Expert Systems
ET:	Evapotranspiration
Fc:	Field Capacity
IPM:	Integrated Pest Management
IRR:	Internal Rate of Return
KBS:	Knowledge-Based Systems
Kc:	Coefficient Factor (for evapotranspiration)
LAI:	Leaf Area Index
LEPA:	Low Energy Precision Application
LEPA-CP:	Low Energy Precision Application – Centre Pivot
MAD:	Maximum Allowable Depletion
MAPAQ:	Ministère de l'Agriculture et des Pêcheries du Québec
NPSH:	Net Positive Suction Head
NPV:	Net Present Value
PET:	Potential Evapotranspiration
PTO:	Power Take-Off
PVC:	Polyvinyl Chloride
PWP:	Permanent Wilting Point
Re:	Effective Rainfall
P.E.I.:	Prince Edward Island
SDI:	Subsurface Drip Irrigation
UPA:	Union des Producteurs Agricoles
WHP:	Water Horse Power

1.0 INTRODUCTION

1.1 Background

The Ottawa-Montreal region is an important agricultural zone producing and providing most of the food consumed by the two main urban centres, representing a total population of approximately 3.5 million. Most of the prime agricultural land, in particular the clay soils of the St. Lawrence valley, is presently occupied by intensive agricultural activities such as dairy, grain, cereals and forage crops. Soils of lesser quality for agriculture, such as sandy soils, which are very common in Quebec, have historically been less intensively used for agriculture. In fact, sandy soils were considered unproductive for agriculture and left mainly for forestry. The challenge today is to assist farmers faced with such soil conditions to exploit them on an economical and sustainable basis.

Sandy soils in southwestern Quebec and eastern Ontario are known to have soil water deficit problems (Madhian and Gallichand, 1996). Studies have confirmed that supplemental irrigation is essential for sandy soils in order to ensure maximum crop yield. However, due to the high cost of irrigation equipment, only high value crops, such as potatoes, are considered. Potatoes need a steady input of water, particularly in the early and mid stages of growth. Uncertain weather conditions prevail in Quebec and a lack of supplemental irrigation during a dry season can mean total crop loss. Furthermore, supplemental irrigation has been reported to increase potato yields by at least 25% (Fulton, 1974; Dwyer and Boisvert, 1990; Rioux, 1987; Porter and McBurnie, 1996; Marra and Kezis, 1987; Madhian and Gallichand, 1997a).

Different water management techniques for sandy soils in Quebec have been studied and developed in the past decade. These studies (Madramootoo et al., 1995; Memon et al., 1987; Papineau, 1987) have examined mostly subirrigation techniques using existing underground drainage installations (watertable management). Very few studies have been conducted on surface irrigation techniques such as sprinklers or micro-irrigation. Subirrigation offers a cost-effective solution to irrigating potatoes. Unfortunately, it is only possible on relatively flat, shallow light-textured soils (ie. +/- 1.5m) lying on a less permeable soil layer where excessive seepage loss is avoided. Micro-irrigation in potato production is too recent a technique to judge, however from past experience on other crops, it has a number of severe handicaps: high cost of equipment, difficulty of soil tillage operations when installed and an obligation to intensely filter the water to avoid clogging the emitters. Eliminating these two techniques, for technical reasons, provides an opportunity to evaluate more closely the economic and technical justification and benefits of sprinkler irrigation systems. Very few studies have been conducted on this subject in Quebec, perhaps because of the perception, justified or not, that such equipment is too expensive and thus not viable. There is a need to review these irrigation systems in order to guide potato farmers in Quebec on whether the investment for such equipment is warranted.

"Si la saison (de pomme de terre) est bonne, précise M. Dolbec, le rendement à l'acre sera de 300 à 500 quintaux. L'an dernier, la saison n'a pas été tellement bonne. La rareté de pluie a fait en sorte que le rendement a chuté à 225 quinteaux à l'acre (-75%)". (article from the newspaper "Le Soleil" (Quebec City), Saturday, May 1996).[1]

1.2 Objectives

The objectives of this thesis are the following:

1. Based on a case study in southwestern Quebec, compare the technical advantages and disadvantages of three sprinkler irrigation systems for potato production, being i) the centre pivot (towable and non-towable); ii) the traveller rain gun and iii) the portable pipe with high-volume sprinkler gun.

2. Determine, based on a comparative economic study, the benefits and costs associated with each system, their relative profitability by conducting an investment analysis. Unirrigated conditions will also be considered in the comparative analysis.

3. Simulate results through the computer model that a farmer could use in selecting an appropriate sprinkler irrigation system for his particular situation.

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[1] Translation: "If the season (for potatoes) is favourable, says Mr. Dolbec, then the yield per acre will be from 300 to 500 cwt. Last year, was a bad season. Because of sparse rainfall, yields plunged to 225 cwt/acre (-75%)". (1cwt/acre = 112kg/ha).

1.3 Scope

The results of this study will indicate the feasibility of sprinkler systems for deep sandy soils (> 2m unit period) in southwestern Quebec (also pertinent to southeastern Ontario conditions) with respect to the production of potatoes. A proposed simplified model comparing different irrigation sprinkler systems for a typical mid-sized potato farm (28 ha) will enable a farmer to measure the cost and benefit for each system and aid him to make the optimum choice (maximum return on investment). Because of simplifying assumptions and parameters (field and farm conditions, water availability, etc.) the model is a first order estimate of the economic and technical feasibility for such farm equipment. If the farmer decides to select one of the irrigation systems discussed in this study, a more detailed plan and cost estimate would be required, as the model cannot be used to obtain precise design and operation specifications.

2.0 LITERATURE REVIEW

This chapter begins with a general overview of the potato production situation in Quebec and briefly compares its productivity to other provinces and US states. The subsequent sections are then divided into three principal topics. The first examines the principal dynamics of potato crop growth and water requirements, as well as the factors that affect proper crop-water management, particularly in sandy soils. The second topic in this section covers sprinkler irrigation in Quebec, again with special reference to potatoes, and discusses the different types of irrigation systems that will be selected and studied in further detail in the following chapters. Finally, the third topic is on existing technical decision models used in the field of irrigation, as well as economic considerations for irrigation studies.

2.1 Potato Production in Quebec

The potato (*Solanum tuberosum*) is the most important vegetable crop produced in Quebec, with a total cultivated area of 18,600ha (MAPAQ, 1995). Its production provides nearly 65% percent of the provincial needs. It is well adapted to light sandy soils and the cool climate found along the entire stretch of the St. Lawrence River. Three different types of production are found: table, chip and seed. The two most popular varieties produced in Quebec (Superior and Kennebec) represent 90% of the production (MAPAQ, 1995). The Superior variety has good properties for table consumption, while the Kennebec variety is renowned for its chip qualities.

Potato yields in Quebec are among the lowest in Canada as shown in the following table of total acreage/average yields (per ha) by province for 1990. For the sake of interest and comparison, the table also provides data for selected US states.

Table 2.1 Production of Commercial Potatoes in Canada & USA (1990)		
Province/State	**Area (potato production) (ha)**	**Average provincial yield (kg/ha)**
New Brunswick	19,845	28,560
P.E.I.	30,375	28,000
Ontario	13,365	27,328
Alberta	10,328	26,880
Quebec	***17,496***	***22,064***
Manitoba	19,035	18,480
Other provinces	6,723	-
Canada	**117,167**	**24,976**
Washington	53,460	57,680
Idaho	159,165	32,032
New York	11,543	31,024
Maine	30,780	30,240
U.S.A.	**550,679**	**32,480**

From: Rowe, R. 1993. Potato Health Management. APS Press. U.S.A

In 1997, the three principal and the three most productive (per hectare) potato production regions in Quebec were:

Principal potato production regions (from MAPAQ, 1998)	Three most productive potato regions (from MAPAQ, 1998; Brochu, 1982)
Quebec-Beauce region (4,200 ha)	Outaouais region (28,633 kg/ha)[2]
Lanaudière (3,095 ha)	Gaspé / Lower St. Lawrence (26,006 kg/ha)
S. Que.& East. Townships (2,493 ha)	St. Hyacinthe (24,103 kg/ha)

A thorough investigation was conducted to find data on the proportion of average marketable/nonmarketable yields from farmers' fields, however such information is non-existent from government or UPA agencies. Contact with a potato packager[3] did however reveal that 13.45% of a farmer's crop received at the packaging depot is rejected (nonmarketable) because of non-conformity to the Canadian Grade Standards (size, appearance, damage, disease, etc.). This percentage loss concurs with a potato producer's

[2] : The Outaouais region is where the present study case is situated (Notre-Dame-de-la-Paix)
[3]: PROPUR, Saint-Ambroise, Que.

own estimate of yield/handling losses (+/- 10% loss) on his farm[4]. This proportion of nonmarketable potatoes represents a heavy loss to farmers considering the invested time, agricultural inputs, machinery and transportation. Although there are various causes for rejected potatoes, irrigation is known to substantially reduce the number of nonmarketable tubers (Porter and McBurnie, 1996; Rioux, 1987; Ackerson *et al*, 1977).

Quebec's poor performance in comparison to other Canadian provinces can be partially explained by inconsistent rainfall during the growing season (Payen, 1982), a lack of incentives for better productivity, a lack of R&D on potatoes by the provincial agricultural ministry in the past decade and poorly equipped farms with dated production techniques (Sauriol, 1999; CPVQ, 1990, 1995 and 1996; Cloutier, 1975). It is interesting to note, however, that the highest yield obtained in the province (the Outaouais region at 28,633kg/ha) slightly surpasses the highest average yield found in Canada (New Brunswick at 28,560 kg/ha)[5]. It is fair to conclude that there are interesting prospects for potato production in Quebec when improved production methods are used, resulting in better yields (tonnage and quality) and revenues.

Potatoes are known to require intensive crop management and care, particularly with respect to crop-water consumption. They are sensitive to water stress and in most years can benefit from supplemental irrigation, even in the humid and sub-humid areas of eastern Canada (Gallichand et al., 1990; Boisvert et al., 1992). In spite of favourable climatic conditions for potato production in Quebec, inconsistent rainfall during the growing season is a principal constraint for optimal yields.

2.2 Characteristics of Potato Production and Growth Stages

The potato is an annual herbaceous dicotyledonous plant with tubers that arise from underground while the aboveground stem provides the main source of photosynthesis. Potato propagation is done vegetatively by either whole or cut tubers, termed seed pieces.

4 Discussion with a potato farmer in Notre-Dame-de-la-Paix.
5 This situation could be explained by the presence of irrigated potato farms in the Outaouais region.

In Quebec, the usual practice uses cut seed pieces [6] planted in early May for early varieties and mid-May for normal varieties [7].

As illustrated in Figure 2.1, there are five principal growth stages of the potato plant:

1) sprout development;
2) vegetative growth;
3) tuber initiation;
4) tuber bulking;
5) senescence and tuber ripening (or maturation).

The following presents a short description of these stages, as well as an overview of the ideal moisture conditions (discussed in more detail in Section 2.4).

Growth Stage 1- Sprout development: Sprouts develop from eyes on the seed tubers (after a dormancy period) and grow upward to emerge from the soil, with roots developing at the base of the emerging sprouts. The seed piece is the sole energy source for growth during this stage, as photosynthesis has not yet begun. The duration is approximately 15-25 days, depending on the variety. *Moisture conditions:* planting in excessively wet or dry soil should be avoided. The soil profile should include a moderate amount of moisture ie. 40-50% of available soil water (ASW)[8] and receive roughly 14-16 mm/week of water (Dubé and Rochette, 1985) to ensure good planting conditions and adequate sprout development. If the soil is excessively dry, it should be irrigated prior to planting. Postplanting irrigation prior to crop emergence is not advisable, due to the risk of inducing seed piece decay.

Growth Stage 2 - Vegetative Growth: leaves and branch stems develop from aboveground nodes along emerged sprouts. Roots and underground stems called *stolons* develop from underground nodes. While the plant still obtains some energy from the seed tuber in the early part of this growth stage, photosynthesis begins during this period,

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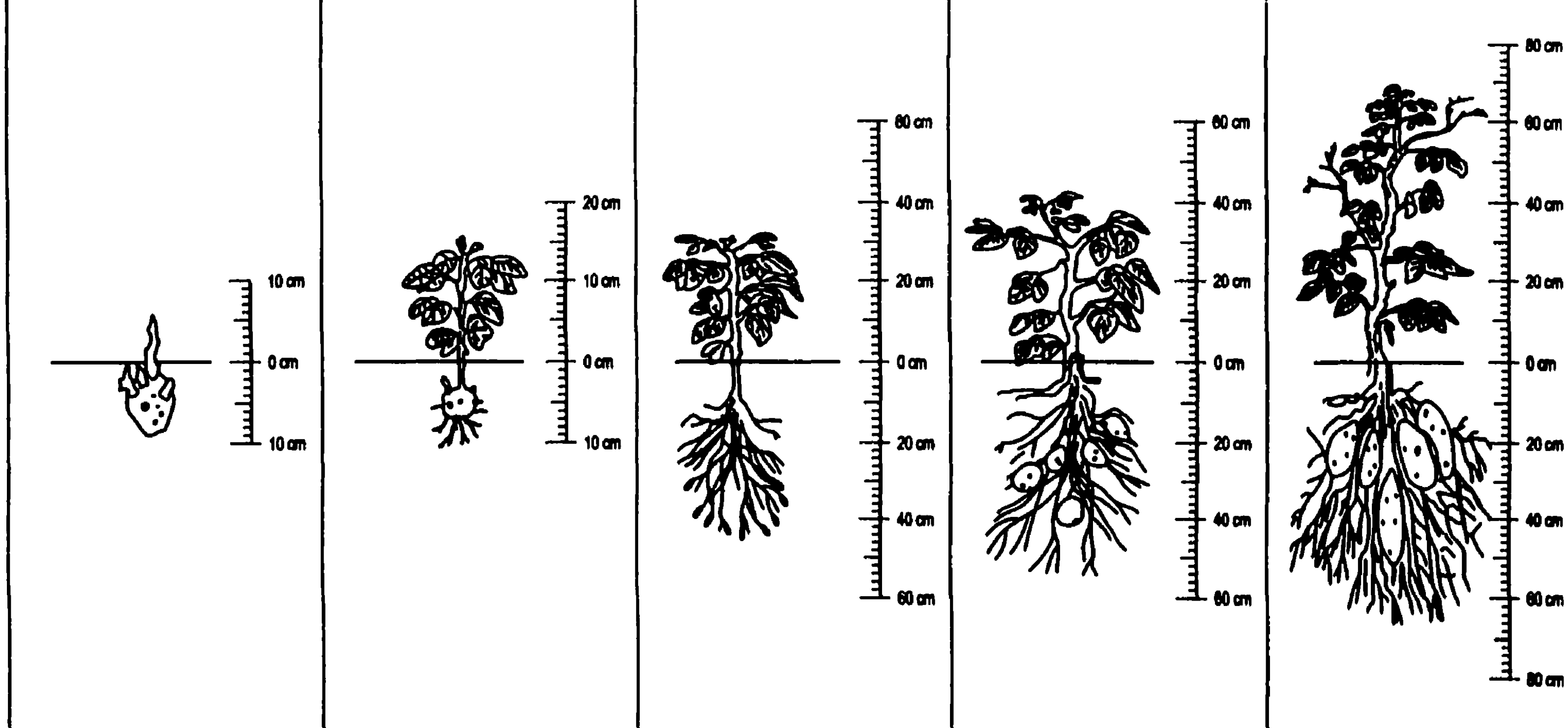
[6]: Most potato producers in Quebec plant cut seed pieces, however experiments have been done with whole pieces, with rather unsuccessful results to date.

[7]: Ewing (1997) notes that in Europe and in many parts of the world, seed tubers are planted whole partly because Europeans prefer, for fresh table consumption, smaller tubers than in the USA (and Canada). Cultural practices thus favour production of small tubers and make use of the abundant small tubers produced in the field for seed supply. Consumers in the USA prefer potatoes up to 0,5 kg in weight, and the cultivars grown for fresh market and processing give a low percentage of tubers in the small size range used for whole seed.

[8]: Available soil water (ASW) or available water (AW) is water between the field capacity (fc) and permanent wilting point (PWP) which is available to plant roots. It is calculated as follows: AW = Drz (fc-pwp)/100 where AW = available water; Drz = root depth; fc = field capacity in %/volume; pwp = permanent wilting point in %/volume (James, 1988).

Figure 2.1 : Potato - Growth Stages[1]



	I. Sprout Development	II. Vegetative Growth	III. Tuber Initiation	IV. Tuber Bulking	V. Maturation
Period	15-25 days	30-40 days	10-20 days	45-55 days	15-20 days
Leaf/branch	None	First leaves and branches appear. Ht. of plant : 15 cm	Growth of leaves & branches, full photosynthesis. Ht. of plant : 35 cm. First flowers.	Vine growth at maximum development stage. Flower ht. of plant : 25 cm	Vines turn yellow and then die. Ht. of plant : 75 cm
Tuber	None	None	Tubers form at stolon tips	Tuber bulking proceeds in a nearly linear fashion	Tuber growth rate slows, ready for harvest
Roots	Seed tuber planted. Sprouts develop from eyes, roots begin to develop	Roots and stolons develop. Energy shifts from seed tuber to early vegetative growth	90% of roots found in first 40 cm of soil profile	Root growth reaches near maximum depth.	Maximum root depth (50-60 cm deep)
Water status and requirement	ASW*: 40-50%. Water req't = 14-16mm/week	ASW*: 50%. Water req't = 20-22 mm/week	ASW*: ≥ 50%. Water req't = 24-28 mm/week	Water content critical for optimal tuber growth and quality. ASW*: 60-65%. Water req't = 30-35 mm/week	Decrease in water content. ASW*: 55%. Water req't = 20-22 mm/week only if persistant dry period.

(ASW : Available Soil Water)

1 : Adapted from: FAO (1979) ; Rowe (1993).

enabling the plant to produce carbohydrates as a source of energy for further growth and development. This stage, in which all vegetative parts of the plant are formed, begins at emergence and lasts until tubers start to develop at the tips of the underground stolons. The duration is approximately 30-40 days, depending on the planting date, soil temperature and other environmental factors, the physiological age of the seed tubers, and the characteristics of the particular cultivars. *Moisture conditions*: as plants emerge and grow, most soils should be maintained above 50% ASW on average and receive 20-22 mm/week of water (Dubé and Rochette, 1985). In sandy soils such as in Notre-Dame-de-la-Paix, the percentage can be slightly lower, to provide a water storage buffer (Rowe, 1993). This also reduces the risk of nitrate leaching as a result of heavy rainfall before the root system of the plant has developed sufficiently to take up applied nitrogen.

<u>Growth Stage 3 - Tuber Initiation</u>: tubers form at stolon tips but are not yet appreciably enlarging. Tuber initiation is controlled by growth-regulating hormones produced in the plant. This stage is relatively short, lasting 10-20 days, and in most cultivars the end of this period coincides with flowering, when a few open flowers are visible. It is generally recognised that most tubers of harvestable (commercial) size are initiated during this period. Early-maturing cultivars usually begin tuber initiation earlier than late-maturing cultivars. Late-maturing types may continue to initiate tubers during growth stage 4, but they usually do not reach harvestable size and may even be resorbed by the plant (Kleinkopf, 1982). 90% of the roots are found in the first 40 cm of the soil profile. *Moisture conditions:* the soil should be maintained well above 50% ASW (ie.: 65-75%) during tuber initiation and receive 24-26 mm/week of water (Dubé and Rochette, 1985). This provides the moisture required for optimal tuber setting and reduces the development of the common scab on newly formed tubers. If problems with brown center and hollow heart are anticipated, the soil should be kept drier (55-65% ASW), especially during cool weather.

<u>Growth Stage 4 - Tuber bulking</u>: tuber cells expand with the accumulation of water, nutrients and carbohydrates. Tuber bulking occurs in a nearly linear fashion if no growth factor becomes limiting. During growth stage 4 (approximately 45-55 days), tubers become the dominant site for the deposition of carbohydrates and mobile inorganic nutrients within the plant. Vine and root growth are at their maximum development and continue to proceed more slowly, but the increase in total plant dry matter is largely due to tuber bulking. *Moisture conditions:* Potatoes have a high water – and nitrogen – requirement during tuber bulking. Tuber development at this stage, particularly in the mid-bulking stage, increases linearly as water application is increased (Ojala et al., 1990). The soil should be maintained above 50% ASW (ie. 60-65%) during tuber bulking and receive 30-35 mm/week of water (Dubé and Rochette, 1985). Water stress during bulking can significantly affect tuber yield and quality and the development of disease in the crop. However excessive irrigation (in which the soil is kept near saturation and vines are wet for long periods) should be avoided, to minimise the development of early blight, aerial stem rot and Sclerotinia stalk rot (Rowe, 1993).

<u>Growth Stage 5 - Maturation</u>: vines turn yellow and lose leaves, photosynthesis gradually decreases, the tuber growth rate slows, and the vines eventually die. The dry matter

content of the tubers reaches a maximum and the skins of the tubers thicken. This stage lasts 15-20 days. *Moisture conditions:* Demand for water is reduced as the plants begin natural senescence. Soil moisture can be allowed to decline to 55% ASW to promote skin setting (the development of the tuber periderm) and water application should be around 20-22 mm/week (Dubé and Rochette, 1985). High soil moisture (above 65% ASW) should be avoided during maturation, to minimise problems with pink rot and Pythium leak of tubers and development of enlarged lenticels, which can increase the potential for bacterial soft rot in storage. Excessively dry soil at harvest (below 55% ASW), however, can hinder effective harvesting, increase tuber bruising caused by soil clods and favour blackspot bruising.

In summary, a lack of water at the following specific crop stages will likely cause:

1) at sprout development & vegetative growth: a delay in leaf canopy development which is responsible for intercepting a high percentage of the incident radiance (Ewing, 1997) and ensuring high biomass production;
2) at tuber initiation: a significant decrease in the number of initiated tubers;
3) at tuber bulking: physiological disorders and inferior quality potatoes, development of various diseases, particularly late blight.

Rotations: the traditional crop rotation practised on Quebec potato farms follows a 3-year sequence of cereal (barley, winter-wheat), red clover and potatoes. Some farms produce two successive years of potatoes (rarely more) but the yields diminish the second year due to pest and disease infestations. Rotation is particularly important for maintaining soil productivity, minimising check weeds and reducing crop loss from insect damage and disease, particularly soil-borne diseases. Although the traditional crop rotation was well adapted to the farming context in the past, recent observations and research in Quebec (Simard, 1997) have concluded that:

- barley can increase the occurrence of blight (*Streptomyces scabies*);
- soy limits the spread of blight but won't eradicate it if the disease is well established in the field;
- grain-corn is especially suited due to a high level of crop residue (6-8t) compared to cereals (4-6t), however heavy dosages of fertiliser are required (a risk for sandy soils);
- wheat and canola are well adapted for a potato rotation, however sandy soils with limited soil humidity is not recommended for canola in particular;
- peas are very favourable for potatoes because of their ability to fix atmospheric nitrogen. Their main drawback is that they leave very little crop residue (1-2t).

Research conducted in Notre-Dame-de-la-Paix (Clément, 1990) on ways to increase organic matter content in sandy soils for potatoes – which should be maintained at 2.5-3.0% - recommended alternating potatoes with oats left to full maturity. Yet the same author concluded that oats would not generate enough organic matter (in the form of humus) in the long term and suggested the addition of composted wood chips found in abundance from nearby forestry operations.

In the Canadian prairies, farmers who grow potatoes every 3 or 4 years in a field alternate with cereals. As current prices result in little benefit from irrigating cereal crops, the irrigation equipment is moved in rotation with the potato crop. This technique maximizes the economic benefit of the irrigation equipment (Manitoba Potato Council, 1996).

It is firmly believed by the author that further studies should be conducted on crop choices for potato-based rotations in favour of higher value crops such as market vegetables (corn, peas, etc.) which could also use farm irrigation equipment and consequently accelerate repayment and returns on capital investment.

Fertilisation and crop protection: to fully benefit from the irrigation of potatoes, it is necessary to combine other crop management factors, notably soil fertility (nitrogen in particular), pest and disease management, soil preparation, etc. Much of the research conducted on the effect of irrigation on potato yields include these crop management factors. While these interrelated factors are important to consider (Gallandt et al., 1998), it is beyond the scope of this study to review them individually. For the purpose of this research, it is assumed that the beneficial effects of appropriate water management on potato is combined with Best Management Practices[9] (BMP).

Quality: as potato quality is an important factor influencing marketability and consumer preference, potato producers are interested in the marketable yield as opposed to total

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[9]: BMP includes proper soil tillage, effective soil fertilization management and prudent crop protection practices, such as IPM.

tuber yield[10]. As will be seen later, research station experiments on the effect of irrigation on potato yields also take into account marketable yield. Broadly, Canada Grade No.1 and 2 are calibrated according to specific physical characteristics (size, diameter, etc.), quality standards (absence of disease, insects, dirt, sprouts, etc.) and general appearance (colour, texture, shape, etc.). A recent Quebec study on potato quality in retail food outlets found that local production contained 20-25% defects, compared to 10.9% for P.E.I. potatoes (CPVQ, 1996) [11]. From the consumer point of view, quality is gauged on aspects not necessarily covered by government standards, such as cleanliness, size (bigger is better), high uniformity of shape and size, unmarked skin, firm flesh, no internal defects and shallow eyes.

The percentage of dry matter in potato tubers commonly ranges from 16% to 23%, depending upon the cultivar and environment. Because tubers are sold by fresh weight, one might conclude that it is desirable to aim for a high water content. However, the food transformation industry (e.g. frozen French fries), which accounts for over 50% of potatoes consumed, requires different quality standards, as a higher dry matter content of the raw product results in a higher yield of the finished product. Thus, in general, high dry matter tubers usually command a higher price. High dry matter is associated with high levels of irradiance, cool night temperatures and appropriate amounts of water applications. Irrigation, when applied in sufficient quantities at the appropriate time (preferably at the tuber-bulking stage) is also known to increase dry matter content and improve chipping and processing properties (Wright and Stark, 1990).

2.3 Particularities of Potato Production in Sandy Soils

Potato plants require well-drained soil so that the roots have adequate oxygen. The most attractive tuber shape and skin appearance are achieved with light, sandy soils, or with

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[10]: Canadian standards for potato quality and calibration are set and verified by the Canadian Food Inspection Agency (CFIA) of the Ministry of Agriculture and Agri-Food Canada. Under the Canada Agricultural Products Act, Fresh Fruit and Vegetable Product Regulations, potatoes are graded and sold in the market according to specific grades and standards, the two principal grades being *Canada no.1* and *Canada no. 2*.

[11]: the Canadian standard of maximum tolerance for defects in 'Canada No.1' is set at 10%.

muck soils (Ewing, 1997). Unless irrigation is available, the soil should not be too arid. Lake and Broughton (1969) showed that supplemental irrigation of sandy soils in southern Quebec could be beneficial in 4 out of 5 years. Sandy soils present several challenges, in particular:

- poor water retention;
- poor natural soil fertility;
- loss of applied mineral fertilisers through leaching;
- erosion of sloped terrain.

Sandy soils, because of their very coarse texture (>2 mm), have particular water availability (for plants) and retention properties. The following table presents a comparison with other soil textures (James, 1988):

Soil Texture	Field Capacity (% by volume)	Permanent wilting point (% by volume)	Available Water (% by volume)	mm/m
Sandy	15[1] (10-20)[2]	7 (3-10)	8 (6-10)	80 (70-100)
Loam	31 (25-36)	14 (11-17)	17 (14-20)	170 (140-190)
Clay	44 (36-49)	21 (19-24)	23 (20-25)	230 (200-250)

[1] Average Value [2] Typical Range

Because of their low available water-holding capacities, timely water applications or precipitation is important. Moreover, sandy soils with low water-holding capacities can accumulate only limited amounts of water during a given period before it is quickly lost through percolation. As mentioned in Section 2.1, yield increases due to irrigation are most dramatic in sandy soils (Rioux and Comeau, 1982). Coarse-textured soils, however, present an inherent problem – the risk of excessive loss of nutrients and agrochemical products due to percolation by excess water. This problem is prevalent on irrigated farms using trickle systems, especially in sandy soils with limited potential for lateral flow of water, as the soil may become wetted only in very narrow strips. This can cause problems because the water may reach only a limited proportion of the roots. The ideal pH for potatoes grown in mineral soils is between 4.8-5.4 to prevent excessive scab problems.

Fortunately, sandy soils in southwestern Quebec (originating from glacial outwash deposits) generally have a pH of 5.1-5.5.

Papineau (1987), in a study conducted in the Richelieu and St.Hyacinthe counties of Quebec (east of Montreal), distinguished two categories of sandy soils – deep sandy soils (± 1.50 m) overlying a clay layer and very deep sandy soils at depths over 1.50 m. For each of these categories, a specific type of irrigation was recommended: subirrigation and sprinkler irrigation respectively. The same author used the available water (AW) set at <18 cm/m for very deep sandy soils (> 1.50 m). Based on that criteria, 16,545 ha were found to be suitable for sprinkler irrigation while 15,697 were appropriate for subirrigation, represent in 22% and 21% respectively (a total of 43%) of the total agricultural land of the two counties.

2.4 Water Availability and the Effect on Potato Yield and Quality

The following section presents a discussion of the water requirements of potatoes and the beneficial effects of irrigation on potato yield and quality.

Water requirements for potatoes:

Water is a major constituent of potato plants, comprising 75-85% of tubers. Under optimal conditions, well-watered potato plants transpiring at an average rate will replace their entire water content about four times a day (Rowe, 1993). Potatoes are sensitive to water deficiency and have a shallow root zone (40 cm). Potato plants are relatively poor conductors of water, possibly a result of having a relatively small root length per unit land area compared to more drought-resistant plant species (Gregory and Simmonds, 1992). This inefficiency requires a continuous yet appropriate quantity of supplemental watering. Therefore, reduction of soil moisture can have significant consequences on tuber yield and quality.

Water stress, whether from too little or too much water, can significantly affect the health of a potato crop. Too little moisture and soil moisture fluctuations can affect tuber quality and create various disorders such as (Ojala et al., 1990; Rowe, 1993; Ewing, 1997):

- secondary growth: knobbiness, pointed ends, dumbbells and bottlenecks);
- growth cracks and bruises;
- physiological disorders: brown centre, hollow heart, translucent end.

On the other hand, excess soil moisture following planting can delay emergence and cause bacterial seed piece decay. Adams and Stevenson (1990) pointed out the importance of not over-irrigating as overhead irrigation (as opposed to furrow, trickle or subirrigation) can alter the potato canopy microclimate and thereby indirectly affect disease development. Furthermore, through the increased relative humidity and extended dew duration, combined with the direct effect of adding free moisture to the foliage, increased development of potato early blight, white mold and bacterial stem rot can occur. The same authors suggest that potato growers should devote more attention to better integration of disease and irrigation management strategies and that irrigation be carefully timed so that water is applied only when crop demands warrant, while minimising the duration of leaf wetness.

According to different authors (Ewing,1997; Gallichand et al., 1990; Fulton and Murwin, 1955; Hang and Miller, 1986; Trout et al., 1994), to obtain maximum yields, soil moisture should not drop below 50% of crop available water in the soil, although others suggest 25% or 75% (Boisvert et al., 1992; Doorenbos and Pruitt, 1977; Hane and Pumphrey, 1984; Kleinkopf, 1982; Rioux, 1987). There is much debate on the rate of available soil water (ASW) – or the soil depletion level – that should be used for water management and scheduling. Wright and Stark (1990) concluded, after reviewing past studies, that for optimum production of water-sensitive cultivars such as the Russet Burbank, soil water should remain above 65% of the available water holding capacity. Gregory and Simmonds (1992) state that irrigation at 50% depletion offers considerable practical and economic advantages by reducing the number of irrigation applications without substantially reducing marketable yield. Dubé and Rochette (1985) in Quebec recommend a minimum of 50% ASW for all growth stages, a level also used by Boisvert et al. (1992) in Ottawa for experiments on irrigated potato production. These differing rates can be explained by climatic, plant and soil characteristics (van Loon, 1981; Hoffman et al., 1992).

As discussed in Section 2.2, sensitivity to water stress varies with the growth stage of the potato plant. Water stress during tuber initiation has been reported to reduce the number of tubers produced per plant (Hang and Miller, 1986; van Loon, 1981); however this trend is not consistent for all cultivars. Miller and Martin (1987) showed no effect of deficit irrigation during tuber initiation on the number of Russet Burbank tubers produced in sandy soils, although the average tuber size and specific gravity were significantly reduced. At the tuber bulking stage, water shortage is known to decrease yield to a larger extent than during other growth stages because of the reduced leaf area or reduced photosynthesis per unit leaf area (van Loon, 1981). Deficit irrigation that causes short periods of severe moisture stress during either the tuber initiation or bulking stages of Russet Burkank growth severely reduces total and U.S. No. 1 yields (Miller and Martin, 1987).

Effects of irrigation on potato quality and yield

Literature abounds on the subject of favourable effects of irrigation on the yield and quality of potato production. Table 2.2 presents research the results of experiments conducted mainly in Canada, with a few from the USA. Differences have been observed in the response to water stress of various cultivars (Dwyer & Boisvert, 1990) and in the economic benefits of irrigation applied to potatoes (Mara and Kezis, 1987; Rioux, 1987). In Alberta, Lynch et al. (1995) confirm previous research conclusions that transient moisture stress in the late season has less of an impact on marketable tuber yield than stress in the early and midseason. Studies conducted on water requirements for potato production in Quebec indicate a direct relationship between irrigation applications and increased yields. Rioux (1987), following a 3-year study on potato-cum-irrigation and nitrogen applications in La Pocatière (eastern Quebec), reported a 38% increase in yield for irrigated potatoes over non-irrigated conditions combined with 179 kg/ha of nitrogen (the MAPAQ recommended rate on loamy sands "sable loameux"). The same study reported that improved water applications resulted in a significant increase (+58%) in the

Table 2.2 : List of research and results on difference of yield between irrigated and non-irrigated potatoes

Author, year	Location of experiment	Variety	E M L	Water applied	Soil texture	Yield increase Overall t/ha	Overall %	Marketable t/ha	Marketable %	Comments
Dwyer, L.M. & J.B. Boisvert (1990).	Ottawa, Canada	Kennebec Superior	M M	(//)	Sandy loam			9,2 10,5	19% 20%	Date & duration of experiment: 1987-88. (//) : when available water (AW)* = or is less than 50%, then 20 mm was applied
Bilodeau, B. (1983)	St. Pacôme, Que. Canada	Superior	M	--	Gravel sandy loam		44%		22(*) 53(**)	Date & duration of experiment: 1986-89. (*) : Canada Grade 1; (**) : Canada Grade 2.
Rioux, R. (1987) - I	La Pocatière, Quebec, Canada	Kennebec	M	25mm/wk &/or at + 0,1bar	- Loamy sa -GravSdyLo - Clay-loam	22,6 12,9 0,4	62% 35% 5%	10,2 8,0 --	143% 100% --	Date & duration of experiment: 1978-79-80. Irrigation experiment conducted with various nitrogen rates, results shown here are with 175kg/ha (rate which is recommended by CPVQ (1992)).
Rioux, R. (1987) - II	La Pocatière, Quebec, Canada	Kennebec, Netted Gem	M M	at + 0,1bar	- Loamy sand	2,1 3,1	5,3% 8,6%			Date & duration of experiment: 1981. Irrigation experiment conducted with two nitrogen rates (0 & 160kg/ha), results shown here are with 160kg/ha (rate which is closest to CPVQ (1992) recommendation (= 175kg/ha)). <u>*Experiment done in very wet year*</u>.
Rioux, R. (1987) - III	La Pocatière, Quebec, Canada	Superior Kennebec Kennebec	M E M	at + 35% RAW	- Loamy sand	18,5 15,0 15,0	72% 62% 35%	22,1 15,9 30,1	188% 109% 55%	Date & duration of experiment: 1982. Irrigation experiment conducted with 160kg/ha of 10-10-10 fertilizer. 205 mm of irrigation water applied over season.
Fulton, J.M. (1978)	Harrow, Ont. Canada	n.a.	n.a.	25mm/wk	Sandy loam	8	61%		-	Date & duration of experiment: 1953-64.
Walsh, J. (1999)	New Brunswick, Canada	Shepody, Russ. Burbank	M L	--	n.s.	5,6 5,3				Date & duration of experiment: 1992-98. Yield response to irrigation varied widely from year to year (depending on rainfall), in driest year, total yields increased by nearly 100cwt-a. Note: irrigation increased occurrence of hollow-heart. Experiment done by McCains - not all information could be disclosed.
Brown, M. (1990)	Alliston, Ontario, Canada	Norchip	n.s.	--	Fine sandy loam	14,3				Date & duration of experiment: 1986-89.
White, R.P., and J.B. Sanderson (1989).	Research Station Charlottetown, P.E.I., Canada.	Kennebec, Russet Burbank	M L	--	--	13,6 14,0	31% 33%	19,0 11,3	112% 365%	Date & duration of experiment: 1988. Irrigation was also found to increase the average tuber weight of Kennebec to 168g/tuber from 129g/tuber without irrigation.
Porter and McBurnie (1996)	Aroostook Cty, Maine, USA.	Superior, Shepody Atlantic Russet Bur.	M M M M	--	Loam	1,6 2,8 8,1 11,4	4% 8% 24% 38%			Date & duration of experiment: 1992-95. Marketable yield based on U.S.no.1 - which is quite similar to Canada no.1.
Marra and Kezis (1987)	Aroostook Cty, Maine, USA.	Superior, Russet Bur.	M L	15cm/ha	--	4,38 3,69	--		16% 11%	Date & duration of experiment: 1985. Marketable yield based on U.S.no.1 - which is quite similar to Canada no.1.

* : available water is defined as that water held between field capacity (-0,03 Mpa) and permanent wilting point (-1,05 Mpa).

E, M, L : Early, Midseason and Late varieties calibre of marketable potatoes (>70 mm) in addition to superior physiological properties (colour, specific weight, etc.). Similarly, over an 11-year period in Ontario, the average yield increase of early potatoes due to irrigation was 8t/ha (Fulton, 1974). Dwyer and Boisvert (1990) conducted studies on the response of potatoes to irrigation applications in the Ottawa region and found the following results (study conducted over two successive years):

- rooting depth and plant height were unaffected by irrigation;
- leaf area index (LAI) and aboveground dry matter were increased by 49% and 50% respectively;
- irrigation produced more tubers, with an increased yield of 20.2% over non-irrigated production, and a 9.5% increase in the proportion of marketable tubers (i.e. Canada No.1 & 2).

Similar studies have been conducted in Ontario, Maine and New York State. The importance of irrigation frequency was demonstrated in Alberta (Manitoba Agricultural Department, 1997) where the effect of maintaining soil moisture depletion levels below 40% and at 60% of the total available moisture on three varieties was studied over six years, with the following results:

- increased marketable yield by 7%, 5% and 0% on Russet Burbank, Norland and Norchip potatoes, respectively;
- increased yield of small and Canada No. 1 small tubers by 23%, 40% and 10% on Russet Burbank, Norland and Norchip, respectively;
- increased dry matter of Russet Burbank, a late maturing variety, with little difference on Norland and Norchip;
- increased presence of small, brown spots in the centre of the tubers of Russet Burbank potatoes;
- reduced number of irregular shaped culls and Canada No. 2 tubers.

The most critical period to avoid moisture stress for potatoes is from tuberization to the onset of vine maturity. A shortage of soil moisture during this period will reduce yield and tuber quality.

Avoiding moisture stress at the time of tuber initiation increases the number of tubers and reduces the average size of the tubers. This is an important benefit for seed producers who wish to increase the yield of medium-sized tubers. Most of the potato plant water storage deficits occur when water stored in the soil is depleted below a critical level. Soil water storage is expressed as a percentage of available soil water, and usually the moisture status of the soil becomes critical when the percentage of available soil water drops below 60-65%.

The Gleadthorpe EHF (Great Britain) experiment, although conducted in a totally different environment than Eastern Canada and tested with varieties not used in Canada, merits a special mention as the experiments on irrigated potatoes were conducted over a thirty-year period (1958-1988). Bailey (1990) reports that the yield response in dry years was around 24t/ha on light soils (sandy), but on average the response over the 30 years was 10-11t/ha.

Research conducted in Maine concluded that irrigation is economically feasible in about three out of every four years (Bourgouin, 1984). The Aroostock Research Centre studied climatic data and run-off records for a 30-year period and suggested that even in the wettest years, potato production could possibly have been helped by properly-timed supplemental irrigation.

Finally, Mahdian and Gallichand (1997b) conducted a study aimed at quantifying the regional spatial variability of the growing season water deficit and the potato yield increase due to <u>irrigation</u> for the entire agricultural territory of Quebec. The analysis was done through both experimentation and simulation using the SUBSTOR crop growth model. The essential conclusions of the study were:

- with supplemental irrigation, yield increases were greater for sandy soils (31.5%) than for loamy soils (22%);
- the yield increase for irrigated (supplemental) potatoes decreases from the southwest to the northeast of the province; that is, when the water deficit is high in southwestern Quebec *(including Notre-Dame-de-la-Paix)*, the crop will better respond to supplemental irrigation and thus give a higher yield.

It is particularly interesting to note from the same study that Notre-Dame-de-la-Paix – the selected research site for this present thesis – is precisely located in the zone where the seasonal variation of water deficit for sandy soils was the highest in the province (300-350mm/season). This explains why Notre-Dame-de-la-Paix was also situated in the zone where the highest yield increase due to supplemental irrigation was attained.

2.5 Irrigation Systems in Quebec - Recent Trends and Developments

Quebec farmers have traditionally produced rain-fed crops and have not been inclined to invest in irrigation. The use of irrigation systems - in essence sprinkler systems - in Quebec began in the late 1940's in the tobacco growing region of Joliette, north of Montreal (Shady, 1989). Since that time, irrigation has expanded to other crops, particularly horticultural products, berries, apples and market vegetables, including potatoes.

Increased market competition has forced farmers to optimise their farming systems and consider irrigation among other techniques. Statistics Canada reports that in 1986 Quebec had 15,284 ha of irrigated farmland (all systems; sprinkler and trickle), which increased to 21,848 ha by 1990 and to 33,611 ha by 1995, representing a 55% increase over 10 years. 1986 was the only year the data was broken down by type of irrigation equipment, with 50% reported to be using the hand-move type, 25% using volume guns (*"canon mobile"*), 13% using wheelroll systems and the rest (12%) using all other methods. In comparison, Ontario had 66,090 ha of irrigated land in 1995, roughly double that of Quebec (StatsCan, 1995) [12].

The preceding observations indicate that there is a definite upward trend towards the use of irrigation systems by Quebec farmers. In the specific case of potato production, irrigation systems are seldom used. Most of the potato farmers spoken to during the

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[12]: Regrettably, Statistics Canada, MAPAQ and the Canadian irrigation industry maintain far less systematic detailed census data on irrigation use, practices or equipment distribution than in the United States. Yearly irrigation information is available for every US state, including: irrigated acreage, % change, acreage irrigated by different irrigation systems (centre pivot, flooded, etc.), crop type and surface being irrigated, types of irrigation power units and number and types of irrigation wells and well pumps.

present study mentioned the high capital cost of irrigation equipment as their main objection to using such equipment. However, these same farmers acknowledge that without irrigation, consistent average or high levels of potato yields are impossible to achieve[13]. There is a risk of having no yield at all during a very dry season in all Quebec potato-growing regions; a fact known and feared by all producers (see section on rainfall predictions). To offset this situation and assure consistent quantities and quality to markets and contract buyers, farmers must crop more surface area than necessary and find a means to sell the excess after a successful season.

As mentioned in Section 2.2, the potato production and distribution sector in Quebec is undergoing a steady transformation regarding farmer organisation, production standards (variety, quality, etc.) and consumer demand. Potato producers have been forced to adapt to these changes and become more efficient, better equipped and, especially, more responsive to market demands. In this evolving and difficult context, potato farmers in Quebec are beginning to understand the benefits of irrigation and are more open to investing in irrigation equipment.

While there are no comprehensive records in Quebec on the kinds of sprinkler irrigation systems being used on potato farms, a rapid survey (telephone conversations to farmers, extensionists and irrigation salesmen; information in rural newspapers and bulletins) indicates that the travelling rain gun is the preferred system of specialised potato farmers. Farms producing a variety of crops, including potatoes, seem to prefer hand (or portable) pipes with high pressure sprinklers or volume guns. Although the use of these two systems is relatively recent, owners of such equipment report that the main drawbacks are the wind factor, high labour requirement and the constant surveillance required during its operation. During the 1970's, several potato producers in Quebec acquired central pivot systems (particularly the mobile type), however these producers report strong dissatisfaction with this system as they required too much maintenance, labour, surveillance during operation and had high energy costs. Currently, lateral or centre pivot

[13]: The producers contacted were from such locations as Notre-Dame-de-la-Paix, St.Ubald (Portneuf County), Joliette and Drummondville.

systems, though rare, are essentially found on large scale vegetable farms situated in the organic soil regions southeast of Montreal (ie. Napierville), in the Lac St.Jean/Saguenay area (potato seed, blueberries) and on both sides of the Outaouais River – in the Montebello region of Quebec (ie. potato farms in Notre-Dame-de-la-Paix, the present project site) and in Ontario (ie. potato farms in Plantagenet).

