McGILL UNIVERSITY

MacDonald CAMPUS

Department of Agricultural and
Biosystem Engineering

Senior Undergraduate Project
on

The Design of a Drip Irrigation System on an Apple Orchard

Presented by:

Leo Yeung, Kin Yip
Student No. 9343141

Mikhael Solaiman
Student No. 9340194

Date: March 6th, 1997

Acknowledgments

The authors wish to thank Professor C.A. Madramootoo for the helpful discussions and his valuable suggestions to this project.

The comments and helpful suggestions of Professor Bob Bonnell are deeply appreciated. Thanks are also extended to all the staff at Horticulture Center, at the MacDonald Campus, of McGill University, for assistance in surveying and in the collection soil samples.

Special thanks to Professor Watson, Plant Science Department, for his comments and suggestions on the project.

Table of Content

(I) Executive Summary

The aim of our senior undergraduate project is to design a point source drip irrigation system on an apple orchard located east of the Horticultural Center, on the MacDonald Campus farm of McGill University. The area of interest was surveyed on October 16 Th., 1996. From the data collected, we were able to produce a topographic map thus enabling us to design the irrigation system. Sketches of our design are included in this report. A soil analysis was performed, in order to identify the properties of the soil, the composition of the soil, and the average rooting depth. In addition, from the analysis of the soil, which was determined to be St. Bernard-sandy loam, it enabled us to determine the crop water requirement, the evapotranspiration rate and enable us to devise a suitable irrigation schedule. This project also discusses the difference between drip, sprinkle and flood irrigation, the advantages and disadvantages of drip, and defines problems which arise from a drip system. We also provide a list of recent drip irrigation developments, discuss the versatility of drip irrigation and devise recommendations which could improve the design of our drip irrigation system.

In designing the system we have taken into account the landscape, the economic situation and have highly weighed the environmental ramifications. In the installation of our system, we recommended the most reliable and capable products, and provide a detailed operations manual.

The total cost of the entire project is approximately $ 10 000 for a field size of approximatly 2000m^2 (0.2 hectares). A further break down of the expenses are presented in the cost analysis. Implementation of this project will take from one to two months.

(II) Introduction

"Human dependence on irrigation can be traced to early biblical reference; and in very early times irrigation was practiced by the Egyptians, the Asians and the Native Americans."[1] For the most part, water was attained only after periods of heavy runoff. "Current concepts of irrigation such as sprinkle, flood and drip have been made possible only by the application of modern power sources to deep-well pumps and by the storage of large quantities of water in reservoirs."[2] Using an irrigation system, increases yield per hectare, the efficiency in the farmers' dollar per hectare and has the ability to reduce drought conditions.

The objective of this senior undergraduate project is to design and develop a irrigation system for an apple orchard. The apple orchard is located east of the Horticultural Center, which is located on the MacDonald Campus, of McGill University. We found the land has natural drainage due to its slope and that the soil is composed of St.Bernard-sandy loam. The project was implemented because the apple orchard did not have a permanent or existing irrigation system. We determined that a microirrrigation system, also known as drip or trickle, would best suit this type of crop, field and soil conditions. In addition with "declining water resources and increases in energy cost, greater importance has been placed on using an efficient irrigation system." [3]

Microirrigation, or drip irrigation is "the precise and slow application of water as discrete drops, continuous drops, small streams or miniature sprays through mechanical devices called emitters located at selected points along water delivery lines." [4] Emitters are water applicators, which dissipate the pressure from the distribution system by means of an orifices; thus only allowing a limited amount of water to be discharged. In the system, water enters the irrigation system through the main laterals, then through the lateral lines, and final to the emitters. "The primary objective of drip irrigation is to frequently supply each plant with sufficient soil moisture, to meet its evapotranspiration demand." [5]

Development into drip or trickle irrigation originally started with research into subirrigation in which there aim was to raise the water table. Research into this type of irrigation started in Germany about 1860, where clat pipes were used in combination with tube drainage systems. The first work into drip irrigation, (applying water directly into the root zone), led to the conclusion that it was too expensive for practical use. Drip irrigation advanced with the introduction of perforated pipes and the development of plastics. In addition, drip irrigation became popular with the development of good filters and screens, thus reducing the amount of maintenance and management required on the irrigation system. There have been many recent developments and improvements in drip irrigation since its inspection in the mid-1800s, such as in integrating design procedure with soil properties, the enhancing of emitter flow, and a better understanding in water, plant, root and oxygen distribution. Furthermore, there are great differences between drip irrigation, sprinkle and flood irrigation.

In designing the drip irrigation system for the apple orchard, we decided to use a surface drip system with point source emitters. In drawing up the design for the irrigation system, we considered the environmental issues, the economic situation, and have based our designs on the data gathered from the soil analysis. We will also discuss the versatility of drip irrigation in developing countries, provide product recommendations on system components and prepare an operations manual with a water management schedule. We will also provide a cost analysis of the entire project; and recommendations which could enhance our drip irrigation system. Further analysis of the designs, calculation and soil analysis are presented in the appendices.

(III) Objectives:

(1) Discuss differences between drip, sprinkle and flood irrigation

(2) Identify problems in drip irrigation

(3) Advantages and disadvantages of drip irrigation

(4) Drip irrigation in apple orchards

(5) The versatility of drip irrigation in developing countries

(6) Recent and future developments in drip irrigation

(7) Economic consideration

(8) Environmental concerns

(9) Recommendations which can better our drip irrigation system

(10) Calculations of the Drip Irrigation system

(11) Discussion of our designs

(12) Soil analysis — which one?

(13) Product recommendations of system components

(14) Operation manual for the drip system

(15) Cost analysis of the entire project

(IV) Drip Irrigation

(4.1) Comparison between Drip, Sprinkle and Flood irrigation

(4.1.1) Drip Irrigation:

Drip irrigation is the slow application of water on, above or beneath the soil by surface, subsurface, mechanical-move drip system or by a pulse system. "The drip irrigation method is similar to those employed when watering with a soaker horse, in which streams of water are released through hosing." [6] This type of irrigation method is by far more efficient, because of the new hardware used in regulating the amount of water released. It also has the ability to disperse less water per hour, ensuring that garden soils do not puddle and that the roots are not drowned. A drip irrigation system delivers water to individual plants or to rows of plants. In addition, unlike other irrigating methods, the outlets are generally placed at short intervals along small tubing, only the soil near the plant is watered, and unlike any other type of irrigating system it can be set up to combat weeds. Drip irrigation also offers an advantage in its ability to apply fertilizers, or other chemical amendments directly to the soil without spraying or running water down furrows.