Subirrigation is also presently used as a supplemental irrigation technique for potato production in Quebec. Subirrigation is the addition of irrigation water to a subsurface drainage system via water control chambers, on the collector or lateral lines. Water moves upward by capillary rise from the water table to the root zone. Certain natural conditions must be met for subirrigation to be possible. Because subirrigation involves actual management of the water table, an impermeable layer or a permanent water table should exist at a rather shallow depth (1.5 – 2.0m) to prevent excessive seepage losses. Furthermore, the topography should be nearly flat (slopes of under 0.5%) and the soil should have high hydraulic conductivity so that reasonable drain spacing can be used to provide both subirrigation and drainage. If any of these conditions is absent, subirrigation cannot be considered. Thus subirrigation is not feasible for deep sandy soils at depths of more than 2m (Barnett et al., 1997; Memon et al., 1987), as in the case of the present study site (Notre-Dame-de-la-Paix).

2.6 Selection of Sprinkler Irrigation Systems in Quebec

No information or studies exist on the comparative technical efficiency or even the costs of different sprinkler irrigation systems for potato production in the province other than a dated summary study by Laroche (1982). Farmers that do decide to invest in sprinkler irrigation equipment must base their decision on reports and experience from outside the province (ie. Ontario, Maritime Provinces, USA), on their own judgement or, as is most often the case, on the irrigation equipment supplier's recommendations. The lack of objective comparative studies on such equipment is one of the principal motives that prompted the present study.

Of the various sprinkler irrigation systems are available on the market, those that could best address the specific needs of potato producers in Quebec are:

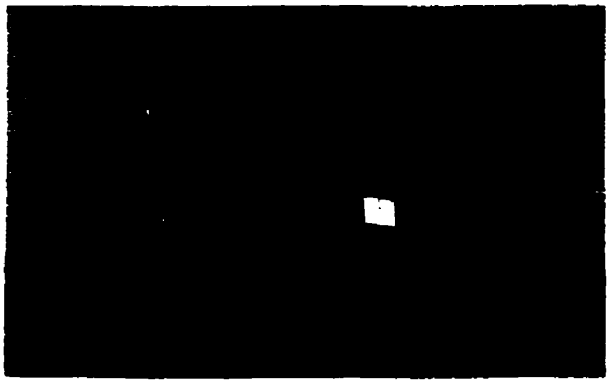
- centre (or lateral) pivot (high or low energy);
- traveller or hose-reel gun;
- portable pipe with high-volume sprinklers (gun).

These three irrigation systems are briefly discussed hereafter, including a critical evaluation of each.

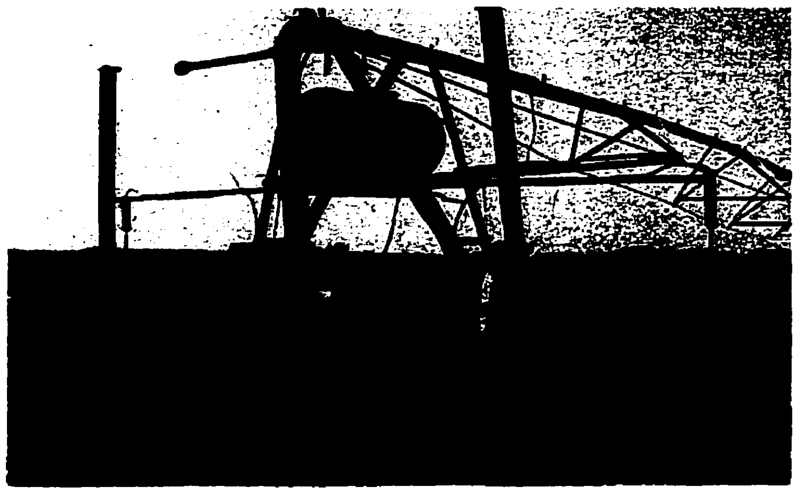
Centre (or lateral) pivot (high or low energy)

The centre pivot irrigation system is a sprinkler system that moves in a continuous circular pattern. Figure 2.2 illustrates the centre pivot, as well as its main components. It consists of a long lateral pipeline fixed at one end (the "pivot point") which is connected to a pressurised water source[14]. The lateral consists of a series of spans ranging in length from 30m to 60m. Each span is carried about 3m above ground level by a drive unit, an 'A-frame' tower supported on wheels propelled by electric (or hydraulic) motors. Mechanical devices at each tower keep the lateral in alignment. The rotational speed of the system is governed by the speed of the far end-drive unit, which can be controlled by the operator. An end-gun is usually situated on the overhang of the last tower to increase the effective wetted radius of the centre pivot. Centre pivot systems utilize a variety of sprinkler configurations, according to crop, soil type and terrain. In the case of potatoes, the principal characteristics can include low volume/impact nozzles. At present, the trend for centre pivots is towards water applications through low pressure, commonly known as LEPA (Low Energy Precision Application). Centre pivot systems

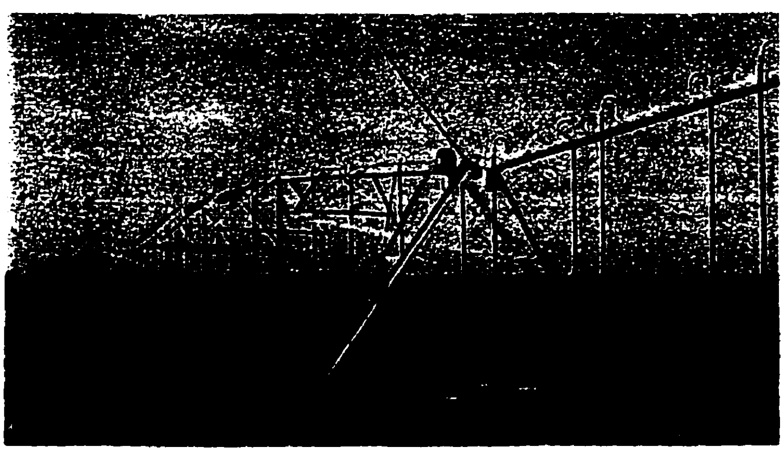
[14]: It should be noted that centre pivot systems with end guns introduce significant practical implications in their overall design, performance and use of energy. In centre pivot systems whose sprinkler nozzles along the lateral operate at low pressure, the end gun may receive the additional pressurization necessary for effective operation from an electric booster pump located near the end gun (Scaloppi and Allen, 1993).



End-gun hooked at last span



Centre tower of a towable centre pivot
(small engine for booster pump of end-gun)



Centre pivot with drop tubes (reducing risks of wind drift)

Figure 2.2 : Centre pivot

are reported to have a combined efficiency of 78% and an estimated of economic life of 15 years[15].

Major advantages: centre pivots can irrigate frequently, have a high uniformity of water application, are less affected by wind (than travellers), have low labour requirements and ease of operation. From OMAFRA, 1995 and other sources:

- continuous movement of the system reduces the labour requirements and increases the number of acres that can be covered at a given pumping rate;
- a wide selection of nozzle types ranging from low pressure 30 psi (210 kpa) to high pressure 70 psi or (480 kpa) is available, so the system can be tailored to the infiltration rate of the soil;
- centre pivots, designed for low pressure application of water, are energy efficient;
- centre pivots are suitable for chemigation, as water is applied uniformly to the crop;
- centre pivots are efficient applicators of water, with relatively low water loss due to evaporation.

Major disadvantage: high initial capital cost of the machines. Technical disadvantages include the high energy cost to operate the system and lack of experience of the farmer in operating a rather sophisticated system. Other disadvantages:

- difficult to transport from field to field, although it is feasible with the towable version;
- designed to irrigate in a circle, thus not suitable for irrigating odd shaped fields or fields segmented with mature shelterbelts;
- strong winds can affect the equal distribution of water.

Traveller or Hose-reel gun

Hose-reel or hard hose traveller units have the propulsion motor, sprinkler assembly and a large reel containing the water supply hose carried on a mobile carriage. Figure 2.3 illustrates the hose traveller system, as well as its main components. A high-volume

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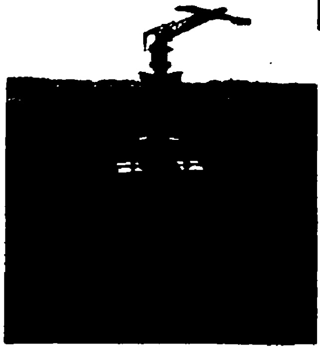
[15]: Combined efficiency: the volume of water stored in the root zone compared to the volume delivered to the application devices (ie. sprinkler nozzles of the centre pivot). It takes into account deep percolation, wind factor, evaporation, etc.). (Cuenca, 1989). Economic life: the reasonable life-cycle value of the system for economic planning, but not necessarily the maximum full life of the equipment involved (Gilley, 1996).

The "Traveller sprinkler"➜



The skid with volume gun

Wind is a main factor for the traveller sprinkler's inefficiency.

The traveller sprinkler is carried to the field by tractor.

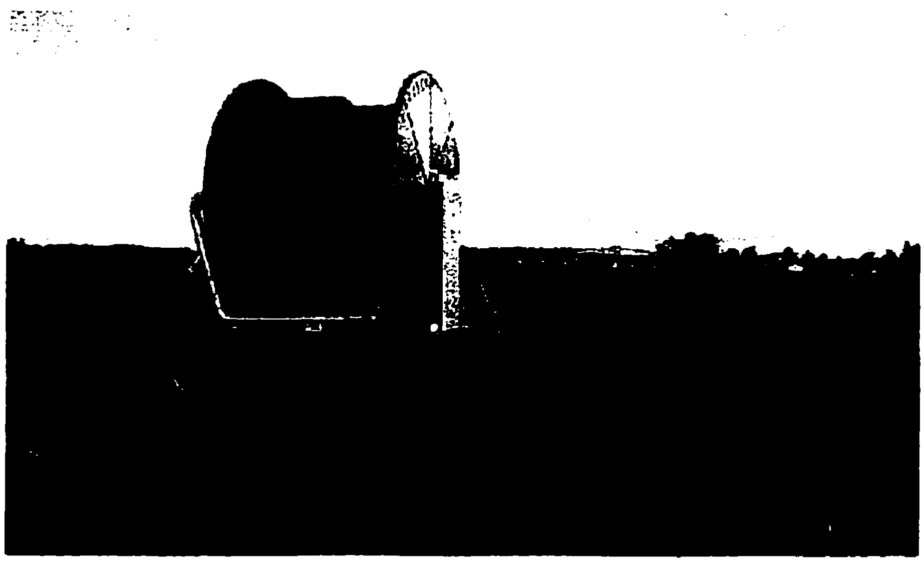


Figure 2.3 : Traveller system

sprinkler (gun), at the end of a 50-100 mm diameter, 200-1750m long PVC hosepipe, is pulled out from the hosereel drum to the far end of the field strip using a tractor. The drum rotates to pull in the raingun, whose end is attached to a cart on two small wheels (or skids). The machine is then moved from one strip of the field to another, once or twice a day, until the whole field is irrigated. Labour is thus required to move the machine between strips, and from field to field. Recent models feature constant drum rotation speeds to ensure even water applications over the length of the field. Traveller units are the most commonly-used irrigation system in Quebec and typically address farms of 30-100ha; it is not uncommon to see several (2 or 3) travellers on a farm. Hose-reel systems are reported to have a combined efficiency of 70% (Cuenca, 1989) and an estimated economic life of 10 years (Gilley, 1996).

Major advantages: (from OMAFRA, 1995 and other sources)

- easy to transport from field to field;
- capable of irrigating odd shaped fields or fields segmented with mature shelterbelts;
- the water application rate can be adjusted for variability in soil moisture conditions in the field. This option is available on some models equipped with micro-processors;
- low labour requirements, ie. 0.5 hr/ha/irrigation (OMAFRA, 1995); requires some surveillance and frequent resetting of sled gun to the end of each strip.

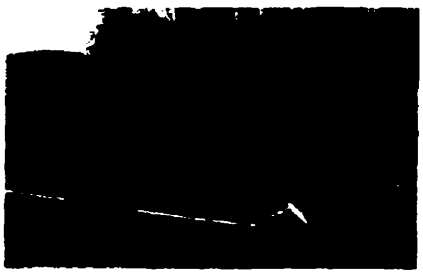
Major disadvantages:

- less efficient than the centre pivot as irrigating time and labour is wasted while resetting the main unit at a new location in the field;
- "big guns" are not energy efficient, as 150 psi of water pressure is required at the main unit;
- "big guns" are not suitable for chemigation, as water application is not uniform;
- "big guns" are less efficient applicators of water than centre pivots, with relatively high water loss due to evaporation during application.

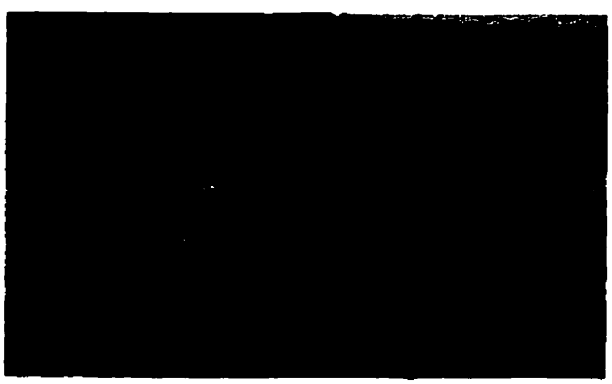
Portable pipe with high volume sprinkler (gun);

This system consists of lateral aluminium pipes laid on the ground and sprinkler "guns" spaced 30 - 50 m. apart hooked onto the laterals. Figure 2.4 illustrates the portable pipe with gun irrigation system, as well as its main components. The laterals and associated volume guns are hand-moved from one set to another to irrigate the entire field. Laterals commonly consist of aluminium tubing 4-6 in. (10- 15 mm) in diameter and 6, 9 or 12 m in length that are easily coupled and uncoupled. Water is fed from portable or buried

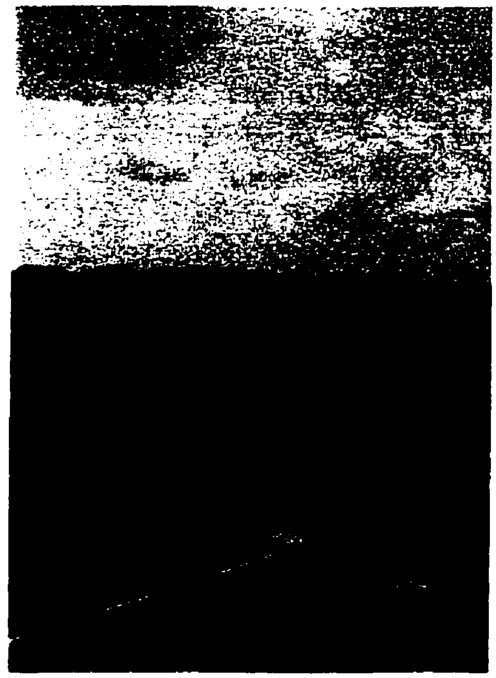
Centrifugal (horizontal) pumping station (diesel)



Lateral pipe storage, main pipe with end-screen at bottom of picture



Manuel operations (hook-ups, lateral changes, connections, etc.) increases chances of equipment failure.



Volume gun attached to hydrant and tee

Figure 2.4 : Portable pipe with volume gun

mainline pipes. Hand-move systems have relatively large labour requirements and are more suited to small-sized farms (5 - 25 ha).

Portable pipe systems are reported to have a combined efficiency of 70% (Cuenca, 1989) and an estimated economic life of 15 years (Gilley, 1996).

Major advantages: (from OMAFRA, 1995 and other sources)

- well adapted to small odd-shaped fields;
- well suited for beginning farmers eager to gain experience in irrigation techniques;
- easy to use/maintain;
- low initial capital costs.

Major disadvantages:

- labour intensive, ie. 2.5 hr/ha/irrigation (OMAFRA, 1995); requires constant surveillance and frequent resetting of guns due to high application rates;easy to mismanage;
- can cause runoff and erosion on sloped land and compaction (surface crusting);
- low efficiency due to sensitivity to wind.

Pipes and pumping stations:

Irrigation systems use either aluminium or PVC pipes. The latter is more expensive, but can easily be buried, permitting easy access for farm machinery. Aluminium, on the other hand, is preferred for its lightness and thus is mostly used for frequently displaced lateral pipes. All three systems require a pumping station, preferably situated close to the irrigation site in order to reduce pumping head and therefore energy costs. Two types of motors to drive the pump are often considered - electric motors and diesel engines. Electric motors are generally preferred for large-scale systems and are much cheaper to run than diesel, however diesel power units are usually more practical due to the limited availability of three-phase electric power. For security reasons, farmers always prefer relying on two pumps in case one breaks down, although this is rarely considered in technical or economic studies.

2.7 Economic Analysis and Decision-Making Systems and Models

Economic analysis

An economic analysis of alternative irrigation systems is essential if maximum profits are to be achieved with the selected system. Extensive literature research on economic studies comparing different irrigation systems reveals that most of the studies conducted compare sprinkler irrigation to furrow irrigation (eg. Bosch et al., 1988; Hagan and Roberts, 1981; Sharp et al, 1979), to trickle irrigation (eg. O'Brien et al., 1998; Bosch et al, 1992) and to subsurface (irrigation or watertable management) (eg. Evans et al., 1988; Worm et al., 1982). Very few economic studies, however, compare the different sprinkler irrigation systems (Kumar et al., 1992(a); Kruse et al., 1990). The most noteworthy study is by Kumar et al. (1992(a)) of Virginia, USA. His study consisted of designing a cost model aimed at providing a preliminary evaluation of the economic feasibility of portable pipe, travelling gun and centre pivot (fixed and towable) irrigation systems and then comparing the systems with respect to total profit. The economic analysis model takes into account the initial investment costs and the variable and fixed costs related to each irrigation system (including the pumping station and operation) and provides annual profits using a given annual interest rate (provided by the user). The highest profit increase per hectare (over nonirrigated) on a 34 ha corn field was obtained with the portable pipe (with stationary volume guns) at 94%, followed closely by the towable centre pivot at 86%; the lowest increase was with the traveler gun (56%). On a larger field (60 ha), the towable centre pivot provided the highest profit increase per hectare (102%) followed by the portable pipe (70%) and the traveler gun (26%). The increase in profitability with the centre pivot on a larger surface is consistent with other comparative studies, such as O'Brien et al. (1998) who compared Subsurface Drip Irrigation (SDI) to centre pivots for corn, and concluded that SDI had a distinct disadvantage in net returns on a 65 ha field, but as field size diminished, net returns for SDI increased. The net returns of the two systems were approximately equal at a surface area of 25.9 ha, below which, SDI was clearly more profitable. A Manitoba Agriculture Department (1997) cost comparison study of different irrigation equipment (CP, travelling gun, lateral move, wheel move) with different pumps (diesel, gas, electricity (single and three phase)) revealed that the centre pivot functioning on single phase electricity had the lowest annual cost; the three phase electric motor would have been much more competitive, but a line extension at a cost of $35,000 significantly increased the annual cost . Different economic analysis methods have been used in the past for irrigation studies and to compare irrigation systems. Hall et al. (1988) used an annual budgeting approach to compare the profitability of various irrigation systems (LEPA Centre pivots, SDI, High pressure CP, furrow). LEPA-CP systems were found to be the most profitable. Bosch et al. (1992) analysed the economic returns of similar choices in Virginia using Net Present Value (NPV) analysis and concluded the same as O'Brien et al. (1998) mentioned precedently. Other methods for the economic analysis of irrigation equipment include partial budgeting (Dhuyvetter et al., 1994), potential annual net return (O'Brien et al., 1998; Evans et al., 1988), a fixed-cost analysis approach (Letey et al., 1990), and an adaptation of the PriceGittinger (1982) farm investment analysis. In all of these approaches, Finkel (1983) recommends using reliable econometric indicators such as benefit-cost ratio, net benefits and internal rate of return as effective ways of demonstrating and comparing the economic feasibility of irrigation alternatives. Whatever the economic analysis approach used, any study on irrigation systems should consider the whole, rather than the individual parts of the system (Israelsen and Hansen, 1979; Cuenca, 1989).

Decision-making systems and models

Kumar et al. (1992(a)) noted that carrying out a detailed design and analysis of each irrigation system can be time-consuming and require expensive technical expertise and that it may not be necessary for an individual interested in a preliminary, or so-called first-cut evaluation of the suitability of irrigation development. Knowledge-Based Systems (KBS) and concepts have advantages over conventional programming techniques, as knowledge based systems allow for a detailed explanation of reasoning procedures, utilization of incomplete and uncertain data, and utilization of experimental knowledge (Waterman, 1986). Knowledge-based systems and expert systems (ES) are being used in agriculture to solve problems characterised by incomplete and heuristic data. Other similar decision tools include "Decision Support Systems (DSS)" based on multi-objective decision models which can be very elaborate and include other considerations such as environmental concerns (eg. sediment yield, nutrient transport, irrigation return flows, etc.). Various DSS models have been developed since the 1980's (Martin et al., 1996; King and Busch, 1990), they are essentially designed to facilitate effective planning for the design of on-farm irrigation systems. Such models allow for the development of alternative plans, including farm layout, cropping patterns and irrigation systems to be evaluated, and provide information for analysis and decisions prior to the detailed design.

This study shall attempt to develop a computer program inspired by the work of the above-mentioned authors. The program is intended to assist a potato producer in southwestern Quebec in comparing three irrigation systems, providing the cost and benefit ratio for each option. The model is, however, in a preliminary design stage and, if used by an individual, would require special assistance (from an irrigation specialist, for example) to ensure sound results and to validate the recommendations. The program is built on Excel to make it easier for a non-professional computer operator to adapt it to the particular needs of a given farm enterprise. For the purpose of this research, the model has been designed with particular reference to the study site in Notre-Dame-de-la-Paix; thus certain basic input data, such as field size, pumping rates, etc and especially economic prices such as market prices of potatoes, price of fuel & electricity, cost of various equipment, etc could be modified by another user.

2.8 Crop Insurance Systems in Quebec

Potato farmers in Quebec rely heavily on the government crop insurance programme to overcome poor harvests due to a lack of rainfall or other similar events (pest infestation, hail, etc.). The *"Assurances Stabilisation des Revenus Agricoles" (ASRA)*, which is administered strictly at the provincial level, guarantees net annual returns to participating potato producers (or other selected crops). The program calculates commodity support levels according to a cost of production model. This formula includes fixed and variable costs, depreciation, and an adjustment for differences between the average wage of farm workers and the average wage of other workers in the province. For potato producers, an insured yield is determined based on historical average yields for the province. The gross payout per hectare equals the insured yield multiplied by the *"compensation finale"* (the predetermined support price/kg) and ASRA cash advances. The province pays 2/3 of the cost, with producer premiums covering the remainder.

3.0 THE MODEL

3.1 Introduction

An economic evaluation is needed to advise a potato producer situated in Notre-Dame-de-la-Paix on which sprinkler irrigation system to select. Such decision-making is complex due to the substantial number of variables and parameters to be considered. As sprinkler irrigation systems are expensive and lead to heavy operational costs (fuel, labour, etc.), such an investment must be studied beforehand and guided by expert advice. To carry out a comparative analysis of irrigation system options, an iterative model can be helpful in assisting the decision-maker to analyse various hypothetical irrigation layouts and systems. The present model was developed to assist a farmer in Notre-Dame-de-la-Paix with a first level (or order) feasibility analysis of three irrigation systems for his potato production. This chapter will explain the model and the basic principals involved, while the following chapter applies the model to the selected potato farm.

3.2 Model Development

3.2.1 Regional Application and Background

The model consists of a technical and economical analysis to help the potato farmer decide which irrigation system to choose for his particular situation. The model provides a choice between the three sprinkler systems most commonly found on potato farms in Quebec: portable pipe with volume gun, traveller with volume gun and a towable/non-towable centre pivot system. The choice of sprinkler systems for this model was discussed with and approved by the farmer.

The present proposed model is inspired from Kumar's model (Kumar et al., 1992(b)) which was designed for corn production in West Virginia, and has been extensively modified to correspond specifically to the agro-environmental conditions of Quebec. It is intended for the preliminary selection and economic evaluation of three sprinkler irrigation systems for a potato farm in southwestern Quebec. The entire model is constructed on Excel (a commonly-used spreadsheet) in several files and sub-files, each of them linked and interacting to obtain instant information and results. The model uses basic engineering and hydraulics equations and formulas, does metric conversions (or vice versa), asks the user to provide suppliers' product recommendations and prices and finally produces a complete economic analysis. The model is limited in its possibilities and is not intended for detailed design decision-making; its purpose is to provide the user with a first approximation of economic costs and benefits for each type of irrigation system. It does offer some interesting flexibility in that it can accept and analyse different system configurations (pipeline layout, size of field, dynamic head, etc.). It must be pointed out, however, that a user of this model should have significant irrigation experience and should be well acquainted with spreadsheet software, as this model has never been tested outside the selected farm site in Notre-Dame-de-la-Paix.

3.2.2 Main Features

The model consists of two distinctive components: a basic engineering design analysis and an economic analysis. This chapter will discuss the engineering aspects of the model, the economic aspects will be covered in more detail in the regarding the economic analysis chapter.

On the computer screen, the model requests that the user enter certain basic and preliminary data in ***green*** entry boxes (in place of *"XX")*. This entered data is a prerequisite for the model to accomplish subsequent tasks such as: calculation of irrigation system equations (done automatically), data retrieval (from a database) or both. The calculated operations appear in ***red*** boxes where digits cannot, theoretically, be modified since they are linked to existing or entered data or equation[16]. The basic paper format of the model is presented at the end of this section (*). The model consists of:

[16]: This is theoretic since the user, if knowledgeable in irrigation and spreadsheet computation (Excel), could modify the program to suit his need.
(*) : for black and white paper presentation of this model, green entries correspond to 'XX' while red entries are left empty.

1. *An input file:* where the user provides the following basic data common to all irrigation systems:

   - water requirements (total annual, per cycle (application));
   - size of field (width & length);
   - shortest distance between water source and edge of field;
   - maximum elevation between water source and highest field elevation;
   - costs and prices (labour, potatoes, diesel, electricity, etc.) and yields per tonne;
   - factors for friction losses;
   - area lost by irrigation equipment circulation & operation;
   - irrigation application efficiencies (specific to each system);
   - choice of PVC or aluminium pipe, buried or non-buried pipe;
   - choice of diesel or electrical powered pump (centrifugal);
   - the need to install an electric cable (3-phase) and distance from pump to power line.

2. *A sprinkler irrigation model file*: there are three sub-files, each providing a description of a particular sprinkler system (portable, traveller, centre pivot). The user inputs the following data:

   Portable pipe:

   - number of laterals the user wants to install and operate (simultaneously);
   - pressure and flow at the gun(s);
   - wetted diameter per gun, sprinkler overlap;
   - daily irrigation operation desired by the farmer;
   - diameter of main, submain and lateral pipes;
   - riser height (of sprinkler), Net Positive Suction Head (NPSH), friction losses;
   - pump efficiency;
   - cost of equipment and materials;
   - labour time (hired labour).

   Traveller system:

   - lane spacing, travel rate;
   - hose diameter & length of traveller, input pressure, pressure at gun, flowrate;
   - daily irrigation operation desired by the farmer;
   - diameter of main, submain;
   - riser height (of sprinkler-gun on sled), Net Positive Suction Head (NPSH), friction losses;
   - pump efficiency;
   - cost of equipment and materials;
   - labour time (hired labour).

Centre pivot system (towable & non-towable):

- length of span, number of sprinklers, discharge per sprinkler, system capacity;
- pressure at end-corner gun;
- daily irrigation operation desired by the farmer;
- diameter of main, submain;
- height of spans, Net Positive Suction Head (NPSH), friction losses;
- pump efficiency;
- cost of equipment;
- labour time (hired labour).

Quantities are determined for the main components: piping, the pumping unit, and other specific irrigation components unique for each system. This data can be entered into the model, and be readily updated with values obtained from irrigation product catalogues or irrigation dealers. Water pressure and losses, discharge and friction characteristics are calculated (or provided by the manufacturer) separately for the pipeline network and for the sprinkler irrigation system. Operation time for each system and their components (sprinkler, pumping station, etc.) is calculated according to the watering frequency.

The second component of the model is designed to conduct a full economic analysis of each selected irrigation system. It requires two sets of inputs: (1) site-specific data; and (2) cost factors for irrigation system components. The following input data are required in order to perform the economic analysis: interest rate, crop prices, non-irrigated yields in normal and dry years, irrigated yields, cost of additional crop inputs, labour costs, cost of diesel and lubricating oil, and water source development costs (if any). The economic analysis model determines returns under non-irrigated and irrigated conditions for both average and dry years (determined from Section 3.4) or the user's choice. Since crop prices may fluctuate significantly, returns are calculated according to the crop price selected by the user. In addition, the output includes the total initial investment, annual fixed cost, annual cost of additional (non-irrigation) inputs and annual operating costs for the irrigation systems. The economic analysis component of the model is explained in more detail later in this study.

The following 9 pages present a blank version of the engineering design model. The subsequent sections discuss the various aspects of the model in more detail.

3.2.3 Climatic and Agronomic Parameters

Certain compulsory parameters are required to operate the model. These key parameters include the climatic and certain basic crop production factors for the selected crop (potatoes) and must be entered first in order to determine the type and scale of irrigation systems required. The following sections describe these parameters.

3.2.3.1 Rainfall Records and Predictibility with Respect to Irrigation Needs

A sprinkler system can be justified if there is a high probability of a dry season that can seriously affect the potato yield, and hence the economic viability of the farm enterprise. To complement the decision, the frequency of water applications will determine the costs of operating and maintaining the irrigation equipment. To obtain this information it is necessary to:

A. Analyse rainfall data and determine:

- the probability and recurrence of dry, normal and wet seasons;
- the rainfall distribution throughout the crop season.

B. Calculate the evapotranspiration (Et) for a potato crop by:

- using the Baier-Robertson equation and IRRIGATE software (Agriculture Canada, 1990);
- applying the Kc factors recommended by IRRIGATE.

C. Determine crop water use and irrigation requirements for potatoes by:

- using the water balance method;
- defining all parameters: rainfall (PP) and effective rainfall (PPt), field capacity (Fc), Permanent Wilting Point (PWP), Maximum Allowable Depletion (MAD), root depth, Readily Available Water (RAW), Critical Moisture (CM), Deep Percolation (DP), Run-off (RO), Soil Moisture Status (SMS);
- calculating total daily, weekly and yearly irrigation applications.

Input Data

Legend :

Enter value	(Manually entered data by user)
XX	(Data calculated automatically by model based on data entered by user and/or with equations stored in model)

CROP->	POTATO

Water Requirements

Water Requirements	Annual Water Requirement		*Enter value*	mm
	Depth of application/cycle	di	*Enter value*	mm
	# irrigation cycles/yr		XX	

Field Characteristics

FIELD	Width	Wf	*Enter value*	m
	Length	Lf	*Enter value*	m
	Area Irrigated	Ai	XX	ha
Shortest Distance of water source to edge of Field (=length of main pipeline)			*Enter value*	metres
Max. elev. difference: field-water source		V	*Enter value*	metres

highest point of field

COSTS

Cost of Labour ($/hr)	Price of Potatos $/tonne	Yield tonnes/ha	Cost Of Diesel ($/litre)	Cost ($ per KW-hour)		WHP/unit of fuel (hours WHP/l)	
Enter value	*Enter value*	*Enter value*	*Enter value*	*Enter value*	*Enter value*	*Enter value*	*Enter value*

(B.C. Irrig. Man., 1989)

Coefficient Ks for Scobey's Equation

Ks - Aluminium	Ks =	*Enter value*	(Schwab, 1993)
Ks - PVC	Ks =	*Enter value*	assumed

System Specific Parameters

Yield Losses due to Operation And Maintenance of Equipment

Portable Pipe	Traveller	Center Pivot	
Area Lost (%)	Area Lost (%)	Area Lost (%)	
Enter value	*Enter value*	*Enter value*	*Enter value*

(Source: Kumar, 1992)

Irrigation Application Efficiencies (Ea)

Portable Pipe	Traveller Gu…	Center Pivot
Ea	Ea	Ea
Enter value	*Enter value*	*Enter value*

(Source: Kumar, 1992)

Main water supply pipe options:

Main Line Buried (enter yes or no)
Enter value

Material of Sub-main		
PVC ?	*Enter yes or no*	*Enter value*
PVC pipe buried ?	*Enter yes or no*	*Enter value*
Aluminum		XX

Pump Purchase Options (Diesel or Electric)

Diesel ?		
Enter yes or no :	*Enter value*	(If no, assumed electric)

Installation for electric line ?		Distance of Cable to be installed (m)	
Enter yes or no	*Enter value*	*Enter distance in metres :*	Enter value

Conversions:

kg/cm2 * 14.22 = psi	liter/second (l/s) = 15.852 US gallons /minute (gpm)
psi * 6.895 = kPa	head (m) * 9.8 = kPa
gpm * 0.227 = m3/hr	

PORTABLE PIPE WITH VOLUME GUN

From input file			
Total Depth of Application per cycle	di	XX	mm
# irrigation cycles/yr	Dd	XX	
FIELD Width	Wf	XX	m
Length	Lf	XX	m
Area Irrigated	Ai	XX	ha
Shortest distance of Water source to edge of Field (=length of main)	Dm	XX	m
System application efficiency (*)	Ea	XX	decimal

(*) : James (1988)

Portable Pipe Specifications						
Sprinkler Spacing	Sspr	XX	m	XX	ft	
Lateral Spacing	Slat	XX	m	XX	ft	
Length of lateral	Llat	XX	m	XX	ft	
Length of Submain	Lsm	XX		XX	ft	
Number of Sprinkler Spacings	Nssp	XX	(Rounded up. Nssp also = number of sprinkler hydrants)			
Number of Sprinklers acquired	Nspr	Enter value				
Number of Lateral Connections	Nlc	XX	(Rounded up. Nlc also = number of sub-main hydrants)			
Number of Laterals in operation simultaneously	Nlat	Enter value	Two laterals are installed for maXXimum pipe installation efficiency, only 4 guns operational			
Design pressure of each gun	Pg	XX	kPa	Enter value	psi	*Manu. Rec.
Wetted area : per sprinkler		XX	m2			

Gun Specifications				
Wetted diameter per gun	Wd	Enter value	m*	*Manu. Rec.
Sprinkler overlap	Sov	Enter value	%	
Lateral overlap	Lov	Enter value	%	

Operating Times			
Time to cover 1 set (4 sprinklers)	XX	hours	
Operating time/day	Enter value	hrs/day	
Number of Sets Req'd	XX		(there are 56 sprinkler-hydrant connections)
Time for entire field	XX	hours	* includes application efficiency (75%)
	XX	days	* by adjusting time of application

FLOW						
Sprinklers						
Flow per sprinkler gun (0.8" nozzle dia.)		Enter value	gpm	XX	L/s	Manuf. Spec.
Total Flow with 4 operating guns	Qt	XX	gpm	XX	L/s	

Calculation for Friction Losses (Hf) using Scobey's Equation			
Ks - Aluminium	Ks =	XX	Schwab (1993)
Ks - PVC	Ks =	XX	
Flow Rate	Q =	XX	L/s

Friction Losses in Piping and Fittings						
Component	Material	D*		L		Hf (Scobey's)
		mm	in	m	ft	m
Main	PVC	XX	Enter value	XX	XX	XX
Sub-Main	Aluminum	XX	Enter value	XX	XX	XX
	PVC	XX	Enter value	XX	XX	XX
Laterals	Aluminum	XX	Enter value	XX	XX	XX
Fittings		D		K		Hf
		mm	in	unitless		m
Elbow (90)	Aluminium	XX	Enter value	Enter value		XX
* Diameter of Pipe chosen to best suit friction/cost factors				TOTAL Htf		XX

Data needed for Determination of Pumping Requirements				
Elevation difference on field	V =	XX	m	
Operating pressure at Guns	Ps =	XX	m	*Manu. Rec.
Riser Height	Hrh=	Enter value	m	
Net positive Suction Head	NPSH=	Enter value	maXX (NPSH, Hsl, Hm) =	
Friction loss in suction line	Hsl=	Enter value	maXXimum	*NPSH = Manuf. Rec.
Friction Loss in the Main	Hm=	XX	value of the three heads	
Drawdown	Hs=	Enter value	m	

PORTABLE PIPE WITH VOLUME GUN (continued)

Total Pumping Requirements

Ht = V + Htf + Ps + Hs+Hrh+maXX(NPSH,Hsl,Hm)		
= XX m	XX kPa XX psi	Schwab (1993)

Pump Efficiency (Ep)	Water Horse Power (WHP)		Brake Power Pb=9.8(Ht*Q)/(Ep)		
Enter value	XX	WHP	XX	KW	(WHP = Ht*3.2808*Qt / 3960)
			XX	BHP	KW*1.341 = BHP

Piping Pressure Rating (based on pipe material and thickness:

Component	Category	Material	Series	D/t	S* (PVC) Ftu (Al)*	Pressure** Rating (Kpa)	Pressure Rating (psi)	Acceptable
Main	Low Pressure	PVC	1120	XX	*Enter value*	XX	XX	No
Main	High Pressure	PVC	1120	XX	*Enter value*	XX	XX	No
Submain	Low Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	XX
Submain	High Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	XX

* S from Table 10-1, Cuenca (1989)
*Ftu from AppendiXX D, Cuenca (1989)
**(Bursting Pressure for Al pipes)

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1989)*

Description			Quantity	Price/unit	Cost $	
Main	PVC	not buried	XX	XX	XX	
Submain	Aluminum	not buried	XX	*Enter value*	XX	
	PVC	not buried	XX	XX	XX	*Note: 2 laterals installed, 1 in operation*
Lateral	Aluminum	not buried	XX	*Enter value*	XX	
Tees			*Enter value*	*Enter value*	XX	
Hydrants			*Enter value*	*Enter value*	XX	
Open Valves			*Enter value*	*Enter value*	XX	
Plug (for 6" pipe)			*Enter value*	*Enter value*	XX	
Gun nozzle stands (tripods)			*Enter value*	*Enter value*	XX	
Pipe plug (6" alum.)			*Enter value*	*Enter value*	XX	
Pipe parts (estimated)			*Enter value*	*Enter value*	XX	
Nelson Canons (Series 150 - 0.8" nozzle)			*Enter value*	*Enter value*	XX	
Elbow (6"by 30") Z-pipe ass.			*Enter value*	*Enter value*	XX	
85 HP IVECO - Diesel pump unit			*Enter value*	*Enter value*	XX	
Electric Pump (575 Volts; 60 hp; 500 gpm @ 145 psi 3 600 RPM) & accessories			*Enter value*	*Enter value* *Enter value*	XX	
Installation cost for electrical line (estimated at $25/m installed)			XX	*Enter value* *Enter value*	XX	
				Total	XX	
					XX	*with GST & PST*

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total per year	
Enter value	XX	XX	XX	source: Kumar (1992)

Losses due to equipment operation & maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)	
XX	XX	XX	XX	source: Kumar (1992)

Diesel engine: Cost Of Diesel Fuel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost of diesel ($/l)	WHP/unit of fuel (WHP/l)	Cost/cycle $CDN	Cost/year	Cost/year/ha
XX	XX	XX	XX	XX	XX	XX

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour)	Cost/cycle $CDN	Cost/year	Cost/year/ha
XX	XX	XX	XX	XX

Total Costs: 1989 Canadian $

Total Fixed Costs		XX
Total Operating costs/year	(with diesel)	XX
Total Operating costs/year	(electricity)	XX

Traveller System

From input file				
	Total Depth of Application per cycle	di	XX	mm
	# irrigation cycles/yr	Dd	XX	
FIELD	Width	Wf	XX	m
	Length	Lf	XX	m
	Area Irrigated	Ai	XX	ha
Shortest distance of Water source to edge of Field (=length of main)			XX	metres
System application efficiency		Ea	XX	

*Manuf. Rec.: Ea taken into consideration

Traveller & Gun Technical Specifications					
lane spacing	*Enter value*	m	XX	ft	*Manuf. Rec.
hose length	*Enter value*	m	XX	ft	*Manuf. Rec.
hose diameter	XX	m	*Enter value*	in	*Manuf. Rec.
input psi at traveller	XX	kPa	*Enter value*	psi	*Manuf. Rec.
gun psi	XX	kPa	*Enter value*	psi	*Manuf. Rec.
flowrate	XX	l/s	*Enter value*	gpm	*Manuf. Rec. : 450 gpm
travel rate	XX	m/min	*Enter value*	2ft/min (for application of 1") (Manuf. Rec.)	
number of lanes	XX	XX	(rounded off)		
length of pass	XX	m	(minus (-) radius of sprinkler path (r = 50m) at each end)		
number of passes	XX				
time to make one pass	XX	hours			
Time to cover entire field per traveller	XX	hours			
Number of Travellers in Use	*Enter value*	unit(s)			

*Takes into account overlap

head in m = psi*9.8/6.85

Operating Time

Time to cover field	XX	hours	*(1hour/acre as per Manuf. Rec.)
Operating time/day	*Enter value*	hrs/day	
	XX	days	*Efficiency taken into account (time adjusted)

Flow rate of Traveller

Manufacturer's Recommendation : 450 gpm		
	XX	gpm

Friction Losses in Piping and Fittings

Component	Material	D		L		Hf (Scobey's)
		mm	in	m	ft	m
Mainline	PVC	XX	*Enter value*	XX	XX	XX
Submain	Aluminium	XX	*Enter value*	XX	XX	XX
	PVC	XX	*Enter value*	XX	XX	XX
Traveller*	PVC					XX
Fittings		D		K		
		mm	in	unitless		
Elbow (90)	Aluminium	XX	*Enter value*	Enter value		XX
				TOTAL Htf		XX

*Not calculated by Scobey's
*Manu.Rec.: 45 psi lost between the intake of traveller & end-gun

Friction losses - Htf (using Scobey's calculation for friction)

Aluminium	Ks =	XX		
PVC	Ks =	XX		
Flow Rate	Q =	XX	L/s	
lev. difference watersource - field	V =	XX	m	
Operating pressure	Ps =	XX	m	(= 85 psi at end gun)
Riser Height	Hrh=	*Enter value*	m	(= height of gun on end-
Net positive Suct. Head	NPSH=	*Enter value*	: for Htf, maXX (NPSH, Hsl, Hm)	
Friction loss in suction line	Hsl=	*Enter value*	= highest value of the three	
Friction Loss in the Main	Hm=	XX	heads	
Drawdown	Hs=	*Enter value*	m	

Manuf. Recom. : 130 psi @ intake; this number accounts for pressure losses corresponding to the Manuf. Rec. pressure of 85psi at the end-gun, for the length of pipe specified

*Manuf. Rec.

Traveller System (continued)

Pumping Characteristics & Requirements

Ht = V + Htf + Ps + Hs+Hrh+maXX(NPSH,Hsl,Hm)			
= XX m	XX kPa	XX	psi
Pump Efficiency Ep=	*Enter value*	Manuf. Rec.	

Brake Power (Pb)	Pb=9.8(Ht*Qs)/(Ep)	
	Pb = XX	KW
	KW*1.341 = XX	BHP
Water HorsePower (WHP)	= XX	WHP

(WHP = (Ht (m)*3.2808) *GPM/3960)

Piping Pressure Rating *(based on pipe material and thickness)*:

Component	Category	Material	Series	D/t	S* (Kpa)	Press. Rating (Kpa)	Pressure Rating (psi)	Acceptable
Main	Low Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	No
Main	High Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	No
Submain	Low Pressure	PVC	1120	XX	*Enter value*	XX	XX	XX
Submain	High Pressure	PVC	1120	XX	*Enter value*	XX	XX	XX

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1999)*

Prices provided by local supplier

Description		Quantity	Price $/unit	Cost	
Main (ft) PVC	not buried	XX	XX	XX	
Submain (ft) PVC	not buried	XX	XX	XX	
Submain (ft) Aluminium	not buried	XX	*Enter value*	XX	
Traveller Unit (1750 ft - PVC pipe)		*Enter value*	*Enter value*	XX	
Tee Valves (6" by 4")		*Enter value*	*Enter value*	XX	
Pipe & fiXXtures		*Enter value*	*Enter value*	XX	*(Includes: z-pipe, relief valves, vents, plugs, etc)*
120 HP IVECO Diesel Pump unit (Based on a 66 BHP pump and 100 HP engine)		*Enter value*	*Enter value*	XX	
Electric Pump (575 Volts; 60 hp; 500 gpm @ 14 psi; 3 600 RPM) & accessories		*Enter value*	*Enter value*	XX	
Installation cost for electrical line (estimated at $25/m installed)		XX	XX	XX	
			Total	0 $	
				0 $	*with GST & PST*

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total per year
Enter value	XX	XX	XX

(Source: Kumar (1992), Hlavek (1995))

Losses due to equipment operation and maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
XX	XX	XX	XX

Diesel engine : Cost Of Diesel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost Of Diesel ($/litre)	WHP/unit of fuel (*)	Cost /cycle $CDN	Cost/year	Cost/year/ha
XX	XX	XX	XX	XX	XX	XX

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour)	Cost/cycle $CDN	Cost/year $CDN	Cost/year/ha
XX	XX	XX	XX	XX

Total Costs: 1999 Canadian

Total Fixed Costs		0 $	$
Total Operating costs/year	(with diesel)	XX	$
Total Operating costs/year	(electricity)	XX	$

CENTER PIVOT   Non-Towable

From Input File			
Total Depth of Application per cycle	di	XX	mm
# irrigation cycles/yr	Dd	XX	
FIELD width	Wf	XX	m
length	Lf	XX	m
Area Irrigated	Ai	XX	ha
System application efficiency	Ea	XX	decimal
Shortest distance of Water source to edge of Field (=length of main)		XX	metres

*Source BC Manual, 1989; Cuenca, 1989; James, 198

Center Pivot Specifications					
Total Span of Center Pivot Arm	XX	m	XX	ft	
Number of Sprinklers	XX	units			
Average Lateral Sprinkler Spacing	XX	m	XX	ft	* Variable
Discharge per sprinkler	XX	L/s	Enter value	gpm	* Man. Rec.
Pressure required at end gun	XX	Kpa	Enter value	psi	*Man. Rec.
End Gun Discharge	XX	L/s	Enter value	gpm	*Man. Rec.
System Capacity: Q=	XX	L/s	Enter value	gpm	*Manu. Rec

Operating Time		
Max. hrs of irrigation/day	Enter value	hrs
Max. No.of days/irrigation	XX	days
Total time of irrigation	XX	hrs

* Takes into account efficiency (Ea)

Time = Volume applied per cycle/Flow
Time = (di*A/Ea)/Q where di (m), A (m2), Ea (decimal), Q (m3/s)

Total Flow through Centre-Pivot (= Q)

XX l/s XX gpm (Manuf. Recom.)