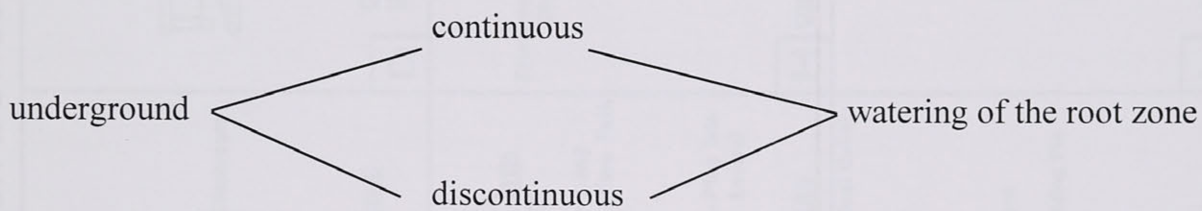
There are several components which comprise a drip irrigation system. Every drip system should have shut-off valves between the main water supply and all the components. These valves prevent dirt, fertilizer and other contaminants from being sucked backwards into the pipes. An important component of drip irrigation is the emitter, which control the flow water from the laterals to the soil. Emitters are placed along a water delivery line near the plant's root zone; and dissipate the pressure in the pipe distribution network by means of either a small diameter orifice or by a long flow path, thereby a low water discharge rates. Pressure head of water can also be decrease by vortex chambers, disc, steel balls, or by mechanical means. The emitted water moves within the soil system largely by unsaturated flow and the wetted area for widely spaced emitters is normally elliptical in shape. These emitters range from simple perforated pipe to individual or multiple outlet devices inserted into plastic pipes. Some emitters may be pressure regulated or have pressure compensating devices within the emitters. The emitters are usually placed on the soil surface, which guarantee direct water application to the root zone of the plant. Furthermore emitters are self cleaning - some having automatic flushing or fixed discharge rates.

The 4 major types of drip irrigation systems are: (1) Surface which is primarily used on widely spaced plants but can also be utilized for row crops. A surface drip irrigation, which is most commonly practiced, is a system with lateral lines laid on the soil surface, with the emitters placed on the ground or buried. The emitters may be point source which distribute water to high value crops; or line source, which is the running of porous pipes and tubes with small openings along the sides' of the tube. (2) Subsurface - a drip irrigation system free from anchoring of tubing at the beginning of the growing season and can be removed at the end of the growing season. This type of system provides little interference with cultivation or other cultural practices and may prolong operational life span. (3) Mechanical-move drip system - this is drip irrigation system which acts as a traveling drip/sprinkler irrigating system. Using this type of system may reduce clogging problems, result in a less expensive pipe network and have advantages over solid-set drip irrigation systems. (4) Pulse systems - a system developed to obtain a low, time averaged application rate where a high discharge rate emitters are used. A pulse irrigating system uses a series of irrigation time cycles with an operating or water discharge phase.

In designing the drip irrigation system for the apple orchard located on the MacDonald Campus farm, we have decided to use a surface drip system with point source emitters. These emitters range in size in terms of flow rates, have narrow increments in operating pressure, have consistent and reproducible rates for long periods of time, and are insensitive to temperature changes. Point source emitters can also withstand weathering affects, and have large flow area, thus reducing clogging potential. The emitters are connected to, or are a part of the lateral lines. These lines, which are made of plastic have diameters of 9 to 19 mm and are usually placed one or two per tree, or in rows along the plants. Lateral lines are seldom longer than 305m because as distance increases water flow and pressure head decrease. The lateral lines are connected to main lines which carry the brunt of the water. The main lines are made of plastic, are normally buried under the soil, and their size depends on the amount of water required to flow to the laterals. Another component of the drip irrigation system is the control station, which is the most essential component of a drip irrigation system. The control station or "head" is where the water is measured, filtered or screened and regulates the pressure and timing of application. The control station also houses the injection equipment, which is used to apply the fertilizer, algaecides or other materials through the drip irrigation systems.

The drip irrigation method has caused a rapid change in orchard irrigation, and has increased the growth uniformity in irrigated plants and trees. In addition the system can provide a high moisture level on sandy soils. This type of irrigation system reduces obstructions in field operations, allows the application of fertilizers in conjunction with ground water and has a long lifespan. In addition there are many advantages and disadvantages with each type of system; and using any of these types of irrigating methods will depend on the economic situation, the soil conditions and in the type of crop, plant or tree.

Methods of Drip Irrigation



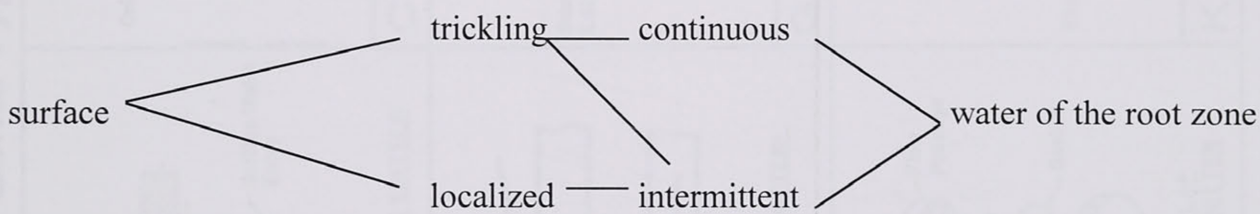
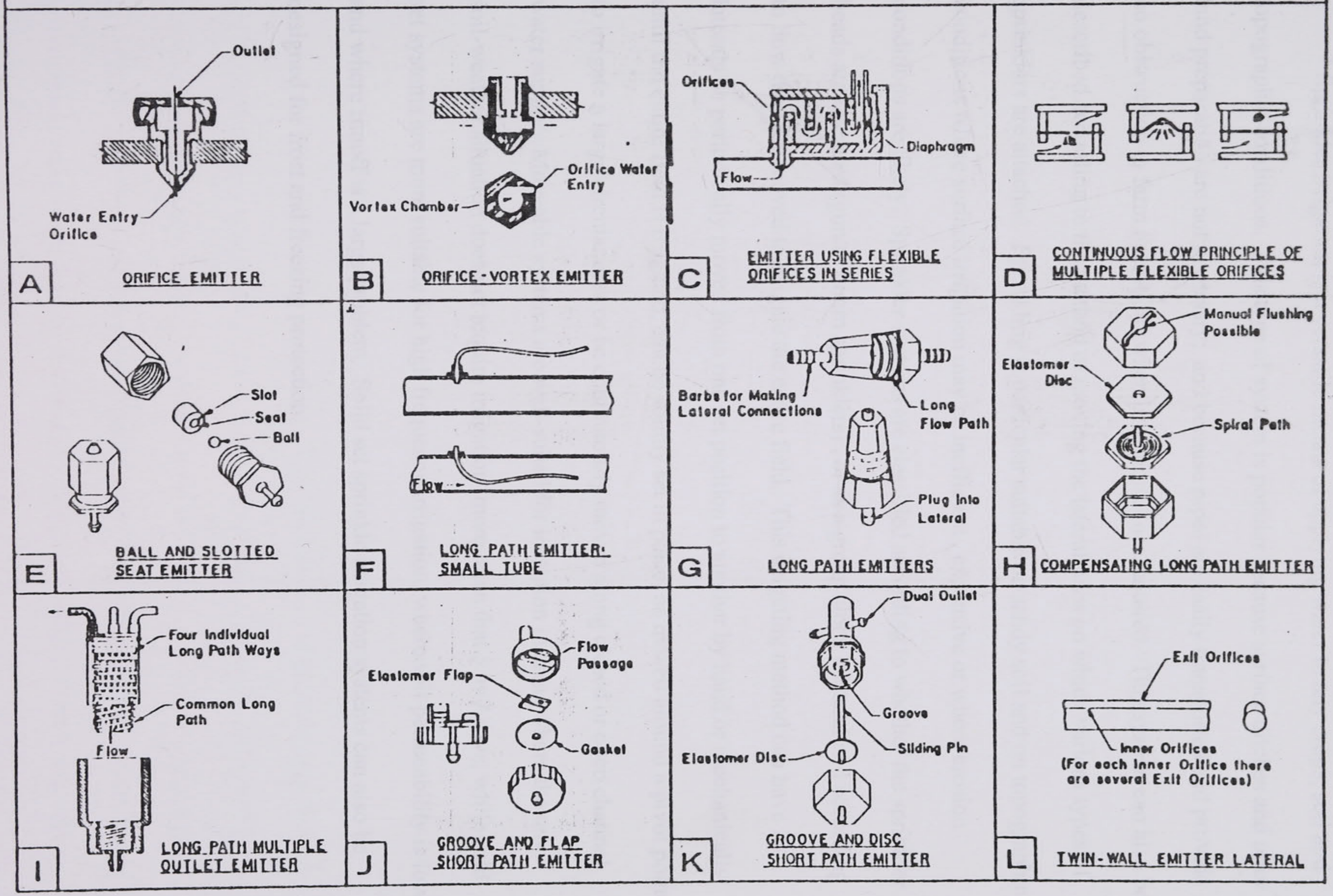