Friction Losses in Piping, Fittings and Spans

Component	material	D mm	D in	L m	L ft	Hf (Scobey's) m
Mainline	PVC	XX	Enter value	XX	XX	XX
Submain	PVC	XX	Enter value	XX	XX	XX
	Aluminum	XX	Enter value	XX	XX	XX
Spans	Aluminum	XX	Enter value	XX	XX	XX
Fittings		D mm	D in	K unitless		Hf m
Elbow (90)	Aluminium	XX	Enter value	Enter value		XX
					TOTAL Htf	0.00

Friction loss (Htf) (Scobey's equation)

Ks - Aluminium	Ks =	XX	
Ks - PVC	Ks =	XX	
Flow Rate	Q =	XX	L/s
Elev difference on field	V =	XX	m
operating pressure	Ps =	XX	m
Net positive Suct. Head	NPSH=	Enter value	: for Htf, max (NPSH, Hsl, Hm)
Friction loss in suction line	Hsl=	Enter value	= highest value of the three heads
Friction Loss in the Main	Hm=	XX	
Height of C-P spans	Hsp=	XX	m
Drawdown	Hs=	Enter value	m

*Manu. Rec.

Pumping Requirements

Ht = V + Htf + Ps + Hsp + Hs + Hrh + max(NPSH,Hsl,Hm)
= XX m   XX kPa   XX psi

Pump Efficiency	Ep=	Enter value	(From pump curves)

Brake Power (Pb)	Pb=9.8*(Ht*Q)/(Ep)		
	Pb =	XX	KW
	KW*1.341 =	XX	BHP
Water Horse Power (WHP)	=	XX	WHP

(WHP = (Ht (m)*3.2808) *GPM/3960)

CENTER PIVOT Non-Towable (continued)

Piping Pressure Rating (based on pipe material and thickness:

Category	Material	Series	DR	S* (PVC) Ftu (Al)*	Press. Rating** (Kpa)	Press. Rating (psi)	Acceptable
Low Pressure	PVC	1120	XX	*Enter value*	XX	XX	Yes
High Pressure	PVC	1120	XX	*Enter value*	XX	XX	Yes
Low Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	Yes
High Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	XX

*Value of S, Ftu from Cuenca, 1989
**(Bursting Pressure for Al pipes)

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1999)*

Description		Quantity	$/unit	Cost $
Main 6" (ft) PVC	not buried	XX	XX	XX
Submain 6" (ft) PVC	not buried	XX	XX	XX
Submain 6" (ft) Aluminum	not buried	XX	*Enter value*	XX
Pipe fittings, valve, z-pipe, etc		*Enter value*	*Enter value*	XX
Fixed Center Pivot				
Pivot Structure		*Enter value*	*Enter value*	XX
Solid Tower Structure		*Enter value*	*Enter value*	XX
Non-tow Gearboxes		*Enter value*	*Enter value*	XX
Pivot Anchor		*Enter value*	*Enter value*	XX
Common Components				
Pivot Power Control		*Enter value*	*Enter value*	XX
Aims Transducer/Switch		*Enter value*	*Enter value*	XX
Pivot Accessories		*Enter value*	*Enter value*	XX
Span (ft of 6" aluminum)		XX	*Enter value*	XX
Joints		*Enter value*	*Enter value*	XX
Overhang		*Enter value*	*Enter value*	XX
Wire (ft)		XX	*Enter value*	XX
Tower Boxes		*Enter value*	*Enter value*	XX
Wheel Sets		*Enter value*	*Enter value*	XX
Center Drive		*Enter value*	*Enter value*	XX
End Gun		*Enter value*	*Enter value*	XX
Freight & Installation cost for centre-pivot		*Enter value*	*Enter value*	XX
Diesel engine pump (85 HP)		XX	*Enter value*	XX
Electric Pump (30HP; 575 VAC) + access.		XX	*Enter value*	XX
Installation fee for electricity (based on length of Main + Submain at 25$/m)		XX	XX	XX
TPS				0 $
TQS				0 $
		Total		0 $

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total/year	
Enter value	XX	XX	XX	Kumar (1992)

Losses due to equipment operation and maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
XX	XX	XX	XX

Diesel engine: Cost Of Diesel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost Of Diesel ($/litre)	WHP/unit of fuel (WHP/l) (*)	Cost per cycle $CDN	Total Cost/year	Cost/year/ha
XX	XX	XX	XX	XX	XX	XX

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour) from table 8.4 BC Irrig. Man	Cost/cycle $CDN	Cost/year	Cost/year/ha
XX	XX	XX	XX	XX

Total Costs: 1999 Canadian

Total Fixed Costs		0.00 $
Total Operating costs/year	(with diesel)	XX
Total Operating costs/year	(electricity)	XX

CENTER PIVOT   Towable

From Input File				
Total Depth of Application per cycle	di	XX	mm	
# irrigation cycles/yr	Dd	XX		
FIELD width	Wf	XX	m	
length	Lf	XX	m	
Area Irrigated	Ai	XX	ha	
System application efficiency	Ea	X	decimal	*Source BC Manual, 1989; Cuenca, 1989; James, 1988)
Shortest distance of Water source to edge of Field (=length of main)		X	metres	

Center Pivot Specifications						
Total Span of Center Pivot Arm		XX	m	XX	ft	
Number of Sprinklers		XX	units			
Average Lateral Sprinkler Spacing		XX	m	XX	ft	* Variable
Discharge per sprinkler		XX	L/s	*Enter value*	gpm	* Man. Rec.
Pressure required at end gun		XX	Kpa	*Enter value*	psi	*Man. Rec.
End Gun Discharge		XX	L/s	*Enter value*	gpm	*Man. Rec.
System Capacity:	Q=	XX	L/s	*Enter value*	gpm	*Manu. Rec

Operating Time			
Max. hrs of Irrigation/day	*Enter value*	hrs	* Takes into account efficiency (Ea)
Max. No.of days/Irrigation	XX	days	
Total time of Irrigation	XX	hrs	Time = Volume applied per cycle/Flow

Time = (di*A/Ea)/Q where di (m), A (m2), Ea (decimal), Q (m3/s)

Total Flow through Centre-Pivot (= Q)				
XX	l/s	XX	gpm	(Manuf. Recom.)

Friction Losses in Piping, Fittings and Spans						
Component	**material**	D		L		Hf (Scobey's)
		mm	in	m	ft	m
Mainline	**PVC**	XX	*Enter value*	X	XX	XX
Submain	**PVC**	XX	*Enter value*	XX	XX	XX
	Aluminum	XX	*Enter value*	XX	XX	XX
Spans	**Aluminum**	XX	*Enter value*	XX	XX	XX
Fittings		D		K		Hf
		mm	in	unitless		m
Elbow (90)	**Aluminium**	XX	*Enter value*	*Enter value*		XX
					TOTAL Htf	XX

Friction loss (Htf) *(Scobey's equation)*				
Ks - Aluminium	Ks =	XX		
Ks - PVC	Ks =	XX		
Flow Rate	Q =	XX	L/s	
Elev difference on field	V =	XX	m	
operating pressure	Ps =	XX	m	
Net positive Suct. Head	NPSH=	*Enter value*	: for Htf, max (NPSH, Hsl, Hm)	*Manu. Rec.
Friction loss in suction line	Hsl=	*Enter value*	= highest value of the three	
Friction Loss in the Main	Hm=	XX	heads	
Height of C-P spans	Hsp=	XX	m	
Drawdown	Hs=	*Enter value*	m	

Pumping Requirements				
Ht = V + Htf + Ps + Hsp + Hs + Hrh + maXX(NPSH,Hsl,Hm)				
= XX m	XX	kPa	XX	psi

Pump Efficiency	Ep=	*Enter value*	(From pump curves)

Brake Power (Pb)	Pb=9.8*(Ht*Q)/(Ep)			
	Pb =	XX	KW	
	KW*1.341 =	XX	BHP	
Water Horse Power (WHP)	=	XX	WHP	(WHP = (Ht (m)*3.2808) *GPM/3960)

CENTER PIVOT **Towable (continued)**

Piping Pressure Rating (based on pipe material and thickness:

Category	Material	Series	D/t	S* (PVC) Ftu (Al)*	Press. Rating** (Kpa)	Press. Rating (psi)	Acceptable
Low Pressure	PVC	1120	XX	*Enter value*	XX	XX	Yes
High Pressure	PVC	1120	XX	*Enter value*	XX	XX	Yes
Low Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	Yes
High Pressure	Al-Class 150	3003 H16	XX	*Enter value*	XX	XX	Yes

*Value of S, Ftu from Cuenca, 1989
**(Bursting Pressure for Al pipes)

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1999)*

Description			Quantity	$/unit	Cost $
Main 6" (ft)	PVC	not buried	XX	XX	XX
Submain 6" (ft)	PVC	not buried	XX	XX	XX
Submain 6" (ft)	Aluminum	not buried	XX	*Enter value*	XX
Pipe fittings, valve, z-pipe, etc			*Enter value*	*Enter value*	XX
Towable Center Pivot					
Pivot Structure			*Enter value*	*Enter value*	XX
Swivel Tower Structure			*Enter value*	*Enter value*	XX
Towable Gearboxes			*Enter value*	*Enter value*	XX
Common Components					
Pivot Power Control			*Enter value*	*Enter value*	XX
Aims Transducer/Switch			*Enter value*	*Enter value*	XX
Pivot Accessories			*Enter value*	*Enter value*	XX
Span (ft of 6" aluminum)			XX	*Enter value*	XX
Joints			*Enter value*	*Enter value*	XX
Overhang			*Enter value*	*Enter value*	XX
Wire (ft)			XX	*Enter value*	XX
Tower Boxes			*Enter value*	*Enter value*	XX
Wheel Sets			*Enter value*	*Enter value*	XX
Center Drive			*Enter value*	*Enter value*	XX
End Gun			*Enter value*	*Enter value*	XX
Freight & installation cost for centre-pivot			*Enter value*	*Enter value*	XX
Diesel engine Pump (85 HP)			XX	*Enter value*	XX
Electric Pump (30HP; 575 VAC) + access.			XX	*Enter value*	XX
Installation fee for electricity (based on length of Main + Submain at 25$/m)			XX	XX	XX
TPS					0 $
TQS					0 $
			Total		0 $

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total/year	
Enter value	XX	XX	XX	Kumar (1992)

Losses due to equipment operation and maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
XX	XX	XX	XX

Diesel engine: Cost Of Diesel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost Of Diesel ($/litre)	WHP/unit of fuel (WHP/l) (*)	Cost per cycle $CDN	Total Cost/year	Cost/year/ha
XX	XX	XX	XX	XX	XX	XX

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour) from table 8.4 BC Irrig. Man	Cost/cycle $CDN	Cost/year	Cost/year/ha
XX	XX	XX	XX	XX

Total Costs: 1999 Canadian

Total Fixed Costs		0.00 $
Total Operating costs/year	(with diesel)	XX
Total Operating costs/year	(electricity)	XX

The present model makes use of IRRIGATE as an exterior software in order to analyse temperature and to calculate evapotranspiration (ET). The user can easily transfer the results into the irrigation file (on Excel), and determine the depth and schedule of irrigation using the water balance method. The above steps are explained hereafter:

A- Collection and analysis of meteorological and rainfall data

Weather data is required to calculate evapotranspiration (ET) and to determine irrigation needs. Climatic data should be gathered for the largest number of years possible in order to conduct a reliable probability analysis. Cuenca (1989) states that 15-20 years of data is the minimum needed to provide a reasonable estimate. As planting dates can vary by 2-3 weeks based on farming practices and production strategies, it is difficult to determine which period of climatic data should be analysed. Climatic analysis can either cover a six-month period to include all farming practices, or can be based on the most probable growing period for the given crop. In this study, the growing period for potatoes (120 days from the May 1 to August 30) - was selected. Wet, normal and dry growing seasons are selected using rainfall probabilities for a 80%, 50% and 20% occurrence based on the total number of years of data. These are calculated in Appendix B and discussed in the next chapter.

B- Site specific evapotranspiration (ET) for potatoes:

The Baier-Robertson equation, known as VB-4, was used to determine reference evapotranspiration (ETo)[17] mainly because of its reliability in providing good simulation results compared to experimental pan values in Eastern Canada. When Barnett et al. (1998) compared five ET equations (Penman (modified), Jensen-Haise, Baier-Robertson (Laval), FAO and SCS-Blaney-Criddle) to corrected pan evaporation experimental data in southwest Quebec, they found that the Baier-Robertson (Laval)[18] equation gave the

[17]: Reference evapotranspiration (ETo or ETr) is the same as potential evapotranspiration (ETp or PET). (Cuenca, 1989).

[18]:The original Baier-Robertson equation was developed and calibrated based on data from six agricultural weather stations situated across Canada. The equation takes into account solar radiation effects as a function of upper atmospheric extraterrestrial radiation, as well as daily maximum and minimum temperatures. The Baier-Robertson equation was later adapted *(continued on next page)*

best estimate on a seasonal basis (potential ET estimates were within 10% of adjusted pan evaporation values, compared to 15-25% for the others). Another reason for selecting the VB-4 equation is its facility of use through the IRRIGATE software developed by Agriculture Canada (1990), which was used to determine ET values. Moreover, Kc coefficients, which account for the selected crop and its phenological stage with respect to the ETo (reference evapotranspiration), were also taken from the IRRIGATE manual. The resulting ETc values for each year and month, including the Kc factors used for each growth stage, are presented in Appendix A.

C- Determining crop water use and irrigation requirements for potatoes

The water balance method was used to determine the daily water consumption for potatoes. A detailed explanation on how the effective rainfall, soil moisture, readily available moisture, critical deficit water and irrigation requirement were determined is provided in Appendix A. Results of the water balance analysis are entered into the model as a total depth of irrigation application for the growing season (eg. 250 mm) and also on the basis of water-depth per application (called a 'cycle'). It is common practice to apply irrigation depths of 2.5 cm (or 1 inch) per cycle (irrigation systems are usually designed on that premise), however the user may choose to enter a different application depth. If the user decides to apply an amount of water other than 2.5 cm, he must verify the rate and time of application with the irrigation system manufacturer. Potato producers in Quebec generally follow the rule-of-thumb water application rate for potatoes and apply 2.5cm once a week. This application rate was in fact recommended by Agriculture Canada (Fulton and Murwin, 1955, 1974 and 1978) and in general agricultural extension information documents published in the United States. Finally, precipitation data should be analysed to determine probabilities of wet, normal or dry seasons to obtain indications of the probability and quantity of irrigation applications for each case. The result of this analysis can only be entered into the model for a single particular season (wet, normal or dry), however the user should repeat the same model for each season condition and save

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by Rochette (Rochette et al., 1990) for Quebec specifically. It is probable that the IRRIGATE program (Agriculture Canada, 1990) used for this study in N.D-de-la-Paix site is based on climatic data from the them as separate files (named for examples: "Wet Season Analysis") [19]. The procedure for determining rain season probabilities can be followed in the example shown in Appendix B.

3.2.3.2 Field Characteristics

For the travelling gun and portable pipe models, the total area to be irrigated must be specified. The centre pivot model requires the following inputs to determine the total area that can be irrigated by the different centre pivot systems:

- diameter of the largest single circle that can fit in the field;
- diameter over which an end-gun can operate for the largest single circle in a corner .

Field slope is not considered by the model as it was designed for a level field. The water source is a critical asset to an irrigation scheme and must be carefully studied to ensure:

- sufficient quantity of water throughout the growing season, particularly during dry spells, and an adequate flow that will not affect water-users downstream during intense water pumping;
- water quality to avoid clogging in spray nozzles;
- reasonable distance to the field to minimise pumping costs.

The model requests information on the distance between the field and the watercourse, for which the user should select the shortest distance. The user must also enter the difference in height between the maximum elevation of the field and the water level at the water source (explained later under Head parameters).

The following section describes the principal engineering characteristics that are entered into the model for each irrigation system.

Assomption region, some 70km southwest of the study site, but this should not significantly affect the accuracy (P. Rochette: personal communication, September, 1999).
[19]: A linked sub-file could be created to obtain a table with composite results for each season.

3.2.4 Engineering Factors

The irrigation design characteristics used by each system are organised and presented in a similar order in the model, including:

1. Irrigation and sprinkler gun specifications;
2. Operating times;
3. Flow of the irrigation system;
4. Pipe network, friction losses in piping and fittings;
5. Total pumping requirements;
6. Irrigation component costs (irrigation system and pumping station);
7. Labour requirements and costs;
8. Cost of fuel for a diesel engine;
9. Cost of electricity for an electric motor.

The above-mentioned parameters are explained hereafter:

1. <u>Irrigation and sprinkler gun specifications</u>

   This information is essential for determining pump capacity, pipe network and irrigation application operations and costs. Irrigation and gun specifications provided by the manufacturer are entered into the model (ie. diameter of irrigation application by a gun sprinkler), or the user can enter his own values. For each system, one can modify certain specifications, however such changes should be verified with the manufacturer or by an irrigation specialist. The specific changes that can be made for each irrigation system is discussed in the section pertaining to the individual systems. The user is required to specify certain basic irrigation equipment information, such as the amount of equipment (eg. number of volume guns on a line or the number of travellers planned). Overlap within each sprinkler pass is an important consideration to ensure proper irrigation coverage; recommendations for which are provided by the manufacturer. Once the overlap parameter is known, it should be taken into account in the wetted area per sprinkler.

2. <u>Operating times</u>:

   The operating time (per hectare or for a given area of land) of an irrigation system is a function of crop water needs (determined by the crop water balance method), sprinkler capacity and wetted diameter per application. The operator and his time dedicated to irrigation operations can also be an important factor that dictates the characteristics of the irrigation system. Depending on the type of irrigation system analysed, the user must discuss with the supplier the application capacity of the system so that it meets his time availability. Operating time will be determined by the supplier based on the characteristics of the irrigation system. The user will then enter this data into the model, which will then calculate days and total hours of operation. This value is essential for determining pumping hours.

3. Pipe network, friction losses in piping and fittings

The model adjusts automatically to different field sizes (ha) but it must be carefully reviewed to ensure proper adjustment for all pipe network calculations and layouts. The following assumptions about field shape and pipe orientations are made:

- mainline pipe length is the distance from the water source to the near edge of the field for all systems;
- a square field is assumed for the travelling gun and portable pipe systems, although a rectangular field can also be considered, with submains distributing water from the mainline to the field submains. The field submains run through the field and distribute water either to the laterals for the portable system or through regularly spaced hydrants for the traveller;
- a full rotation (360^0) is assumed for the centre pivot system (fixed or towable) with the mainline running from the edge of the field to the center of the field;
- if the farmer opts to bury the water delivery pipes, the price of burying a mainline PVC pipe (usually 1 meter deep) should be entered as $/m (pipe including cost of installation);
- the model provides an estimated cost per length of installed pipe (buried or non-buried), although the user will probably choose his own estimate from a local contractor.

Pipe sizing for mainlines, submains, and laterals is based on a given pipe size's maximum allowable flow velocity, which results in the most cost-effective pipe size over the life of the system. Friction loss in pipes is computed using Scobey's[20] equation with appropriate friction adjustment factors for flow in multiple outlet pipes, such as the centre pivot and portable pipe laterals. These limits are primarily based on rule-of-thumb guidelines and are available from the manufacturer's product information specifications. The mainline and submain for all systems can be PVC or aluminium, as entered by the user. For the portable pipe systems, aluminium laterals are assumed.

4. Total pumping requirements

Pumping requirements are a function of the discharge necessary to meet the evaporative demand of the crop, and the total pumping head resulting from the given physical conditions. The power requirement of the pump is determined from:

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[20]: Scobey's formula: $H_f = ((K_s LQ^{1..9}) / D^{4.9}) * (4.10 * 10^6)$; H_f = total friction loss in line; K_s: Scobey's coefficient of retardation; L = length of pipe (m); Q = total discharge (L/s); D = inside diameter of pipe (mm). Formula is adapted for lateral pipes with sprinklers by applying a factor F to the value of H_f.

$$P_b = 9.8\,(H_T Q) / E_p$$

(Pair et al.,1983) where P_b = brake power of the pump unit, kW (hp); H_T = total pumping head, m (ft); E_p = pump efficiency (enter a value, usually between 0.65-0.85). The total pumping head, H_T in m (Ft) is determined from:

$$H_t = V + H_{tf} + P_s + H_s + H_{rh} + max\,(NPSH,\, H_{sl},\, H_m)$$

where V = vertical distance, or lift, from water source to the highest point in the field, m (ft); H_{TF} = cumulative friction loss in mainline, submains, and laterals to most distant sprinkler position, m (ft); P_s = sprinkler operating pressure, m (ft)); H_{rh} = sprinkler height from ground (m); $NPSH$ = Net Positive Suction Head (m); $H_{sl)}$: friction in suction line (m); H_m: friction loss in the main pipe. The calculations provided above by the model will be useful for the pump supplier when calculating rated horsepower (a horsepower unit used by pump manufactures and suppliers).

5. Irrigation component costs (irrigation system and pumping station):

All irrigation equipment and pumping station component costs (including electrical installation) are entered. Prices are provided by local suppliers; in general it is good practice to request quotes from various suppliers in order to ensure the best prices. All prices should be entered without sales taxes, as they are calculated at the end of the total price list (GST and PST (Quebec)). The user should remember to include installation costs of complex irrigation systems, such as the centre pivot.

6. Labour requirements and costs:

Labour inputs include hourly salary (including benefits) and total hours worked per hectare. The user can either accept the proposed time in the model (time estimates from a variety of research: Kumar et al., 1992(b); Hlavek, 1995; Pair et al., 1983) or enter his own time estimates. In general, the farmer can calculate labour requirements of irrigation-related activities by referring to past years expenditures and dividing that time per hectare. Labour includes both hired labour and the time spent by the farmer himself, unless he decides to neglect this factor in the model. Once the hourly wage and labour hours per hectare is entered, the model calculates the yearly labour cost based on the total irrigation time.

7. Cost of fuel for a diesel engine and cost of electricity for an electric motor

Cost of diesel fuel is determined based on the number of irrigation hours multiplied by the conversion factor of fuel equivalents into Water Horse Power (WHP) hours per unit of fuel (British Columbia Ministry of Agriculture & Fisheries, 1989):

Fuel	WHP hours per unit fuel
Gasoline	2.14 /liter
Diesel	2.9 /liter
Electricity	0.0885 / kWhr

The above values are entered in the model and the user enters the cost of diesel fuel #3 (per liter) or the cost of electricity. Either a diesel or an electric pumping unit is assumed for all systems. Although electric motors are often preferred for large-scale systems, diesel power units are usually a more practical selection because of the limited availability of three-phase electrical power. However, if necessary, the user must provide additional information on his intention to install an electric line to the site of the motor.

The following table presents a summary of the essential operating characteristics assumed for each irrigation system.

Table 3.1: Design Characteristics of Irrigation Systems (1)

Irrigation System	System efficiency (%)	Operating time (hr/day)	Labor per cycle (hr/ha)*	Area lost (%)**
Centre pivot:	80	12	0.25	2.5
Traveller System:	75	10	0.75	4.0
Portable pipe:	70	11	1.90	1.0

(1) : data from Kumar et al. (1992(b)), OMAFRA (1995), Hlavek (1995).
*: Conversions: hr/ha x 0.405 = hr/acre.
**: % of land area lost due to equipment operation and movement.

3.2.5 Specific Characteristics

This section presents specific features for each irrigation system that should be onsidered when working with the model.

(i) Portable Pipe Cost Model

For the portable pipe systems, design parameters include sprinkler spacing and the number of sets per day in addition to the parameters given in Table 3.1. A 70 x 64 m spacing and four sets per day are assumed for high-pressure systems (stationary big guns on tripod stands operating at 510 kPa or 75 psi). The user can modify the configuration in accordance to manufacturer's recommendations (gun pressure and sprinkler diameter) and according to pipeline layout and proper water pressure/discharge in the network (user must determine and enter these parameters). The number of field submains required is based on the sprinkler-wetted diameter. Assuming a square field, the length of the laterals and field submains, along with the flow in the field submains, is determined in a manner similar to that for the travelling gun model.

In order to save time in the data entry and analysis, certain hydraulic parameters have not been included. However, most of the essential elements are available and can be readily arranged and calculated, depending on the user's intentions. An example of further calculations is the determination of the flow in the laterals at specific points ($Q_l = Q_s/N_l$: where $Q_{l)}$ = flow in lateral, l/s (gpm); Q_s= system capacity, l/s (gpm); N_l = number of laterals).

(ii). Traveller System Model

For the traveller system, the number of irrigation cycles and the size and cost of the mainline (per unit length) are determined by the model. The system capacity of the traveller itself is provided in the manufacturer. The cost of the hose is included in the cost of the traveller system, which is assumed to be a linear function of the flow rate in the hose. The lane spacing is provided by the manufacturer's specifications or it can be estimated by multiplying the maximum possible wetted diameter (obtained from the flow in the hose) by a suitable reduction factor (eg. 0.7) to ensure overlap between adjacent lanes (Kumar et al., 1992(b)). The number of travel lanes will be equal to the number of hydrants required per gun. The cost of a single hydrant is assumed to be a linear function of the field submain diameter. The traveller gun operating pressure depends on the selected hose diameter and can range from 510 kPa (75 psi) to 655 kPa (95 psi).

(iii) Centre Pivot Cost Model

The area irrigated by the fixed (or towable) centre pivot system (full-circle system) is calculated as follows:

$$A_i = ((L \times W) - (\pi r^2)) * 0.91$$

where A_i = area irrigated, ha; L & W = length and width of field (m); r = radius; 0.91 = 91% of field covered by irrigation due to imperfect watering of corners by end-gun. For the end-gun, it is assumed that 60% of the area in each corner is correctly watered. This assumption is justified because in practice, the extreme end of the corner cannot be reached (Gilley, 1996). The system capacity and number of irrigation cycles are recommended by the manufacturer, based on field-site information provided by the farmer. The supplier then determines the size of the mainline (taking into account the system capacity proposed by the irrigation manufacturer) from a list of available sizes. The pump is sized using P_b (brake power) and H_t (total pumping head), with the centre pivot sprinklers assumed to be operating at 37.85 l/s (600gpm). The total cost of the pumping unit is obtained from the total amount of time the centre pivot is in operation, presented as total time of irrigation.

4.0 APPLICATION OF THE MODEL ON A POTATO FARM

4.1 Introduction

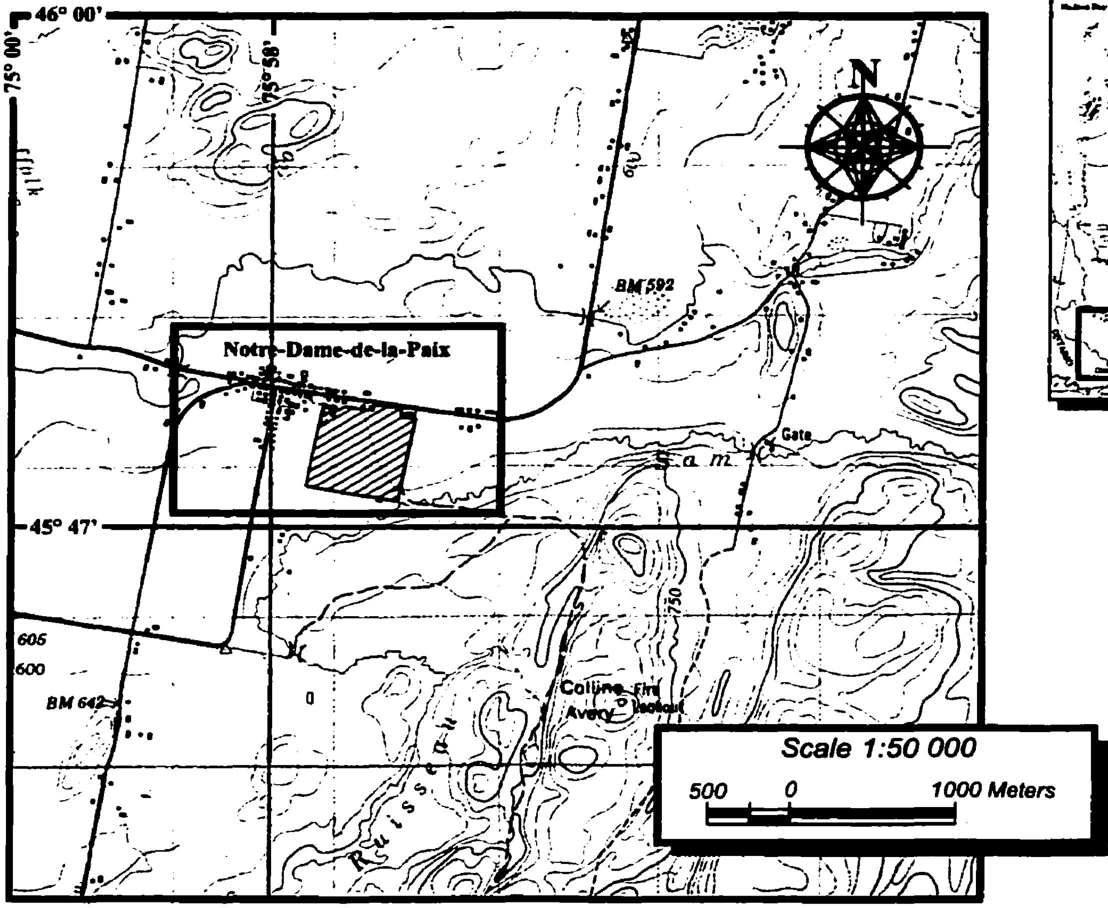
The present section applies the model discussed in the precedent chapter on a potato farm situated in Notre-Dame-de-la-Paix in southwestern Quebec. The model will be used to make a technical and economical comparison of three sprinkler irrigation systems on a case study farm called "Pommes de terres Laurentiennes Inc.". A location map is presented in Figure 4.1. Following a general description of the farm and the specific site chosen for the layout of each irrigation system, an analysis of climatic data with crop water requirement calculations is presented. Next a description is given of the layout of each sprinkler irrigation system and their specific characteristics. The model is then used to compare each system and their costs.

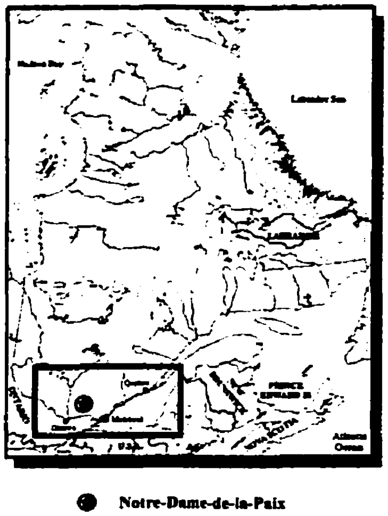
4.2 Description of the Site Used for Analysis

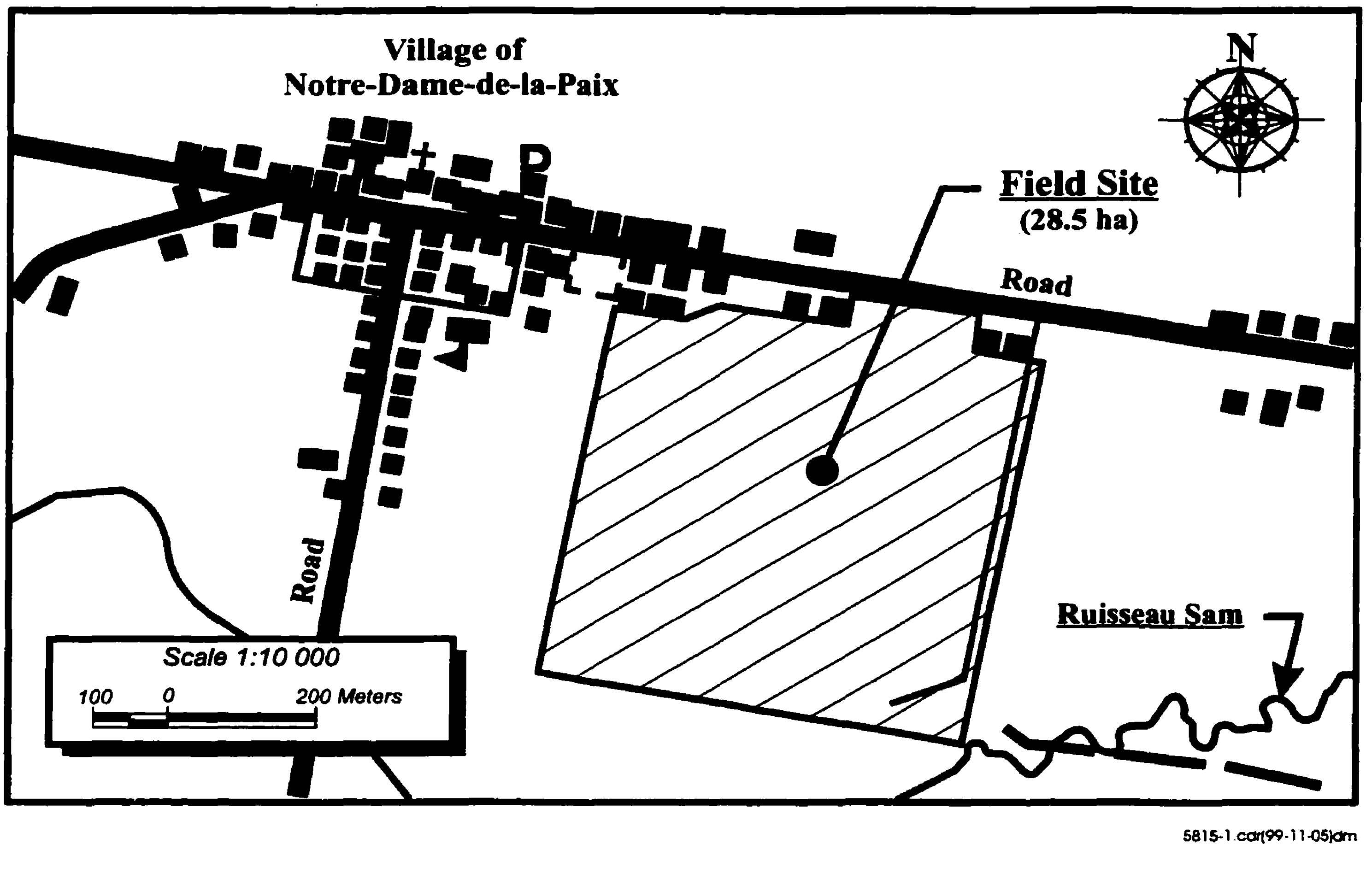
Description of the region and the farm in general

The farm is situated on a sandy plain surrounded by hills that feed nearby small rivers (eg.: Petite Rivière Rouge), streams (eg. Ruisseau Sam) and natural ponds and marshes. The farm - a total of 222 ha - consists of several farmlots dispersed within a 2-kilometer radius from the central farm. The soils are classified as Orthic Podzols and belong to the Morin and St. Gabriel series (Lajoie, 1967). Both series are deep (>3 m), highly permeable and non-calcareous sand deposits and contain little or no small gravel. The farmer's soil tests indicate they are relatively poor in organic matter (2-3%), have low fertility (CEC = 8-10 meq/100g) and a pH of 5.3 (average). These analyses concur with Lajoie's (1967) comment on the general fertility of these two soil series. The owner recently acquired this land (in the mid-1990's), which has been used for potatoes since the 1980's. The Notre-Dame-de-la-Paix region is particularly known for its potato production, with a half-dozen producers.

Figure 4.1
Location Map







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The owner of the studied site produces an average of 70 ha of potatoes, spread over several fields each year. The rest of his fields (roughly 150 ha) are used for his rotation crops (in order of importance: oats and clover, oats, and some soy, corn and rye). The rotation he follows is essentially two years of oats and clover and one year of potatoes. He presently owns and operates 1 traveller sprinkler and 2 winch driven (by PTO from his tractor) travellers. He has expressed concern about the cost of labour linked to irrigation operations (for potatoes) and seeks to diminish this cost as much as possible. His intention is to expand the surface area for potatoes and consequently update his existing irrigation equipment. He is presently studying several options regarding this expansion, either by modifying his rotation and increasing the potato crop surface to 100 ha, or by purchasing more farmland.

Description of the site

The farmer chose the field on which he would like to install an irrigation system. The selected field (see Location Map) covers 28.5 ha and is presently used for potatoes (under the traditional rotation system) and is situated next to a perennial small stream from which water can be pumped for irrigation. Figure 4.2 presents pictures of the site and the topography, soils and vegetation. The field was carefully inspected with regard to the minimum conditions required for the layout of irrigation equipment. From local knowledge, this stream is always flowing, even in dry periods (flow not measured) and is exploited by nearby potato farmers (3 in all). Visual estimation of the stream size would be around 6-8 m wide by 3-4 m deep. It can be considered a very reliable water source on many accounts: quantity, regularity of flow and quality of water (no industry or pollution declared in the region). The land is almost perfectly flat and consists of a broad sandy plain, containing the St. Gabriel series and characterised by loamy sand soil on the surface (0-25 cm) underlain by nearly pure sand to a depth of at least 3 meters (confirmed by the farmer). The profile is well drained throughout, with no appearance of mottling or concretions. This field, according to the farmer, requires irrigation for a successful potato harvest. Water to his irrigation systems is provided by a diesel pump taking water from the nearby perennial stream. The height difference between the stream and the average field elevation (for dynamic head consideration) is around 5 m.

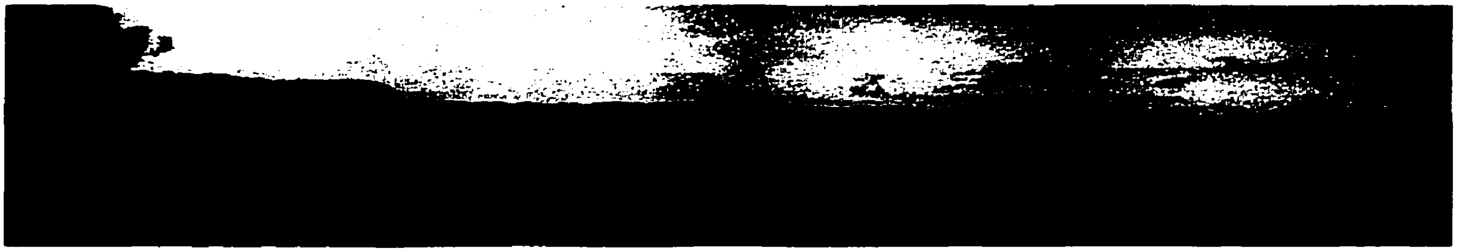


Figure 1a
Field site (approx. 28,5 ha). Notre-Dame-de-la-Paix

Figure 1b
Loamy sand soil (Podzol).
Note : oats + clover as cover crop

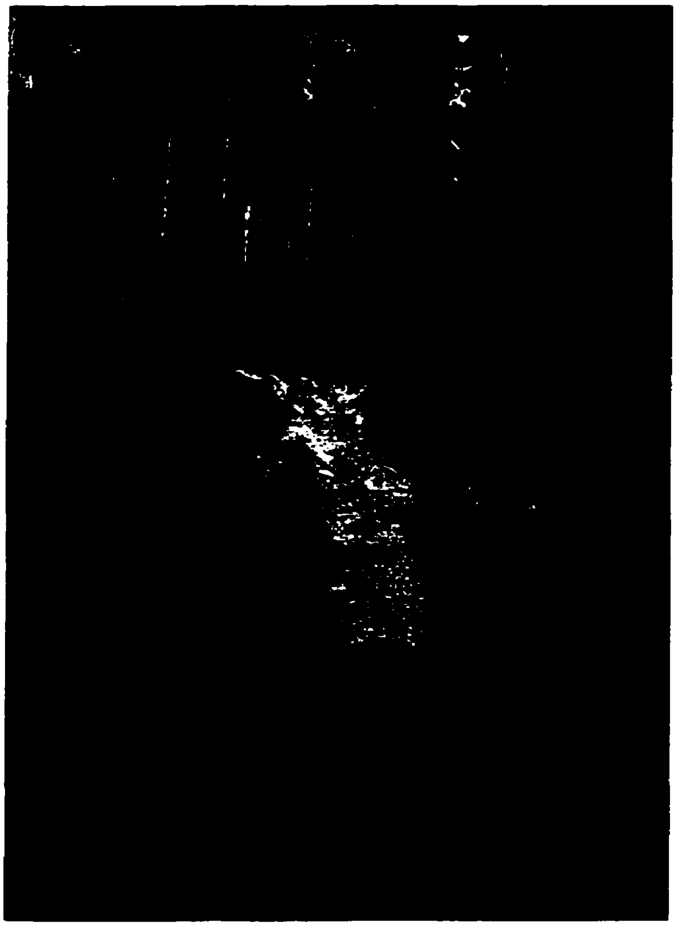


Figure 1c
Soil pit showing depth of sand material (>5 m).
Small scotch pine plantation.

Figure 4.2 : Photos of site

4.3 Method and Procedures

An economic evaluation is needed to advise the farmer on which sprinkler irrigation system is the most efficient and profitable. Key production parameters for the selected crop (potatoes) must be outlined first to determine the economic model and simulations that will be developed; these parameters are described hereafter.

4.4 Determination of Crop Water Requirement and Irrigation Applications

Crop water requirements were determined for potatoes on the basis of rainfall data, evapotranspiration and the soil water holding capacity. These parameters were then used in the water balance method to determine irrigation depth, frequency and scheduling. The results are summarised in Table 4.1 and a short discussion of the results is given hereafter. Detailed results are presented in Appendices A and B.

4.4.1 Rainfall Records and Predictibility with Respect to Irrigation Needs

Climatic data were obtained from the Notre-Dame-de-la-Paix weather station where daily rainfall and temperature data has been recorded since 1980 (the station is situated 1-2 kilometers from the study site). The data acquired cover the 1981-1998 period, however records for 1990 and 1994 to 1996 were rejected because of missing data during critical periods of the growing season. A summary of the 1981-98 monthly precipitation data for a six-month period and for a standard crop growing period (May to September) is presented in Table 4.1 below. Detailed data is presented in Appendix A. An analysis of the 14 years of climatic data indicate that 1982 was the driest growing season[21] (270 mm) and 1981 was the wettest (511 mm), while 1988, with 359 mm of precipitation, represents a year close to that of the average rainfall (360 mm). Table 4.2 presents rainfall according to rainfall class:

[21]: Growing season months: May, June, July and August (120 days).

Table 4.1 Summary of Average and Effective Precipitation, Potential ET and Irrigation Requirements for Notre-Dame-de-la-Paix					
Average Values over 1981 – 1998 Monthly Summary (6 months)					
Month	**PET**	**Rainfall mm**	**Effective Rainfall Mm**	**Irrigation mm**	**Effective Rf+ Irrigation mm**
April	49,76	69,79	41,36	26,81	59,22
May	99,30	85,43	57,32	54,20	94,82
June	132,09	92,24	54,64	78,88	118,93
July	133,09	83,94	56,87	77,94	122,94
August	115,00	98,93	64,31	64,25	114,31
Sept	67,48	85,16	46,99	28,64	66,63
Oct	20,00	87,68	45,00	2,44	45,00
TOTALS	**617,62**	**603,18**	**366,49**	**333,16**	**621,85**
Average Values over 1981 – 1998 Monthly Summary (growing season)					
Month	**PET**	**Rainfall mm**	**Effective Rainfall Mm**	**Irrigation mm**	**Effective Rf+ Irrigation mm**
May	99,30	85,43	57,32	54,20	94,82
June	132,09	92,24	54,64	78,88	118,03
July	133,09	83,94	56,87	77,94	122,94
August	115,00	98,93	64,31	64,25	114,31
TOTALS	**479,48**	**360,55**	**233,15**	**275,27**	**451,00**

Table 4.2 Rainfall Frequency (1981 – 1998) in Notre-Dame-de-la-Paix			
Rainfall class (mm)	**No. Of Years**	**Years**	**%**
250-300	3	1982,85,97	21
310-350	2	1983,91	14
351-400	6	1987,88,89,92,93,98	42
401-450	1	1984	7
451-500	0	-	0
501-550	2	1981,86	14
Total	14		100

From Table 4.2 above, past rainfall records indicate that 11 out of 14 years (75%) had precipitation below the 400 mm/growing season level (400 mm level chosen arbitrarily). Similarly, a probability analysis for a wet, normal and dry season on the 14 years of data was performed on a yearly and monthly basis; the results and calculations appear in Appendix B. At 20% probability (P20) for a dry year, predicted rainfall was 282.1 mm, at

P50 (normal) rainfall was 368.15 mm and at P80 (wet year) rainfall was 437 mm. At P50 (normal), it is reasonably accurate to take the year 1988 as corresponding to a normal rainfall season since in that year there was 359.20 mm (a difference of 9 mm).

4.4.2 Evapotranspiration (ET) Results and Irrigation Requirements

The IRRIGATE program was used to determine ET values based on 14 years of climatic data and the results are presented in Table 4.1. The ET results indicate that during the normal growing season (May to September), the average potential evapotranspiration (PET = 479.48 mm) exceeds average rainfall (360,55mm) by approximately 130 mm. Based on probabilities, at P50 (normal season) 368,15 mm rain is predicted, which corresponds closely to 1988 which had an ET of 496 mm, or a difference of nearly 127 mm. Irrigation applications for potato crop water needs, when taking into account effective rainfall, seepage and efficiencies, averages 250 mm for a normal year. This amount (250 mm) is similar to the conclusions of different researchers in Eastern Canada: Fulton (1974), Dwyer and Boisvert (1990) and Rioux (1987). Gallichand et al. (1990) recommended 257/341 mm of irrigation (early/late variety potatoes) for the dry season and 127/150 mm for a normal season in southwestern Quebec. However the author points out that these amounts are underestimated since they did not take into account inefficiencies or effective rainfall. For the purposes of the model and the present case study, a normal year was chosen, which means that a total seasonal application of 250 mm of irrigation is required. This total amount is actually equivalent to 10 applications of 25 mm (or 1 inch) of irrigation at critical moments during the growing season.

4.4.3 Estimation of Potato Yield with Irrigation

While the effect of irrigation on potato yield, as discussed in Section 2.4, is variable and depends on many factors, the proper quantity of water applied at the right time is critical for a successful harvest. Based on research conducted in Eastern Canada (Bilodeau, 1983; Rioux, 1987; Fulton, 1978; Walsh, 1999; White and Sanderson, 1989) it seems that the minimum increase in yield that can be obtained with irrigation is 25%. This rate, considered conservative, was assumed for the model, though it can easily be changed to any value the user might want. Irrigation also has a favourable effect on the yield of higher grade potatoes (Grade size) and therefore should bring in higher revenues per hectare for the farmer, however this situation was not considered in this demonstration due to uncertain data[22].

4.5 Description of Three Irrigation Design Layouts

Model implementation is presented in this section to design three sprinkler irrigation systems for the selected farm in Notre-Dame-de-la-Paix. The preliminary Input File, presented on the following page, contains the data discussed Section 4.4 and presents the common information needed for the analysis of each individual irrigation system. This information was discussed with the farmer.

4.5.1 Design of the Portable Pipe with Volume Gun

The portable pipe system with a volume gun is used frequently in Quebec, particularly for potatoes. A proposed design layout for this irrigation system on the given field site in Notre-Dame-de-la-Paix is presented in Figure 4.3, followed by the irrigation model. The main characteristics of the proposed layout are now discussed:

<u>Layout of the main pipe network</u>: a 6" PVC pipe – called the main line - brings water through a 'suction line' directly from the nearby stream to the pump (discussed later) and continues towards the edge of the field, for a total distance of 50 m. At the edge of the field, the mainline is connected to a 6" PVC (same diameter) submain pipe. The submain runs along the edge of the entire length of the field, on which 8 tees and hydrants are installed for easy connection to the portable laterals. Two lateral lines of portable 6" aluminium pipe are planned for the entire field. One person would be in charge of changing the laterals to the subsequent line and connecting it to the hydrant. It could be

[22] Table 2.2 Indicates that the yield increase in marketable potatoes ranged from 11% to 365% (!).

Input Data

Legend : **Manually Entered Data** (Data entered by user)
Calculated by Model (Data calculated automatically by model based on data entered by user and/or with equations stored in model)

CROP->	POTATO

Water Requirements

Water Requirements	Annual Water Requirement		250	mm
	Depth of application/cycle	di	25	mm
	# irrigation cycles/yr		10	

Field Characteristics

FIELD	Width	Wf	530	m
	Length	Lf	530	m
	Area Irrigated	Ai	28.09	ha
Shortest Distance of water source to edge of Field (=length of main pipeline)			50	metres
Max. elev. difference: field-water source		V	5	metres

highest point of field

COSTS

Cost of Labour ($/hr)	Price of Potatos $/tonne	Yield tonnes/ha	Cost Of Diesel ($/litre)	Cost ($ per KW-hour)	WHP/unit of fuel (hours WHP/l)
11.25	172	25	0.25	0.06	2.9

(B.C. Irrig. Man., 1989)

Coefficient Ks for Scobey's Equation

Ks - Aluminium	Ks =	0.4	(Schwab, 1993)
Ks - PVC	Ks =	0.4	assumed

System Specific Parameters

Yield Losses due to Operation And Maintenance of Equipment

Portable Pipe	Traveller	Center Pivot
Area Lost (%)	Area Lost (%)	Area Lost (%)
1	4	2.5

(Source: Kumar, 1992)

Irrigation Application Efficiencies (Ea)

Portable Pipe	Traveller Gun	Center Pivot
Ea	Ea	Ea
0.7	0.7	0.8

(Source: Kumar, 1992)

Main water supply pipe (PVC) options for buried/non-buried:

Main Line (PVC) buried (enter yes or no for buried pipe)
no

Material of Sub-main		
PVC ?	*Enter yes or no*	yes
PVC pipe buried ?	*Enter yes or no*	no
Aluminum		no

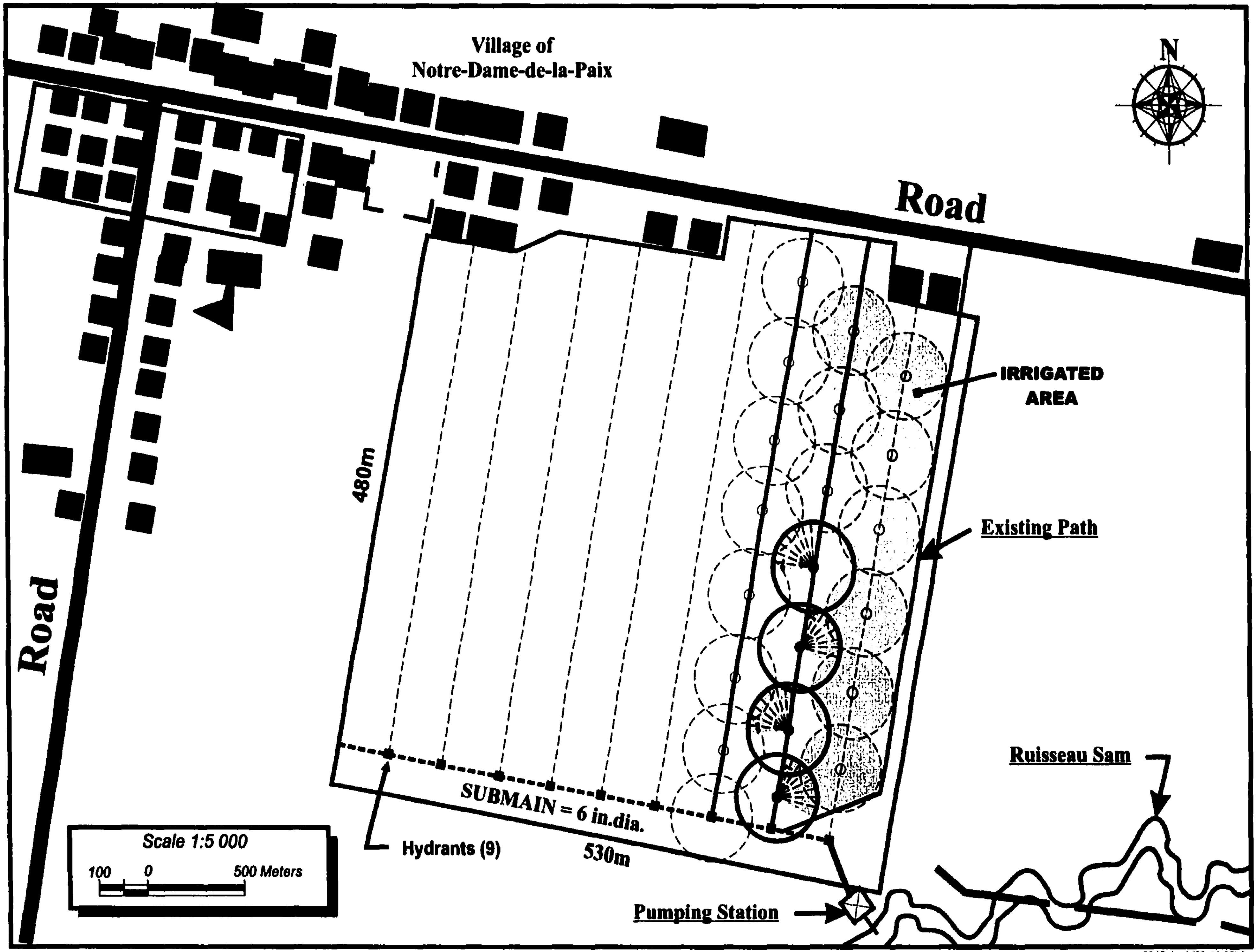
Pump Purchase Options (Diesel or Electric)		
Diesel ? *Enter yes or no :*	no	(If no, assumed electric)

Installation for electric line ?	Distance of Cable to be installed (m)
Enter yes or no yes	*Enter distance in meters :* 600

Conversions:

kg/cm2 * 14.22 = psi | liter/second (l/s) = 15.852 US gallons /minute (gpm)
psi * 6.895 = kPa | head (m) * 9.8 = kPa
gpm * 0.227 = m3/hr

Figure 4.3 - Field Site - Portable Pipe with Volume Gun



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possible to reduce the diameter of the submain to 5" halfway to maintain pressure and reduce pumping. For demonstration purposes, none of the pipes in this model application are buried although it would be preferable, not only for ease of farm machinery trafficability, but also because PVC is known to deteriorate when exposed to intense sunlight (British Columbia Ministry of Agriculture & Fisheries, 1989). Also, PVC pipes have poor resistance to cold (pipes can snap or crack when disturbed), therefore the farmer should store his pipes during the winter.

Volume guns: 4 volume guns are planned to operate simultaneously, each irrigating a wetted diameter of 82 m with a 14% overlap (11.5 m or 5.25 m on both sides). The overlap should be increased if a site is subject to frequent and strong winds. Each volume gun, with a 0.8" nozzle, has a 342 kPa (50 psi) operating pressure and a discharge of 8.3 l/s (132 gpm) for a total flow, with all four guns in operation, of 33.18 l/s (526 gpm). Guns are available with larger nozzles and larger wetted diameters, however operating pressures increase proportionally.

Pumping station: to provide sufficient pressure for the pipe network, including four operating volume guns, total dynamic head was estimated by the irrigation model at 676 kPa (98 psi). This is quite high and further investigation would be needed to reduce the total head in the system, including reducing feeder pipe diameters. Although this was not done by the model, if necessary a subroutine to select optimum pipe size could be added by an irrigation specialist. The type of pump planned for the irrigation system is a diesel powered horizontal centrifugal pump although an alternative electric pump is also planned in the model. The break horsepower of the pumping station is initially estimated at 28 kw. However, considering the relative inefficiency (70%) of the portable pipe system (Cuenca, 1989; Kumar et al., 1992(b); FAO, 1982) and the possible expansion of the irrigation system (ie. additional volume guns on the laterals or perhaps additional operating laterals), the break horsepower requirement of the pumping station is increased to 62 kw (at 55% pump efficiency according to pump rating charts from the manufacturer). An alternative 45 kW electric pump could be selected, with a lower power level due to higher efficiency (75 – 80%). For this case the installation cost was assumed

PORTABLE PIPE WITH VOLUME GUN

From Input file			
Total Depth of Application per cycle	di	25	mm
# irrigation cycles/yr	Dd	10	
FIELD Width	Wf	530	m
Length	Lf	530	m
Area irrigated	Al	28.09	ha
Shortest distance of Water source to edge of Field (=length of main)	Dm	60	m
System application efficiency (*)	Ea	0.75	decimal

(*) : James (1988)

Portable Pipe Specifications					
Sprinkler Spacing	Sspr	70.62	m	232.00	ft
Lateral Spacing	Slat	63.96	m	209.00	ft
Length of lateral	Llat	507.04	m	1 663.50	ft
Length of Submain	Lsm	493.92		1 620.45	ft
Number of Sprinkler Spacings	Nssp	7	(Rounded up. Nssp also = number of sprinkler hydrants)		
Number of Sprinklers acquired	Nspr	4			
Number of Lateral Connections	Nlc	8	(Rounded up. Nlc also = number of sub-main hydrants)		
Number of Laterals in operation simultaneously	Nlat	1	Two laterals are installed for maximum pipe installation efficiency, only 4 guns operational		
Design pressure of each gun	Pg	342.60	kPa	[illegible]	psi
Wetted area : per sprinkler		6 290.36	m2		

*Manu. Rec.

Gun Specifications				
Wetted diameter per gun	Wd	92.00	m*	*Manu. Rec.
Sprinkler overlap	Sov	14	%	
Lateral overlap	Lov	22	%	

Operating Times

Time to cover 1 set (4 sprinklers)	5.9	hours
Operating time/day	11	hrs/day
Number of Sets Req'd	14	
Time for entire field	82.6	hours
	7.5	days

(there are 56 sprinkler-hydrant connections)
* includes application efficiency (75%)
* by adjusting time of application

FLOW

Sprinklers					
Flow per sprinkler gun (0.8" nozzle dia.)	Qs	[illegible]	gpm	8.30	L/s
Total Flow with 4 operating guns	Qt	526.00	gpm	33.18	L/s

Manuf. Spec.

Calculation for Friction Losses (Hf) using Scobey's Equation

Ks - Aluminium	Ks =	0.4	Schwab (1993)
Ks - PVC	Ks =	0.4	
Flow Rate	Q =	33.18	L/s

Friction Losses in Piping and Fittings

Component	Material	D* mm	D* in	L m	L ft	Hf (Scobey's) m
Main	PVC	152.6	6	60	194.04	1.27
Sub-Main	Aluminum	152.6	6	0	0.00	0.00
	PVC	152.6	6	494	1 620.46	12.60
Laterals	Aluminum	152.6	6	507	1 663.50	12.93
Fittings		D mm	D in	K unitless		Hf m
Elbow (90)	Aluminium	152.6	6	0.45		0.06
				TOTAL Hf		26.87

* Diameter of Pipe chosen to best suit friction/cost factors

Data needed for Determination of Pumping Requirements

Elevation difference on field	V =	6.00	m
Operating pressure at Guns	Ps =	34.96	m
Riser Height	Hrh=	0.15	m
Net positive Suction Head	NPSH=	2.00	max (NPSH, Hsl, Hm) =
Friction loss in suction line	Hsl=	2.00	maximum
Friction Loss in the Main	Hm=	1.27	value of the three heads
Drawdown	Hs=	0	m

*Manu. Rec.
*NPSH = Manuf. Rec.

PORTABLE PIPE WITH VOLUME GUN (continued)

Total Pumping Requirements

Ht = V + Htf + Ps + Hs+Hrh+max(NPSH,Hsl,Hm) = 68.97 m	675.92 kPa	98.03 psi

Schwab (1993)

Pump Efficiency (Ep)	Water Horse Power (WHP)		Brake Power Pb=0.8(Ht*Qt/Ep)	
0.8	30.06	WHP	28.04	KW
			37.60	BHP

(WHP = Ht*3,2808*Qt / 3960)
KW*1.341 = BHP

Piping Pressure Rating (based on pipe material and thickness;

Component	Category	Material	Series	DR	S* (PVC) Ftu (Al)*	Pressure** Rating (Kpa)	Pressure Rating (psi)	Acceptable
Main	Low Pressure	PVC	1120	64.77	13 [illegible]	321.80	46.68	No
Main	High Pressure	PVC	1120	15.09	13 [illegible]	1 633.74	236.90	Yes
Submain	Low Pressure	Al-Class 150	3003 H16	64.77	14 [illegible]	342.12	49.64	Yes
Submain	High Pressure	Al-Class 150	3003 H16	15.09	14 [illegible]	1 824.62	266.37	Yes

* S from Table 10-1, Cuenca (1989)
*Ftu from Appendix D, Cuenca (1989)
**(Bursting Pressure for Al pipes)

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1999)*

Description			Quantity	Price/unit	Cost $
Main	PVC	not buried	164	4.50	738 $
Submain	Aluminum	not buried	0	[illegible]	0 $
	PVC	not buried	1620	4.50	7 292 $
Lateral	Aluminum	not buried	3327	4.50	14 971 $
Tees			6	[illegible]	1 242 $
Hydrants			8	[illegible]	1 440 $
Open Valves			2	241.30	482 $
Plug (for 6" pipe)			1	18.30	18 $
Gun nozzle stands (tripods)			4	[illegible]	740 $
Pipe plug (6" alum.)			3	33.00	99 $
Pipe parts (estimated)			1	1 000.00	1 000 $
Nelson Canons (Series 150 - 0.8" nozzle)			4	1 [illegible]	5 640 $
Elbow (6"by 30") Z-pipe ass.			1	272.00	272 $
85 HP IVECO - Diesel pump unit			0	[illegible]	0 $
Electric Pump (460 Volts; 60 hp; 500 gpm @ 145 psi; 3 600 RPM) & accessories			1	13 000.00	13 000 $
Installation cost for electrical line (estimated at $25/m installed)			1	15 000.00	15 000 $
				Total	61 934 $
					71 127 $

Note: 2 laterals installed, 1 in operation
with GST & PST

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total per year
1.9	11.26	600	6 004

source: Kumar (1992)

Losses due to equipment operation & maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
1	172	26	1 206

source: Kumar (1992)

Diesel engine: Cost Of Diesel Fuel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost of diesel ($/l)	WHP/unit of fuel (WHPh)	Cost/cycle $CDN	Cost/year	Cost/year/ha
82.6	826.1	0.25	2.9	214 $	2 138 $	76 $

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour)	Cost/cycle $CDN	Cost/year	Cost/year/ha
82.6	0.06	145 $	1 446 $	51 $

Total Costs: 1999 Canadian $

Total Fixed Costs		61 934 $
Total Operating costs/year	(with diesel)	8 142 $
Total Operating costs/year	(electricity)	7 451 $

excluding GST & PST

for an electric line over a distance of 600 m, from the road to the pumping site near the stream. The pumping capacity has not been fully optimised and would require further investigation in order to minimise the cost of the pump and pumping.

General operation of the irrigation system: some farmers appreciate the portable system for its simplicity of operation, its relative low initial cost (arounds $50,000) and the ease of irrigating odd-shaped fields. However they soon realise its limitations with respect to limited surface coverage, the need for constant surveillance during operation, high labour requirements [23], and risks of malfunction due to human error during the frequent manoeuvring and pipe changing. As well, volume guns have the inherent problem of being inefficient under windy conditions, which can cause serious problems on the field where drenching will occur in certain areas (thus causing puddling, soil crust and erosion) and other areas are left dry.

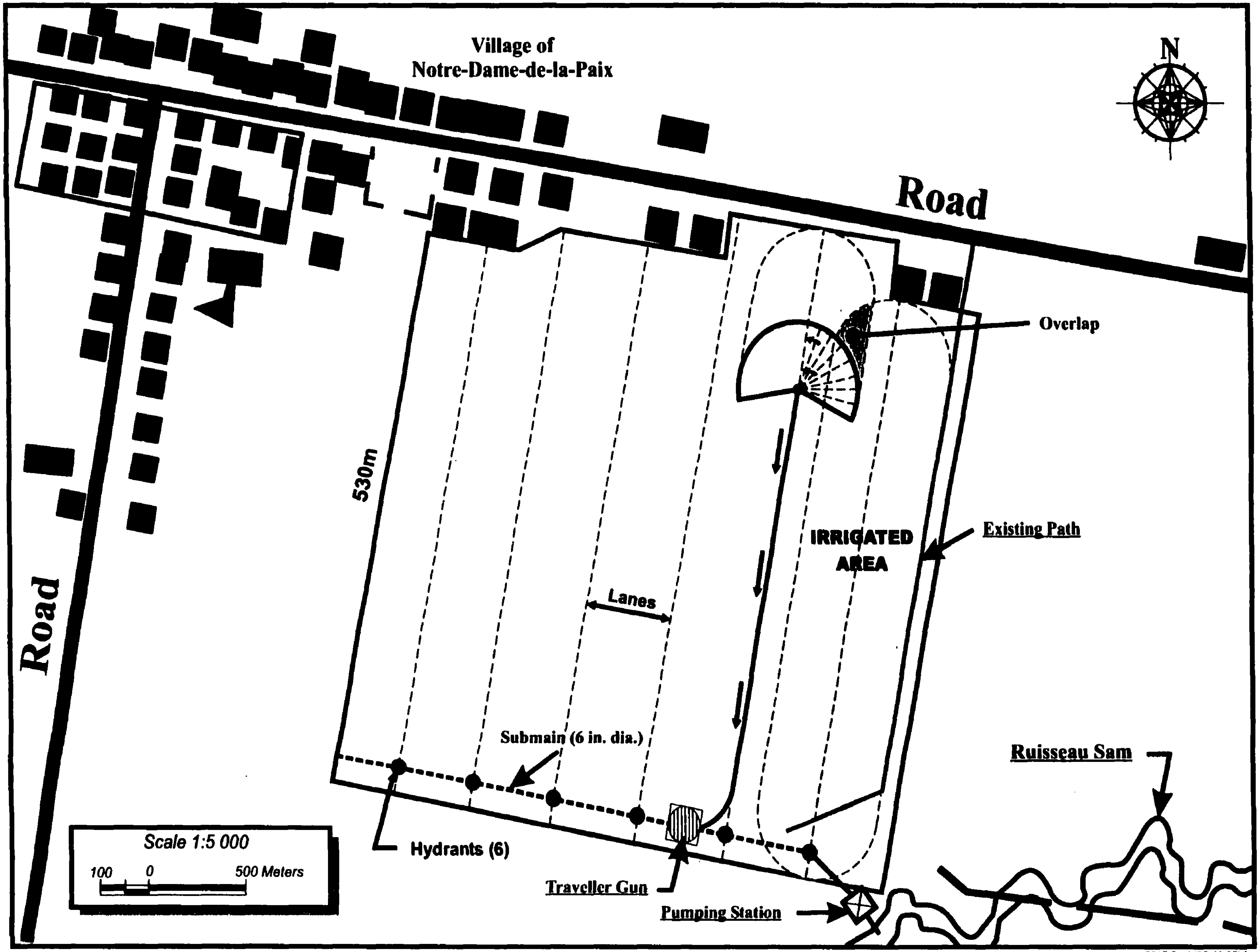
4.5.2 Design of the Traveller System with Volume Gun

Traveller guns began in Europe and have been very successful in Ontario and recently in Quebec for potato production. A proposed design layout for this irrigation system on the given field site of Notre-Dame-de-la-Paix is presented in Figure 4.4, followed by the irrigation model for a traveller system. The main characteristics of the proposed layout are discussed hereafter:

Layout of the main pipe network: the pipe layout is similar to that of the portable pipe system above. A 6" PVC pipe – called the main line - brings water directly through a 'suction line' from the nearby stream to the pump (discussed later) and continues on towards the edge of the field for a total distance of 50 m. At the edge of the field the mainline is connected to a 6" PVC (same diameter) submain pipe. A 6" PVC, submain pipe was designed to run along the edge of the entire length of the edge of the field on which 5 tees and hydrants (5 traveller lanes are planned) are installed for easy connection to the intake pipe of the traveller. It could be possible to reduce the diameter of the

[23]: Labour time was calculated based on research studies (Kumar et al., 1992(b); Gilley, 1996; OMAFRA, 1995; FAO, 1982) and from discussions with potato farmers in the Notre-Dame-de-la-Paix region.

Figure 4.4 - Field Site - Traveller Gun



5815-3.cdr(99-11-05)dm

Traveller System

From Input file			
Total Depth of Application per cycle	di	25 mm	
# irrigation cycles/yr	Dd	10	
FIELD Width	Wf	530 m	
Length	Lf	530 m	
Area irrigated	Al	28.09 ha	
Shortest distance of Water source to edge of Field (=length of main)		50 metres	
System application efficiency	Ea	0.7*	*Manuf. Rec.: Ea taken into consideration

Traveller & Gun Technical Specifications

lane spacing	100 m	328.20 ft	*Manuf. Rec.	*Takes into account overlap
hose length	530 m	1739.48 ft	*Manuf. Rec.	
hose diameter	0.10 m	4 in	*Manuf. Rec.	
input psi at traveller	896.35 kPa	130 psi	*Manuf. Rec.	
gun psi	582.26 kPa	85 psi	*Manuf. Rec.	
flowrate	28.39 l/s	450 gpm	*Manuf. Rec. : 450 gpm	
travel rate	0.61 m/min	2	2ft/min (for application of 1") (Manuf. Rec.)	
number of lanes	4.3	5 (rounded off)		
length of pass	430 m	(minus (-) radius of sprinkler path (r = 50m) at each end)		
number of passes	5			
time to make one pass	11.94 hours			
Time to cover entire field per traveller	59.72 hours			
Number of Travellers in Use	1 unit(s)			

head in m = psi*9.8/6.85

Operating Time

Time to cover field	69.36 hours	*(1hour/acre as per Manuf. Rec.)
Operating time/day	10 hrs/day	
	6.9 days	*Efficiency taken into account (time adjusted)

Flow rate of Traveller

Manufacturer's Recommendation : 450 gpm

450 gpm

Friction Losses in Piping [illegible]

Component	Material	D (mm)	D (in)	L (m)	L (ft)	Hf (Scobey's) (m)
Mainline	PVC	152.6	6	50	164.04	0.96
Submain	Aluminium	152.6	6	0	0.00	0.00
	PVC	152.6	6	430	1 410.74	8.15
Traveller*	PVC					32.06
Fittings		D (mm)	D (in)	K (unitless)		
Elbow (90)	Aluminium	152.6	6	0.45		0.06
					TOTAL Htf	41.20

*Not calculated by Scobey's
*Manu Rec.: 45 psi lost between the intake of traveller & end-gun

[illegible]

Aluminium	Ks =	0.4	
PVC	Ks =	0.4	
Flow Rate	Q =	28.39 L/s	
lev. difference watersource - field	V =	5.00 m	
Operating pressure	Ps =	59.41 m	(= 85 psi at end gun)
Riser Height	Hrh=	1.20 m	(= height of gun on end-
Net positive Suct. Head	NPSH=	2.00	: for Htf, max (NPSH, Hsl, Hm)
Friction loss in suction line	Hsl=	2.00	= highest value of the three
Friction Loss in the Main	Hm=	0.96	heads
Drawdown	Hs=	0 m	

Manuf. Recom : 130 psi @ intake; this number accounts for pressure losses corresponding to the Manuf. Rec. pressure of 85psi at the end-gun, for the length of pipe specified

*Manuf. Rec.

Traveller System (continued)

Pumping Characteristics & Requirements

Ht = V + Htf + Ps + Hs+Hrh+max(NPSH,Hsl,Hm)		
= 108.87 m	1068.90 kPa	154.74 psi
Pump Efficiency Ep=	0.8	Manuf. Rec.

Brake Power (Pb)	Pb=9.8(Ht*Qs)/(Ep)	
	Pb = 37.86	KW
	KW*1.341 = 50.77	BHP
Water HorsePower (WHP)	= 40.60	WHP

(WHP = (Ht (m)*3.2808) *GPM/3960)

Piping Pressure Rating (based on pipe material and thickness)

Component	Category	Material	Series	DR	S* (Kpa)	Press. Rating (Kpa)	Pressure Rating (psi)	Acceptable
Main	Low Pressure	Al-Class 150	3003 H18	84.77	14 000	342.12	49.94	No
Main	High Pressure	Al-Class 150	3003 H18	15.89	14 000	1 824.62	266.37	Yes
Submain	Low Pressure	PVC	1120	84.77	13 800	321.80	46.98	No
Submain	High Pressure	PVC	1120	15.89	13 800	1 633.74	238.50	Yes

Costs of Irrigation and pump components ($) : (Prices from Local Supplier -1998)

Prices provided by local supplier

Description			Quantity	Price $/unit	Cost
Main (ft)	PVC	not buried	164	4.50	738 $
Submain (ft)	PVC	not buried	1411	4.50	6 348 $
Submain (ft)	Aluminium	not buried	0	6.00	0 $
Traveller Unit (1750 ft - PVC pipe)			1	38 638.00	38 638 $
Tee Valves (6" by 4")			6	166.00	996 $
Pipe & fixtures			1	2 800.00	2 800 $ (Includes. z-pipe, relief valves, vents, plugs, etc)
100 HP IVECO Diesel Pump unit (Based on a 60 BHP pump and 100 HP engine)			0	16 000.00	0 $
Electric Pump (480 Volts; 60 hp; 500 gpm @ 145 psi; 3 600 RPM) & accessories			1	13 000.00	13 000 $
Installation cost for electrical line (estimated at $25/m installed)			1	15 000.00	15 000 $
		Sub-Total of Equipment cost:			77 117 $
					88 704 $ (with GST + PST)

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total per year
0.75	11.25	237 $	2 370 $

(Source: Kumar (1992), Hlavek (1995))

[illegible]

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
4	172	28	4 831 $

Diesel engine - Cost Of [illegible]

No. of Hrs per cycle	No. of Hrs per annum	Cost Of Diesel ($/litre)	WHP/unit of fuel (*)	Cost /cycle $CDN	Cost/year	Cost/year/ha
69.4	693.6	0.25	2.9	242.88 $	2 428.80 $	86 $

[illegible]

No. of Hrs per cycle	Cost ($ per KW-hour)	Cost/cycle $CDN	Cost/year $CDN	Cost/year/ha
69.4	0.05	164 $	1 642 $	58 $

Total [illegible]

Total Fixed Costs		77 117 $	excluding GST & PST
Total Operating costs/year	(with diesel)	4 797 $	$
Total Operating costs/year	(electricity)	4 012 $	$

submain to 5" halfway to maintain pressure and reduce pumping. For demonstration purposes, none of the pipes in this model application are buried although it would be preferable, not only for ease of farm machinery trafficability but also because PVC is known to deteriorate when exposed to intense sunlight or to harsh winter conditions (British Columbia Ministry of Agriculture & Fisheries, 1989).

Traveller and volume gun: the traveller selected for the irrigation model trial has a 533 m (1,700 ft) long PVC pipe (10 cm (4") diameter), a 896 kPa (130 psi) operating pressure and a 28.39 l/s (450 gpm) flowrate. The volume gun on the sled operates at 582 kPa (85 psi) pressure with a nozzle size of 3.04 cm (1.2") and delivers a wetted diameter of 100 m. A 20% overlap is accounted for and, as for portable pipe system, the overlap should be increased if the site is subject to frequent and strong winds. The hose retrieval system of the traveller is designed for constant water application on the entire length of the lane.

Pumping station: to provide sufficient pressure for the pipe network, including the traveller system and its single volume gun, the dynamic head for pumping capacity was estimated by the irrigation model at 1,067 kPa (155 psi). This is quite high and further investigation would be needed to find ways to reduce the total head in the system, including progressively reducing feeder pipe diameters. The type of pump planned for the irrigation system is a diesel powered horizontal centrifugal pump although an alternative electric pump is also planned in the model. The capacity of the pump for the traveller is similar to the portable pipe pump design. The break horsepower requirement of the pumping station is estimated at 37 kw with a 55% pump efficiency, thus requiring a maximum power unit of 77 kw at 70% efficiency (rated power as per manufacturer's specifications). An alternative 45 hp electric pump (efficiency 75-80%), similar to the portable pipe case, is recommended for the traveller system. The traveller gun's maximum efficiency is estimated at 70% (Gilley, 1996; FAO, 1982) which is comparable to the portable pipe system (75%).

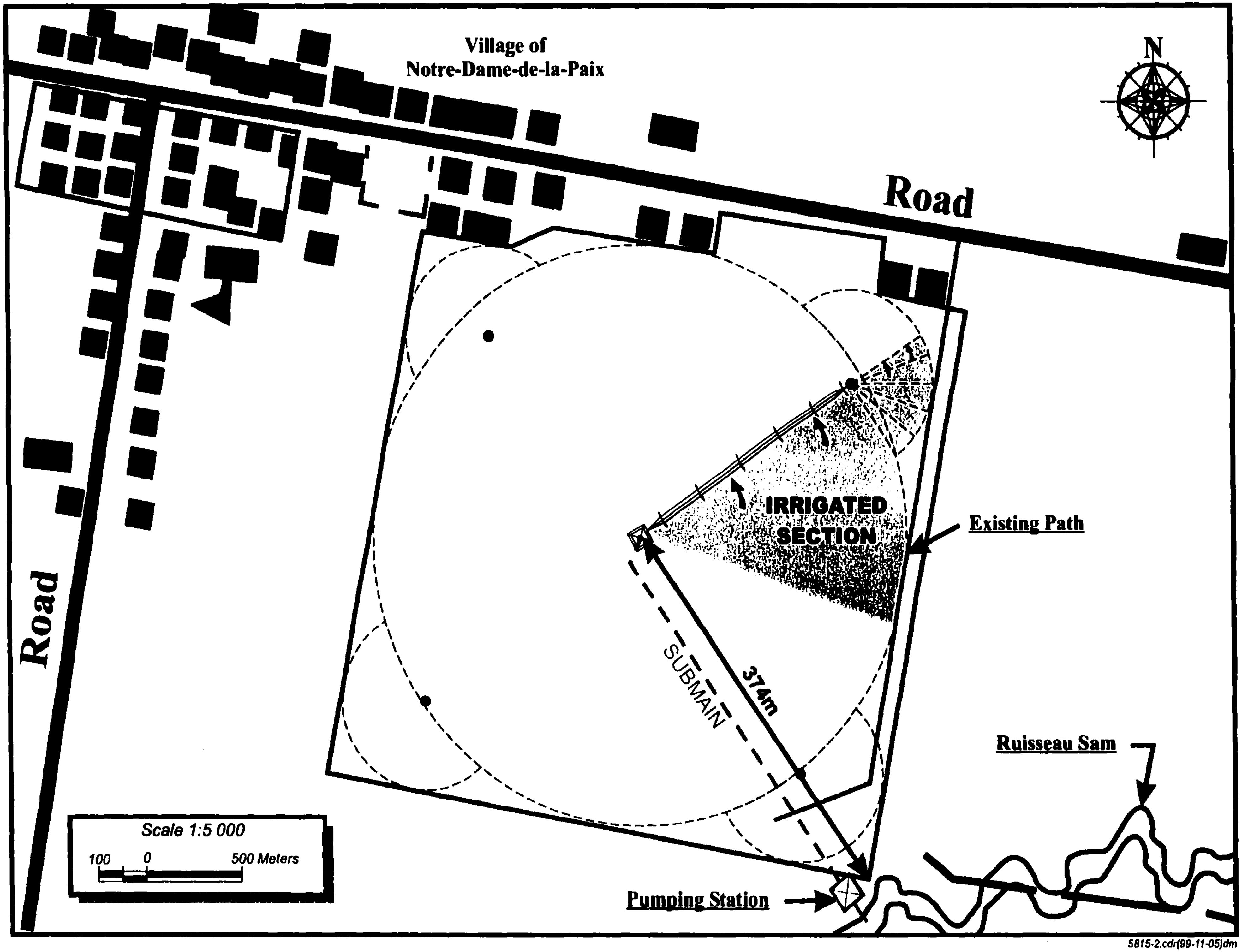
General operation of the irrigation system: the traveller is a dependable machine that allows the farmer to accomplish other farm tasks while irrigation is in process. While the traveller does require labour for lane changes (in this case there are 5 lanes), the operation is done quickly as it consists of positioning the traveller (with the tractor) to each hydrant of the sub-main, pulling out the sled gun to the extreme end of the field (533 m) by foot and opening the valve (about a half-hour operation). The traveller is a relatively simple machine, reasonably priced (around $65,000 for the machine only) and can irrigate odd-shaped fields with relative ease, making it a well adapted system for medium-sized farms. Its major inconvenience, however, is the need to plan for pathways for the traveller itself (and to a certain extent for the end-skid) and some surveillance during operation. As discussed with the portable pipe system, the volume gun has the inherent problem of being inefficient due to wind.

4.5.3 Design of the Centre pivot System (non-towable/towable)

Centre pivot irrigation systems were developed in the USA and are used extensively in the western states for potato production (Idaho, Washington, etc.), in the Canadian prairies and in Ontario. Very few are used in Quebec. A proposed design layout for this irrigation system on the given field site of Notre-Dame-de-la-Paix is presented in Figure 4.5 followed by the irrigation model for a centre pivot. Two centre pivot models were considered – fixed and towable – the idea being that a towable model will allow the farmer to move the irrigation equipment to another potato field where irrigation is needed instead of having a fixed centre pivot unused when another crop is grown in the field (for crop rotation reasons). According to the manufacturer's price, the towable centre pivot costs around 10-15% more than the non-towable version. The main characteristics of the proposed layout, as presented in Figure 4.5 are discussed below:

<u>Layout of the main pipe network</u>: the pipe lay-out is relatively simple compared to the two preceding irrigation systems. A 6" PVC pipe – called the main line - brings water directly through a 'suction line' from the nearby stream to the pump (discussed later) and continues to the edge of the field, for a total distance of 50 m and then towards the cen-

Figure 4.5 - Field Site - Centre Pivot



tres of the field where the tower structure of the centre pivot is installed. For demonstration purposes, none of the pipes in this model application are buried although it would be preferable, not only for ease of farm machinery trafficability but also because PVC is known to deteriorate when exposed to intense sunlight (British Columbia Ministry of Agriculture & Fisheries, 1989). As unburied pipes for a centre pivot system can complicate the movement of the spans, the irrigation industry has developed small reversed v-shaped ladders installed on the pipe for tower wheels to roll over. The investment in buried pipes seems more justified for a fixed centre pivot than for a towable centre pivot because of its permanency in the field.

Centre pivot system design: the design specifications for a centre pivot are identical for fixed and towable models. The centre pivot used for the model consists of 5 spans (1 @ 157'; 4 @ 179') with 126 rotating low pressure sprinklers attached to drop tubes at variable distances (to take into account the speed and position on the span). On the last span, an end-gun is installed in order to irrigate the corners of the field, which operates only when the end span reaches the corner angle. At that moment, the end-gun is activated (an additional booster pump is provided) and sweeps water over a partial circumference. The entire centre pivot system (including the end-gun) functions on a 308 kPa (45 psi) operating pressure and a 37.85 l/s (600 gpm) flowrate. The volume end-gun placed on the last span has a discharge rate of 8.2 l/s (130 gpm) assisted by a booster pump. The sprinklers (126 in total) are distributed along the entire length of the spans at set distances that include an overlap. Because of the relatively small wetted diameter of each sprinkler, the overlap is less important than for the portable pipe or traveller systems. The centre pivot advances by way of individual ¾ hp electric motors at each span tower, with an electric supply line running from the centre tower to each span tower. Electricity is provided by the diesel engine used for the pump, which also acts as a generator, and an electric cable is extended to the centre pivot.

Pumping station: to provide sufficient pressure for the pipe network, including the centre pivot and its single volume end-gun at the last span, the dynamic head for pumping capacity was estimated by the irrigation model at 625 kPa (90 psi). The type of pump planned for the irrigation system is a diesel powered horizontal centrifugal pump, although an alternative electric pump is also planned in the model. The break horsepower requirement of the pumping station is estimated at 34 kw with a 74% pump efficiency, requiring a maximum power unit of 62 bhp at 70% efficiency (rated horsepower as per manufacturer's specifications). The maximum efficiency for the centre pivot is estimated at 85% (Gilley, 1996) which is superior to both the portable pipe system and the traveller system (75%).

General operation of the irrigation system: the centre pivot is a very dependable machine that allows the farmer to accomplish other farm tasks while irrigation is in process. It is a complex machine and requires some minimal surveillance of its main components (span tubing, span tower motors, sprinklers, etc.). It also takes time (1 or 2 growing seasons) for the farmer to fine-tune the machine for optimal performance. Once the technique is well mastered by the farmer, the centre pivot is a very reliable irrigation machine that saves time and water and can be virtually hassle-free. Although the centre pivot does require occasional surveillance during operation, most recent models operate with a small on-site computer (in a control box) which effectively controls (and adjusts) all movement and operation system (King and Wall, 1998). As well, some models have computerised telemetric systems which enable the farmer to monitor the status of the centre pivot or respond to any system breakdown (pump shutdown, power loss, etc.). The centre pivot's main constraint – besides its high cost - is the circular pattern, which necessitates the installation of a supplementary end-gun to avoid losing the area in the corners (a circle in a square causes a total 21% loss of area at the corners). Some farmers prefer growing a special crop or a wind barrier at the corners instead of investing in costly optional volume guns (and associated increased pumping). On the other hand, centre pivots can also be used for precision application of farm chemicals without being subject to wind problem if drop tubes are used. The centre pivot system alternative is especially interesting for potatoes as they are not grown in more than two consecutive years, resulting in at least one year that the fixed centre pivot might not be used. The farmer can move the towable centre pivot with his tractor (wheels of the towers are swivelled perpendicular from the former irrigating trackline position) to another field. Consequently, the farmer must

CENTER PIVOT   Non-Towable

From Input File			
Total Depth of Application per cycle	di	25	mm
# irrigation cycles/yr	Dd	10	
FIELD width	Wf	530	m
length	Lf	530	m
Area irrigated	Al	28.09	ha
System application efficiency	Ea	0.8	decimal
Shortest distance of Water source to edge of Field (=length of main)		60	metres

*Source BC Manual, 1989, Cuenca, 1989; James, 1988)

Center Pivot Specifications					
Total Span of Center Pivot Arm	265	m	869.41	ft	
Number of Sprinklers	126	units			
Average Lateral Sprinkler Spacing	2.1	m	6.91	ft	* Variable
Discharge per sprinkler	0.24	L/s	3.7	gpm	* Man. Rec.
Total pressure required by C-P (+ end-gun)	308.28	Kpa	45	psi	*Man. Rec.
End Gun Discharge	8.20	L/s	130	gpm	*Man. Rec.
System Capacity: Q=	37.86	L/s	600	gpm	*Manu. Rec

Operating Time

Max. hrs of irrigation/day	12.0	hrs
Max. No.of days/irrigation	5.37	days
Total time of irrigation	64.42	hrs

* Takes into account efficiency (Ea)

Time = Volume applied per cycle/Flow
Time = (di*A/Ea)/Q where di (m), A (m2), Ea (decimal), Q (m3/s)

Total Flow through Centre-Pivot (= Q)

37.86 l/s   600 gpm (Manuf. Recom.)

Friction Losses in Piping, Fittings and Spans

Component	material	D (mm)	D (in)	L (m)	L (ft)	Hf (Scobey's) (m)
Mainline	PVC	152.6	6	50	164.04	1.64
Submain	PVC	152.6	6	375	1 229.63	12.27
	Aluminum	152.6	6	0	0.00	0.00
Spans	Aluminum	152.6	6	265	869.41	8.68
Fittings		D (mm)	D (in)	K (unitless)		Hf (m)
Elbow (90)	Aluminium	152.6	6	0.45		0.10
					TOTAL Htf	22.69

Friction loss (Htf) (Scobey's equation)

Ks - Aluminium	Ks =	0.4	
Ks - PVC	Ks =	0.4	
Flow Rate	Q =	37.86	L/s
Elev difference on field	V =	5.00	m
operating pressure	Ps =	31.46	m
Net positive Suct. Head	NPSH=	2.00	: for Hf, max (NPSH, Hsl, Hm)
Friction loss in suction line	Hsl=	2.00	= highest value of the three
Friction Loss in the Main	Hm=	1.64	heads
Height of C-P spans	Hsp=	2.50	m
Drawdown	Hs=	0	m

*Manu. Rec.