Fig. 1 Sketches of Some Types of Emission Devices



__(4.1.2) Sprinkler Irrigation__

Sprinkler irrigation is a versatile means of applying water to any crops, soil and topographic conditions. This type of system is popular because surface ditches and prior land preparation are not necessary; and because pipes are easily transported and provide no obstruction to farm operations when irrigation is not required. This system can also be described according to the method of moving the lateral lines on which various types of sprinklers are attached. Sprinkling is particular suitable on sandy soil and on topographic conditions where surface irrigation may be inefficient , expensive or where erosion conditions are likely. Sprinkler systems are classified according to whether the sprinkler heads are operated (gun or boom sprinklers) , or as a group along a lateral and according to how they are moved to irrigate the entire field. This irrigating method can have its laterals be periodically moved from one set position to another by hand or mechanically until the entire field is irrigated, can be solidly set in place, be moved around a pivot point to irrigate a large circular area or be continuously moved along closed or open channel water supply. Moveable systems are well-suited for irrigation in areas where the crop-soil-weather situation does not require irrigation more often that 5 to 7 days, while sold set systems are more suitable for high frequency irrigation, where soil permeability is low and where runoff is a large problem. Solid set sprinkle irrigation systems can also be designed for frost and freezing protection.

(4.1.3) Flood Irrigation

Flood irrigation is regarded as surface irrigation and is especially used in arid regions. In this type of irrigation, the flow of water and its application is uncontrolled, where flow is controlled by furrows, corrugation, border dikes, contour dikes or basins. Furthermore, for flood irrigation to be effective the land should be carefully prepared before irrigation, that the rate of water application be carefully controlled and that the land be properly graded. The extent of grading required, depends on the topography, the soil, and on the amount of unproductive subsoil. The driving force in such a system is gravity, and once water has been applied over the surface and entered into the soil, the water is then redistributed by force other than gravity. Flood irrigation is low in initial cost, high in labor requirement, and is generally low in the efficiency of water application. In addition there are 2 types of flooding, ordinary flooding is most suitable for close crops, particular where slopes are steep; while in contour ditch flooding, ditches are usually spaced 15 to 45 m apart, depending on the slope, texture, depth of soil, size of the stream and crop to be grown. Contour ditches are used on rolling land and is only feasible with an adequate water supply. Flood irrigation will ensure water infiltration between the surges of water, decreases roughness while increasing infiltration rates, has the ability to improve uniformity, and reduces deep percolation and runoff.

Each of these irrigation methods has their advantages and disadvantage, but are only affected if they are properly used and correctly installed. A major difference between these types of irrigation systems is in the fact that in drip, water is applied direct to the individual plants or trees, while in sprinkler or flood irrigation water is applied to cover certain areas of the farm land. The other differences between these irrigating methods is in the efficiency, the effectiveness, in the amount of energy required and in the amount of water used.

(4.2) Comparison of Irrigation Methods

Factors	Flood / Surface Irrigation	Sprinkle Irrigation	Drip Irrigation (emitter or porous tubes)
Infiltration Rate	medium	medium to high	high
Topography	rolling	level to rolling	all
Crops/Plants	all	short crops, vineyards and trees	high value
Water Supply	large streams	small streams, nearly continuous	small streams, continuous and clean
Water Quality	any type	only water without salts, salts may harm plants	all, water with high salts can be used
Efficiency	60-70 %	70-80 %	80-90 %
Labor Requirement	high to low, training required	moderate, some training	high, training required
Capital Requirement	low to moderate	moderate	high
Management Skill	moderate	moderate to high	high
Duration of Use	short to long	medium to short	long term durability
Weather	all	poor performance in windy conditions	all
Chemical Application	fair	good	excellent

(4.3)Advantages and Disadvantages of Drip Irrigation

There are many advantages inherent in the use of drip irrigation system. Maximizing the amount of available water, which is its greatest advantage can result in high to moderate. Another advantage of drip irrigation is in the systems ability to control water application rates by the drip emitter, that irrigation can be applied during or immediately before some mechanical or cultural operation, such as weeding, spraying or harvesting, that plant protection from diseases and insects are improved by the direct wetting of just the root zone and not the leaves; and that weed growth and potential pest hosts are greatly limited. Since only a small area around the crop, tree or plant are wetted; water is saved, total evaporative surface is reduced, runoff is decreased and deep percolation is controlled. Limited soil wetting will also permit uninterrupted orchard cultural operations and minimize labor scheduling problems.

Using of a drip irrigation system also allows the satisfactory use of saline water for crop germination and production under most soil conditions. The use of saline water is possible because of and frequent or daily application of water which keep salts in soil water more dilute and leached to outer limits of the wetting pattern. The low application rates increase the water to soil absorption rates while reducing the effect wind has on wetting patterns. Furthermore, this type of system is unaffected by the wind, thus allowing the round the clock irrigation at lower discharge rates; and can automation fairly easy, thereby resulting in low energy consumption by both machines and by manpower. Drip irrigation is also low in labor and has relatively low operating cost. Note that this excludes maintenance cost. The operation of a drip irrigation system only requires skilled to semi-skilled workers, with their chief job occupied in checking running time and in the intervention of the system during unexpected breakdowns.