Pumping Requirements

Ht = V + Htf + Ps + Hsp + Hs + Hrh + max(NPSH,Hsl,Hm)
= 63.64 m   623.63 kPa   90.45 psi

Pump Efficiency	Ep=	0.75	(From pump curves)

Brake Power (Pb)	Pb=9.8*(Ht*Q)/(Ep)		
	Pb =	31.06	KW
	KW*1.341 =	41.65	BHP
Water Horse Power (WHP)	=	31.63	WHP

(WHP = (Ht (m)*3.2808) *GPM/3960)

CENTER PIVOT   Non-Towable (continued)

Piping Pressure Rating (based on pipe material and thickness:

Category	Material	Series	D/t	S* (PVC) Ftu (Al)*	Press. Rating** (Kpa)	Press. Rating (psi)	Acceptable
Low Pressure	PVC	1120	84.77	13 800	321.80	46.68	Yes
High Pressure	PVC	1120	15.89	13 800	1 633.74	238.50	Yes
Low Pressure	Al-Class 150	3003 H16	84.77	14 500	342.12	49.94	Yes
High Pressure	Al-Class 150	3003 H16	15.89	14 500	1 824.62	266.37	Yes

*Value of S, Ftu from Cuenca, 1989
**(Bursting Pressure for Al pipes)

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1999)*

Description			Quantity	$/unit	Cost $
Main 6" (ft)	PVC	not buried	164.04	4.50	738 $
Submain 6" (ft)	PVC	not buried	1230	4.50	5 533 $
Submain 6" (ft)	Aluminum	not buried	0	5.00	0 $
Pipe fittings, valve, z-pipe, etc			1	500.00	500 $
Fixed Center Pivot					
Pivot Structure			1	2 986.00	2 986 $
Solid Tower Structure			5	465.00	2 325 $
Non-tow Gearboxes			5	915.00	4 575 $
Pivot Anchor			1	90.00	90 $
Common Components					
Pivot Power Control			1	6 765.00	6 765 $
Aims Transducer/Switch			1	1 342.80	1 343 $
Pivot Accessories			1	798.00	798 $
Span (ft of 6" aluminum)			869	20.83	18 105 $
Joints			6	222.80	1 336 $
Overhang			1	660.00	660 $
Wire (ft)			869	2.36	2 047 $
Tower Boxes			5	273.00	1 365 $
Wheel Sets			5	705.00	3 525 $
Center Drive			5	495.00	2 475 $
End Gun			1	2 870.00	2 870 $
Freight & installation cost for centre-pivot			1	10 000.00	10 000 $
Diesel engine pump (85 HP)			0	15 000.00	0 $
Electric Pump (50HP; 460 VAC) + access.			1	6 500.00	6 500 $
Installation fee for electricity (based on length of Main + Submain at 25$/m)			1	15 000.00	15 000 $
Sub-Total equipment					88 630 $
GST + PST	GST:	6 204 $			13 317 $
			Total		101 947 $

PST: 7113

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total/year
0.25	11.25	79.00 $	790.03 $

Kumar (1992)

Losses due to equipment operation and maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
2.5	172	25	3 020 $

Diesel engine: Cost Of Diesel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost Of Diesel ($/litre)	WHP/unit of fuel (WHPh) (*)	Cost per cycle $CDN	Total Cost/year	Cost/year/ha
64.4	644.2	0.25	2.9	175.67 $	1 756.74 $	63 $

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour) from table 8.4 BC Irrig. Man	Cost/cycle $CDN	Cost/year	Cost/year/ha
64.4	0.06	125.10	1251.00	45 $

Total Costs; 1999 Canadian

Total Fixed Costs		88 630 $
Total Operating costs/year	(with diesel)	2 547 $
Total Operating costs/year	(electricity)	2 041 $

without GST & PST

p4

CENTER PIVOT Towable

From Input File			
Total Depth of Application per cycle	di	25	mm
# irrigation cycles/yr	Dd	10	
FIELD width	Wf	630	m
length	Lf	630	m
Area Irrigated	Al	28.09	ha
System application efficiency	Ea	0.8	decimal
Shortest distance of Water source to edge of Field (=length of main)		50	metres

*Source BC Manual, 1989; Cuenca, 1989, James, 1988)

Center Pivot Specifications					
Total Span of Center Pivot Arm	265	m	869.41	ft	
Number of Sprinklers	126	units			
Average Lateral Sprinkler Spacing	2.1	m	6.91	ft	* Variable
Discharge per sprinkler	0.24	L/s	3.7	gpm	* Man. Rec.
Total pressure required by C-P (+ end-gun)	308.25	Kpa	45	psi	*Man. Rec
End Gun Discharge	8.20	L/s	130	gpm	*Man. Rec
System Capacity: Qs	37.85	L/s	600	gpm	*Manu Rec

Operating Time

Max. hrs of irrigation/day	12.0	hrs
Max. No.of days/irrigation	5.37	days
Total time of irrigation	64.42	hrs

* Takes into account efficiency (Ea)

Time = Volume applied per cycle/Flow

Time = (di*A/Ea)/Q where di (m), A (m2), Ea (decimal), Q (m3/s)

Total Flow through Centre-Pivot (= Q)

37.85 l/s 600 gpm (Manuf. Recom.)

Friction Losses in Piping, Fittings and Spans

Component	material	D		L		Hf (Scobey's)
		mm	in	m	ft	m
Mainline	PVC	152.6	6	50	164.04	1.64
Submain	PVC	152.6	6	375	1 229.63	12.27
	Aluminum	152.6	6	0	0.00	0.00
Spans	Aluminum	152.6	6	265	869.41	8.68
Fittings		D		K		Hf
		mm	in	unitless		m
Elbow (90)	Aluminium	152.6	6	0.45		0.10
					TOTAL Hf	22.68

Friction loss (Hf) (Scobey's equation)

Ks - Aluminium	Ks =	0.4	
Ks - PVC	Ks =	0.4	
Flow Rate	Q =	37.85	L/s
Elev difference on field	V =	5.00	m
operating pressure	Ps =	31.45	m
Net positive Suct. Head	NPSH=	2.00	: for Hf, max (NPSH, Hsl, Hm) *Manu Rec.
Friction loss in suction line	Hsl=	2.00	= highest value of the three
Friction Loss in the Main	Hm=	1.64	heads
Height of C-P spans	Hsp=	2.50	m
Drawdown	Hs=	0	m

Pumping Requirements

Ht = V + Hf + Ps + Hsp + Hs + Hrh + max(NPSH,Hsl,Hm)

= 63.64 m | 623.63 kPa | 90.45 psi

Pump Efficiency	Ep=	0.76	(From pump curves)

Brake Power (Pb)	Pb=9.8*(Ht*Q)/(Ep)		
	Pb =	31.06	KW
	KW*1.341 =	41.65	BHP
Water Horse Power (WHP)	=	31.63	WHP

(WHP = (Ht (m)*3.2808) *GPM/3960)

CENTER PIVOT Towable (continued)

Piping Pressure Rating (based on pipe material and thickness:

Category	Material	Series	DR	S* (PVC) Ftu (Al)*	Press. Rating** (Kpa)	Press. Rating (psi)	Acceptable
Low Pressure	PVC	1120	64.77	13 800	321.80	46.68	Yes
High Pressure	PVC	1120	15.89	13 800	1 633.74	236.60	Yes
Low Pressure	Al-Class 150	3003 H16	64.77	14 500	342.12	49.64	Yes
High Pressure	Al-Class 150	3003 H16	15.89	14 500	1 924.62	266.37	Yes

*Value of S, Ftu from Cuenca, 1989

**(Bursting Pressure for Al pipes)

Costs of irrigation and pump components ($) : *(Prices from Local Supplier -1999)*

Description		Quantity	$/unit	Cost $
Main 6" (ft) PVC	not buried	164.04	4.50	738 $
Submain 6" (ft) PVC	not buried	1230	4.50	5 535 $
Submain 6" (ft) Aluminum	not buried	0	5.00	0 $
Pipe fittings, valve, z-pipe, etc		1	500.00	500 $
Towable Center Pivot				
Pivot Structure		1	7485.00	7485.00
Swivel Tower Structure		5	645.00	3225.00
Towable Gearboxes		5	1275.00	6375.00
Common Components				
Pivot Power Control		1	6 765.00	6 765 $
Aims Transducer/Switch		1	1 342.50	1 343 $
Pivot Accessories		1	795.00	795 $
Span (ft of 6" aluminum)		869	20.82	18 105 $
Joints		6	222.50	1 335 $
Overhang		1	660.00	660 $
Wire (ft)		869	2.36	2 047 $
Tower Boxes		5	273.00	1 365 $
Wheel Sets		5	705.00	3 525 $
Center Drive		5	495.00	2 475 $
End Gun		1	2 970.00	2 970 $
Freight & installation cost for centre-pivot		1	10 000.00	10 000 $
Diesel engine Pump (85 HP)		0	15 000.00	0 $
Electric Pump (50HP; 460 VAC) + access.		1	6 500.00	6 500 $
Installation fee for electricity (based on length of Main + Submain at 25$/m)		1	15 000.00	15 000 $
Sub-total Equipment cost				95 740 $
GST + PST GST :	6 702 $			14 385 $
		Total		110 125 $

PST: 7 683 $

Labour Costs Per Irrigation Cycle

Labour (Hrs/ha)	Cost of Labour ($/hr)	Total	Total/year
0.25	11.25	79.00 $	790.03 $

Kumar (1992)

Losses due to equipment operation and maintenance

Area Lost (%)	Potato Price $/tonne	Yield tonnes/ha	Loss ($)
2.5	172	25	3 020 $

Diesel engine: Cost Of Diesel to Operate the Pump

No. of Hrs per cycle	No. of Hrs per annum	Cost Of Diesel ($/litre)	WHP/unit of fuel (WHPR) (*)	Cost per cycle $CDN	Total Cost/year	Cost/year/ha
64.4	644.2	0.25	2.9	175.67 $	1 756.74 $	63 $

Electric motor: Cost of Electricity to Operate the Pump

No. of Hrs per cycle	Cost ($ per KW-hour) from table 8.4 BC Irrig. Man	Cost/cycle $CDN	Cost/year	Cost/year/ha
64.4	0.05	126.10	1261.00	45 $

Total Costs: 1999 Canadian

Total Fixed Costs		95 740 $	*excluding GST & PST*
Total Operating costs/year	(with diesel)	2 547 $	
Total Operating costs/year	(electricity)	2 051 $	

must also transport the pipes and the mobile pumping station to the new site, unless he decides to have a permanent pumping station and buried pipes.

4.6 Discussion of Results on the Three Sprinkler Irrigation Systems

The above descriptions of the three sprinkler irrigation systems indicate that each system must be studied in detail in order to make an optimal choice. On a comparative basis, once the technical investigation is undertaken, the final financial analysis can be easier to conduct. Table 4.3 provides a summary comparison of the three systems.

As Table 4.3 demonstrates, each sprinkler irrigation system presents technical (irrigation technique), operational (operation of equipment) and financial (initial cost of equipment and operating cost) differences. The costs indicated for each system are the supplier's prices, which will be used and analysed in the economic model in the next chapter.

Back-up pumps should be planned for each system and can be included in the model by specifying prices for two pumps. It is interesting to note that the least expensive equipment (portable pipe) is nearly half the cost of the most expensive equipment (towable centre pivot), yet requires more than seven times the labour (per hectare) and 20% more pumping (per hectare) than the centre pivot (fixed or towable). Such basic conclusions are important for the farmer to consider. The farmer of Notre-Dame-de-la-Paix – in his search for an optimal irrigation system – has stated that he wishes to minimise labour costs, as well as pumping costs. The traveller system might be an appealing choice since its capital and operating costs are mid-way between the portable pipe and the centre pivot. In the case of the centre pivot, further investigation should be conducted on the use of low-energy precision application (LEPA) systems which require less energy than the one under study. LEPA systems, however, are still much more expensive than the common model.

The economic analysis in the next chapter will investigate, in more detail, the cost and benefit aspects of each system and provide further information with respect to the decision-making process.

Table 4.3 : Summary of principal characteristics of three sprinkler irrigation systems

Equipment	System application efficiency (%)	Time to apply 2.54 cm/ha (hrs/ha.)	Pipe network: Total length PVC (6" dia.) (m)	Pipe network: Total cost ($)	Irrigation system: kPa	Irrigation system: psi	Irrigation system: l/s	Irrigation system: GPM	Irrigation system: Total cost of system ($)	Pumping station (diesel only): Ht - Total dynamic head m / kPa / psi	Pumping station (diesel only): BHP	Pumping station (diesel only): Pump capacity selection (hp)	Pumping station (diesel only): Total cost of pump station ($)	Pumping station (diesel only): Cost of pumping $/year/ha	Labour time (hrs/ha)	Total cost of equipment on a 28,5 ha farm ($) *(without tax)*	Principal operational advantages / disadvantages to recommend to the farmer in Notre-Dame-de-la-Paix
Portable pipe with volume gun	75%	2.9	<u>Main</u> : 50 m <u>Sub-m</u>: 494 m <u>Lat.</u> : 507 m	$23 165	343 At each gun	50	33 Total system	526	$10 830 (4 guns + pipe access.)	Ht = 69 m 676 kPa 98 psi	38	85 hp	$15 000	$76	1.9	*Total system =* <u>$48 995</u> *Cost per Ha. =* <u>$1 719</u>	<u>*Advantages:*</u> - low cost, suits any field shape, - well adapted to rotations <u>*Disadvantages :*</u> - labour dependant, constant surveillance - inefficiency due to wind effect
Traveller with volume gun	75%	2.9	<u>Main</u> : 50 m <u>Sub-m</u>: 430 m	$7 250	896 Of traveller 525 At gun	130 85	28,4 Total system	450	$42 000 (+ pipe access.)	Ht = 109 m 1067 kPa 155 psi	51	120 hp	$17 300	$86	0.75	*Total system =* <u>$66 550</u> *Cost per Ha. =* <u>$2 335</u>	<u>*Advantages:*</u> - adaptable to odd-shaped fields - little labour, easy to use, rotations <u>*Disadvantages :*</u> - requires high intensity discharge - inefficiency due to wind effect
Centre-pivot : *Fixed :*	85%	2.29	<u>Main</u> : 50 m <u>Sub-m</u>: 375 m	$6 935	308 Of C-P 238 At end-gun	45 15	37.8 Total system	600	$61 360 (total system + freight + install.)	Ht = 63.6 m 623 kPa 90,5 psi	42	85 hp	$15 000	$63	0.25	*Total system =* <u>$83 295</u> *Cost per Ha. =* <u>$2 923</u>	<u>*Advantages:*</u> - almost labour-free due to computer assisted operation & surveillance - very efficient due to LEPA technology + low drop tubes above potato plant - can spray farm chemicals <u>*Disadvantages :*</u> - costly & sophisticated system - fixed C-P not adapted for rotation crop - field shape limited to circle - high power requirements (Sprinklers + tower motors) - towable C-P well adapted to rotated crops but requires shifting of pipe + pump station to other field
Towable : *(= : identical to fixed)*	85%	2.29	=	$6 935	=	=	=	=	$69 470	=	42	85 hp	$15 000	$63	0.25	*Total system =* <u>$91 405</u> *Cost per Ha. =* <u>$3 207</u>	

5.0 ECONOMIC ANALYSIS

5.1 Introduction

An economic analysis is needed to advise farmers, or future farmers, on which irrigation equipment to acquire. The previous sections demonstrated the relative advantages and disadvantages of each system from a technical point of view. The present section will compare the relative profitability of each system for potato production, based on the same case example in Notre-Dame-de-la-Paix.

The irrigation economic analysis model proposed will provide a framework for the preliminary evaluation of the economic feasibility of irrigation systems for the specific site of this research. Further studies will be required to validate its application for other sites. The objectives of this study model are the following:

1. develop an economic evaluation model that can be used as a decision-making tool for selecting the best sprinkler irrigation system (among three types) for a given farm;
2. apply the economic model to the Notre-Dame-de-la-Paix site and discuss the results for the three irrigation systems with respect to potato production on a 28 ha field.
3. test each irrigation system and its profitability with various hypotheses, such as different yields, labour costs, and energy prices.

5.2 Presentation of the Model and Various Economic Analyses

The proposed economic model is a logical continuation and integral part of the technical irrigation model presented in the preceding chapters. It is designed to calculate the annual operating cost for each system: portable pipe, traveller gun, and center-pivot system (fixed and towable). This cost model, developed on Excel, is intended to generate data to evaluate the feasibility of each system for potato production and to compare their economic advantages using Internal Rate of Return (IRR) and Net Present Value (NPV) analyses. The cost model simulates each irrigation component based on assumptions discussed later. To measure the effects of irrigation on potatoes, a comparison will be made on the basis of a partial[24] farm budget analysis, with and without irrigation capability. To better understand the operations and features of the economic model, it was studied using the Notre-Dame-de-la-Paix case as discussed in Chapter 4.

The model consists of the following sub-files:

1. *Economic data input file*: contains data for all expected revenues and costs. Revenues include the price per ton (metric) of potatoes multiplied by the yield (ton/ha) and all other expected revenues directly related to potato production (ie. ASRA and crop insurance compensations). Costs are categorized as variable costs (direct) or fixed costs (indirect). The economic data input file presented in Appendix C contains economic and financial data obtained from the farmer in Notre-Dame-de-la-Paix and was cross-checked with the 1997 Quebec Ministry of Agriculture Farm Budget for Potatoes (CRÉAQ-AGDEX, 1997). The data were used to analyse each irrigation system. The user can replace any of the prices given in the present model with new data.

2. *Summary of Costs from Irrigation Model*: this sub-file summarises all capital (initial price of the equipment) and operating costs derived from the irrigation model (a dynamic link is set between the irrigation model and the economic model) for each irrigation system under two pumping station scenarios – diesel or electric. Capital costs include three major components: irrigation system, pipe network and pump station and associated costs (eg. cost of installation of an electric line from power line to pump site, cost of gas tank, etc). Variable operating costs include labour and fuel/electricity. The user can change this data only in the original irrigation model. Assumptions used for the present farm analysis are indicated in the sub-file (refer to print-out in Appendix D).

3. *Historical potato market prices & ASRA/Crop Insurance*: this sub-file provides average potato market prices for the past ten years in Quebec (source: MAPAQ, 1998) and is presented in Appendix C. For the purpose of this research, an average of $172/ton used for the analysis, though the user may input any value desired.

4. *Irrigated / Non-irrigated Farm Budgets*: these subfiles, presented on the following pages, are standard farm budgets specifically designed for potatoes under non-irrigated and irrigated conditions. The costs and revenues indicated are obtained from the initial economic data input file and are linked with the present file. The user should find this file useful for validating, comparing and adjusting data to any individual situation. To enable an effective economic analysis in the subsequent files,

[24]: A partial budgeting approach was used to compare the irrigation systems. Unlike a whole-farm budget, a partial budget does not indicate whether the entire operation is profitable but only if one aspect of the entreprise has a net return advantage over another. In the present case, the advantage of irrigated over non-irrigated production is sought, along with a profitability comparison of the three irrigation systems.

various costs related to the irrigation equipment and its operation need to be entered, including annual maintenance and repairs (4% of the initial cost of the equipment/year was assumed) and equipment insurance (2% of initial cost of equipment). A fundamental parameter in an economic analysis is the choice of amortisation period. As a period of 10 years is commonly used in farming, this was used for the present study (this value can be altered by the user). The three main components (sprinkler, pipes, pump) of each irrigation system and accessories were all amortised over 10 years. This was done to simplify the economic analysis, however there are ways to account for variable amortisation periods.

5. *Cost-Return Projections for Non-irrigated/Irrigated (3 systems) potato production*: This file produces a summary table which compares the costs and returns for non-irrigated or irrigated potato production, with the latter case expanded to include the three irrigation systems being studied. Results are presented in Table 5.1.

6. *Cash Flow, Internal Rate of Return (IRR) & Net Present Value (NPV)*: these sub-files determine and compute the comparative profitability of each irrigation system. Calculations are done automatically by obtaining data from the above-mentioned files. Methods used for the economic comparative analysis include *Internal Rate of Return (IRR)* and *Net Present Value (NPV)*. These shall be further discussed in the next section. The model also provides the user with useful information on the payback period and cash flow.

The following sections present the assumptions used for applying the economic model, a discussion of the results obtained and finally, a profitability comparison of the three irrigation systems.

5.3 Basic Assumptions for Model Application

- All three systems are based on the same experimental site measuring 28.09 ha, with a watercourse situated 410 m from the centre of the field. It is also assumed that water is abundant at all times during the growing season and that there is no public cost for water consumption;

- most irrigation equipment has a useful life of 10-15 years. To compare all irrigation systems on an equal basis, it is proposed that an amortisation period of 10 years be used and that salvage values be adjusted accordingly;

- all economic analyses presented have been conducted and valued in constant 1999 dollars. Federal and provincial sales taxes were not considered due to variable tax rates and deductions on goods and services available to farmers;

- it is assumed that each irrigation system will be installed and operational in the same year (ie. center-pivot and pumping station will be installed in the autumn and operating the following spring);

- field, labour and irrigation characteristics, as well as unit operating costs related to the irrigation systems, are identical to the irrigation model applied in Chapter 4;

- irrigated potato production is assumed to provide a 25% yield increase over non-irrigated production. A marketable yield of 24 t/ha for non-irrigated production and 30 t/ha for irrigated production was used. This yield increase is based on research findings (see Chapter 2) and on the farmer's (Notre-Dame-de-la-Paix) advice;

- a two-year period is suggested for fine-tuning irrigation operations and applications. Thus, yield increases will be progressive for the first two years. In the first year, yield increase will be limited to 70% of the normal expected yield increase (6 t/ha *0.7) and to 80% in the second year (6 t/ha *0.8). Full yield increase (6 t/ha) and benefits would commence only in year 3;

- because precise water application rates can vary from one farmer to another, the same yield increase was assumed for all three irrigation systems, although differences in the coefficient of uniformity of water application between each machine can have an effect on yield;

- the same irrigation frequencies in the target area were used, corresponding to a normal year (probability of 50%) and a total seasonal application of 250 mm.

Other assumptions apply for specific cases, which will be mentioned when appropriate.

5.4 Benefits of the Irrigation Systems

Table 5.1 contains a summary of results from the data sub-files presented in Section 5.2, along with gross net benefit per hectare. Given the above-mentioned assumptions (Section 5.3), the portable pipe system with the electric pump gives the highest profit per hectare ($501/ha) and increases the farmer's benefit over non-irrigated production by 50%. If a farmer prefers a system which is less dependent on labour (a portable system requires $214/ha of labour), or decides to expand production, the centre-pivot (non-towable) appears to be a profitable alternative since it rendered $481/ha, a 44% increase in profit over non-irrigated production. Centre-pivots, when well operated by the user, are generally hassle-free and require the least labour ($28/ha). The traveller gun system is

TABLE 5.1 : SUMMARY OF ANNUAL COSTS & RETURNS (/HA) FOR NON-IRRIGATED & IRRIGATED POTATO PRODUCTION (3 DIFFERENT IRRIGATION SYSTEMS)

	Non irrigated	Portable pipe with volume gun		Traveller gun		Center pivot			
						Non-towable		*Towable*	
		Diesel	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*
	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA
REVENUES *Irrigated yield incr:*									
Marketable production ($) (non-irrigated : 24t/ha) 125%	4 128	5 160	5 160	5 160	5 160	5 160	5 160	5 160	5 160
ASRA* + Crop Insurance compensations (ha)**	150	188	188	188	188	188	188	188	188
Potato price per ton: 172 $									
TOTAL ANNUAL REVENUES	**4 278**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**
VARIABLE COSTS									
Supplies (Crop production inputs) *	1 751	1 926	1 926	1 926	1 926	1 926	1 926	1 926	1 926
Farm machinery *	455	455	455	455	455	455	455	455	455
Marketing operations (hauling)	210	263	263	263	263	263	263	263	263
Labor costs	563	563	563	563	563	563	563	563	563
Other costs (insurance, ASRA, interests, joint plan, etc.)	506	506	506	506	506	506	506	506	506
Sub-total 1 (Variable costs)	***3 485***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***
Irrigation system									
Pumping fuel	0	76	n/a	86	n/a	63	n/a	63	n/a
Electrical power	0	n/a	51	n/a	58	n/a	45	n/a	45
Pumping lubricants (assumed)	0	6	0	7	0	5	0	5	0
Annual maintenance and repairs (irrigation + pump)	0	56	49	73	88	95	80	103	109
Hired labour costs	0	214	214	84	84	28	28	28	28
Yield loss by irrig. equip.	0	43	43	172	172	108	108	108	108
Contingencies	0	25	25	50	50	50	50	50	50
Sub-total 2 (Variable costs)	***0***	***419***	***382***	***473***	***453***	***348***	***310***	***356***	***339***
TOTAL ANNUAL VARIABLE COSTS	**3 485**	**4 132**	**4 095**	**4 186**	**4 166**	**4 061**	**4 023**	**4 069**	**4 052**
FIXED COSTS									
General costs (land taxes, insurance, maintenance, etc.)	283	283	283	283	283	283	283	283	283
Linear depreciation of farm infrastructures	176	176	176	176	176	176	176	176	176
Sub-total 1 (Fixed costs)	***459***	***459***	***459***	***459***	***459***	***459***	***459***	***459***	***459***
Irrigation and pump system									
Annual tax and insurance (Larry James, p.103)	0	28	25	37	44	47	40	51	44
Annual ownership cost (Irrig.: depreciation, interest, etc.)	0	116	116	157	157	217	217	240	240
Annual ownership cost (Pump : depreciation, interest, etc.)	0	152	152	152	152	128	128	128	128
Sub-total 2 (Fixed costs)	***0***	***296***	***293***	***345***	***352***	***393***	***385***	***419***	***412***
TOTAL ANNUAL FIXED COSTS	**459**	**755**	**752**	**804**	**811**	**852**	**844**	**878**	**871**
TOTAL ANNUAL COSTS (Variable + Fixed Costs)	**3 944**	**4 888**	**4 847**	**4 990**	**4 977**	**4 913**	**4 867**	**4 947**	**4 923**
NET PROFIT ($/HA)	**334**	**460**	**501**	**358**	**371**	**435**	**481**	**401**	**425**

easier to use than the pivot system, however its comparatively low efficiency and middle range price (between the portable and non-towable centre-pivot) along with $84/ha of labour makes it barely profitable when compared to non-irrigated production (11% increase). The above analysis was discussed with the farmer in Notre-Dame-de-la-Paix and it was agreed that each system must indeed be evaluated on all aspects and not just on financial terms.

5.5 Investment Analysis and Discussion of the Results

An investment analysis[25] is performed to determine the comparative economic advantage of the three irrigation systems. Projected cash flows were determined for a 10-year period and the data were analysed using the Net Present Value (NPV) and the Internal Rate of Return (IRR) methods. The NPV was determined using a general discount rate of 8%, and the effect of the discount rate on the investment decision is tested at various rates (8, 10 & 12%). It is important to remember that these investment analyses are intended as methods of ranking, accepting or rejecting various investment alternatives (Barry et al., 1988). Consequently, the IRR or NPV results are not absolute values but rather they provide relative values and are used as economic indicators to compare each alternative. When determining the IRR or the NPV, the initial investment (of the irrigation equipment) is always taken into account, indeed both IRR and NPV provide indicators of the financial interest of the investment and the relative profitability among alternative investment projects (Barry et al.,1988). The IRR and NPV[26] analysis was performed with the initial cost of the equipment on the basis of a simple loan calculation (8% interest x cost of equipment /10 (payment period), 20% initial down payment by the farmer). When speaking to the farmer of N.D.de-la-Paix about the economic analysis and the results, he expressed interest in finding out how the results would be if the initial capital

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[25] *Investment analysis*: (or capital budgeting) is an orderly sequence of steps that produces information relevant to an investment choice. These steps are (1) the identification of investment alternatives (ie. 3 different irrigation systems), (2) the selection of an appropriate method (ie. IRR, NPV, etc.), (3) the collection of relevant data (ie. cash flow data), (4) the analysis of the data and (5) interpretation of the results (Barry et al., 1988).

[26]: Barry et al. (1988) indicates that "return on assets measures the profitability before interest is paid to the lender and that return on equity measures profitability after the costs of borrowed funds are accounted for. Though NPV and IRR can be calculated both ways, choice is based on careful judgement regarding characteristics of the farm business and the investments being analysed".

investment (of the irrigation equipment) were not included. His reason for wanting to disregard the initial capital investment was based on the fact that he presently owns and uses irrigation equipment (1 traveller sprinkler & 2 winch driven travellers), thus he wants to know how each system fares economically based just on operating and maintenance cost. Such analysis is easy to perform on the economic model and was done for that specific purpose however the results must be interpreted with great caution. Calculation details for both situations – with and without consideration for the initial capital investment - are presented in Appendices C and D, while Table 5.2 presents a summary of the results.

5.5.1 Net Present Value (NPV)

Net Present Value (NPV)[27] determines the present value of net returns by discounting the streams of benefits and costs back to the beginning or "base year" (t=0). The financial viability of an investment is evaluated by comparing the flow of revenues generated to the flow of costs incurred over a certain period of time (in this case 10 years). To effectuate this comparison, the flows of revenues and costs must be discounted (three discount rates were used: 8%, 10%, 12%) to the base year to obtain the NPV of each scenario. The sign (+ or -) and size of an investment's net present value determine its ranking and acceptability. The investment with the largest NPV is the most favoured (Barry et al., 1988). Table 5.2 indicates the NPV results. Results indicate that at an 8% discount rate, the system with the highest NPV was the portable pipe system with an electric pump ($27,206) followed closely by the non-towable centre-pivot with the electric pump ($24,814). These two results demonstrate a much higher profitability than for the non-irrigated situation where the NPV was only $10,522. Thus the farmer could expect his investment in irrigation equipment such as the portable pipe or the fixed centre-pivot to be profitable. If the farmer's goal is to optimise his investment, then the traveller system seems to be the least interesting option, as it had an NPV consistently

[27]: The NPV can be expressed mathematically as follows: (Price Gittinger, 1982)

$$NPV = \sum_{t=1}^{n} (B_t - C_t) / (1 + r)^t$$

where: B: benefits; C: costs; r: discount rate; n: years

Table 5.2 : SUMMARY OF ECONOMIC ANALYSIS FOR NON-IRRIGATED & IRRIGATED POTATO PRODUCTION WITH THREE IRRIGATION SYSTEMS

		Non irrigated	Portable pipe with volume gun		Traveller gun		Centre pivot			
							Non-towable		*Towable*	
	Disc. Rate		*Diesel*	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*
Net Present Value (NPV)	8%	$10 522	$20 778	$27 206	$5 682	$7 840	$17 856	$24 814	$12 613	$16 543
	10%	$7 268	$15 908	$21 693	$2 271	$4 203	$13 232	$19 503	$8 493	$12 033
	12%	$4 580	$11 854	$27 206	-$521	$1 215	$9 390	$15 068	$5 088	$8 290
Net Present Value (NPV) (with loan)	8%	$10 522	$3 515	$10 942	-$9 637	-$6 922	$3 922	$10 893	-$607	$3 182
	10%	$7 268	$39	$6 695	-$12 016	-$9 616	$78	$6 372	-$4 059	-$636
	12%	$4 580	-$2 769	$3 224	-$13 853	-$11 721	-$3 011	$2 696	-$6 804	-$3 698
Internal Rate of Return (IRR)		17%	22%	26%	12%	13%	19%	24%	16%	18%
Internal Rate of Return (IRR) (with loan)		17%	10%	14%	3%	4%	10%	14%	8%	10%
Payback period (with loan) * (years)			8	7	10	10	8	7	9	8

* : number of years before the farmer has a net positive cumulative cash flow (inclusive of the loan repayment spread over 10 years)

lower than the rest of the other irrigation systems and, in fact, to the non-irrigated situation. Higher discount rates (10%, 12%) gave similar results. All NPV values were positive except for the traveller with the diesel pump (a negative NPV at a 12% discount rate). From the results, it should be noted that while an electrical pump is more profitable than a diesel pump, future investigation would be required to determine the exact costs of each alternative. The most common system in Quebec is the travelling gun with diesel engine, a possible explanation being the prohibitive cost of longer distance of electrical line than our case study. The farmer in Notre-Dame-de-la-Paix has expressed interest in converting his diesel motors to electricity. Consequently, calculations were done taking into consideration the initial investment (through a loan) of all equipment including an electric pump. The results, provided on the same Table 5.2, indicate that only the portable pipe system and the centre-pivot give positive net returns ($10,942 and $10,893 respectively) at a comparable level to the non-irrigated situation ($10,522). The traveller was not profitable at any discount rate.

5.5.2 Internal Rate of Return (IRR)

IRR[28] is defined as the rate of return on an investment which will equate the present value of benefits and costs (Price-Gittinger, 1982). It is the discount rate that would result in a zero net present value for an investment project. The procedure is essentially a trial-and-error search for the interest rate (r) that will yield a zero NPV (Barry et al., 1988). Ranking is similar to the NPV, although the IRR is compared to the investor's required rate of return (in this case we considered 8%). IRR calculations assume that net cash inflows from the investment are reinvested into the same project and that they procure the same rate of the IRR (Barry et al., 1988); a minor problem but one which must be taken into account when making the choice.

Table 5.2 provides the IRR values for all sprinkler irrigation systems. The portable pipe

[28]: The mathematical expression for internal rate of return (IRR) (Price-Gittinger, 1982).:

$$IRR = \sum_{t=1}^{n} B_t / (1+r)^t = \sum_{t=1}^{n} C_t / (1+r)^t$$

where: B: benefits; C: costs; r: discount rate; n: years system with an electric pump gave the highest IRR rate: 25.9% followed closely by the non-towable centre-pivot with an electric pump at 24%. In financial terms, an IRR above the discount rate (8% in this case) is considered a good investment decision. Results in Table 5.2 indicate that all IRR values are above 8% in both cases (return on asset or equity) except for the traveller gun system which rendered less than 8% for return on equity. Moreover, an IRR of 25% (ie. portable and centre-pivot systems) clearly indicates that the investment will be highly profitable. The traveller gun system appears to be a poor choice compared to either the portable pipe or centre-pivot (towable or non-towable). It is also possible to conclude that the electric pump is more cost-effective, probably due to its low maintenance cost and high salvage value (at year 10) in spite of an initial high investment for an electric line (estimated at $15,000). In conclusion, any of the above irrigation systems that provide an IRR superior to 16.64% (= IRR for non-irrigated production) would be a good investment. On this basis, the portable pipe system and the centre-pivot (non-towable) with a diesel or electric pump should be considered, and the towable centre-pivot with an electric pump would also be a good investment.

5.5.3 Payback Period

The payback period of the initial investment can be determined from the last column of the tables in Appendix D (cumulative cash flow). In the analysis that did not take into account the initial investment of the equipment, the payback period can be estimated by adding the positive cumulative cash flows until the amount is equivalent to the cost of the equipment. In the analysis that includes payment on a loan, the payback period is completed as soon as the cumulative cash flow is positive. Table 5.2 indicates the payback period for each irrigation system. The most profitable irrigation equipment (portable pipe and centre pivot) can be fully paid within 7 years, which is a significant length of time and would need to be optimised by an accountant (for taxes, interest and loans).

5.5.4 Test of Hypothesis

It is a useful procedure to test the irrigation model for different scenarios: each irrigation system and its profitability can be tested using various hypothesis, such as different yield levels, labour inputs, and energy prices, etc. This was accomplished using both the irrigation and the economic models and running them each time with different hypotheses, which are presented in Table 5.3. The details of these analyses are not included, as they are similar to the calculations done in the preceding section. One of the hypotheses chosen, Variant #1, was a potential increase of yield to 35t/ha (such an increase would be the equivalent of an above-average U.S. yield), which gave a very high NPV result of $120,000 compared to $10,522 for non-irrigated production. Different variants based on other hypotheses such as increased labour or energy cost, however, gave high negative NPV or IRR results. An interesting finding is that non-irrigated production of potatoes at an average commodity price of $172/100kg is unprofitable at a yield less than 23 t/ha (both NPV and IRR were slightly negative). Moreover, when irrigation applications are increased to 300 mm during a dry growing season, the NPV is slightly affected (negatively) – the highest NPV value was $22,615 for the non-towable centre pivot compared to $24,814 in a normal year.

TABLE 5.3 : ECONOMIC ANALYSIS OF DIFFERENT IRRIGATION SYSTEMS AND VARIANTS

Parameter selection for variants	Investment analysis indicators		Non irrigated	Portable pipe with volume gun		Traveller gun		Center pivot			
								Non-towable		*Towable*	
		Discount Rate		*Diesel*	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*
Original situation	Net Present Value (NPV)	8%	$10 522	$20 778	$27 206	$5 682	$7 840	$17 856	$24 814	$12 613	$16 543
		10%	$7 268	$15 908	$21 693	$2 271	$4 203	$13 232	$19 503	$8 493	$12 033
		12%	$4 580	$11 854	$27 206	-$521	$1 215	$9 390	$15 068	$5 088	$8 290
Data from Table 5.2, same conditions as described in section 5.3.	Net Present Value (NPV) (with loan)	8%	$10 522	$3 515	$10 942	-$9 637	-$6 922	$3 922	$10 893	-$607	$3 182
		10%	$7 268	$39	$6 695	-$12 016	-$9 616	$78	$6 372	-$4 059	-$636
		12%	$4 580	-$2 769	$3 224	-$13 853	-$11 721	-$3 011	$2 696	-$6 804	-$3 698
	IRR	-	17%	22%	26%	12%	13%	19%	24%	16%	18%
	IRR (with loan)	-	17%	10%	14%	3%	4%	10%	14%	8%	10%
	Payback period (with loan)	-	-	8	7	10	10	8	7	9	8
Variant # 1											
Dry season : 300mm irrigation application (instead of 250 mm). Non-irrig. yield = 23t/ha	NPV	8%	-$12 555	$11 845	$19 170	$360	$3 515	$14 958	$22 615	$9 716	$14 344
	IRR	-	-3%	16%	20%	8%	10%	17%	22%	14%	17%
	Payback period	-	-	9	8	10	10	9	8	10	9
Variant # 2											
Same as above + 10% labour salary increase 10% energy cost increase	NPV	8%	-$21 037	-$25 134	$17 209	-$34 454	-$30 639	-$18 399	-$10 264	-$23 642	-$18 535
	IRR	-	-11%	-10%	-3%	n.a.	n.a.	-4%	1%	-8%	-4%
	Payback period	-	-	> 10 years	> 10 years	> 10 years	> 10 years	> 10 years	> 10 years	> 10 years	> 10 years
Variant # 3											
250 mm irrig. application 10% labour salary increase 10% energy cost increase	NPV	8%	$2 040	$7 755	$14 707	-$5 537	-$2 805	$7 849	$15 232	$2 606	$6 961
	IRR	-	10%	13%	17%	4%	6%	13%	18%	10%	12%
	Payback period	-	-	10	9	> 10 years	> 10 years	10	9	11	10
Variant # 4											
Yield = 35t/ha. 20 % downpayment.on irrigation equipment	NPV	8%	$10 522	$119 202	$126 630	$106 050	$108 765	$119 610	$126 580	$115 081	$118 869
	IRR	-	17%	124%	141%	92%	95%	113%	129%	102%	109%
	Payback period (with loan)	-	-	4	4	5	5	5	4	5	5

6.0 SUMMARY AND CONCLUSION

6.1 Summary

An irrigation model was designed to compare three different sprinkler irrigation systems for potato production, being a portable pipe system with volume guns, a traveller system with a volume gun and a centre pivot (towable and non-towable). Two pump alternatives were also considered: diesel and electric. The proposed model, designed on Excel software, consists of two parts: a preliminary technical design and an economical analysis. The model was applied to a potato farm in Notre-Dame-de-la-Paix (southwestern Quebec) and simulated for a 28 ha field consisting of deep (> 2 m) sandy soil (Morin and St. Gabriel series). The farmer of this field states that irrigation is necessary due to unpredictable weather and dry periods, which too often compromise a profitable harvest.

A complete water balance was performed using IRRIGATE software (Agriculture Canada, 1990) to calculate irrigation requirements and determine all costs associated to the irrigation operation: labour, pumping fuel and electricity, O&M, etc. The irrigation model performed satisfactorily for the study site and was discussed thoroughly with the farmer during the design and application stage. It can be used for different scenarios (type of sprinkler system, type of pump) or various hypotheses (change in field configuration or size, different costs for various inputs and outputs, etc.). However, to assure proper operation of the model and valid results, the assistance of an irrigation specialist knowledgeable in spreadsheet software (Excel) is strongly recommended.

6.2 Limitations of the Model

Throughout the study, design and application of the proposed irrigation model, careful attention was given to the most important aspects of the irrigation components and layout configuration, as well as to the economic analysis. However such comprehensive design usually requires routine applications of the model in order to improve it and attain perfection. Besides its application to the farm in Notre-Dame-de-la-Paix, the model was not tested elsewhere, thus certain limitations to the model should be underlined:

With regard to the Irrigation & Economic model:

1. Calculations for crop water requirement and irrigation scheduling are not done by the model, however they can easily be obtained from either existing softwares (ie. IRRIGATE from Agriculture Canada) or from local weather stations.

2. Certain assumptions had to be made without further possible investigation, such as the wind factor (which could affect the efficiency factor of the irrigation machine), deep percolation rate, etc.

3. Engineering parameters could not all be integrated into the model, such as the optimisation of pipe size and pump capacity, details of electrical connection, etc.

4. Social issues were not addressed, such as the farmer's knowledge, comprehension and acceptance towards complex irrigation equipment and operations, the financial burden of costly equipment to the farmer, water user fee to ensure fair distribution and utilisation, etc.

5. Environmental issues, although sometimes implicit in the model (ie. the user would know if the quality of water is safe), are not considered, such as water availability and hydrological status, rate of percolation of farm chemicals by irrigation methods, soil erosion due to unequal water distribution patterns by some irrigation equipment, etc.

With regard to the application of the model in Notre-Dame-de-la-Paix

1. The demonstration study took only the case of a normal season with average rainfall (thus a normal irrigation depth application (250 mm); dry seasons or wet seasons were not compared.

2. Crop rotations were not studied, however this aspect would definitely need more attention as crops other than potatoes are known to reap few or no benefits from irrigation.

3. Pipeline for all scenarios were entered in the model as non-buried, however most farmers would want to bury the main pipes.

4. The Internal Rate of Return was calculated in two ways; the first based on a strict cost-benefit analysis without taking into consideration the initial capital investment of the irrigation equipment, to study the benefit of irrigation over non-irrigation production. It is recognised that the Internal Rate of Return should normally take into

account the initial capital investment. The second method took this into consideration (a 10-year loan was planned).

6.3 Conclusion

Based on the results of the model applied to the case study farm, the following conclusions were drawn:

1. Based on 14 years of climatic data analysis and a water balance calculation, irrigation was found to be necessary for potato production in any rainfall situation. A wet year with an average of 437 mm rain during the growing season required 225 mm of supplemental irrigation; a normal year with 359 mm of rain required 275 mm of irrigation and a dry year with 282 mm of precipitation required 275 – 300 mm. These results concur with other similar studies in the region.

2. Potato yield and tuber quality are seriously affected by drought. Water applications on irrigated farms are generally done on a weekly basis at 2.54 cm per water application. At this rate of application, the present study calculated 10 applications for a normal year.

3. While it is understood that each farm has its own specificity, and therefore no model can represent or simulate perfectly each situation, this model attempts to provide preliminary information on the design and the economic implications for a farm planning to invest in sprinkler irrigation.

4. The irrigation model was simulated for a 28 ha field with three different sprinkler irrigation systems, which provided comparative technical and economical information. The results of the model showed that further optimisation is needed in order to lower the costs of the irrigation equipment. The model is thus a very useful decision-making tool which offers the user the opportunity to measure and compare all options.

5. The cost of a portable pipe system with four volume guns was estimated at $49,000 with a diesel pump. It requires 1.9hrs/ha of labour for operating the system (installing pipes, changing lateral sets and volume gun positions) and the cost of pumping/growing season is $76/ha.

6. The cost of a traveller system with a diesel pump was estimated at $66,500. It requires 0.75hrs/ha of labour for operating the system (change of traveller lanes and positioning of sled end-gun) and the cost of pumping/growing season is $86/ha.

7. The cost of a non-towable (or fixed) centre pivot system with a diesel pump is $83,300 and a towable centre pivot is $91,500. It requires 0.25hrs/ha of labour for operating the system (general adjustment and inspection of span movement and spraying application) and the cost of pumping/growing season is $63/ha.

8. Each system has its advantages and disadvantages, which must be carefully compared and analysed to determine which system is most suited for a given farm context. Economic factors are also an integral part of the decision-making, and the presented model allows for an investment analysis indicating which option is most profitable.

9. Average non-irrigated yield in potato producing areas of Quebec is nearly 24t/ha. Based on a 10-year average price of $172/t for potatoes, the farmer's net profit is estimated to be around $334/ha. A review of research conducted in eastern Canada on the effects of irrigation on potato yields indicate that an increase in yield to 30t/ha is likely. At this yield level, the model indicated a maximum net profit of $501/ha with the portable pipe system, $481/ha with the non-towable centre pivot and $371/ha with the traveller system. This is a 50%, 44% and 11% increase respectively in net profit over non-irrigated production.

10. The results of the investment analysis indicate that the portable pipe with an electrical pump gave the highest net present value (NPV) of $10,942 followed closely by the non-towable centre pivot at $10,893 (also with the electrical pump), while non-irrigated production gave a NPV of $10,522.

11. Internal rates of return (IRR) based on a 10-year loan for irrigation & pump equipment (20% initial down payment, 8% interest on loan) were highest at 14% for the portable pipe system and the centre pivot with the electric pump, however they are lower than the IRR for the non-irrigated which gave an IRR of 17%. Further investigation is needed to optimise these two systems and obtain a better IRR.

12. Payback period for the equipment was shortest for the portable pipe system and the non-towable at 7 years. The traveller had the longest payback period, estimated at 10 years.

13. The electrical pump, in spite of a high initial cost for a line installation ($15,000 was estimated in the model) was more profitable than the diesel, due to its superior efficiency, low maintenance cost and higher salvage value (after 10 years). However, an electrical pump is a permanent installation due to the electricity line, compared to a diesel pump which can be easily towed from one field to another.

14. For a field of only 28 ha, the overall financial picture is that the acquisition of an irrigation sprinkler system is a financial risk. Other parameters that should be further examined include and increasing in field size (a minimum of 50 ha appears reasonable) and optimising the irrigation equipment use (such as for chemical spraying) which diminishes labour and special machinery costs, etc. The magnitude of the financial benefits was found to be strongly influenced by the price of potatoes, fuel and labour.