Drip irrigation like any other irrigation method, will not fit every single agricultural crop, specific site or objectives. Eventhough this type system has its disadvantages, such as in its reduction of deep percolation, the system can increase the soil to water interaction and can improve crop quality. It can be used for a variety of climates, soils and crops, such as almonds, grapes, apples. pears, figs, vegetable crops and sugar cane.

There are many disadvantages associated with the drip irrigating method. The greatest disadvantage of drip irrigation is emitter clogging, which could be complete or partial. Emitter clogging is caused by inorganic , or organic suspended materials, by precipitation of chemicals from water in the emitter passage, by poor water distribution along the laterals and from biological growth in the pipe or emitter. When clogging occur, emission uniformity is greatly reduced and crop damage may occur. Improvements in filtration processes and chemical treatment of water could greatly prevent and decrease clogging within the emitters.

A disadvantage caused by using drip irrigation is the accumulation of salts along the fringes of the wetted surface strip, to minimize this hazard the system should be operated during rainfall periods to keep salts moving down through the profile. Another disadvantage of drip irrigation, is in the high cost and extent of the equipment per land area; these expenses are generally comparable to those for sprinkler irrigation, but are higher than surface irrigation. In addition, since only parts of the soil are wetted by the drip irrigation system, the development of crop, plant, or tree root system is limited to the area of moisture surrounding each emitter. The wet soil volume or wetted perimeter is proportional to the emitter discharge, its distance between each emitter and the soil type.

The advantages of drip or trickle irrigation must be weighed against the disadvantages of implementing the irrigation system. It can be established that drip irrigation gives a good possibility to the farmer to increase his yields and improve their quality while saving cost. In addition, with numerous varieties in drip irrigation, engineers and agronomists find it easy to solve problems in certain crops and plantation to suit different environmental conditions ensuring optimal water supply of their land. With the economic situation of farming being the greatest concern, the initial cost of drip irrigation cost several times that of sprinkler and flood.

(4.4) Problems in Drip Irrigation

Many problems in a drip irrigation system, can be minimized through proper design, management and maintenance of system. Complete or partial clogging in the emitters, which reduce discharge rates, is regarded as the most serious problem in drip irrigation. "The causes of clogging are attributed to physical, chemical and biological factors. Filtration of the irrigation water, and the use of a filter with a 150 to 200 mesh screen must be plumbed in before the pressure regulator is applied to the system."[7] The pressure regulators consist of drip hoses and parts which are designed to operate at pressures much lower than the usual domestic water pressure. If pressure is not reduce nor regulated, there is a risk of drip fittings blowing apart.

Contaminants in the water are particularly troublesome for drip irrigation, these include sand, sediment, slit, dissolved calcium and soluble or dissolved iron. These contaminants may lead to clogging within the emitter. "For soils containing sand, sediment and silt, it is best to use a filter with a mesh screen of at least 200. Using the largest orifice emitter is the best methods in deal with the calcium problem. In the case of iron the best method in dealing with this problem would be a water softener or water treatment system."[8] Wind erosion, the built up of salts and the presence of rodents are other problems which greatly affect the performance of drip irrigation. Dust, which is namely blown by the wind, can considerably damage cultivated stripes between the rows and result in soil erosion. The built up of salt is a direct result of all irrigation water containing more or less dissolved salts. Salinization can be reduced with applying significantly more water than the plants consume, or by using the irrigation system during periods of rainfall. Both of these methods will eventually push or leach the salt down below the root zone. If the rodent population is high, hoses should not be left on the surface; burring the hoses with mulch will not solve these problems but encourage the rodents to destroy the hoses and emitter. Note that in drip surface irrigation, drip hoses become brittle in cold climates and should be stored during the winter months where it will not be destroyed.

The problems of drip irrigation are very different than those found in sprinkler, or flood irrigation. If a sprinkle throws out more water than the soil can absorb, the soil will become waterlogged and less productive. When these soils become too wet, it becomes anaerobic, a condition which allows for the growth of harmful fungi, and molds, causing rotting of the roots and it slows or stops the growth of root hairs. Excessive moisture will also cause the soil temperature to drop. In cold temperature soils, worms and other soil life die and will cause nutrients to be leached beyond the plants' root zone. Over watering, which may occur in all types of irrigating methods, causes platelike particles of clays to slip closer together, making clay soils stickier and more difficult for roots to penetrate. Problems also occur when soils receive too little moisture. Overly dry soils result in died root hairs, causes worms and other organisms to leave, go dormant or die. Nutrients in dry soils become "locked up" and unavailable to the root hairs. In addition, when dry soils are walked on or tilled, fractures or cracks in the soil occur. Cracks in the soil caused by the lack of water allow so much air to enter that small roots can die from exposure, thus reducing root and plant development. "The healthiest growth and greatest yields occur when there is a constant in the moisture level, not cyclical conditions of wet or dry."[9]

(4.5) Drip Irrigation in Apple Orchard

Drip irrigation in apple orchards is growing in popularity. There are many advantages inherent in drip irrigation system, including the reduction of water usage by almost 50 %. In addition, the lengthy, low volume water application provided by a drip system has increased the production up to 84 % over other methods of irrigation. Drip irrigation also alleviates problems created by over application of water. The saturated condition by other irrigation methods can damage the tree's root zone and will create an anaerobic condition that prevents oxygen from entering the tree at their root zone. Drip irrigation delivers very low volumes of water over a long period of time. Its method of slow application makes it easy to maintain optimal soil moisture thus allowing the orchard to achieve greater yields with the fewest amounts of water.

Drip irrigation is far more efficient than the sprinkler system when used in an apple orchard. The newly developed hardware used in this method regulates exactly the amount of water applied. It can also disperse water flow rate, ensuring that the field soils do not puddle nor the roots drown. New parts for filtration (figure 4.4a) allow wider range of water supply and have pressure compensator (figure 4.4b), which can compensate for changes in water pressure. This will also allow the water to be delivered evenly on long lateral pipe or on landscape with high elevation.