7.0 CONSIDERATION FOR FUTURE RESEARCH

The present irrigation model was designed to assist a farmer in selecting the optimal irrigation system for potato production. In that respect, the following future research and development is recommended:

1. conduct studies on profitable potato crop rotations under irrigated methods;

2. improve the present proposed irrigation model to include other engineering and socio-economic parameters, as well as making it more flexible towards other farm situations;

3. study other irrigation systems such as the traveller with boom on a carriage (75 m wide span), LEPA centre pivots (low pressure), subsurface drip irrigation.

4. Carry out a comprehensive census in Quebec on irrigation equipment use and operations.

5. Develop better linkages between research centres in Canada on potatoes and irrigation.

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(*) : in the presented model, this reference appears as : B.C. Irrig. Manual, 1989)

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Appendix A

- Part 1 : Explanation of calculations on Water Balance and Irrigation Depths & Scheduling
- Part 2 : Data Analysis and Results for Year 1998 (sample) & Graphs
- Part 3 : Yearly and Monthly Rainfall, ET and Irrigation Needs at Notre-Dame-de-la-Paix

Appendix A

EXPLANATION OF CALCULATIONS ON WATER BALANCE AND IRRIGATION DEPTHS & SCHEDULING

The following pages present the method used for determining ETc and irrigation application depth & scheduling. A sample calculation for most of the parameters is provided below followed by a Table of results for ETc, Effective rainfall, and irrigation application depths for the year 1998.

Parameters for ETc calculation:
Date: day/month/year
T° max. : maximum temperature (C°)
T° min. : minimum temperature (C°)
ETc : Crop evapotranspiration

Parameters for the water balance & irrigation depth application
PP : precipitation (mm)
Effective PPt : effective precipitation
Moisture content : field capacity (%)
Moisture content : field capacity (mm)
Irrigation / no-irrigation recommended
Irrig. Applic. : irrigation application (mm)
RAW : readily available water (mm)
Critical CM : Critical moisture (mm)
Critical MC : Critical moisture (%)

ETc calculation:

ET was calculated using the Irrigate software (Agriculture Canada, 1990). The calculation is based on the Baier-Robertson equation (an energy based equation) and requires, for the software, the following daily data: Date / day / month / year / maximum temperature (C°) / minimum temperature (C°)/latitude (= 45.81) Results are provided in millimeters. Daily conversion factors and crop coefficients for irrigation planning, crop water consumption is required to obtain a reference crop ET. Root depth for potato was established at 60 cm. The value for the crop coefficients of potato is different for each growing stage (Doorenbos, 1979). The following values were used:

Growth stage	Kc Value used	Duration (days)
(1) Emergence	0.43	17 days
(2) Tuber Initiation	0.71	23 days
(3) Tuber Bulking	1.05	30 days
(4) Beginning of Senescence	0.86	30 days
(5) Senescence	0.67	20 days

The duration for each stage was taken from Dwyer and Boisvert's study on potatoes done in Eastern Canada (1990).

Water Balance

To perform a water balance and to determine the moisture content on subsequent days the following general equation applies (from : James, 1987):

Rain + Irrigation = ET + RO + DP - (Change in SMS/time)

Where:

Rain	=	measured precipitation (mm)
Irrigation	=	Irrigation application (mm)
Etc	=	Crop Evapotranspiration (mm)
RO	=	Runoff (mm)
DP	=	Deep percolation (mm).
SMS	=	Soil moisture status (mm)

From daily results for ETc the equation for water balance can be rearranged to:

$$SM_{i+1} = SM_i - (ET + DP - P_e - Irrigation)$$

Where:

SM_i	=	Soil Moisture content on day i
SM_{i+1}	=	Soil Moisture content on day i +1
ETc	=	value provided from Irrigate software (mm); (ETc = ETo * Kc)
DP	=	deep percolation (mm) = 2 mm/day were subtracted from moisture content when soil moisture content exceeded 72,6 mm (Fc + RAW = 64,5 + 8,1 = 72,6 mm) [1].
P_e	=	Effective rainfall (mm) (effective rain = measured precipitation x correction factor from : Schwab, 1993; Cuenca, 1989). Note: By using effective rainfall (Pe), runoff is taken into account as well as any excess percolation.

Note: For this equation we assumed the initial soil moisture for a loamy sand to be at field capacity.

This new equation allows us to calculate the soil moisture content for each day. A water balance was performed to determine the daily soil moisture content of the soil. After determining irrigation requirements, this calculation was repeated again to give the final daily soil moisture content.

Sample Calculation for May 13, 1998:

$$(SM)_{May\ 13} = (SM)_{May\ 12} - (ET + Seepage - P_e - Irrigation)$$
$$(SM)_{May\ 13} = 10.98\% - \{(5.2\ mm + 0 - 0 - 0)/600\ mm\} * 100$$
$$(SM)_{May\ 13} = 10.11\% \text{ (or } 10.11\% * 600 = 60,67\ mm)$$

(Note: We are expressing soil moisture in terms of percentage of root depth, where D_{rz} = 600mm).

Irrigation Scheduling:

After performing the water balance it is now possible to determine irrigation requirements on a daily basis. The assumption was made that when the soil moisture content dips below the critical moisture level (defined on the next page) irrigation is needed. Water applications were nevertheless maintained at 25 mm per cycle, as desired by the farmers and their usual practice.

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1 : this is a conservative approach but considering the cost of irrigation application (costs of pumping, labour, etc) it is reasonable to say that a progressive farmer shall limit any excess amounts of water application, thus reducing the chance of deep percolation.

Determining the critical soil moisture level for irrigation scheduling:

Critical Soil Moisture = Fc - RAW
MAD = 0.3 for potatoe (From L. James, 1988)
RAW = MAD*AW
AW = D_{rz}*(fc-pwp)/100

where :
Fc : field capacity = 10.75% (Gallichand, 1997); or 10.75%*600/100 = 64.5 mm
RAW = Readily available water (%) (RAW = (MAD) $D_{RZ}(f_c - pwp)/100$)
AW = Available water (%): the soil moisture between field capacity and permanent wilting point
D_{rz} = Depth to root zone in cm (600 mm)
pwp = Permanent Wilting Point (6.25% from Gallichand, 1997) or 6.25%*600/100 = 37.5 mm
MAD = Maximum Allowable Depletion

Example for a loamy sand soil:

RAW = 0.3*600*(10.75% - 6.25%) / 100
RAW = 8.1 mm
Or in terms of percentage: RAW = 1.35%

Critical Soil Moisture = fc - RAW
= **10.75% – 1.35% = 9. 4 %** or 9.4%*600/100 = 56.4 mm

Now that the critical soil moisture has been defined, a simple 'IF' Statement can be implemented in the spreadsheet to reflect when irrigation applications are needed.

Each depth of irrigation for a given day was entered manually at 25 mm/cycle whenever it was specified in the spreadsheet. This could have been done automatically, but the manual way has the advantage that one can verify and test the optimal irrigation scheduling programme. The preliminary irrigation schedule (referred to hereafter as Irrigation Schedule 1) is based simply on applying 25 mm of irrigation water whenever it is specified in the spreadsheet that the soil moisture content is below the critical level. This is one simple method of determining irrigation scheduling however more sophisticated methods can be used for better water efficiency.

The following pages present data for year 1998, it is presented as an example of the method which was applied to all 14 years of climatic data for Notre-Dame-de-la-Paix. The data includes the calculation for the water balance as well as the irrigation scheduling.

Water Balance

To perform a water balance and to determine the moisture content on subsequent days the following general equation applies (from : James, 1987):

Rain + Irrigation = ET + RO + DP - (Change in SMS/time)

Where:

Rain = measured precipitation (mm)
Irrigation = Irrigation application (mm)
Etc = Crop Evapotranspiration (mm)
RO = Runoff (mm)
DP = Deep percolation (mm).
SMS = Soil moisture status (mm)

From daily results for ETc the equation for water balance can be rearranged to:

$$SM_{i+1} = SM_i - (ET + DP - P_e - Irrigation)$$

Where:

SM_i = Soil Moisture content on day i
SM_{i+1} = Soil Moisture content on day i +1
ETc = value provided from Irrigate software (mm); (ETc = ETo * Kc)
DP = deep percolation (mm) = 2 mm/day were subtracted from moisture content when soil moisture content exceeded 72.6 mm (Fc + RAW = 64.5 + 8,1 = 72.6 mm) [1].
P_e = Effective rainfall (mm) (effective rain = measured precipitation x correction factor from : Schwab, 1993; Cuenca, 1989; Jensen et al., 1980). Note: By using effective rainfall (Pe), runoff is taken into account as well as any excess percolation.

Note: For this equation we assumed the initial soil moisture for a loamy sand to be at field capacity.

This new equation allows us to calculate the soil moisture content for each day. A water balance was performed to determine the daily soil moisture content of the soil. After determining irrigation requirements, this calculation was repeated again to give the final daily soil moisture content.

Sample Calculation for May 13, 1998:

$$(SM)_{May\ 13} = (SM)_{May\ 12} - (ET + Seepage - P_e - Irrigation)$$
$$(SM)_{May\ 13} = 10,98\% - \{(5.2\ mm + 0 - 0 - 0)/600\ mm\}*100$$
$$(SM)_{May\ 13} = 10.11\%\ (or\ 10.11\%*600 = 60,67\ mm)$$

(Note: We are expressing soil moisture in terms of percentage of root depth, where D_{rz} = 600mm).

Irrigation Scheduling:

After performing the water balance it is now possible to determine irrigation requirements on a daily basis. The assumption was made that when the soil moisture content dips below the critical moisture level (defined on the next page) irrigation is needed. Water applications were nevertheless maintained at 25 mm per cycle, as desired by the farmers and their usual practice.

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1 : this is a conservative approach but considering the cost of irrigation application (costs of pumping, labour, etc) it is reasonable to say that a progressive farmer shall limit any excess amounts of water application, thus reducing the chance of deep percolation.

Data Analysis Results for Year 1998

1998 Mo	da	Tmax C	Tmin C	PP mm	ET mm	Effect. Precip.	Moisture Content (SM) (%)	Moisture Content (SM) (mm)	IF statement (to determine irrigation)	Irrigation Applic (mm)	RAW (mm)	Critical MC (mm)	Critical MC (%)
4	1	4.5	1.8	14.3	0.0	6.85	10.75	64.5	no irrigation		8.1	56.4	9.4
4	2	4.2	1.8	11.9	0.0	5.70	11.70	70.20	no irrigation		8.1	56.4	9.4
4	3	6.8	0.5	0.7	0.0	0.34	11.76	70.53	no irrigation		8.1	56.4	9.4
4	4	5.0	-0.8	0.0	0.0	0.00	11.76	70.53	no irrigation		8.1	56.4	9.4
4	5	9.4	0.0	0.0	0.8	0.00	11.62	69.73	no irrigation		8.1	56.4	9.4
4	6	12.2	-1.5	0.0	1.8	0.00	11.32	67.93	no irrigation		8.1	56.4	9.4
4	7	14.3	-2.5	0.0	2.6	0.00	10.89	65.33	no irrigation		8.1	56.4	9.4
4	8	14.1	-2.2	0.0	2.5	0.00	10.47	62.83	no irrigation		8.1	56.4	9.4
4	9	11.0	-1.2	0.0	1.5	0.00	10.22	61.33	no irrigation		8.1	56.4	9.4
4	10	11.3	-2.0	0.0	1.8	0.00	9.92	59.53	no irrigation		8.1	56.4	9.4
4	11	13.1	-4.8	0.0	2.7	0.00	9.47	56.83	no irrigation		8.1	56.4	9.4
4	12	16.5	-4.5	0.0	3.7	0.00	13.02	78.13	***irrigation***	***25***	8.1	56.4	9.4
4	13	18.2	-3.8	0.0	4.1	0.00	12.34	74.03	no irrigation		8.1	56.4	9.4
4	14	18.2	4.0	0.0	3.0	0.00	11.84	71.03	no irrigation		8.1	56.4	9.4
4	15	19.1	5.7	0.0	3.0	0.00	11.34	68.03	no irrigation		8.1	56.4	9.4
4	16	18.2	4.5	12.6	2.9	6.03	11.86	71.16	no irrigation		8.1	56.4	9.4
4	17	17.3	9.9	1.2	1.9	0.57	11.64	69.84	no irrigation		8.1	56.4	9.4
4	18	14.8	4.1	0.0	2.1	0.00	11.29	67.74	no irrigation		8.1	56.4	9.4
4	19	13.8	1.5	1.5	2.2	0.72	11.04	66.26	no irrigation		8.1	56.4	9.4
4	20	13.0	6.0	0.5	1.3	0.24	10.87	65.20	no irrigation		8.1	56.4	9.4
4	21	16.8	-3.0	0.0	3.7	0.00	10.25	61.50	no irrigation		8.1	56.4	9.4
4	22	20.2	-2.2	0.0	4.6	0.00	9.48	56.90	no irrigation		8.1	56.4	9.4
4	23	20.8	0.5	0.0	4.4	0.00	12.92	77.50	***irrigation***	***25***	8.1	56.4	9.4
4	24	18.2	2.2	10.1	3.5	4.83	13.14	78.83	no irrigation		8.1	56.4	9.4
4	25	9.2	1.9	0.0	0.9	0.00	12.99	77.93	no irrigation		8.1	56.4	9.4
4	26	9.8	-5.2	0.0	2.2	0.00	12.62	75.73	no irrigation		8.1	56.4	9.4
4	27	9.0	-2.2	0.0	1.5	0.00	12.37	74.23	no irrigation		8.1	56.4	9.4
4	28	15.9	-2.0	0.0	3.5	0.00	11.79	70.73	no irrigation		8.1	56.4	9.4
4	29	21.2	2.1	0.0	4.4	0.00	11.06	66.33	no irrigation		8.1	56.4	9.4
4	30	23.5	0.0	0.0	5.4	0.00	10.16	60.93	no irrigation		8.1	56.4	9.4
				52.8	72.0								
5	1	25.8	2.8	0.0	5.7	0.00	13.37	80.23	***irrigation***	***25***	8.1	56.4	9.4
5	2	17.5	9.5	3.6	2.4	2.82	13.44	80.65	no irrigation		8.1	56.4	9.4
5	3	17.0	10.6	0.4	2.1	0.31	13.14	78.86	no irrigation		8.1	56.4	9.4
5	4	19.8	11.2	4.3	2.8	3.37	13.24	79.43	no irrigation		8.1	56.4	9.4
5	5	22.4	13.0	3.8	3.3	2.98	13.18	79.11	no irrigation		8.1	56.4	9.4
5	6	21.5	13.8	12.2	3.0	9.56	14.28	85.66	no irrigation		8.1	56.4	9.4
5	7	22.0	13.0	0.1	3.3	0.08	13.74	82.44	no irrigation		8.1	56.4	9.4
5	8	22.0	12.2	0.0	3.4	0.00	13.17	79.04	no irrigation		8.1	56.4	9.4
5	9	19.0	11.4	0.2	2.7	0.16	12.75	76.50	no irrigation		8.1	56.4	9.4
5	10	20.0	11.5	0.0	3.0	0.00	12.25	73.50	no irrigation		8.1	56.4	9.4
5	11	22.5	11.0	0.0	3.8	0.00	11.62	69.70	no irrigation		8.1	56.4	9.4
5	12	22.1	10.2	0.0	3.8	0.00	10.98	65.90	no irrigation		8.1	56.4	9.4
5	13	24.0	4.0	0.0	5.2	0.00	10.12	60.70	no irrigation		8.1	56.4	9.4
5	14	27.0	4.0	0.0	6.1	0.00	13.27	79.60	***irrigation***	***25***	8.1	56.4	9.4
5	15	29.0	11.2	0.0	5.7	0.00	12.32	73.90	no irrigation		8.1	56.4	9.4
5	16	30.2	8.0	0.0	6.5	0.00	11.23	67.40	no irrigation		8.1	56.4	9.4
5	17	28.0	14.5	0.0	4.9	0.00	10.42	62.50	no irrigation		8.1	56.4	9.4
5	18	25.8	8.8	0.0	5.1	0.00	9.57	57.40	no irrigation		8.1	56.4	9.4
5	19	25.5	7.0	0.0	5.3	0.00	12.85	77.10	***irrigation***	***25***	8.1	56.4	9.4
5	20	27.2	10.0	0.2	5.4	0.16	11.98	71.86	no irrigation		8.1	56.4	9.4
5	21	11.0	8.0	0.1	1.0	0.08	11.82	70.93	no irrigation		8.1	56.4	9.4
5	22	18.0	5.0	0.0	3.5	0.00	11.24	67.43	no irrigation		8.1	56.4	9.4
5	23	22.0	3.0	0.0	4.9	0.00	10.42	62.53	no irrigation		8.1	56.4	9.4
5	24	25.8	2.5	0.0	6.1	0.00	9.41	56.43	no irrigation		8.1	56.4	9.4
5	25	27.0	5.8	0.4	6.0	0.31	12.62	75.75	***irrigation***	***25***	8.1	56.4	9.4
5	26	19.8	9.5	0.0	3.4	0.00	12.06	72.35	no irrigation		8.1	56.4	9.4

5	27	22.5	2.2	0.0	5.2	0.00	11.19	67.15	no irrigation		8.1	56.4	9.4
5	28	29.2	8.8	0.1	6.2	0.08	10.17	61.03	no irrigation		8.1	56.4	9.4
5	29	24.5	17.5	3.7	3.6	2.90	10.05	60.32	no irrigation		8.1	56.4	9.4
5	30	19.4	10.0	0.0	3.3	0.00	9.50	57.02	no irrigation		8.1	56.4	9.4
5	31	23.0	6.0	14.0	4.9	10.97	10.52	63.09	no irrigation		8.1	56.4	9.4
				43.1	131.6								
6	1	16.0	5.0	0.0	3.0	0.00	10.02	60.09	no irrigation		8.1	56.4	9.4
6	2	21.5	9.0	11.3	4.0	7.28	10.56	63.37	no irrigation		8.1	56.4	9.4
6	3	13.6	6.5	0.2	2.1	0.13	10.23	61.40	no irrigation		8.1	56.4	9.4
6	4	16.0	2.0	1.0	3.5	0.64	9.76	58.54	no irrigation		8.1	56.4	9.4
6	5	17.5	4.0	0.0	3.6	0.00	13.32	79.94	***irrigation***	***25***	8.1	56.4	9.4
6	6	15.2	9.0	0.0	2.2	0.00	12.96	77.74	no irrigation		8.1	56.4	9.4
6	7	14.2	8.5	1.8	2.0	1.16	12.82	76.90	no irrigation		8.1	56.4	9.4
6	8	20.2	8.8	0.6	3.7	0.39	12.26	73.59	no irrigation		8.1	56.4	9.4
6	9	26.1	3.0	0.0	6.3	0.00	11.21	67.29	no irrigation		8.1	56.4	9.4
6	10	28.0	9.0	2.0	6.0	1.29	10.43	62.58	no irrigation		8.1	56.4	9.4
6	11	27.0	10.5	0.1	5.5	0.06	9.52	57.14	no irrigation		8.1	56.4	9.4
6	12	19.0	15.5	24.9	2.4	16.04	11.80	70.79	no irrigation		8.1	56.4	9.4
6	13	20.0	16.0	2.7	2.7	1.74	11.64	69.82	no irrigation		8.1	56.4	9.4
6	14	19.0	15.5	10.5	2.4	6.76	12.36	74.19	no irrigation		8.1	56.4	9.4
6	15	25.5	15.5	11.4	4.3	7.34	12.87	77.23	no irrigation		8.1	56.4	9.4
6	16	20.0	17.0	0.7	2.5	0.45	12.53	75.19	no irrigation		8.1	56.4	9.4
6	17	27.0	17.0	0.8	4.5	0.52	11.87	71.20	no irrigation		8.1	56.4	9.4
6	18	27.0	17.0	2.6	4.5	1.68	11.40	68.38	no irrigation		8.1	56.4	9.4
6	19	28.0	15.0	30.6	5.1	19.71	13.83	82.99	no irrigation		8.1	56.4	9.4
6	20	31.0	15.0	0.1	6.0	0.06	12.84	77.06	no irrigation		8.1	56.4	9.4
6	21	31.0	16.5	0.0	5.8	0.00	11.88	71.26	no irrigation		8.1	56.4	9.4
6	22	30.0	17.0	0.0	5.4	0.00	10.98	65.86	no irrigation		8.1	56.4	9.4
6	23	29.0	18.9	0.0	4.8	0.00	10.18	61.06	no irrigation		8.1	56.4	9.4
6	24	28.0	15.0	0.2	5.1	0.13	13.51	81.08	***irrigation***	***25***	8.1	56.4	9.4
6	25	25.5	17.0	2.8	4.1	1.80	13.13	78.79	no irrigation		8.1	56.4	9.4
6	26	25.0	19.0	6.4	3.7	4.12	13.20	79.21	no irrigation		8.1	56.4	9.4
6	27	27.0	18.0	3.7	4.4	2.38	12.87	77.20	no irrigation		8.1	56.4	9.4
6	28	25.0	16.0	2.0	4.1	1.29	12.40	74.38	no irrigation		8.1	56.4	9.4
6	29	25.0	13.0	0.0	4.5	0.00	11.65	69.88	no irrigation		8.1	56.4	9.4
6	30	24.0	14.5	45.6	4.0	29.38	15.88	95.26	no irrigation		8.1	56.4	9.4
				162.0	122.2								
7	1	19.0	14.0	1.0	2.6	0.59	15.54	93.26	no irrigation		8.1	56.4	9.4
7	2	28.0	9.5	0.0	5.9	0.00	14.56	87.36	no irrigation		8.1	56.4	9.4
7	3	28.0	12.0	10.2	5.5	6.07	14.65	87.92	no irrigation		8.1	56.4	9.4
7	4	19.5	16.0	10.1	2.5	6.01	15.24	91.43	no irrigation		8.1	56.4	9.4
7	5	24.0	9.0	0.0	4.8	0.00	14.44	86.63	no irrigation		8.1	56.4	9.4
7	6	23.0	12.0	0.0	4.1	0.00	13.75	82.53	no irrigation		8.1	56.4	9.4
7	7	26.5	9.0	0.0	5.5	0.00	12.84	77.03	no irrigation		8.1	56.4	9.4
7	8	23.0	12.0	0.0	4.0	0.00	12.17	73.03	no irrigation		8.1	56.4	9.4
7	9	29.0	16.0	8.8	5.2	5.23	12.18	73.06	no irrigation		8.1	56.4	9.4
7	10	21.0	14.0	0.4	3.2	0.24	11.68	70.10	no irrigation		8.1	56.4	9.4
7	11	24.0	14.0	0.0	4.0	0.00	11.02	66.10	no irrigation		8.1	56.4	9.4
7	12	29.0	10.5	1.1	6.0	0.65	10.13	60.76	no irrigation		8.1	56.4	9.4
7	13	26.5	15.5	6.6	4.5	3.92	10.03	60.18	no irrigation		8.1	56.4	9.4
7	14	31.0	17.0	0.0	5.6	0.00	13.26	79.58	***irrigation***	***25***	8.1	56.4	9.4
7	15	32.5	17.0	0.0	6.0	0.00	12.26	73.58	no irrigation		8.1	56.4	9.4
7	16	32.0	16.0	28.5	6.0	16.95	14.09	84.53	no irrigation		8.1	56.4	9.4
7	17	24.0	17.0	3.3	3.5	1.96	13.83	82.99	no irrigation		8.1	56.4	9.4
7	18	26.0	10.0	0.0	5.1	0.00	12.98	77.89	no irrigation		8.1	56.4	9.4
7	19	27.5	16.0	0.0	4.7	0.00	12.20	73.19	no irrigation		8.1	56.4	9.4
7	20	28.0	18.0	0.0	4.5	0.00	11.45	68.69	no irrigation		8.1	56.4	9.4
7	21	30.0	11.0	0.0	6.1	0.00	10.43	62.59	no irrigation		8.1	56.4	9.4
7	22	27.0	20.5	0.0	3.8	0.00	9.80	58.79	no irrigation		8.1	56.4	9.4
7	23	25.0	13.0	4.0	4.3	2.38	9.48	56.87	no irrigation		8.1	56.4	9.4
7	24	20.0	11.0	0.0	3.2	0.00	13.11	78.67	***irrigation***	***25***	8.1	56.4	9.4
7	25	23.0	5.0	0.0	4.9	0.00	12.30	73.77	no irrigation		8.1	56.4	9.4

7	26	25.0	8.5	0.0	4.9	0.00	11.48	68.87	no irrigation		8.1	56.4	9.4
7	27	25.0	11.0	5.8	4.6	3.45	11.29	67.72	no irrigation		8.1	56.4	9.4
7	28	26.0	14.5	26.0	4.3	15.46	13.15	78.88	no irrigation		8.1	56.4	9.4
7	29	23.0	14.5	0.0	3.4	0.00	12.58	75.48	no irrigation		8.1	56.4	9.4
7	30	22.5	11.0	5.4	3.8	3.21	12.48	74.89	no irrigation		8.1	56.4	9.4
7	31	22.0	7.0	0.0	4.2	0.00	11.78	70.69	no irrigation		8.1	56.4	9.4
				111.2	140.7								
8	1	26.0	6.0	0.0	5.5	0.00	10.87	65.19	no irrigation		8.1	56.4	9.4
8	2	27.0	10.0	0.0	5.2	0.00	10.00	59.99	no irrigation		8.1	56.4	9.4
8	3	27.0	15.0	0.0	4.4	0.00	13.43	80.59	*irrigation*	*25*	8.1	56.4	9.4
8	4	25.0	10.0	0.8	4.6	0.50	12.75	76.49	no irrigation		8.1	56.4	9.4
8	5	30.0	12.5	0.0	5.6	0.00	11.82	70.89	no irrigation		8.1	56.4	9.4
8	6	29.0	13.5	0.0	5.2	0.00	10.95	65.69	no irrigation		8.1	56.4	9.4
8	7	25.0	18.0	0.0	3.4	0.00	10.38	62.29	no irrigation		8.1	56.4	9.4
8	8	27.0	19.0	0.0	3.8	0.00	9.75	58.49	no irrigation		8.1	56.4	9.4
8	9	31.0	15.0	12.4	5.5	7.72	10.12	60.71	no irrigation		8.1	56.4	9.4
8	10	23.5	20.5	8.6	2.5	5.35	10.59	63.56	no irrigation		8.1	56.4	9.4
8	11	26.0	18.0	0.2	3.6	0.12	10.01	60.09	no irrigation		8.1	56.4	9.4
8	12	23.0	8.0	0.0	4.1	0.00	13.50	80.99	*irrigation*	*25*	8.1	56.4	9.4
8	13	23.5	7.0	0.0	4.4	0.00	12.76	76.59	no irrigation		8.1	56.4	9.4
8	14	26.8	7.5	0.0	5.3	0.00	11.88	71.29	no irrigation		8.1	56.4	9.4
8	15	29.5	14.0	0.0	5.1	0.00	11.03	66.19	no irrigation		8.1	56.4	9.4
8	16	25.0	12.0	0.0	4.1	0.00	10.35	62.09	no irrigation		8.1	56.4	9.4
8	17	28.0	9.0	0.0	5.3	0.00	9.46	56.79	no irrigation		8.1	56.4	9.4
8	18	16.0	11.5	0.0	1.5	0.00	13.38	80.29	*irrigation*	*25*	8.1	56.4	9.4
8	19	21.6	20.0	0.0	1.9	0.00	13.06	78.39	no irrigation		8.1	56.4	9.4
8	20	20.5	4.0	0.0	3.8	0.00	12.43	74.59	no irrigation		8.1	56.4	9.4
8	21	25.0	14.0	0.0	3.7	0.00	11.81	70.89	no irrigation		8.1	56.4	9.4
8	22	25.0	12.0	0.0	3.9	0.00	11.16	66.99	no irrigation		8.1	56.4	9.4
8	23	21.4	13.6	18.1	2.6	11.27	12.61	75.66	no irrigation		8.1	56.4	9.4
8	24	26.4	17.8	2.0	3.4	1.25	12.25	73.50	no irrigation		8.1	56.4	9.4
8	25	19.5	13.0	28.6	2.1	17.80	14.87	89.21	no irrigation		8.1	56.4	9.4
8	26	24.5	17.0	5.4	3.0	3.36	14.93	89.57	no irrigation		8.1	56.4	9.4
8	27	28.0	10.0	0.0	5.0	0.00	14.09	84.57	no irrigation		8.1	56.4	9.4
8	28	26.0	11.0	0.0	4.2	0.00	13.39	80.37	no irrigation		8.1	56.4	9.4
8	29	23.0	17.0	3.4	2.5	2.12	13.33	79.99	no irrigation		8.1	56.4	9.4
8	30	23.0	8.0	0.0	3.7	0.00	12.71	76.29	no irrigation		8.1	56.4	9.4
8	31	20.5	8.0	0.0	3.0	0.00	12.21	73.29	no irrigation		8.1	56.4	9.4
				79.5	121.9								
9	1	23.0	8.5	0.0	3.6	0.00	11.61	69.69	no irrigation		8.1	56.4	9.4
9	2	22.0	12.0	11.0	2.8	4.91	11.97	71.79	no irrigation		8.1	56.4	9.4
9	3	18.0	9.0	9.6	2.1	4.28	12.33	73.98	no irrigation		8.1	56.4	9.4
9	4	20.0	7.0	0.0	2.9	0.00	11.85	71.08	no irrigation		8.1	56.4	9.4
9	5	23.0	8.0	0.0	3.6	0.00	11.25	67.48	no irrigation		8.1	56.4	9.4
9	6	27.0	13.0	0.0	4.0	0.00	10.58	63.48	no irrigation		8.1	56.4	9.4
9	7	16.0	9.0	0.0	1.4	0.00	10.35	62.08	no irrigation		8.1	56.4	9.4
9	8	18.0	6.5	2.9	2.3	1.29	10.18	61.07	no irrigation		8.1	56.4	9.4
9	9	18.1	10.8	0.1	1.7	0.04	9.90	59.42	no irrigation		8.1	56.4	9.4
9	10	20.0	9.0	0.0	2.5	0.00	9.49	56.92	no irrigation		8.1	56.4	9.4
9	11	23.0	3.0	3.0	4.2	1.34	13.18	79.06	*irrigation*	*25*	8.1	56.4	9.4
9	12	19.0	9.0	0.0	2.1	0.00	12.83	76.96	no irrigation		8.1	56.4	9.4
9	13	20.0	3.0	0.0	3.3	0.00	12.28	73.66	no irrigation		8.1	56.4	9.4
9	14	17.0	9.3	6.5	1.5	2.90	12.51	75.06	no irrigation		8.1	56.4	9.4
9	15	19.0	13.0	5.2	1.5	2.32	12.65	75.88	no irrigation		8.1	56.4	9.4
9	16	20.0	7.0	0.0	2.6	0.00	12.21	73.28	no irrigation		8.1	56.4	9.4
9	17	21.0	4.0	0.0	3.3	0.00	11.66	69.98	no irrigation		8.1	56.4	9.4
9	18	20.0	1.0	0.0	3.4	0.00	11.10	66.58	no irrigation		8.1	56.4	9.4
9	19	23.0	11.0	0.0	2.8	0.00	10.63	63.78	no irrigation		8.1	56.4	9.4
9	20	19.0	14.0	0.0	1.2	0.00	10.43	62.58	no irrigation		8.1	56.4	9.4
9	21	28.0	12.0	1.0	4.0	0.45	9.84	59.02	no irrigation		8.1	56.4	9.4
9	22	13.0	8.0	1.6	0.3	0.71	9.91	59.44	no irrigation		8.1	56.4	9.4
9	23	13.5	-2.0	0.0	1.8	0.00	9.61	57.64	no irrigation		8.1	56.4	9.4

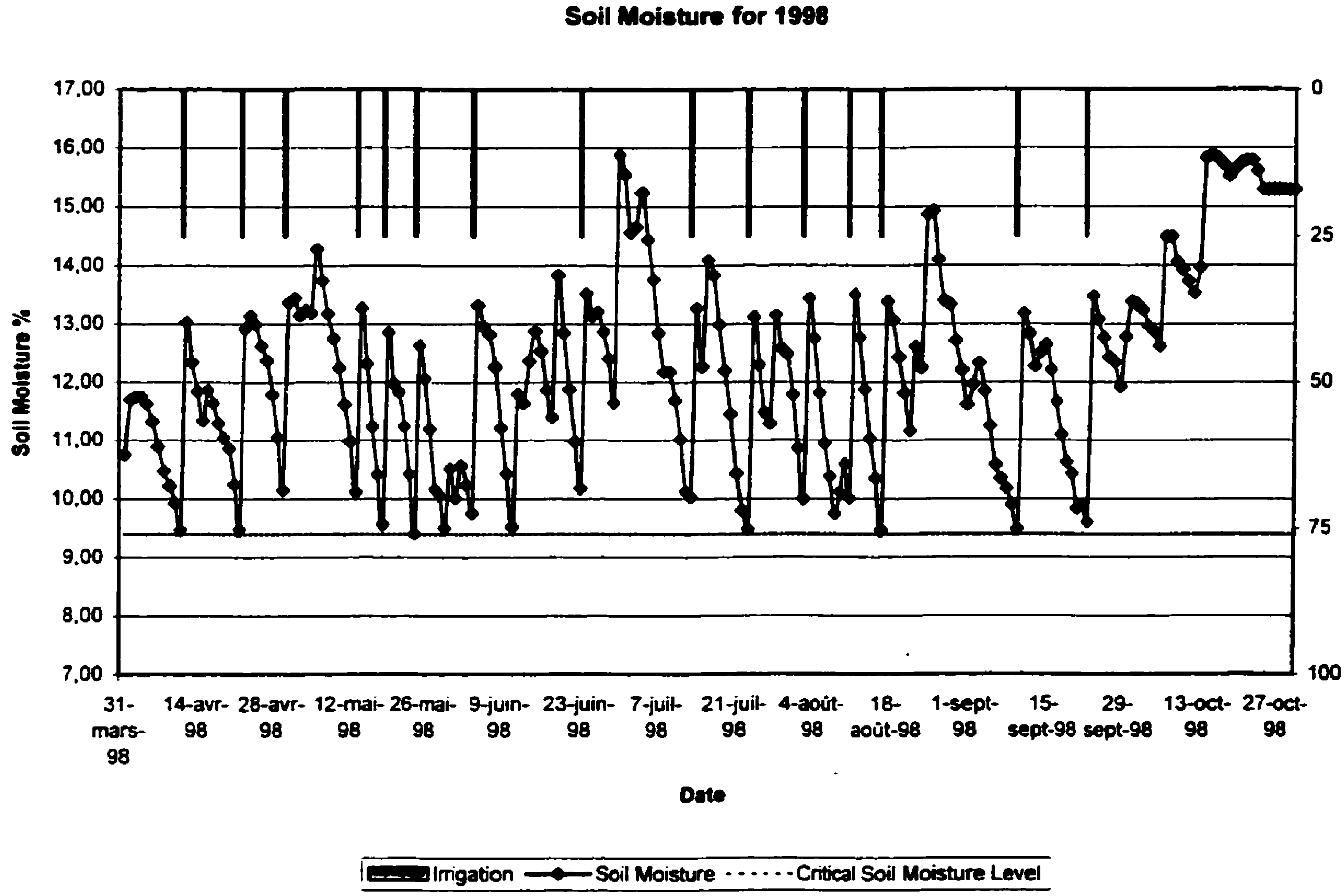
9	24	13.0	-3.0	0.0	1.8	0.00	13.47	80.84	*irrigation*	25	8.1	56.4	9.4
9	25	22.0	10.5	0.0	2.4	0.00	13.07	78.44	no irrigation		8.1	56.4	9.4
9	26	20.0	7.0	1.0	2.3	0.45	12.76	76.59	no irrigation		8.1	56.4	9.4
9	27	24.0	11.0	2.0	2.9	0.89	12.43	74.58	no irrigation		8.1	56.4	9.4
9	28	14.0	7.0	0.0	0.5	0.00	12.35	74.08	no irrigation		8.1	56.4	9.4
9	29	18.0	-1.0	0.6	2.8	0.27	11.92	71.55	no irrigation		8.1	56.4	9.4
9	30	18.0	11.5	13.8	1.0	6.16	12.78	76.70	no irrigation		8.1	56.4	9.4
				58.3	72.6								
10	1	9.0	6.0	6.2	0.0	3.63	13.39	80.33	no irrigation		8.1	56.4	9.4
10	2	10.0	0.0	0.0	0.3	0.00	13.34	80.03	no irrigation		8.1	56.4	9.4
10	3	13.0	4.0	0.0	0.6	0.00	13.24	79.43	no irrigation		8.1	56.4	9.4
10	4	13.0	-4.0	0.0	1.7	0.00	12.96	77.73	no irrigation		8.1	56.4	9.4
10	5	12.0	2.0	0.0	0.5	0.00	12.87	77.23	no irrigation		8.1	56.4	9.4
10	6	13.0	-4.5	0.3	1.7	0.18	12.62	75.71	no irrigation		8.1	56.4	9.4
10	7	13.0	1.0	20.8	0.9	12.17	14.50	86.97	no irrigation		8.1	56.4	9.4
10	8	14.0	9.0	0.0	0.0	0.00	14.50	86.97	no irrigation		8.1	56.4	9.4
10	9	18.0	-1.0	0.0	2.6	0.00	14.06	84.37	no irrigation		8.1	56.4	9.4
10	10	16.0	7.0	0.0	0.8	0.00	13.93	83.57	no irrigation		8.1	56.4	9.4
10	11	18.0	8.0	0.0	1.2	0.00	13.73	82.37	no irrigation		8.1	56.4	9.4
10	12	14.0	0.0	0.0	1.2	0.00	13.53	81.17	no irrigation		8.1	56.4	9.4
10	13	17.0	-1.0	8.2	2.2	4.80	13.96	83.77	no irrigation		8.1	56.4	9.4
10	14	12.0	9.0	19.2	0.0	11.23	15.83	95.00	no irrigation		8.1	56.4	9.4
10	15	11.0	8.0	0.6	0.0	0.35	15.89	95.35	no irrigation		8.1	56.4	9.4
10	16	15.0	7.0	0.0	0.4	0.00	15.82	94.95	no irrigation		8.1	56.4	9.4
10	17	15.0	3.0	0.4	0.9	0.23	15.71	94.28	no irrigation		8.1	56.4	9.4
10	18	20.0	11.0	0.0	1.2	0.00	15.51	93.08	no irrigation		8.1	56.4	9.4
10	19	14.0	8.0	1.4	0.0	0.82	15.65	93.90	no irrigation		8.1	56.4	9.4
10	20	10.0	4.0	1.0	0.0	0.58	15.75	94.49	no irrigation		8.1	56.4	9.4
10	21	8.0	0.0	0.4	0.0	0.23	15.79	94.72	no irrigation		8.1	56.4	9.4
10	22	8.0	2.0	0.0	0.0	0.00	15.79	94.72	no irrigation		8.1	56.4	9.4
10	23	15.0	1.0	0.0	1.1	0.00	15.60	93.62	no irrigation		8.1	56.4	9.4
10	24	18.0	1.0	0.0	1.9	0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	25	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	26	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	27	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	28	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	29	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	30	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
10	31	N/A	N/A			0.00	15.29	91.72	no irrigation		8.1	56.4	9.4
				58.5	19.2					375			
				565.4	680.2	339.3							
						714,27							

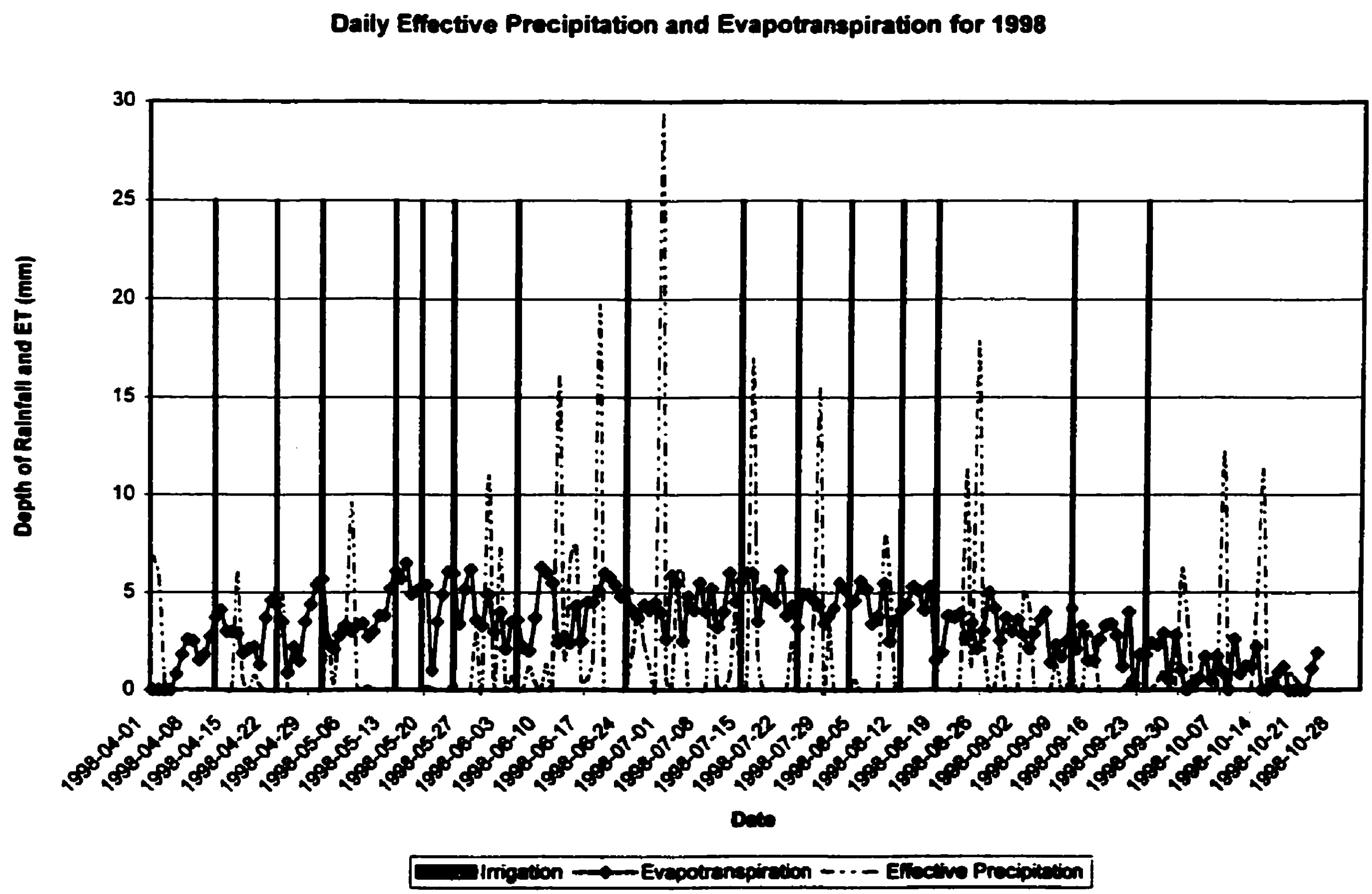
Calc. For Effective Precip.