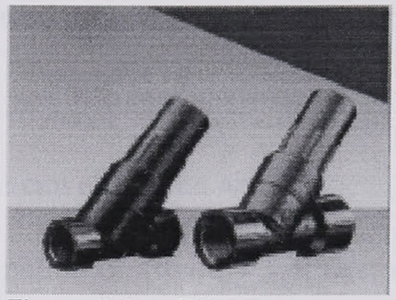


Figure 4.4a - Filter

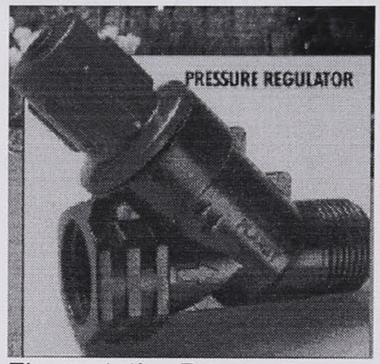


Figure 4.4b - Pressure Compensator

Each drip emitter (figure 4.4c) applies water to a localized spot. The slower the water is applied into the soil, the deeper and narrower the area of irrigated soil. For example, in our case of apple orchard, the irrigated area in the soil profile usually forms a carrot shape on a sandy

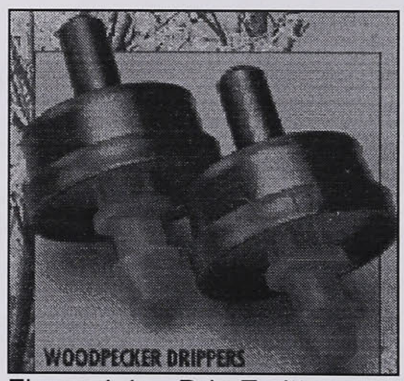


Figure 4.4c - Drip Emitter

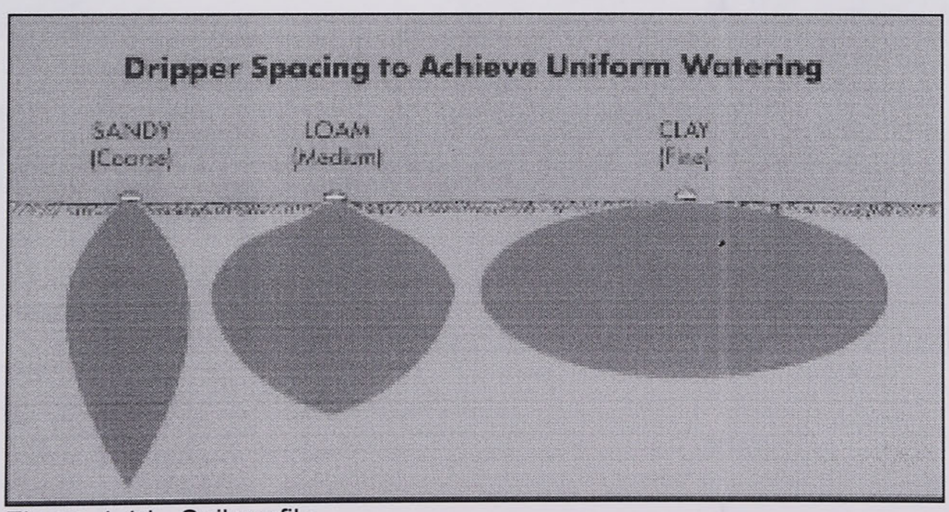


Figure 4.4d - Soil profile

loam soil as shown in figure 4.4d. The emitters will be spaced around two meters apart, the same distance as the trees. There will be an area of dry soil between their moist circles. In Quebec where rains are infrequent, this dry zone can eliminate weeds' problems because there is not enough water to allow germination or growth. With drip irrigation system, there is almost no water loss due to the evaporation from windblown sprays. Furthermore, the irrigation water is able to reach to the tree's root directly, a schematic representation of the field is shown in figure 4.4e.

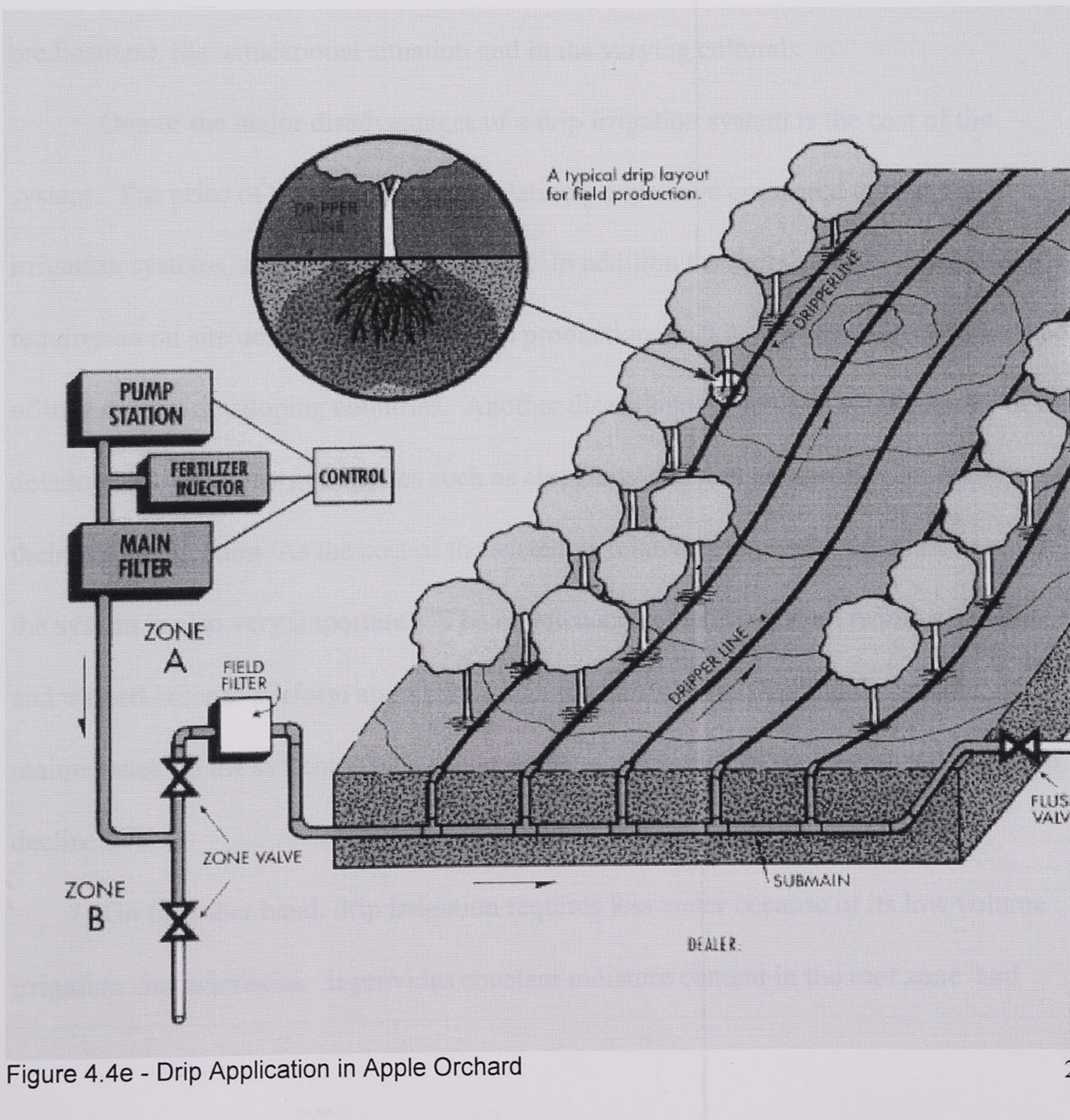


Figure 4.4e - Drip Application in Apple Orchard

(4.6) Versatility of Drip Irrigation System in Developing Countries

Large increases in food production are necessary for the world's increasing population especially those in the development countries where economics are primarily dependent on agriculture activities. "Food production can be obtained by placing more lands under irrigation and by improving the techniques and management of existing irrigation systems."[20] Drip irrigation has been proven to give a positive impact on the efficiency of agriculture production. However, applying this technique to developing countries could have both advantages and disadvantages that depend on the economic predicament, the educational situation and in the varying culturals.