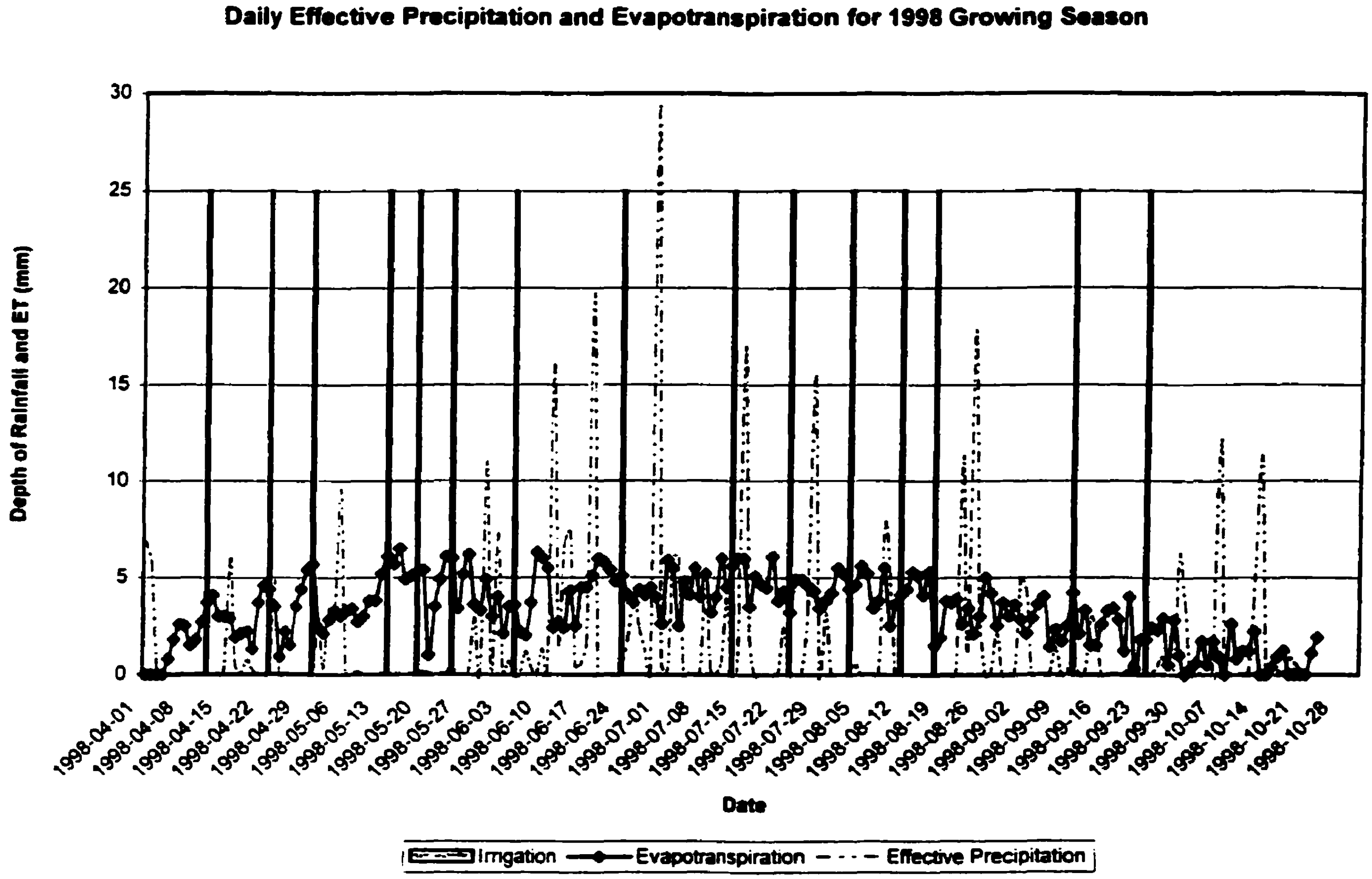
Month	Factor
4	0,4787128
5	0,7832901
6	0,6442762
7	0,5946933
8	0,6225481
9	0,4462978
10	0,5848824
	0,5935287

Year end totals

PPt	= 565.4
Precip. Effect.	= 339.3
ET	= 680.2
Irrigation	= 375.0
Total Precip. Effect.+ irrig.	= 714.2


Soil Moisture for 1998
Soil Moisture %
Irrigation (mm)
17,00
16,00
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
0
25
50
75
100
31-mars-98
14-avr-98
28-avr-98
12-mai-98
26-mai-98
9-juin-98
23-juin-98
7-juil-98
21-juil-98
4-août-98
18-août-98
1-sept-98
15-sept-98
29-sept-98
13-oct-98
27-oct-98
Date
Irrigation
Soil Moisture
Critical Soil Moisture Level


Daily Effective Precipitation and Evapotranspiration for 1998
Depth of Rainfall and ET (mm)
30
25
20
15
10
5
0
Date
Irrigation
Evapotranspiration
Effective Precipitation



Daily Effective Precipitation and Evapotranspiration for 1998 Growing Season
Depth of Rainfall and ET (mm)
30
25
20
15
10
5
0
1998-04-01
1998-04-08
1998-04-15
1998-04-22
1998-04-29
1998-05-06
1998-05-13
1998-05-20
1998-05-27
1998-06-03
1998-06-10
1998-06-17
1998-06-24
1998-07-01
1998-07-08
1998-07-15
1998-07-22
1998-07-29
1998-08-05
1998-08-12
1998-08-19
1998-08-26
1998-09-02
1998-09-09
1998-09-16
1998-09-23
1998-09-30
1998-10-07
1998-10-14
1998-10-21
1998-10-28
Date
Irrigation
Evapotranspiration
Effective Precipitation

Yearly and monthly rainfall, ET and irrigation needs at Notre-Dame-de-la-Paix - 1980-1998

1981 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	58,20	85,00	51,92	25,00	76,92
May	108,30	109,00	72,00	25,00	97,00
June	126,70	173,60	111,67	25,00	136,57
July	143,30	38,20	35,50	100,00	135,50
August	118,70	190,20	118,75	25,00	143,75
Sept	50,30	158,80	87,60	0,00	87,60
Oct	15,50	102,60	55,70	0,00	55,70
Totals	620,00	857,40	533,05	200,00	733,05
Growing season	496,00	511,00	337,83	175,00	512,83

: shaded area indicates normal growth period

1982 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	43,90	62,50	38,33	0,00	38,33
May	124,30	35,60	27,82	100,00	127,82
June	116,80	90,80	48,51	75,00	123,51
July	141,90	48,20	42,54	100,00	142,54
August	115,10	95,40	47,23	75,00	122,23
Sept	69,00	96,40	59,35	0,00	59,35
Oct	26,50	46,00	27,96	0,00	27,96
Totals	637,50	474,90	291,73	350,00	641,73
Growing season	498,10	270,00	166,09	350,00	516,09

1983 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	37,20	129,30	71,36	0,00	71,36
May	82,60	171,00	100,19	0,00	100,19
June	160,80	45,60	37,74	75,00	112,74
July	143,70	73,40	58,13	75,00	133,13
August	129,70	44,40	34,41	100,00	134,41
Sept	92,40	69,00	35,18	50,00	85,18
Oct	19,50	125,50	66,90	0,00	66,90
Totals	685,90	658,40	403,90	300,00	703,90
Growing season	506,80	334,60	230,46	250,00	480,46

1984 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	60,10	109,20	64,86	0,00	64,86
May	83,80	111,20	69,33	25,00	94,33
June	136,90	88,00	58,76	75,00	133,76
July	124,80	102,20	55,76	50,00	105,76
August	123,00	136,40	90,23	75,00	165,23
Sept	67,60	28,00	16,57	25,00	41,57
Oct	36,00	65,40	39,22	0,00	39,22
Totals	633,70	640,40	394,74	250,00	644,74
Growing season	470,00	437,80	274,09	225,00	499,09

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Yearly and monthly rainfall, ET and irrigation needs at Notre-Dame-de-la-Paix - 1980-1998

1985 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	50,10	35,70	15,81	50,00	65,81
May	113,80	48,80	34,69	75,00	109,69
June	116,60	64,60	42,80	75,00	117,80
July	128,20	86,80	57,25	75,00	132,25
August	122,00	70,20	46,59	75,00	121,59
Sept	85,40	54,40	30,05	50,00	80,05
Oct	22,70	83,40	47,23	0,00	47,23
Totals	638,80	443,90	274,42	400,00	674,42
Growing season	480,60	270,40	181,33	300,00	481,33

1986 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	72,10	47,30	24,30	50,00	74,30
May	106,40	164,20	101,98	25,00	126,98
June	114,20	129,40	84,58	0,00	84,58
July	123,30	91,00	55,22	100,00	155,22
August	107,90	123,30	80,02	25,00	105,02
Sept	57,40	156,10	87,69	0,00	87,69
Oct	13,40	55,00	31,96	0,00	31,96
Totals	594,70	766,30	465,75	200,00	665,75
Growing season	451,80	507,90	321,81	150,00	471,81

1987 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	71,30	50,80	24,73	50,00	74,73
May	101,70	65,40	39,95	75,00	114,95
June	130,60	108,50	56,12	75,00	131,12
July	130,70	127,40	51,29	75,00	126,29
August	121,20	43,40	32,67	75,00	107,67
Sept	66,60	123,40	42,76	25,00	67,76
Oct	15,50	76,80	24,38	0,00	24,38
Totals	637,60	615,70	271,91	375,00	646,91
Growing season	484,20	364,70	180,03	300,00	480,03

1988 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	37,30	81,70	47,89	25,00	72,89
May	115,20	50,40	35,81	50,00	85,81
June	132,60	82,20	64,46	100,00	164,46
July	141,80	59,90	50,13	75,00	125,13
August	106,40	166,70	103,30	25,00	128,30
Sept	67,10	54,40	23,62	0,00	23,62
Oct	9,00	119,30	62,57	0,00	62,57
Totals	609,40	614,60	377,79	275,00	652,79
Growing season	496,00	359,20	243,70	250,00	493,70

Yearly and monthly rainfall, ET and irrigation needs at Notre-Dame-de-la-Paix - 1980-1998

1990 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	40,20	38,00	13,41	25,00	38,41
May	110,80	86,20	45,12	75,00	120,12
June	128,40	118,20	48,83	75,00	123,83
July	147,20	83,50	63,94	75,00	138,94
August	118,00	96,80	48,72	75,00	123,72
Sept	79,00	75,80	27,82	50,00	77,82
Oct	28,50	180,60	93,19	0,00	93,19
Totals	649,10	681,10	341,04	375,00	716,04
Growing season	501,40	386,70	206,61	300,00	506,61

1991 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	52,30	130,50	74,36	0,00	74,36
May	114,70	72,20	44,77	50,00	94,77
June	141,00	34,40	28,33	125,00	153,33
July	137,90	103,60	64,45	75,00	139,45
August	115,10	138,10	89,63	25,00	114,63
Sept	64,00	61,40	22,06	50,00	72,06
Oct	19,10	106,40	57,95	0,00	57,95
Totals	644,10	646,50	381,55	325,00	706,55
Growing season	508,70	348,20	227,18	275,00	502,18

1992 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	39,60	26,40	11,38	25,00	36,38
[illegible]	112,60	57,60	38,93	75,00	113,93
[illegible]	121,70	76,30	49,10	75,00	124,10
[illegible]	112,90	174,20	112,50	25,00	137,50
[illegible]	102,90	53,20	34,52	50,00	84,52
Sept	65,10	104,90	63,33	25,00	88,33
Oct	14,50	82,70	46,04	0,00	46,04
Totals	569,40	677,50	355,80	275,00	630,80
Growing season	450,20	363,50	235,05	225,00	460,05

1993 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	39,50	112,80	63,75	25,00	88,75
[illegible]	101,90	67,00	39,78	25,00	64,78
[illegible]	120,00	113,20	46,17	75,00	121,17
[illegible]	[illegible]	49,00	41,03	75,00	116,03
[illegible]	124,20	107,60	53,00	75,00	128,00
Sept	57,60	94,20	56,73	25,00	81,73
Oct	13,90	149,60	76,84	0,00	76,84
Totals	587,30	714,40	377,30	300,00	677,30
Growing season	478,30	387,80	179,98	250,00	429,98

Yearly and monthly rainfall, ET and irrigation needs at Notre-Dame-de-la-Paix - 1980-1998

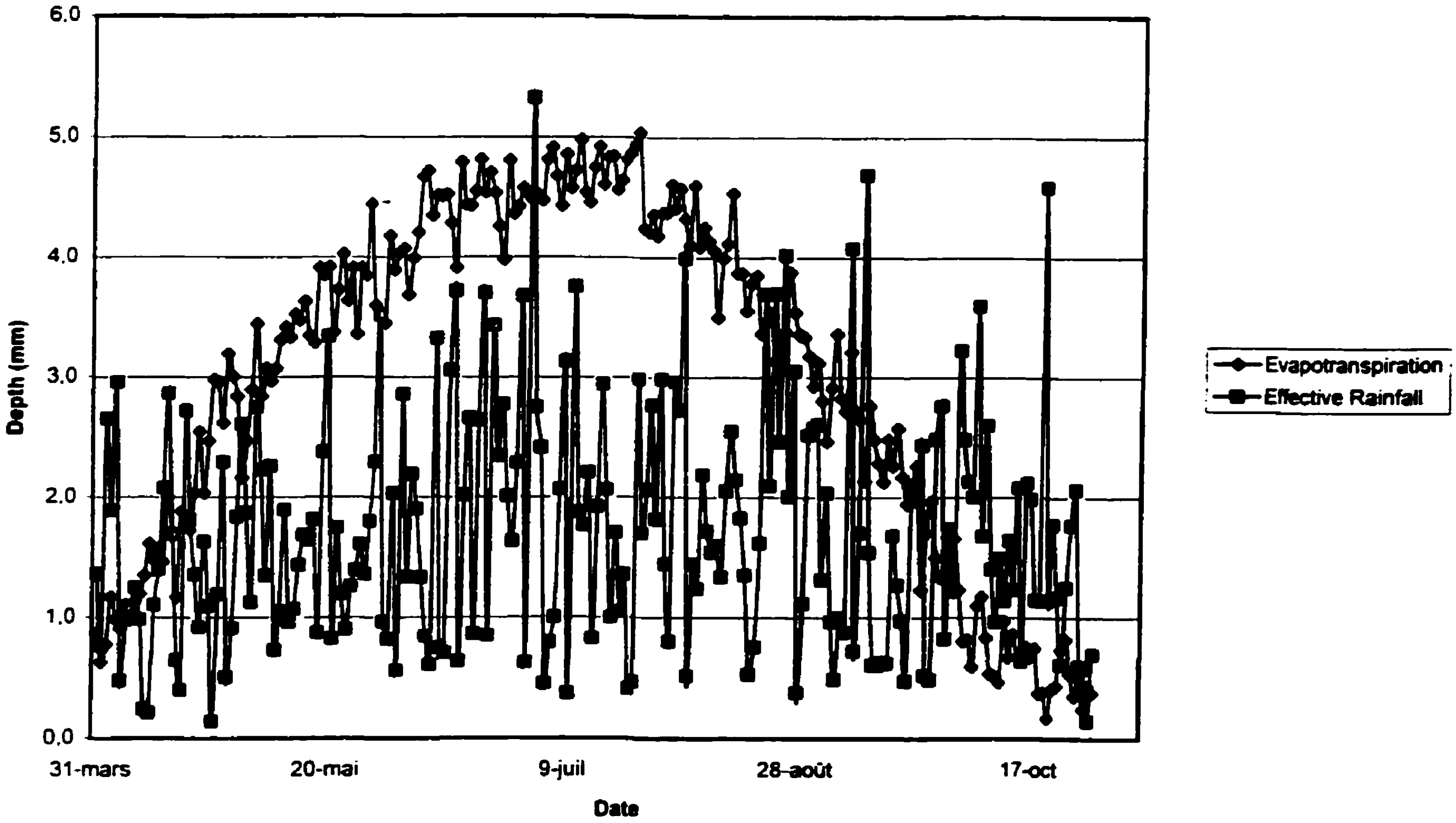
1997 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	42,10	42,60	26,97	25,00	51,97
May	71,30	82,70	52,17	25,00	77,17
June	152,90	60,00	48,00	100,00	148,00
July	148,30	71,80	58,47	75,00	133,47
August	124,30	67,60	46,24	75,00	121,24
Sept	64,90	89,40	55,07	25,00	80,07
Oct	0,00	0,00	0,00	0,00	0,00
Totals	603,80	414,10	286,91	325,00	611,91
Growing season	496,80	282,10	204,87	275,00	479,87

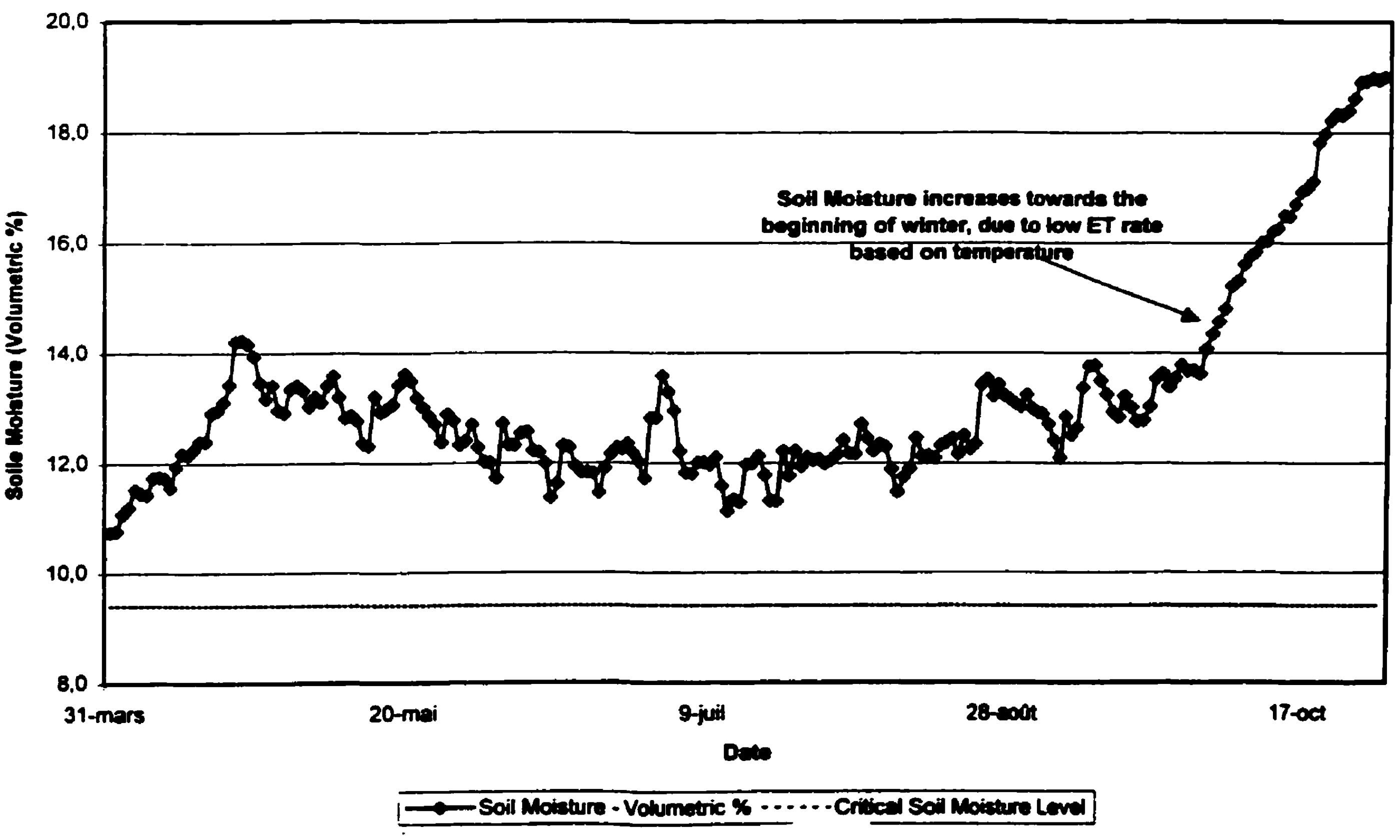
1998 - Monthly Summary

Month	PET	Rain mm	Effective rainfall	Irrigation mm	Effective Rf + Irrigation mm
April	72,00	52,80	25,28	50,00	75,28
May	131,60	43,10	33,76	100,00	133,76
June	122,20	162,00	104,37	50,00	154,37
July	140,70	111,20	66,13	50,00	116,13
August	121,90	79,50	49,49	75,00	124,49
Sept	72,60	58,30	26,02	50,00	76,02
Oct	19,20	58,50	34,22	0,00	34,22
Totals	680,20	585,40	339,27	375,00	714,27
Growing season	516,40	395,80	253,76	275,00	528,76

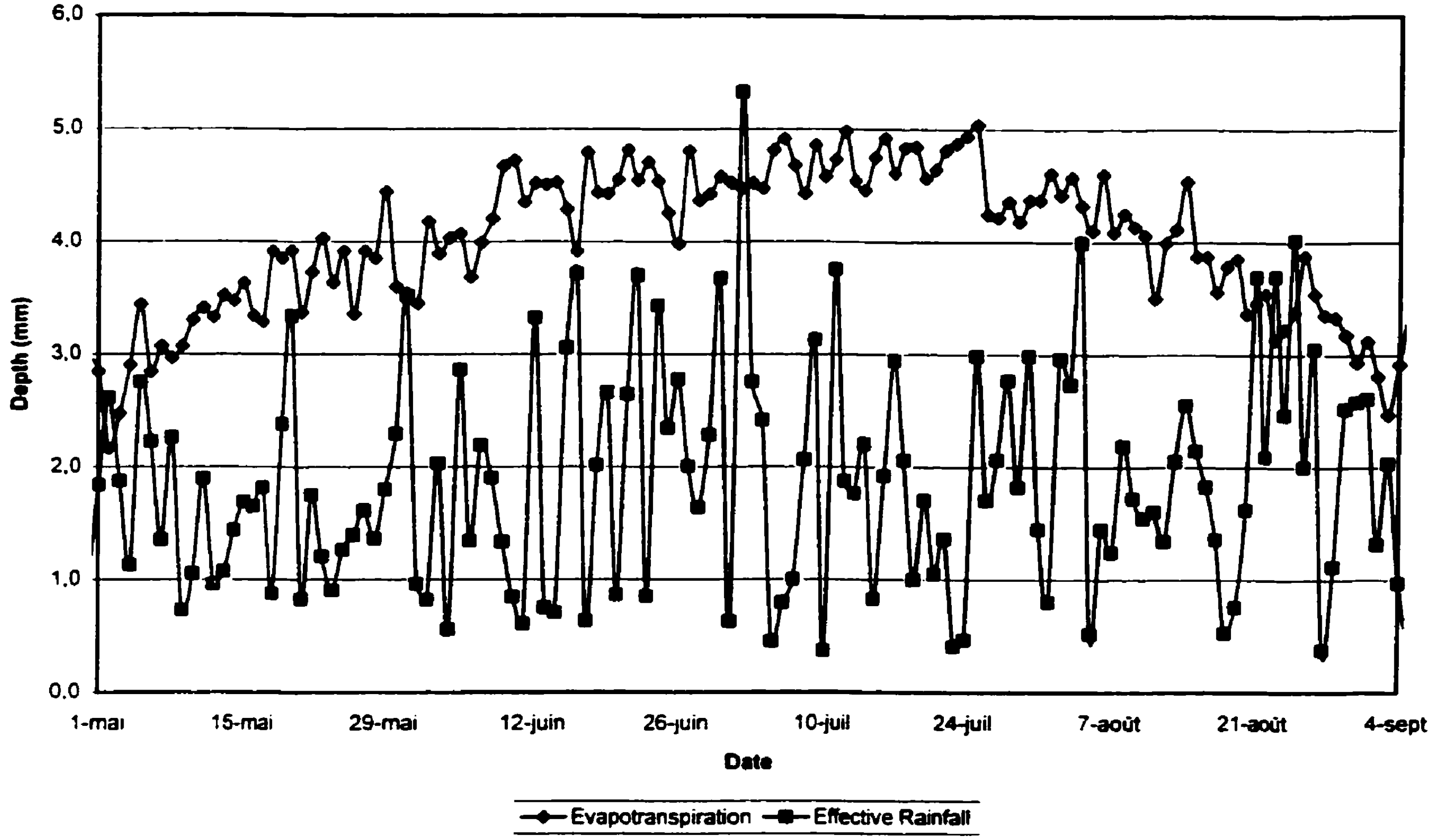
Average Effective Precipitation and Average ET (1981 - 1998)



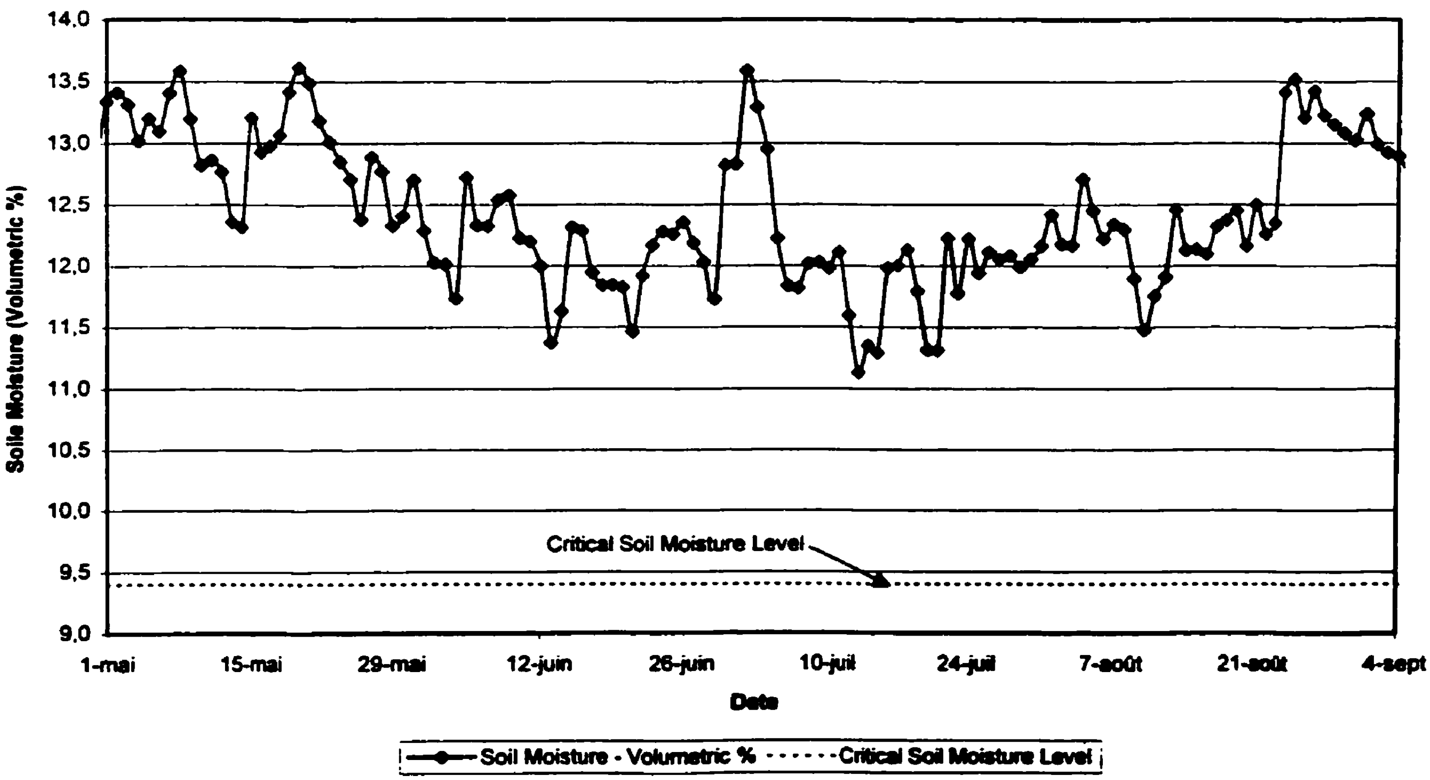
Average Soil Moisture (1981 - 1998)
April to October



Average Daily (120 days: May-August) Effective Precipitation and Average ET (1981 - 1998)



Average Soil Moisture (1981 - 1998)
May to August (= Growing season)



Appendix B

Probability of Dry, Normal and Wet Season Based on 1981-1998 Climatic Data corresponding to the Growing season (120 days) at Notre-Dame-de-la-Paix

Probability analysis on rainfall during the growing season (120 days)

P80 = Dry Year = 282,1 mm
1997 - Monthly Summary

Month	PET	Ppt	PPt Effective	Irrigation	PPt effective+ Irrigation	PPT (Prob. Dry Season)
May	71,30	82,70	52,17	25,00	77,17	82,08
June	152,90	60,00	48,00	100,00	148,00	59,55
July	148,30	71,80	58,47	75,00	133,47	71,27
August	124,30	67,60	46,24	75,00	121,24	67,10
Growing Season	*496,80*	*282,10*	*204,87*	*275,00*	*479,87*	*280,00*

P50 = Average Year = 368,15 mm
1988 - Monthly Summary

Month	PET	Ppt	PPt Effective	Irrigation	PPt effective+ Irrigation	PPT (Prob. Average Season)
May	115,20	50,40	35,81	50,00	85,81	50,51
June	132,60	82,20	54,46	100,00	154,46	82,38
July	141,80	59,90	50,13	75,00	125,13	60,03
August	106,40	166,70	103,30	25,00	128,30	167,07
Growing Season	*496,00*	*359,20*	*243,70*	*250,00*	*493,70*	*360,00*

P20 = Wet Year = 437 mm
1984 - Monthly Summary

Month	PET	Ppt	PPt Effective	Irrigation	PPt effective+ Irrigation	PPT (Prob. Wet Season)
May	83,30	111,20	69,33	25,00	94,33	110,49
June	138,90	88,00	58,76	75,00	133,76	87,44
July	124,80	102,20	55,76	50,00	105,76	101,55
August	123,00	136,40	90,23	75,00	165,23	135,53
Growing Season	*470,00*	*437,80*	*274,09*	*225,00*	*499,09*	*435,00*

Annex B - Explanation for calculation of Rainfall Probalities

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1991	1992	1993	1997	1998
Annual PPt	511	270	334.6	437.8	270.4	507.9	615.7	614.6	681.1	646.5	577.5	717.4	414.1	565.4
Rank	1	12	5	7	13	2	8	9	4	6	10	3	14	11
Sorted	857.4	766.3	717.4	681.1	658.4	646.5	640.4	615.7	614.6	577.5	565.4	474.9	443.9	414.1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FA (plotting position)	6.67	13.33	20.00	26.67	33.33	40.00	46.67	53.33	60.00	66.67	73.33	80.00	86.67	93.33

FA	Ppt	FA	Ppt
0,066667	857.4	93.33333	414.1
0,133333	766.3	86.66667	443.9
0.2	717.4	80	474.9
0,266667	681.1	73.33333	565.4
0,333333	658.4	66.66667	577.5
0.4	646.5	60	614.6
0,466667	640.4	53.33333	615.7
0,533333	615.7	46.66667	640.4
0.6	614.6	40	646.5
0,666667	577.5	33.33333	658.4
0,733333	565.4	26.66667	681.1
0.8	474.9	20	717.4
0,866667	443.9	13.33333	766.3
0,933333	414.1	6.666667	857.4

Pi dry = Pia*Pdry/Pav

Calculation for yearly rainfall probability :

FA = 100 * m (N+1) *From: FAO, 1992*

where:

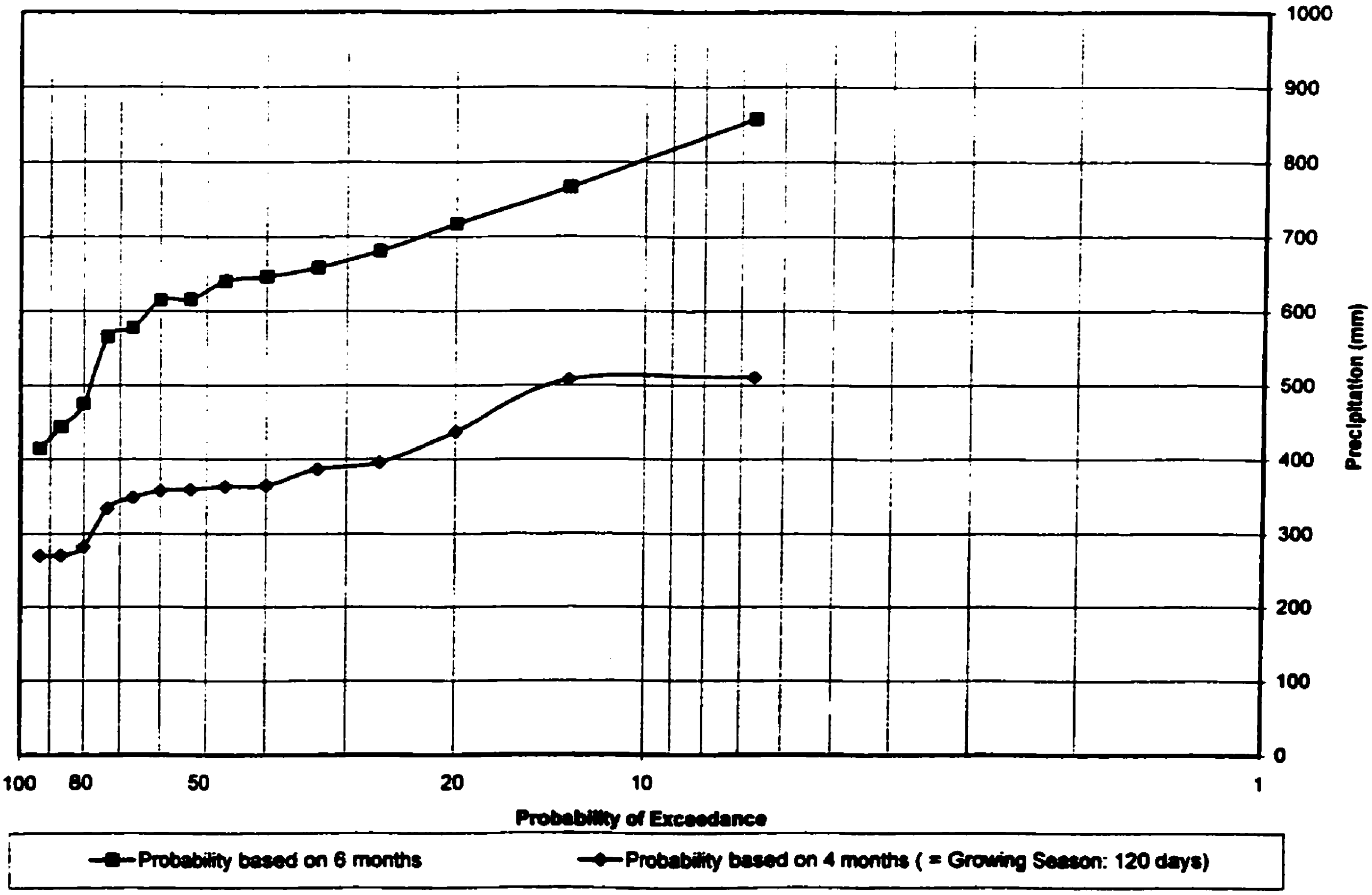
FA = number of records
m = rank number
N = plotting position
Result of Fa is to be plotted on Normal log graph

Similarly, for monthly rainfall probabilities:

*Pi (dry) = Pi (ave) * P(dry) / P(ave)* *From: FAO, 1992.*

where:

Pi (dry) = monthly rainfall(dry year) for month i
Pi (ave) = average monthly rainfall for month i
P(ave) = average yearly rainfall (dry year)
P(dry) = yearly rainfall at 80% probability of exceedance
Result of Fa is to be plotted on Normal log graph



Appendix C

Economic Data Input File (Paper Copy) :

- Fact Sheet
- Annual Crop Budget – Potatoes, Non-Irrigated
- Annual Crop Budgets – Potatoes, Irrigated with three Irrigation Systems
- Price of Table Potatoes in Quebec

Fact Sheet

Crop Prices & Government Compensations		
Marketable potato yields (t)	172.00	$/ton (average price)
ASRA* + Crop Insurance compensations (ha)**	150.00	$ per hectare
***Variable Costs:* Supplies**		
Seed (kg)	0.259	$ per kg
Fertilizers (t)	300.00	$ per ton
Soil improvement (t) (lime, etc.)	25.00	$ per ton
Oats (kg)	1.00	$ per kg
Farm chemical inputs	270.51	$ per hectare/year
Defoliant (l)	19.47	$ per litre
Vine killing agent (40% of area)	25.30	$ per litre
Farm Machinery		
Maintenance and repairs (ha)	355.00	$ per hectare
Power (fuel and lubricants) (ha)	100.00	$ per hectare
Marketing Operations		
Custom hauling (t)	8.75	$ per ton
Other Costs		
Labor costs (hr)	9.00	$ per hour
Crop insurance (ha) (for 80% of yields)	125.00	$ per hectare
ASRA subscriptions (ha)	150.00	$ per hectare
Operating interest (8 months)	8.00%	on operating costs/ha
Joint plan (ha)	40.00	$ per hectare
Miscellaneous	2 500.00	$ per year (fixed rate)

Fixed Costs		
Land taxes (70% reimbursement) (ha)	37.00	$ per hectare
Gen. Insurance (bldings, machin., etc.)	42.55	$ per hectare
Building maintenance ($)	1.09%	percentage of value
Soil maintenance ($)	0.67%	percentage of value
Truck and tractor registration ($)	11.24	$ per hectare
Electricity and heating (ha)	42.00	$ per hectare
Telephone (ha)	10.00	$ per hectare
Car transportation (ha)	40.00	$ per hectare
Professional fees (ha)	25.00	$ per hectare
IPM (ha)	20.00	$ per hectare
Depreciation (linear) of Farm Bldg & Equipment		
Warehouse ($)	4.00%	percentage of value
Shed and garage ($)	2.50%	percentage of value
Machinery and equipment ($)	6.67%	percentage of value

*: *ASRA : Assurance Stabilisation des Revenus Agricoles : information obtained from farmer & confirmed by the Régie*

*: *ARI : Assurance Récoltes Individuelle : information obtained from farmer and confirmed by the Régie*

Price of Table Potato in Quebec (*Source: Régie des Assurances Récoltes du Québec)*

Production	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**Average**
Price of Table Potato ($/T)	191.80	152.12	255.72	260.04	181.22	205.24	55.34	171.53	189.60	119.93	109.37	172.00
ASRA :												
Premium paid ($)	296.53	344.52	310.00	266.00	186.00	221.00	195.00	378.00	208.00	97.00	79.00	234.64
Compensation ($)		36.15		53.99	20.47	74.43			17.42	25.58	(k)	38.01
Crop Insurance :												40.00
Premium paid	344 220	77 029	39 518	48 035	46 026	35 254	24 431	20 360		18 672	12 910	666 455.00
Compensation received	270 334	116 537	116 176	7 511	1 947	37 382	28 338	9 266		0	0	587 491.00
No. of applicants (potato farms)	14	13	8	7	9	8	7	6	4	3	2	
							1996	**1997**	**1998**			
							12 910	11 567	12 453	159.48		
							0	29 060	20 398	(1 559.16)		
							2	2	2			

Annual Crop budget - Potatoes, non irrigated

			(3 907) Total quantity	Expected price	TOTAL
	(Qty/ha)	(ha)	(Qty)	($)	($)
REVENUES					
Marketable potato yields (t)	24.00	1	24	172.00	4 128
ASRA* + Crop insurance compensations (ha)**	1.00	1	1	150.00	150
TOTAL REVENUES					4 278
VARIABLE COSTS					
Supplies					
Seed (kg)	2 313.34	1	2 313	0.259	599
Fertilizers (t)	1.70	1	2	300.00	510
Soil improvement (t) (lime, etc.)	2.00	1	2	25.00	50
Oats (kg)	120.00	1	120	1.00	120
Farm chemical inputs	-	-	1	270.51	271
Defoliant (l)	3.00	1	3	19.47	58
Vine killing agent (40% of area)	5.65	1	6	25.30	143
Sub-total (Supplies)					1 751
Farm machinery					
Maintenance and repairs (ha)	1.00	1	1	355.00	355
Power (fuel and lubricants) (ha)	1.00	1	1	100.00	100
Sub-total (Farm machinery)					455
Marketing operations					
Custom hauling (t)	24.00	1	24	8.75	210
Sub-total (Marketing operations)					210
Other costs					
Labor costs (hr)	62.50	1	63	9.00	563
Crop insurance (ha) (for 80% of yields)	1.00	1	1	125.00	125
ASRA subscriptions (ha)	1.00	1	1	150.00	150
Operating interest (8 months)	3 000.00	1	3 000	8.00%	160
Joint plan (ha)	1.00	1	1	40.00	40
Miscellaneous					31
Sub-total (Other costs)					1 069
TOTAL VARIABLE COSTS					3 485
Return on variable costs					793

FIXED COSTS			Total quantity	Expected price	TOTAL
	(Qty/ha)	(ha)	(Qty)	($/unit)	($)
Land taxes (70% reimbursement) (ha)			2	37.00	22
General insurance ($) (buildings, machinery, etc.)	-	-	1	42.55	43
Building maintenance ($)			3 313	1.09%	36
Soil maintenance ($)			5 000	0.67%	34
Truck and tractor registration ($)	-	-	1	11.24	11
Electricity and heating (ha)	1	1	1	42.00	42
Telephone (ha)	1	1	1	10.00	10
Car transportation (ha)	1	1	1	40.00	40
Professional fees (ha)	1	1	1	25.00	25
IPM (ha)	1	1	1	20.00	20
TOTAL FIXED COSTS					283
SUM OF VARIABLE & FIXED COSTS (before depreciation)					3 768

Depreciation of farm bldg & equip. (linear)	Value/ ha	Percentage	TOTAL
	($)	(%)	($)
Warehouse ($)	766	4.00%	31
Shed and garage ($)	338	2.50%	8
Machinery and equipment ($)	2 057	6.67%	137
Total depreciation			176
TOTAL PRODUCTION COSTS			3 944
Net benefit per hectare			334

Annual Crop budget - Potatoes, Irrigated
PORTABLE PIPE WITH VOLUME GUN
Non-buried main and submain (3 907)
Irrigation equipment (amortization period : 10 years)
Pumping station (amortization period : 10 years)

Total irrigated hectares: 28,09

	Unit	Quantity/ hectare	Price/ Unit *Diesel*	Price/ Unit *Electric*	Value/ Hectare *Diesel*	Value/ Hectare *Electric*
REVENUES						
Marketable potato yields (t)	t	30,00	172,00	172,00	**5 160**	**5 160**
ASRA* + Crop Insurance compensations (ha)**	ha				**188**	**188**
TOTAL ANNUAL REVENUES					**5 348**	**5 348**
VARIABLE COSTS						
Supplies (Crop production inputs) *	ha				**1 926**	**1 926**
Farm machinery *	ha				**455**	**455**
Marketing operations (hauling)	t	30,00	8,75	8,75	**263**	**263**
Labor costs	hr	62,50	9,00	9,00	**563**	**563**
Other costs (insurance, ASRA, interests, joint plan, etc.)	ha				**506**	**506**
Sub-total 1 (Variable costs)					***3 713***	***3 713***
Irrigation system						
Pumping fuel	l	304	0,25		76	n/a
Electrical power	kw/hr	1 030		0,05	n/a	51
Pumping lubricants (assumed)	l	6	1,00		6	0
Annual maintenance and repairs (irrigation + pump)	%	4%	1 563	1 379	56	49
Hired labour costs	hr	19,0	11,25	11,25	214	214
Yield loss by irrig. equip.	ha				43	43
Contingencies	lump sum				25	25
Sub-total 2 (Variable costs - irrigation)					***419***	***382***
TOTAL ANNUAL VARIABLE COSTS					**4 132**	**4 095**
FIXED COSTS						
General costs (land taxes, insurance, maintenance, etc.)					283	283
Linear depreciation of farm infrastructures					176	176
Sub-total 1 (Fixed costs)					***459***	***459***
Irrigation and pump system						
Annual tax and insurance (Larry James, p.103)	% of cost	2%	781	689	28	25
Irrigation equipment (amortization period : 10 years)						
Annual ownership cost (Irrig.: depreciation, interest, etc.)	ha/year				116	116
Pumping station (amortization period : 10 years)						
Annual ownership cost (Pump : depreciation, interest, etc.)	ha/year				152	152
Sub-total 2 (Fixed costs - Irrigation)					***296***	***293***
TOTAL ANNUAL FIXED COSTS					**755**	**752**
TOTAL ANNUAL COSTS (Variable + Fixed Costs)					**4 888**	**4 847**
NET BENEFIT (Total Revenues - Total Costs)					**460**	**501**
BREAKEVEN PRICE/UNIT TO COVER ANNUAL COSTS					131,48	130,24

* Costs increased by 10% to reflect increased production/ha.

Annual Crop budget - Potatoes, Irrigated
TRAVELLER GUN
Non-buried main and submain ######

Irrigation equipment (amortization period : 10 years)
Pumping station (amortization period: 10 years)

Total irrigated hectares: 28,09

	Unit	Quantity/ hectare	Price/ Unit *Diesel*	Price/ Unit *Electric*	Value/ Hectare *Diesel*	Value/ Hectare *Electric*
REVENUES						
Marketable potato yields (t)	t	30,00	172,00	172,00	5 160	5 160
ASRA* + Crop Insurance compensations (ha)**	ha				188	188
TOTAL ANNUAL REVENUES					5 348	5 348
VARIABLE COSTS						
Supplies (Crop production inputs) *	ha				1 926	1 926
Farm machinery *	ha				455	455
Marketing operations (hauling)	t	30,00	8,75	8,75	263	263
Labor costs	hr	62,50	9,00	9,00	563	563
Other costs (insurance, ASRA, interests, joint plan, etc.)	ha				506	506
Sub-total 1 (Variable costs)					*3 713*	*3 713*
Irrigation system						
Pumping fuel	l	346	0,25		86	n/a
Electrical power	kw/hr	1 169		0,05	n/a	58
Pumping lubricants (assumed)	l	7	1,00		7	0
Annual maintenance and repairs (irrigation + pump)	%	4%	2 052	2 468	73	88
Hired labour costs	hr	7,5	11,25	11,25	84	84
Yield loss by irrig. equip.	ha				172	172
Contingencies	lump sum				50	50
Sub-total 2 (Variable costs - irrigation)					*473*	*453*
TOTAL ANNUAL VARIABLE COSTS					4 186	4 166
FIXED COSTS						
General costs (land taxes, insurance, maintenance, etc.)	ha				283	283
Linear depreciation of farm infrastructures					176	176
Sub-total 1 (Fixed costs)					*459*	*459*
Irrigation and pump system						
Annual tax and insurance (Larry James, p.103)	% of cost	2%	1 026	1 234	37	44
Irrigation equipment (amortization period : 10 years)						
Annual ownership cost (depreciation, interest, etc.)	ha/year				157	157
Pumping station (amortization period: 10 years)						
Annual ownership cost (depreciation, interest, etc.)	ha/year				152	152
Sub-total 2 (Fixed costs - irrigation)					*345*	*352*
TOTAL ANNUAL FIXED COSTS					804	811
TOTAL ANNUAL COSTS (Variable + Fixed Costs)					4 990	4 977
NET BENEFIT (Total revenues - Total Costs)					358	371
BREAKEVEN PRICE/UNIT TO COVER ANNUAL COSTS					133,26	132,59

* : Costs increased by 10% to reflect increased production/ha.