One of the major disadvantages of a drip irrigation system is the cost of the system. The price of the drip system is relatively expensive compared to traditional irrigation systems, such as sprinkler system. In addition the fact that each drip system requires an on site design for specific crop production, makes drip an ineffective method of irrigating in developing countries. Another disadvantage is that in some regions of the developing world, energy supplies such as electricity and fuel are insufficient because of their remote location. As the cost of the system is relatively expensive; maintenance of the system is also very important. "The maintenance of a drip system requires skillful and trained labor to perform appropriate maintenance such as flushing the system, of maintenance on the system is not regular perform, efficiency of the system will begin to decline."[21]

On the other hand, drip irrigation requires less water because of its low volume irrigation characteristics. It provides constant moisture content in the root zone and increases the crop yields as well as the income of the farmers. " Drip systems also reduce the amount of pollution due to the overuse of fertilizers, which remain a great environmental concern."[22]

The benefits of a drip irrigation system cannot cover its disadvantages such as the cost, the requirement of skill labor and in its need for artificial power. Due to these reasons, we can conclude that drip irrigation system is not a cost efficient application in developing countries.

(4.7) Developments in Drip Irrigation

Drip irrigation has greatly evolved since its inception in the mid 1800 and has been found to be an acceptable system of irrigating many crops; yet this method of irrigation should not be expected to replace nor compete with other conventional irrigating methods. Since the early 1900, there have been many improvements and development in the field of drip irrigation. The improvements that have been made are in; integrating design procedure with soil properties, determining all of the factors affecting emitter flow, and in understanding water, plant, root and oxygen distribution. Another improvement that has been made is in finding solutions to iron, manganese and other clogging problems caused by iron, manganese and other bacterial slime. Progress also been made in the optimization of the irrigation schedule, in cultural practices and in the agronomic management of the drip system.

The developments and improvements in drip irrigation have come about because of "the potential for using less water per unit of production, which may have provided motivation for changing irrigation methods; and because of the fact that water costs significantly affect profit margins. The rapid expansion of drip irrigation in southern California where water costs are high illustrates this point."[10] Since drip irrigation is not suitable for some crops that sprinkle or flood irrigated, simple area statistics underestimate the acceptance of drip irrigation over the past decades. In addition, when crops, plants or trees are irrigated by the drip method, yield and cash returns per unit area tend to be higher than those crops, trees or plants irrigated under conventional means. "An example of this point is in the experiment performed by professors Clark of the University of Kansas, Maynard of the University of Florida and professor Stanley of the University of Florida, in which they conducted a study to evaluate the growth of watermelons in a humid region under three different application rates The irrigation amount and duration for the base irrigation schedule were based on fraction (irrigation ratios) of grass-based Penman reference evapotranspiration calculated from local weather data." [11] Application amounts were applied daily in a single irrigation cycle, with the first, second and third cycle equal in duration but double and triple in application amounts.

This experiment result in high yields and acceptable quality. The report also stated that yields under drip irrigation were two to four times those reported as state production averages, irrigated or non-irrigated. Generally the highest yields occurred in the second cycle with double application amounts; this was because of the fact that in cycle three excess water from irrigation may have leached the plant nutrients resulting in a yield reduction. It was also determined that fruit quality was generally not affected by the irrigation treatment; and that the lowest irrigation cycle (cycle one) would be acceptable for production conditions. Cycle one was chosen because the applied irrigated water approximately equaled the evaptranspiration rate. Higher water application under these production conditions may not improve yield or quality of the fruit.

Developments in the future will probably continue to be concentrated on high value crops, on extending the limited water supplies and on the utilization of relatively low quality waters. "It is unlikely that drip irrigation will expand into solid stand large-area plants such as forages and cereals, because the system will have little or no advantage with conventional sprinkler or flood systems for the same types of crops."[12]

(V) Design Calculations

Assumptions:

Evapotranspiration (ET) = 5 mm/day

Tree water requirement = 5 mm/day

Emission Uniformity (EU) = 90 %

Using existing pump with:

Pump operation pressure = 242 kPa

Tree irrigation area (A) = 2 x 5 m^2 = 10m^2

Topography : uniform (slope < 2 %)

Area of the field = <u>2,000 m^2</u> (0.2 hectares)

Water volume required per tree (from Soil and Water Conservation Engineering, 4th edition, 1993, p463)

$$V = (ET * A * 1000\ L/m^3) / (1000\ mm/m * EU)$$

$$= (5\ mm/day)(10\ m^2)(1000\ L/m^3) / [(1000\ mm/m * 0.9)]$$

$$= 55.56\ L/day$$

Number of emitters, n = 2

Each emitter must deliver (55.56 L / 2) at maximum of 8 hours,

= 27.78 L / 8 hour

= 3.47 L/h = 9.639 x 10^{-4} L/s

From Fig. 21.6 (Soil and Water Conservation Engineering, 4th edition, 1993)

selected the small long-path emitter with K = 0.151 & x = 0.63

emitter discharge : $q = K\,h^x$

then average pressure head (h_{avg}),

$$h_{avg} = (q / K)^{1/0.63}$$

$$h_{avg} = (3.47 / 0.151)^{1/0.63}$$

$$h_{avg} = 145.0 \text{ kPa}$$

Discharge rate in each of the laterals

Line	No. of Trees	No. of emitters	Required Discharge (L/s)
1 lateral	27	54	0.052 L/s
7 lateral (whole area)	189	378	0.364 L/s

For a point source device : $C_v = 0.05$

where C_v = Manufacturer's Coefficient of variation

$$EU = 100 * (1 - (1.27\,_{Cv} / n^{0.5})) * q_{min} / q_{avg}$$

(from Soil and Water Conservation Engineering, 4th edition, Eqn. 21.2, pg. 459)

$$q_{min} = (EU * q_{avg}) / [100*(1-(1.27C_v / n^{0.5})]$$

$$= (90*3.47) / [100*(1-(1.27*0.05)/ 2^{0.5})]$$

$$= 3.27 \text{ L/h}$$

Minimum head in the last lateral R-7,

$$h_{min} = (q_{min}/0.151)^{1/0.63}$$

$$= 131.8 \text{ kPa}$$

Pressure variation allowed, from SCS (1984)

$$\Delta h = 2.5 * (h_{avg} - h_{min})$$

(Soil and Water Conservation Engineering, 4th edition, eqn. 21.6, pg. 462)

$$= 2.5 * (145 - 131.8)$$

$$= 33 \text{ kPa}$$

Therefore, maximum allowable inlet pressure to the field,

$$= h_{min} + \Delta h$$

$$= (131.8 + 33) \text{ kPa}$$

$= 164.8$ kPa $<$ 242 kPa which is the maximum pressure the existing pump can provide.