Annual Crop budget - Potatoes, Irrigated
NON-TOWABLE CENTER-PIVOT
Non-buried main and submain (3 907)
Irrigation equipment (amortization period: 10 years)
Pumping station (amortization period: 10 years)

Total irrigated hectares: 28,09

	Unit	Quantity/ hectare	Price/ Unit *Diesel*	Price/ Unit *Electric*	Value/ Hectare *Diesel*	Value/ Hectare *Electric*
REVENUES						
Marketable potato yields (t)	t	[redacted]	172,00	172,00	5 160	5 160
ASRA* + Crop Insurance compensations (ha)**	ha				188	188
TOTAL ANNUAL REVENUES					5 348	5 348
VARIABLE COSTS						
Supplies (Crop production inputs) *	ha				1 926	1 926
Farm machinery *	ha				455	455
Marketing operations (hauling)	t	30,00	8,75	8,75	263	263
Labor costs	hr	62,50	9,00	9,00	563	563
Other costs (insurance, ASRA, interests, joint plan, etc.)	ha				506	506
Sub-total 1 (Variable costs)					*3 713*	*3 713*
Irrigation system						
Pumping fuel	l	250	0,25		63	n/a
Electrical power	kw/hr	891		0,05	n/a	45
Pumping lubricants (assumed)	l	5	1,00		5	0
Annual maintenance and repairs (irrigation + pump)	%	4%	2 660	2 236	95	80
Hired labour costs	hr	2,5	11,25	11,25	28	28
Yield loss by irrig. equip.	ha				108	108
Contingencies	lump sum				50	50
Sub-total 2 (Variable costs - irrigation)					*348*	*310*
TOTAL ANNUAL VARIABLE COSTS					4 061	4 023
FIXED COSTS						
General costs (land taxes, insurance, maintenance, etc.)	ha				283	283
Linear depreciation of farm infrastructures					176	176
Sub-total 1 (Fixed costs)					*459*	*459*
Irrigation and pump system						
Annual tax and insurance (Larry James, p.103)	% of cost	2%	1 330	1 118	47	40
Irrigation equipment (amortization period: 10 years)						
Annual ownership cost (depreciation, interest, etc.)	ha/year				217	217
Pumping station (amortization period: 10 years)						
Annual ownership cost (depreciation, interest, etc.)	ha/year				128	128
Sub-total 2 (Fixed costs - irrigation)					*393*	*385*
TOTAL ANNUAL FIXED COSTS					852	844
TOTAL ANNUAL COSTS (Variable + Fixed Costs)					4 913	4 867
NET BENEFIT (Total revenues - Total Costs)					435	481
BREAKEVEN PRICE/UNIT TO COVER ANNUAL COSTS					129,11	127,84

** Costs increased by 10% to reflect increased production/ha.

Annual Crop budget - Potatoes, Irrigated
TOWABLE CENTER-PIVOT
Non-buried main and submain (3 907)
Irrigation equipment (amortization period: 10 years)
Pumping station (amortization period: 10 years)

Total irrigated hectares: 28,09

	Unit	Quantity/ hectare	Price/ Unit Diesel	Price/ Unit Electric	Value/ Hectare Diesel	Value/ Hectare Electric
REVENUES						
Marketable potato yields (t)	t	30,00	172,00	172,00	**5 160**	**5 160**
ASRA* + Crop Insurance compensations (ha)**	ha				**188**	**188**
TOTAL ANNUAL REVENUE					**5 348**	**5 348**
VARIABLE COSTS						
Supplies (Crop production inputs) *	ha				**1 926**	**1 926**
Farm machinery *	ha				**455**	**455**
Marketing operations (hauling)	t	30,00	8,75	8,75	**263**	**263**
Labor costs	hr	62,50	9,00	9,00	**563**	**563**
Other costs (insurance, ASRA, interests, joint plan, etc.)	ha				**506**	**506**
Sub-total 1 (Variable costs)					***3 713***	***3 713***
Irrigation system						
Pumping fuel	l	250	0,25		**63**	**n/a**
Electrical power	kw/hr	891		0,05	**n/a**	**45**
Pumping lubricants (assumed)	l	5	1,00		**5**	**0**
Annual maintenance and repairs (irrigation + pump)	%	4%	2 888	3 064	**103**	**109**
Hired labour costs	hr	2,5	11,25	11,25	**28**	**28**
Yield loss by irrig. equip.	ha				**108**	**108**
Contingencies	lump sum				**50**	**50**
Sub-total 2 (Variable costs - irrigation)					***356***	***339***
TOTAL ANNUAL VARIABLE COSTS					**4 069**	**4 052**
FIXED COSTS						
General costs (land taxes, insurance, maintenance, etc.)	ha				283	283
Linear depreciation of farm infrastructures					176	176
Sub-total 1 (Fixed costs)					***459***	***459***
Irrigation and pump system						
Annual tax and insurance (Larry James, p.103)	% of cost	2%	1 444	1 232	**51**	**44**
Irrigation equipment (amortization period: 10 years)						
Annual ownership cost (depreciation, interest, etc.)	ha/year				**240**	**240**
Pumping station (amortization period: 10 years)						
Annual ownership cost (depreciation, interest, etc.)	ha/year				**128**	**128**
Sub-total 2 (Fixed costs - irrigation)					***419***	***412***
TOTAL ANNUAL FIXED COSTS					**878**	**871**
TOTAL ANNUAL COSTS (Variable + Fixed Costs)					**4 947**	**4 923**
NET BENEFIT (Total revenues - Total Costs)					**401**	**425**
BREAKEVEN PRICE/UNIT TO COVER ANNUAL COSTS					129,37	128,81

* : Costs increased by 10% to reflect increased production/ha.

Appendix D

Economic Analysis:

- Part 1 : Analysis with no Consideration for Initial Capital Cost of Irrigation Equipment
- Part 2 : Analysis with Consideration for Initial Capital Cost of Irrigation Equipment

Appendix D

Part I : Analysis with no consideration for initial capital cost of irrigation equipment

SUMMARY OF COSTS FROM MODEL

ASSUMPTIONS: All systems - Main and Sub-main pipes = Non-buried PVC; Base area: 28.09 hectares; Normal rainfall year; 250 mm irrigation application

	Portable pipe [A]							Traveller gun						
	Diesel $	*Electrical* $	*Useful life* [B]	*Salvage value* [C]	*Repairs maint.* [D]	*Interest 8%* [E]	*Depreciation* [F]	*Diesel* $	*Electrical* $	*Useful Life*	*Salvage value*	*Repairs maint.*	*Interest 8%*	*Depreciation*
Irrigation equipment														
Sprinkler System [1]	25 805	25 805	10	2 581	1 290	227	2 322	38 535	38 535	15	7 707	1 927	370	3 083
Pipe network [1]	8 030	8 030	15	1 606	161	77	642	10 582	10 582	15	2 116	212	102	847
Pump equipment														
Diesel [1]	15 000	n/a	10	1 500	750	132	1350	15 000	n/a	10	1 500	750	132	1 350
Electrical [2]	n/a	28 000	20	2 600	260	245	2 540	n/a	28 000	20	2 600	260	245	2 540
Labor costs per year [3]	6 004	6 004						2 370	2 370					
Yield loss by irrig. equip.	1 208	1 208						4 831	4 831					
Cost of fuel/year [3]														
Diesel	2 138	n/a						2 427	n/a					
Electrical	n/a	1 446						n/a	1 642					

	Center pivot (Non-Towable)							Center pivot (Towable)						
	Diesel $	*Electrical* $	*Useful life*	*Salvage value*	*Repairs maint.*	*Interest 8%*	*Depreciation*	*Diesel* $	*Electrical* $	*Useful Life*	*Salvage value*	*Repairs maint.*	*Interest 8%*	*Depreciation*
Irrigation equipment														
Sprinkler System [1]	61 359	61 359	20	12 272	3 682	589	4 909	68 469	68 469	10	13 694	4 108	657	5 478
Pipe network [1]	6 771	6 771	15	1 354	135	65	542	6 771	6 771	10	1 354	135	65	542
Pump equipment														
Diesel [1]	15 000	n/a	10	1 500	750	132	1350	15 000	n/a	10	1 500	750	132	1 350
Electrical [2]	n/a	20 500	20	1 100	110	173	1 940	n/a	20 500	20	1 100	110	173	1 940
Labor costs per year [3]	790	790						790	790					
Yield loss by irrig. equip.	3 020	3 020						3 020	3 020					
Cost of fuel/year [3]														
Diesel	1 757	n/a						1 757	n/a					
Electrical	n/a	1 251						n/a	1 251					

(1) : full cost of the equipment derived from "Summary of Costs from Irrigation Model"
(2) : includes costs of electrical line installation of ($) : 15 000
(3) : data based from irrigation model for a normal irrigation season (250 mm / growing season)
(A) : for portable pipe, cost of sprinkler system includes all irrigation equipment but excludes Main & Sub-main pipes and pump station
(B) : Useful life : real useful life of the equipment as provided by industry and research
(C) : Salvage value = Original cost equipment x estimated % value (after useful life)
Salvage % values for : *Portable sprinkler system*: 10% ; *Other irrigation sprinkler systems*: 20%; *Diesel pump*: 10%; *Electric pump*: 20%
Note: salvage % values were increased where the useful life exceeded 10 years
(D) : Repairs and Maintenance: 5%/year on initial cost of equipment
(E) : Interest: calculated on a ten year amortization period (formula: ((Cost of equipment + Salvage value)/10 years)*8%)
(F) : Depreciation: (Cost of equipment - Salvage value) / Useful life[1]. ([1]): for simplification 10 years was applied on all equipments.

SUMMARY OF ANNUAL COSTS & RETURNS (/HA) FOR NON-IRRIGATED & IRRIGATED POTATO PRODUCTION (3 DIFFERENT IRRIGATION SYSTEMS)

	Non Irrigated	Portable pipe with volume gun		Traveller gun		Center pivot			
						Non-towable		Towable	
		Diesel	Electrical	Diesel	Electrical	Diesel	Electrical	Diesel	Electrical
	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA
REVENUES *Irrigated yield incr.:*									
Marketable production ($) (non-irrigated : 24t/ha) 125%	4 128	5 160	5 160	5 160	5 160	5 160	5 160	5 160	5 160
ASRA* + Crop Insurance compensations (ha)**	150	188	188	188	188	188	188	188	188
Potato price per ton 172 $									
TOTAL ANNUAL REVENUES	**4 278**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**
VARIABLE COSTS									
Supplies (Crop production inputs) *	1 751	1 926	1 926	1 926	1 926	1 926	1 926	1 926	1 926
Farm machinery *	455	455	455	455	455	455	455	455	455
Marketing operations (hauling)	210	263	263	263	263	263	263	263	263
Labor costs	563	563	563	563	563	563	563	563	563
Other costs (insurance, ASRA, interests, joint plan, etc.)	506	506	506	506	506	506	506	506	506
Sub-total 1 (Variable costs)	***3 485***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***
Irrigation system									
Pumping fuel	0	76	n/a	86	n/a	63	n/a	63	n/a
Electrical power	0	n/a	51	n/a	58	n/a	45	n/a	45
Pumping lubricants (assumed)	0	6	0	7	0	5	0	5	0
Annual maintenance and repairs (irrigation + pump)	0	70	67	91	110	118	105	129	136
Hired labour costs	0	214	214	84	84	28	28	28	28
Yield loss by irrig. equip	0	43	43	172	172	108	108	108	108
Contingencies	0	25	25	50	50	50	50	50	50
Sub-total 2 (Variable costs)	***0***	***433***	***400***	***491***	***475***	***371***	***335***	***382***	***366***
TOTAL ANNUAL VARIABLE COSTS	**3 485**	**4 146**	**4 113**	**4 204**	**4 188**	**4 084**	**4 048**	**4 095**	**4 079**
FIXED COSTS									
General costs (land taxes, insurance, maintenance, etc.)	283	283	283	283	283	283	283	283	283
Linear depreciation of farm infrastructures	176	176	176	176	176	176	176	176	176
Sub-total 1 (Fixed costs)	***459***	***459***	***459***	***459***	***459***	***459***	***459***	***459***	***459***
Irrigation and pump system									
Annual tax and insurance (Larry James, p.103)	0	35	33	46	55	59	52	64	57
Annual ownership cost (Irrig. depreciation, interest, etc.)	0	116	116	157	157	217	217	240	240
Annual ownership cost (Pump : depreciation, interest, etc.)	0	152	152	152	152	128	128	128	128
Sub-total 2 (Fixed costs)	***0***	***303***	***302***	***354***	***363***	***404***	***398***	***432***	***425***
TOTAL ANNUAL FIXED COSTS	**459**	**762**	**761**	**813**	**822**	**863**	**857**	**891**	**884**
TOTAL ANNUAL COSTS (Variable + Fixed Costs)	**3 944**	**4 908**	**4 874**	**5 017**	**5 010**	**4 948**	**4 905**	**4 986**	**4 964**
NET PROFIT ($/HA)	**334**	**440**	**474**	**331**	**338**	**400**	**443**	**362**	**384**

Table 1. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Non Irrigated
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment: Maint. & Insur. Loss of yield	Irrigation equipment: Principal Payments	Irrigation equipment: Interest Payments	Fixed costs	Net benefit	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
0	0	0	n/a	n/a	n/a	0	0	0	0	0
1	90 127	-97 894	n/a	n/a	n/a	-12 893	-20 660	0	-20 660	-20 660
2	102 144	-97 894	n/a	n/a	n/a	-12 893	-8 643	0	-8 643	-29 303
3	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	-21 610
4	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	-13 917
5	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	-6 224
6	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	1 470
7	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	9 163
8	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	16 856
9	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	24 550
10	120 169	-97 894	n/a	n/a	n/a	-12 893	9 382	-1 689	7 693	32 243
								IRR :	16,64%	

Net Present Value (NPV) at discount rates of:	NPV (12%)	4 580	12%
	NPV (10%)	7 268	10%
	NPV (8%)	10 522	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 10
(b) & (f) : Variable costs taken from Annual Crop budget sheet
(g) = (a) - ((b) + (f))
(g) = tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price
(i) = (g) - (h)

Table 2. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Portable pipe with volume gun (Diesel)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment		Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit (MR = 18%)	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs						
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-13 151	-7 536	-12 893	-25 209		0	-25 209	-25 209
2	127 692	-104 298	-13 151	-7 536	-12 893	-10 187		0	-10 187	-35 396
3	150 225	-104 298	-13 151	-7 536	-12 893	12 347	4 884	-1 343	11 004	-24 393
4	150 225	-104 298	-13 151	-7 536	-12 893	12 347	8 790	-640	11 707	-12 686
5	150 225	-104 298	-13 151	-7 536	-12 893	12 347	7 032	-957	11 390	-1 296
6	150 225	-104 298	-13 151	-7 536	-12 893	12 347	5 626	-1 210	11 137	9 841
7	150 225	-104 298	-13 151	-7 536	-12 893	12 347	4 501	-1 412	10 935	20 776
8	150 225	-104 298	-13 151	-7 536	-12 893	12 347	3 601	-1 574	10 773	31 549
9	150 225	-104 298	-13 151	-7 536	-12 893	12 347	2 880	-1 704	10 643	42 192
10	150 225	-104 298	-13 151	-7 536	-12 893	12 347	2 304	-1 808	10 539	52 731

Internal Rate of Return :	IRR :	21,54%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	11 854	12%
	NPV (10%)	15 908	10%
	NPV (8%)	20 778	8%

Table 3. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Portable pipe with volume gun (Electrical)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment		Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs						
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-12 171	-7 536	-12 893	-24 229		0	-24 229	-24 229
2	127 692	-104 298	-12 171	-7 536	-12 893	-9 207		0	-9 207	-33 436
3	150 225	-104 298	-12 171	-7 536	-12 893	13 327	6 184	-1 286	12 041	-21 394
4	150 225	-104 298	-12 171	-7 536	-12 893	13 327	11 130	-395	12 932	-8 462
5	150 225	-104 298	-12 171	-7 536	-12 893	13 327	8 904	-796	12 531	4 069
6	150 225	-104 298	-12 171	-7 536	-12 893	13 327	7 123	-1 117	12 211	16 279
7	150 225	-104 298	-12 171	-7 536	-12 893	13 327	5 699	-1 373	11 954	28 233
8	150 225	-104 298	-12 171	-7 536	-12 893	13 327	4 559	-1 578	11 749	39 982
9	150 225	-104 298	-12 171	-7 536	-12 893	13 327	3 647	-1 742	11 585	51 567
10	150 225	-104 298	-12 171	-7 536	-12 893	13 327	2 918	-1 874	11 454	63 021

	IRR :	25,90%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	17 082	12%
	NPV (10%)	21 693	10%
	NPV (8%)	27 206	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b) to (e) : costs taken from Annual Crop budget sheet x 28,09 ha

(f) = (a) - ((b) + (C) + (d) + (e))

(g) = tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(h) = net benefit x marginal tax rate 18% (Fed.= 13% + Prov.= 5,5%)

(i) = (f) - (h)

Table 5. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Traveller gun (Electrical)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment: Maint. & Insur. Loss of yield	Irrigation equipment: Fixed Costs	Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-14 880	-8 668	-12 893	-28 070		0	-28 070	-28 070
2	127 692	-104 298	-14 880	-8 668	-12 893	-13 047		0	-13 047	-41 117
3	150 225	-104 298	-14 880	-8 668	-12 893	9 486	7 712	-319	9 167	-31 950
4	150 225	-104 298	-14 880	-8 668	-12 893	9 486	13 881	791	10 277	-21 673
5	150 225	-104 298	-14 880	-8 668	-12 893	9 486	11 105	291	9 778	-11 895
6	150 225	-104 298	-14 880	-8 668	-12 893	9 486	8 884	-108	9 378	-2 517
7	150 225	-104 298	-14 880	-8 668	-12 893	9 486	7 107	-428	9 058	6 541
8	150 225	-104 298	-14 880	-8 668	-12 893	9 486	5 686	-684	8 802	15 343
9	150 225	-104 298	-14 880	-8 668	-12 893	9 486	4 549	-889	8 598	23 941
10	150 225	-104 298	-14 880	-8 668	-12 893	9 486	3 639	-1 053	8 434	32 375
								IRR :	12,94%	
					Net Present Value (NPV) at discount rates of:			NPV (12%)	1 215	12%
								NPV (10%)	4 203	10%
								NPV (8%)	7 840	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b) to (e) : costs taken from Annual Crop budget sheet x 28,09 ha

(f) = (a) - ((b) + (C) + (d) + (e))

(g) = tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(h) = net benefit x marginal tax rate 18% (Fed.= 13% + Prov.= 5,5%)

(i) = (f) - (h)

Table 4. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Traveller gun (Diesel)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment: Maint. & Insur. Loss of yield	Irrigation equipment: Fixed Costs	Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-15 068	-8 668	-12 893	-28 258		0	-28 258	-28 258
2	127 692	-104 298	-15 068	-8 668	-12 893	-13 236		0	-13 236	-41 494
3	150 225	-104 298	-15 068	-8 668	-12 893	9 298	6 412	-520	8 779	-32 715
4	150 225	-104 298	-15 068	-8 668	-12 893	9 298	11 541	404	9 702	-23 013
5	150 225	-104 298	-15 068	-8 668	-12 893	9 298	9 233	-12	9 286	-13 727
6	150 225	-104 298	-15 068	-8 668	-12 893	9 298	7 386	-344	8 954	-4 773
7	150 225	-104 298	-15 068	-8 668	-12 893	9 298	5 909	-610	8 688	3 915
8	150 225	-104 298	-15 068	-8 668	-12 893	9 298	4 727	-823	8 475	12 390
9	150 225	-104 298	-15 068	-8 668	-12 893	9 298	3 782	-993	8 305	20 696
10	150 225	-104 298	-15 068	-8 668	-12 893	9 298	3 025	-1 129	8 169	28 865
								IRR :	11,60%	
					Net Present Value (NPV) at discount rates of:			NPV (12%)	-521	12%
								NPV (10%)	2 271	10%
								NPV (8%)	5 682	8%

Table 7. Cash Flow, Internal Rate of Return (IRR). Net Present Value (NPV)
Non-Towable Center Pivot (Electrical)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment Maint. & Insur. Loss of yield	Irrigation equipment Fixed Costs	Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-10 888	-9 699	-12 893	-25 109		0	-25 109	-25 109
2	127 692	-104 298	-10 888	-9 699	-12 893	-10 087		0	-10 087	-35 196
3	150 225	-104 298	-10 888	-9 699	-12 893	12 447	8 863	-645	11 802	-23 395
4	150 225	-104 298	-10 888	-9 699	-12 893	12 447	15 953	631	13 078	-10 316
5	150 225	-104 298	-10 888	-9 699	-12 893	12 447	12 763	57	12 504	2 187
6	150 225	-104 298	-10 888	-9 699	-12 893	12 447	10 210	-403	12 044	14 232
7	150 225	-104 298	-10 888	-9 699	-12 893	12 447	8 168	-770	11 677	25 908
8	150 225	-104 298	-10 888	-9 699	-12 893	12 447	6 535	-1 064	11 383	37 291
9	150 225	-104 298	-10 888	-9 699	-12 893	12 447	5 228	-1 299	11 147	48 438
10	150 225	-104 298	-10 888	-9 699	-12 893	12 447	4 182	-1 488	10 959	59 398

	IRR :	24,00%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	15 068	12%
	NPV (10%)	19 503	10%
	NPV (8%)	24 814	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b) to (e) : costs taken from Annual Crop budget sheet x 28,09 ha

(f) = (a) - ((b) + (C) + (d) + (e))

(g) = tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(h) = net benefit x marginal tax rate 18% (Fed.= 13% + Prov.= 5.5%)

(i) = (f) - (h)

Table 6. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Non-Towable Center Pivot (Diesel)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment Maint. & Insur. Loss of yield	Irrigation equipment Fixed Costs	Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-12 089	-9 699	-12 893	-26 310		0	-26 310	-26 310
2	127 692	-104 298	-12 089	-9 699	-12 893	-11 288		0	-11 288	-37 598
3	150 225	-104 298	-12 089	-9 699	-12 893	11 246	8 313	-528	10 718	-26 880
4	150 225	-104 298	-12 089	-9 699	-12 893	11 246	14 963	669	11 915	-14 965
5	150 225	-104 298	-12 089	-9 699	-12 893	11 246	11 971	130	11 376	-3 589
6	150 225	-104 298	-12 089	-9 699	-12 893	11 246	9 577	-300	10 945	7 357
7	150 225	-104 298	-12 089	-9 699	-12 893	11 246	7 661	-645	10 601	17 957
8	150 225	-104 298	-12 089	-9 699	-12 893	11 246	6 129	-921	10 325	28 282
9	150 225	-104 298	-12 089	-9 699	-12 893	11 246	4 903	-1 142	10 104	38 386
10	150 225	-104 298	-12 089	-9 699	-12 893	11 246	3 923	-1 318	9 928	48 314

	IRR :	19,37%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	9 390	12%
	NPV (10%)	13 232	10%
	NPV (8%)	17 856	8%

Table 9. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Towable Center Pivot (Electrical)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment		Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs						
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-11 900	-10 336	-12 893	-26 759		0	-26 759	-26 759
2	127 692	-104 298	-11 900	-10 336	-12 893	-11 737		0	-11 737	-38 496
3	150 225	-104 298	-11 900	-10 336	-12 893	10 797	9 574	-220	10 577	-27 919
4	150 225	-104 298	-11 900	-10 336	-12 893	10 797	17 233	1 159	11 956	-15 964
5	150 225	-104 298	-11 900	-10 336	-12 893	10 797	13 787	538	11 335	-4 628
6	150 225	-104 298	-11 900	-10 336	-12 893	10 797	11 029	42	10 839	6 210
7	150 225	-104 298	-11 900	-10 336	-12 893	10 797	8 823	-355	10 442	16 652
8	150 225	-104 298	-11 900	-10 336	-12 893	10 797	7 059	-673	10 124	26 776
9	150 225	-104 298	-11 900	-10 336	-12 893	10 797	5 647	-927	9 870	36 646
10	150 225	-104 298	-11 900	-10 336	-12 893	10 797	4 518	-1 130	9 667	46 313

	IRR :	18,45%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	8 290	12%
	NPV (10%)	12 033	10%
	NPV (8%)	16 543	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)
(b) to (e) : costs taken from Annual Crop budget sheet x 28.09 ha
(f) = (a) - ((b) + (C) + (d) + (e))
(g) = tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.
(h) = net benefit x marginal tax rate 18% (Fed.= 13% + Prov.= 5,5%)
(i) = (f) - (h)

Table 8. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Towable Center Pivot (Diesel)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Yr	Total Revenues	Variable Costs	Irrigation equipment		Fixed costs	Net benefit	Tax deduction on depreciation	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs						
0	0	0	0	0	0	0		0	0	0
1	112 669	-104 298	-12 540	-10 336	-12 893	-27 399		0	-27 399	-27 399
2	127 692	-104 298	-12 540	-10 336	-12 893	-12 376		0	-12 376	-39 775
3	150 225	-104 298	-12 540	-10 336	-12 893	10 158	9 024	-204	9 954	-29 821
4	150 225	-104 298	-12 540	-10 336	-12 893	10 158	16 243	1 095	11 253	-18 568
5	150 225	-104 298	-12 540	-10 336	-12 893	10 158	12 995	511	10 668	-7 900
6	150 225	-104 298	-12 540	-10 336	-12 893	10 158	10 396	43	10 201	2 301
7	150 225	-104 298	-12 540	-10 336	-12 893	10 158	8 317	-331	9 826	12 127
8	150 225	-104 298	-12 540	-10 336	-12 893	10 158	6 653	-631	9 527	21 654
9	150 225	-104 298	-12 540	-10 336	-12 893	10 158	5 323	-870	9 287	30 941
10	150 225	-104 298	-12 540	-10 336	-12 893	10 158	4 258	-1 062	9 096	40 037

	IRR :	15,94%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	5 088	12%
	NPV (10%)	8 493	10%
	NPV (8%)	12 613	8%

Appendix D

Part II : Analysis with consideration for initial capital cost of irrigation equipment

SUMMARY OF COSTS FROM MODEL

ASSUMPTIONS: All systems - Main and Sub-main pipes = Non-buried PVC; Base area: 28.09 hectares (3907); Normal rainfall year; 250 mm irrigation application

	Portable pipe [A]							Traveller gun						
	Diesel $	*Electrical* $	*Useful life* [B]	*Salvage value* [C]	*Repairs maint.* [D]	*Interest 8%* [E]	*Depre-ciation* [F]	*Diesel* $	*Electrical* $	*Useful Life*	*Salvage value*	*Repairs maint.*	*Interest 8%*	*Depre-ciation*
Irrigation equipment														
Sprinkler System [1]	20 644	20 644	10	2 581	1 290	227	2 322	30 828	30 828	15	7 707	1 927	370	3 083
Pipe network [1]	6 424	6 424	15	1 606	161	77	642	8 466	8 466	15	2 116	212	102	847
Pump equipment														
Diesel [1]	12 000	n/a	10	1 500	750	132	1 350	12 000	n/a	10	1 500	600	132	1 350
Electrical [2]	n/a	22 400	20	2 600	260	245	2 540	n/a	22 400	20	2 600	148	245	2 540
Labor costs per year [3]	6 004	6 004						2 370	2 370					
Yield loss by irrig. equip.	1 208	1 208						4 831	4 831					
Cost of fuel/year [3]														
Diesel	2 138	n/a						2 427	n/a					
Electrical	n/a	1 446						n/a	1 642					

	Center pivot (Non-Towable)							Center pivot (Towable)						
	Diesel $	*Electrical* $	*Useful life*	*Salvage value*	*Repairs maint.*	*Interest 8%*	*Depre-ciation*	*Diesel* $	*Electrical* $	*Useful Life*	*Salvage value*	*Repairs maint.*	*Interest 8%*	*Depre-ciation*
Irrigation equipment														
Sprinkler System [1]	49 087	49 087	20	12 272	3 682	589	4 909	54 775	54 775	10	13 694	4 108	657	5 478
Pipe network [1]	5 417	5 417	15	1 354	135	65	542	5 417	5 417	10	1 343	134	64	537
Pump equipment														
Diesel [1]	12 000	n/a	10	1 500	750	132	1350	12 000	n/a	10	1 500	750	132	1 350
Electrical [2]	n/a	16 400	20	1 100	110	173	1 940	n/a	16 400	20	1 100	110	173	1 940
Labor costs per year [3]	790	790						790	790					
Yield loss by irrig. equip.	3 020	3 020						3 020	3 020					
Cost of fuel/year [3]														
Diesel	1 757	n/a						1 757	n/a					
Electrical	n/a	1 251						n/a	1 251					

(1) : assumed the farmer makes a down payment of 20% on the cost of the equipment, therefore indicated price = cost of equipment x 80%
(2) : includes costs of electrical line installation of ($) : 15 000
(3) : data based from irrigation model for a normal irrigation season (250 mm / growing season)
(A) : for portable pipe, cost of sprinkler system includes all irrigation equipment and lateral pipes but not Main & Sub-main pipes and pump station
(B) : Useful life : real useful life of the equipment as provided by industry and research
(C) : Salvage value = Original cost equipment x estimated % value (after useful life)
Salvage % values for : *Portable sprinkler system*: 10% ; *Other irrigation sprinkler systems*: 20%; *Diesel pump:* 10%; *Electric pump*: 20%
Note: salvage % values were increased where the useful life exceeded 10 years
(D) : Repairs and Maintenance: 5%/year on initial cost of equipment
(E) : Interest: calculated on a ten year amortization period (formula: ((Cost of equipment + Salvage value)/10 years)*8%)
(F) : Depreciation: (Cost of equipment - Salvage value) / Useful life[1]. ([1]): for simplification 10 years was applied on all equipments.

SUMMARY OF ANNUAL COSTS & RETURNS (/HA) FOR NON-IRRIGATED & IRRIGATED POTATO PRODUCTION (3 DIFFERENT IRRIGATION SYSTEMS)

	Non irrigated	Portable pipe with volume gun		Traveller gun		Center pivot			
						Non-towable		*Towable*	
		Diesel	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*	*Diesel*	*Electrical*
	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA	$/HA
REVENUES — *Irrigated yield incr.*									
Marketable production ($) (non-irrigated : 24t/ha) — 125%	4 128	5 160	5 160	5 160	5 160	5 160	5 160	5 160	5 160
ASRA* + Crop insurance compensations (ha)**	150	188	188	188	188	188	188	188	188
Potato price per ton: 172 $									
TOTAL ANNUAL REVENUES	**4 278**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**	**5 348**
VARIABLE COSTS									
Supplies (Crop production inputs) *	1 751	1 926	1 926	1 926	1 926	1 926	1 926	1 926	1 926
Farm machinery *	455	455	455	455	455	455	455	455	455
Marketing operations (hauling)	210	263	263	263	263	263	263	263	263
Labor costs	563	563	563	563	563	563	563	563	563
Other costs (insurance, ASRA, interests, joint plan, etc.)	506	506	506	506	506	506	506	506	506
Sub-total 1 (Variable costs)	***3 485***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***	***3 713***
Irrigation system									
Pumping fuel	0	76	n/a	86	n/a	63	n/a	63	n/a
Electrical power	0	n/a	51	n/a	58	n/a	45	n/a	45
Pumping lubricants (assumed)	0	6	0	7	0	5	0	5	0
Annual maintenance and repairs (irrigation + pump)	0	56	49	73	88	95	80	103	109
Hired labour costs	0	214	214	84	84	28	28	28	28
Yield loss by irrig. equip.	0	43	43	172	172	108	108	108	108
Contingencies	0	25	25	50	50	50	50	50	50
Sub-total 2 (Variable costs)	***0***	***419***	***382***	***473***	***453***	***348***	***310***	***356***	***339***
TOTAL ANNUAL VARIABLE COSTS	**3 485**	**4 132**	**4 095**	**4 186**	**4 166**	**4 061**	**4 023**	**4 069**	**4 052**
FIXED COSTS									
General costs (land taxes, insurance, maintenance, etc.)	283	283	283	283	283	283	283	283	283
Linear depreciation of farm infrastructures	176	176	176	176	176	176	176	176	176
Sub-total 1 (Fixed costs)	***459***	***459***	***459***	***459***	***459***	***459***	***459***	***459***	***459***
Irrigation and pump system									
Annual tax and insurance (Larry James, p 103)	0	28	25	37	44	47	40	51	44
Annual ownership cost (Irrig.: depreciation, interest, etc.)	0	116	116	157	157	217	217	240	240
Annual ownership cost (Pump : depreciation, interest, etc.)	0	152	152	152	152	128	128	128	128
Sub-total 2 (Fixed costs)	***0***	***296***	***293***	***345***	***352***	***393***	***385***	***419***	***412***
TOTAL ANNUAL FIXED COSTS	**459**	**755**	**752**	**804**	**811**	**852**	**844**	**878**	**871**
TOTAL ANNUAL COSTS (Variable + Fixed Costs)	**3 944**	**4 888**	**4 847**	**4 990**	**4 977**	**4 913**	**4 867**	**4 947**	**4 923**
NET PROFIT ($/HA)	**334**	**460**	**501**	**358**	**371**	**435**	**481**	**401**	**425**

Table 2. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Portable pipe with volume gun (Diesel)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(k)	(l)
Yr	Total Revenues	Variable Costs	Irrigation equipment				Fixed costs	Net benefit	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs	Principal Payments	Interest Payments					
0	0	0	0	0	-3 907	-436	0	0	0	0	0
1	112 669	-104 298	-12 565	-7 536	-3 907	-436	-12 893	-28 966	0	-28 966	-28 966
2	127 692	-104 298	-12 565	-7 536	-3 907	-436	-12 893	-13 944	0	-13 944	-42 910
3	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-764	7 826	-35 085
4	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-202	8 388	-26 696
5	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-455	8 135	-18 562
6	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-658	7 932	-10 629
7	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-820	7 770	-2 859
8	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-949	7 641	4 782
9	150 225	-104 298	-12 565	-7 536	-3 907	-436	-12 893	8 590	-1 053	7 537	12 319
10	150 225	-104 298	-12 565	-7 536	5 687	0	-12 893	18 620	-3 020	15 600	27 919
										IRR :	10,03%
								Net Present Value (NPV) at discount rates of:		NPV (12%)	-2 769
										NPV (10%)	39
										NPV (8%)	3 515

Table 3. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Portable pipe with volume gun (Electrical)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	
Yr	Total Revenues	Variable Costs	Irrigation equipment				Fixed costs	Net benefit	Tax on benefit	Net benefit after tax	Cumulative Cash Flow	
			Maint. & Insur. Loss of yield	Fixed Costs	Principal Payments	Interest Payments						
0	0	0	0	0	-3 907	-436	0	0	0	0	0	
1	112 669	-104 298	-11 429	-7 536	-3 907	-436	-12 893	-27 830	0	-27 830	-27 830	
2	127 692	-104 298	-11 429	-7 536	-3 907	-436	-12 893	-12 808	0	-12 808	-40 638	
3	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-782	8 944	-31 693	
4	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-69	9 657	-22 036	
5	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-390	9 336	-12 700	
6	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-646	9 080	-3 620	
7	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-852	8 875	5 255	
8	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-1 016	8 711	13 965	
9	150 225	-104 298	-11 429	-7 536	-3 907	-436	-12 893	9 726	-1 147	8 579	22 544	
10	150 225	-104 298	-11 429	-7 536	6 787	0	-12 893	20 856	-3 334	17 522	40 066	
									IRR :	14,30%		
							Net Present Value (NPV) at discount rates of:		NPV (12%)	3 224	12%	
									NPV (10%)	6 695	10%	
									NPV (8%)	10 942	8%	

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b, c, d, g) : costs taken from Annual Crop budget sheet

(e) & (f) = principal payments calculated as : (cost of equipment / 10 years) & interest (cost of equipment x 8%)/10 years (*Note* : the farmer is paying a down payment of 20% on the initial cost of equipment)

(i) = net benefit x marginal tax rate 18% (Fed. = 13% + Prov. = 5,5%), column includes tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(j) = (h) +/- (i)

Table 4. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Traveller gun (Diesel)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
Yr	Total Revenues	Variable Costs	Irrigation equipment				Fixed costs	Net benefit	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs	Principal Payments	Interest Payments					
0	0	0	0	0	-3 907	-604	0	0	0	0	0
1	112 669	-104 298	-14 306	-8 668	-3 907	-604	-12 893	-32 006	0	-32 006	-32 006
2	127 692	-104 298	-14 306	-8 668	-3 907	-604	-12 893	-16 984	0	-16 984	-48 990
3	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	33	5 583	-43 408
4	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	772	6 321	-37 086
5	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	439	5 989	-31 097
6	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	173	5 723	-25 374
7	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	-39	5 510	-19 864
8	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	-210	5 340	-14 523
9	150 225	-104 298	-14 306	-8 668	-3 907	-604	-12 893	5 550	-346	5 204	-9 319
10	150 225	-104 298	-14 306	-8 668	11 323	0	-12 893	21 384	-3 413	17 970	8 651

	IRR :	2,87%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	-13 853	12%
	NPV (10%)	-12 016	10%
	NPV (8%)	-9 637	8%

Table 5. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Traveller gun (Electrical)
(base: 28.09 ha)

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
Yr	Total Revenues	Variable Costs	Irrigation equipment				Fixed costs	Net benefit	Tax on benefit	Net benefit after tax	Cumulative Cash Flow
			Maint. & Insur. Loss of yield	Fixed Costs	Principal Payments	Interest Payments					
0	0	0	0	0	-3 907	-716	0	0	0	0	0
1	112 669	-104 298	-13 954	-8 668	-3 907	-716	-12 893	-31 767	0	-31 767	-31 767
2	127 692	-104 298	-13 954	-8 668	-3 907	-716	-12 893	-16 745	0	-16 745	-48 512
3	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	197	5 987	-42 525
4	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	1 086	6 875	-35 650
5	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	686	6 475	-29 175
6	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	366	6 155	-23 019
7	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	110	5 900	-17 120
8	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	-94	5 695	-11 425
9	150 225	-104 298	-13 954	-8 668	-3 907	-716	-12 893	5 789	-258	5 531	-5 894
10	150 225	-104 298	-13 954	-8 668	12 423	0	-12 893	22 836	-3 586	19 249	13 355

	IRR :	4,36%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	-11 721	12%
	NPV (10%)	-9 616	10%
	NPV (8%)	-6 922	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b, c, d, g) : costs taken from Annual Crop budget sheet

(e) & (f) = principal payments calculated as : (cost of equipment / 10 years) & interest (cost of equipment x 8%)/10 years (*Note :* the farmer is paying a down payment of 20% on the initial cost of equipment)

(i) = net benefit x marginal tax rate 18% (Fed. = 13% + Prov. = 5.5%), column includes tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(j) = (h) +/- (i)

Table 6. Cash Flow, Internal Rate of Return (IRR). Net Present Value (NPV)
Non-Towable Center Pivot (Diesel)
(base: 28.09 ha)

Yr	(a) Total Revenues	(b) Variable Costs	(c) Irrigation equipment: Maint. & Insur. Loss of yield	(d) Irrigation equipment: Fixed Costs	(e) Irrigation equipment: Principal Payments	(f) Irrigation equipment: Interest Payments	(g) Fixed costs	(h) Net benefit	(i) Tax on benefit	(j) Net benefit after tax	(k) Cumulative Cash Flow
0	0	0	0	0	-3 907	-786	0	0	0	0	0
1	112 669	-104 298	-11 110	-9 699	-3 907	-786	-12 893	-30 025	0	-30 025	-30 025
2	127 692	-104 298	-11 110	-9 699	-3 907	-786	-12 893	-15 002	0	-15 002	-45 027
3	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	-17	7 515	-37 512
4	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	941	8 472	-29 040
5	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	510	8 041	-20 999
6	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	165	7 696	-13 302
7	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	-111	7 421	-5 882
8	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	-332	7 200	1 318
9	150 225	-104 298	-11 110	-9 699	-3 907	-786	-12 893	7 532	-508	7 024	8 342
10	150 225	-104 298	-11 110	-9 699	15 126	0	-12 893	27 351	-4 358	22 992	31 334

	IRR :	10,05%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	-3 011	12%
	NPV (10%)	78	10%
	NPV (8%)	3 922	8%

Table 7. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Non-Towable Center Pivot (Electrical)
(base: 28.09 ha)

Yr	(a) Total Revenues	(b) Variable Costs	(c) Irrigation equipment: Maint. & Insur. Loss of yield	(d) Irrigation equipment: Fixed Costs	(e) Irrigation equipment: Principal Payments	(f) Irrigation equipment: Interest Payments	(g) Fixed costs	(h) Net benefit	(i) Tax on benefit	(j) Net benefit after tax	(k) Cumulative Cash Flow
0	0	0	0	0	-3 907	-827	0	0	0	0	0
1	112 669	-104 298	-9 830	-9 699	-3 907	-827	-12 893	-28 786	0	-28 786	-28 786
2	127 692	-104 298	-9 830	-9 699	-3 907	-827	-12 893	-13 763	0	-13 763	-42 549
3	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	-154	8 617	-33 932
4	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	867	9 638	-24 294
5	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	408	9 178	-15 116
6	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	40	8 811	-6 305
7	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	-254	8 517	2 212
8	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	-489	8 282	10 493
9	150 225	-104 298	-9 830	-9 699	-3 907	-827	-12 893	8 770	-677	8 093	18 587
10	150 225	-104 298	-9 830	-9 699	14 726	0	-12 893	28 230	-4 479	23 751	42 338

	IRR :	13,78%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	2 696	12%
	NPV (10%)	6 372	10%
	NPV (8%)	10 893	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b, c, d, g) : costs taken from Annual Crop budget sheet

(e) & (f) = principal payments calculated as : (cost of equipment / 10 years) & interest (cost of equipment x 8%)/10 years (*Note :* the farmer is paying a down payment of 20% on the initial cost of equipment)

(i) = net benefit x marginal tax rate 18% (Fed. = 13% + Prov. = 5.5%). column includes tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(j) = (h) +/- (i)

Table 8. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Towable Center Pivot (Diesel)
(base: 28.09 ha)

Yr	(a) Total Revenues	(b) Variable Costs	(c) Irrigation equipment: Maint. & Insur. Loss of yield	(d) Irrigation equipment: Fixed Costs	(e) Irrigation equipment: Principal Payments	(f) Irrigation equipment: Interest Payments	(g) Fixed costs	(h) Net benefit	(i) Tax on benefit	(j) Net benefit after tax	(k) Cumulative Cash Flow
0	0	0	0	0	-3 907	-854	0	0	0	0	0
1	112 669	-104 298	-11 449	-10 331	-3 907	-854	-12 893	-31 063	0	-31 063	-31 063
2	127 692	-104 298	-11 449	-10 331	-3 907	-854	-12 893	-16 041	0	-16 041	-47 104
3	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	284	6 778	-40 326
4	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	1 324	7 817	-32 509
5	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	856	7 349	-25 160
6	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	482	6 975	-18 185
7	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	182	6 676	-11 509
8	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	-57	6 436	-5 073
9	150 225	-104 298	-11 449	-10 331	-3 907	-854	-12 893	6 493	-249	6 245	1 172
10	150 225	-104 298	-11 449	-10 331	16 537	0	-12 893	27 791	-4 389	23 402	24 574

	IRR :	7,69%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	-6 804	12%
	NPV (10%)	-4 059	10%
	NPV (8%)	-607	8%

Table 9. Cash Flow, Internal Rate of Return (IRR), Net Present Value (NPV)
Towable Center Pivot (Electrical)
(base: 28.09 ha)

Yr	(a) Total Revenues	(b) Variable Costs	(c) Irrigation equipment: Maint. & Insur. Loss of yield	(d) Irrigation equipment: Fixed Costs	(e) Irrigation equipment: Principal Payments	(f) Irrigation equipment: Interest Payments	(g) Fixed costs	(h) Net benefit	(i) Tax on benefit	(j) Net benefit after tax	(k) Cumulative Cash Flow
0	0	0	0	0	-3 907	-895	0	0	0	0	0
1	112 669	-104 298	-10 759	-10 331	-3 907	-895	-12 893	-30 414	0	-30 414	-30 414
2	127 692	-104 298	-10 759	-10 331	-3 907	-895	-12 893	-15 392	0	-15 392	-45 806
3	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	254	7 396	-38 410
4	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	1 357	8 499	-29 911
5	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	861	8 003	-21 909
6	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	464	7 606	-14 303
7	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	146	7 288	-7 015
8	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	-108	7 034	19
9	150 225	-104 298	-10 759	-10 331	-3 907	-895	-12 893	7 142	-311	6 831	6 849
10	150 225	-104 298	-10 759	-10 331	16 137	0	-12 893	28 081	-4 404	23 677	30 526

	IRR :	9,63%	
Net Present Value (NPV) at discount rates of:	NPV (12%)	-3 698	12%
	NPV (10%)	-636	10%
	NPV (8%)	3 182	8%

(a) Revenues taken from Annual Crop budget sheet (First year yield increase (over non-irrigated) = 70%; 2nd year = 80%; 3rd year = 100%)

(b, c, d, g) : costs taken from Annual Crop budget sheet

(e) & (f) = principal payments calculated as : (cost of equipment / 10 years) & interest (cost of equipment x 8%)/10 years (*Note* : the farmer is paying a down payment of 20% on the initial cost of equipment)

(i) = net benefit x marginal tax rate 18% (Fed. = 13% + Prov. = 5.5%), column includes tax deduction on depreciation of equipment ("Capital Cost Allowance") = First year : 10% on price of equipment; Second year (and next years) : 20%.

(j) = (h) +/- (i)