Friction Loss along the pipe, Hazen-Williams or Darcy-Weisbach equation (1978)

$$H_f = KLQ^{1.75} D^{-4.75}$$

where H_f = friction loss in m

K = constant = 7.89E4 for water at 20 C

L = pipe length in m

Q = total pipe flow in L/s

D = inside pipe diameter in mm

L_e = 0.3 m for each on-line emitter

	Q (L/s)	Pipe I.D. mm (in.)	$L + L_e$	Correction Factor (F)	H_f
Line-Lateral	0.052	12.7 (1/2")	54.2 + 16.2	0.36	0.65m
Manifold to Lateral	0.364	25.4 (1")	34	0.43	0.43m
Pump to Manifold	0.364	25.4 (1")	27	1	1m

Total head $= 145/9.8$ m $+ 0.75(0.65+0.43)$m $+ 1$m

$= 16.6$ m

Irrigation requirement : pump must deliver flow rate (Q) = 0.364 L/s

head requirement = 16.6 m or

with operation pressure at 162.74 kPa

(VI) Economic considerations:

(6.1) Introduction

When crop yields are significantly higher and more consistent on irrigated than rained lands, irrigation plays a major role in stabilizing food production. Irrigation technology has improved dramatically during the past two or three decades and many existing on-farm irrigation systems have not kept up with technology in over twenty years. "Micro-irrigation or drip systems have the potential to obtain high efficiency up to 95% and may become even more economical in future developments"[13].

Micro-irrigation systems cost more than sprinkler systems and will require management skills and farming practices. Energy and power requirements for drip irrigation systems are less than sprinkler or flood irrigation.

"In order to analyze the economic benefits for the conversion from traditional irrigation system to drip irrigation system, several factors must be taken into account. The concept of profitability indicates the potential rate of return of the new system conversion. Risk analysis provides the probability of how profits can be maximized if the new drip system will be installed."[14]

(6.2) Potential profitability

Potential profitability of the irrigation system is a conversion is based on the concept of Time Value of Money. By using this concept, it is possible to determine the potential rate of return of the system conversion. This rate of return can be compared to a minimum attractive rate of return in order to make a final decision on the conversion of the new system. The minimum attractive rate of return can be calculated from the potential rates of return of other investment opportunities. Potential rate of return for the system conversion can be determined by the review and evaluation of the existing system, the cost of the system conversion and an estimation of the changes in income and expenses (net profit).

(6.2.1) Existing system evaluations

The evaluation of the existing irrigation system will consist of a comparison between the information from past management practices, possible future practices involving system modifications, changes in management techniques, and the conversion to a drip irrigation system. This information will come mainly from farm records and in-field irrigation system evaluations.

The information required to obtain from farm records is those directly related to the irrigation system such as power bills on pumps, costs for water, equipment maintenance costs, costs for cultural practices which are specific to the method of irrigation (e.g. land planning for irrigation), pump performance tests, water use records, techniques of irrigation and irrigation scheduling records. The second set of information is all other records relating to the expenses and income for the crops grown. This information includes seed, fertilizer, cultural operations, labor and interest on loans. They provide the economic approach to evaluate any modifications to the existing system, changes in system management, or system conversion to drip irrigation. The next step is to perform an in-field irrigation system evaluation. The objectives of these steps are to determine the potential rate of return for the system; this could be hardware modifications or changes in management technique. This is shown by the example in which, "hardware changes could range from buying different size pipes to install automated valves and management changes could be changing flow rates to introduce a computerized irrigation scheduling program."[14]

(6.2.2) Conversion to a drip irrigation system

Since a potential rate of return for the existing system has been determined, the next procedure is to determine the cost of conversion to a drip irrigation system. A "typical" cost for an installed system is not accurate enough for a specific evaluation. The actual cost will depend on the pumping plant, the type of filtration used, the type of drip hose selected and the level of automation required by the grower. If on the data on the field in question is available; it would be possible to perform a preliminary evaluation based on local averages for similar scenarios. Positive economic results based on these costs would then be used to decide the time and effort necessary to obtain a design with either an engineering cost estimate or actual costs from dealers for the designed system. The results can also be used to determine some of the other factors involved in the economic evaluation, such as the method of financing where taxes and depreciation come in to effect.

(6.2.3) Estimation of changes in operation expenses and returns

The estimation of changes in operation expenses will give the determination of what potential change will be in returns. Changes in expenses include different fertilizer rates, water costs and labor costs. Expected yield increase will have direct relationship to the change in returns. The best source to estimate these changes will be the past experience of local growers. Data from outside the local area can be modified to represent the local conditions, if there is no local experience available.

(6.2.4) Determine the Profitability (Potential Rate of Return)

Profitability of a proposed drip irrigation system conversion can be determined by the concept of the time value of money. By applying this technique for the analysis, a direct comparison can be easily separate between investment alternatives based on a calculated potential rate of return obtained in previous steps.

The first procedure is to calculate the yearly differences between each of the investment opportunities and the current net income. By comparing the rate of return on these differences, it is possible to calculate the potential rate of return due to the irrigation system conversion alone. Potential rate of return can be determined by using a present worth factor, which can then be use to determine the present day value of each future value. By changing the rate of return value in the net present value calculation and adding the present worth of the difference in present cash flows to future value, it is possible to calculate the rate at which the sum of all future cash flows is equal to the invested value. This rate is known as the potential rate of return.

(6.3) Risk Analysis

Risk measures primarily depend on the probability distribution of profit. When yields are one of the major factors for determining the profit, it is very important to examine the impacts of the new system on expected and variance of profits. In most cases, studies have shown that drip irrigation decreased the operating expenses; on the other hand, profits have been increased since expected yields after the conversion are assumed to be the same or higher. With no changes in the price distribution, this possible increase in both profit and yields indicate an increase in returns for the producer. Costs of new irrigation system must then be subtracted to determine the effect on overall profits. Depending on the situation such as life span of the new system, profits may increase or decrease with the conversion. In most cases, an increase in profits mostly depends on the proper maintenance and operation of the system, which could increase the life span of the system. This could result in the annual cost of the system will decrease and profits increase.

Drip irrigation may not necessarily have less risk than the traditional irrigation system. "Several reasons are given for a possible increase in risk by the introduction of drip irrigation: 1) clogging of the dripper of the system; 2) improper operation and maintenance; 3) skill level of the labor operating the system. Furthermore, investments on a more expensive drip irrigation equipment and labor could expose farms to financial risks that are only partially offset by the reduced production risks."[15] However, the risk of conversion to drip irrigation appears to depend on the perspective of the analysis. " If the farm can provide higher skill labors, proper maintenance on the new system, and not have financial problem as its main concerns; conversion to the new system will be a good long-term investment which will give a higher profit than the existing irrigation system."[16]

(VII) Environmental Concerns:

(7.1) Introduction

"Drip irrigation consumes only fifty percent of the water that is normally required by a sprinkler irrigation system."[17] Due to less water required and only partial wetting of the soil surface, surface runoff can be minimized, less power is required and lower energy is used by the engines and pumping facilities. There must also be better control in the use of the pesticides, to avoid underground water contamination; and to increase the amount of pesticides absorb by the plants' roots. The use of broadcasting fertilizers onto the dry soil surface would cause serious losses because the nutrients can not penetrate into the soil at the same time. However, this type of fertilizer eliminate the possibility of surface runoff to the nearby water sources. Health problems associated with irrigation are also one of the biggest environmental concerns.

(7.2) Energy Requirement

The energy required to pump irrigation water for the apple trees is measured in terms of electric power or the amount of fuel used. Energy use for the field depends on the unit of water applied per unit of fuel or electric power used.

The energy required per unit of water delivered depends on how the irrigation system was designed and on field site characteristics. These parameters can be summarized as the total water head that the pump is operating against and the efficiency of the pumping system. Total water head depends on the vertical distance that the is water lifted, the pressure required to operate the drip emitters, and the friction losses that have to be overcome as water is pumped from its source until it reaches the drip emitters. Efficiency of the pumping system depends on the efficiencies of the pump it elf, the power unit, and connecting drive units.

In a drip irrigation system, the amount of pressure head required is always less than the pressure provided by the pumping system. As new technology becomes available, precise irrigation scheduling can be based on accurate rainfall prediction; and the use of higher capacity solar energy cells can be used for the pumping system since drip systems require lower energy input. High level of efficiency for the system can be achieved through these technologies while ensuring minimum environmental damage.

(7.3) Weed Problems and Pesticides Control

Weeds remain one of the biggest problems for crop production; they not only decrease crop yields but reduce quality of product. Cost of production will also increase dramatically if weeds are present amongst the field. Weeds are also an excellent harbor for disease and insects that will damage the crops. With drip irrigation which has a low water volume flow and applies the water in precise locations, weeds can be controlled more easily because less water is available to the weeds. Pesticides are generally used as a chemical control of weeds and insects. On the other hand, it also becomes one of the major sources of surface runoff and underground water contamination. The insect problem seems to exist more frequently when large amounts of weeds are present on the field site. Drip irrigation reduces the weeds on the field; therefore fewer insects will probably stay, and will also decrease the amount of pesticides used.

(7.4) Fertilizers

A major advantage of drip irrigation is the ability to apply fertilizers through the system. Since nutrients are applied to a limited soil area with the irrigation water, fertilizer efficiency can be improved compared to conventional application methods. Nutrients are easily applied through the drip system due to its high solubility. In using a conventional fertilization methods, excessive amounts of fertilizers are broadcast on the soil surface causing damage to the root system; or in some cases, only a portion of the fertilizers can be penetrate to the root system depending on the soil permeability. Large amounts of dissolved fertilizer solution will cause contamination in surface runoff and ground water resources that may result in serious health problems to human, wild life and live stock.

(7.5) Health risk

Because health considerations are such a major issue of an irrigation project, it is very important to consider health risks in the early planning stages a new system. There is growing evidence that irrigation projects may also cause an increase in health risks through contaminated water resources.

(VIII) Recommendation

The following are suggestion for improving a drip irrigation system:

(1) Using Tensiometer to measure actual moisture content in the soil

Using a drip irrigation system can improve the productivity of marginal soils, has enabled the use of high salinity water, results in less power and reduced water consumption. However, irrigation scheduling for a "drip irrigation system without knowing actual moisture content in the soil will result in inaccuracies which could cause damage to the growth and decrease yield of the crop."[19] There are two basic questions involved in irrigation management; (1) when should the water be turned on, and (2) how much water should be applied. Under these situations, precise control over both the timing and amount of irrigation applied is very crucial for effective production on the field.

A tensiometer directly measures the soil water suction or tension. "This method of measurement eliminates variables such as soil type, salinity, variations in rooting depth, crop coefficients in terms of water use, and measures the true effect of weather on actual evapotranspiration."[20] It also provides a solid base of information that is required for proper irrigation scheduling.

In the case of the apple orchard, the tensiometers are suggested to be placed at 30 cm depth and 60 cm depth; this will reflect the most effective moisture content of the root zone. Since the objective of drip irrigation is to maintain the soil at close to actual evaportranspiration by continuous application of water, tensiometers' readings will provide important information needed for proper irrigation scheduling. In addition high accuracy and reliability of the system are achieved with proper placement of the tensiometers and the frequency of reading.

(2) Using Computer-Models to collect meteorology data, tensiometer readings and to calculate an irrigation schedule for the orchard.

In the past few decades, micro-computer technology has greatly improved soil moisture monitoring. Even though tensiometers have the advantages, such as simple in structure and are inexpensive, they are still less popular because of frequent servicing and the fact that readings must be taken manually. These problems can be solved by the introduction of micro-computers and measurement devices, for example pressure transducer. "This measurement unit allows continuous remote readings of the soil water from different locations at the same time and will also provide a more accurate average reading for the whole field, this information is then combined with the meteorology data, which is then be used to improve and automate the irrigation schedule."[22]

These micro-computer models are composed of a micro-processor, tensiometers, pressure transducers, data acquisition system (DAQ), and electromagnetic valve. These models will require an individual to manually input air temperature, humidity, critical soil water pressure head values, crop requirement and will also require weather forecast data. The radiation, air temperature and air humidity readings can be obtained through an on-going project of the weather station located on the roof of the MacDonald-Stewart Building.

The pressure head reading obtained at the tensiometers will be connected to pressure transducers and is collected by a data acquisition system (DAQ). The collected data is then sent to a micro-processor with the data from the weather station. The data from the DAQ and from the weather station are necessary for calculation of the actual evaportranspiration. Real time irrigation decisions can be made by comparing the pressure head in the soil to the actual evaportranspiration rate of the crop. The pump and electromagnetic valve are controlled by the micro-processor that will adjust the timing of the scheduling. By providing the nutrient requirement of the crop, the micro-processor can also be designed to control the fertilizer tank therefore enabling the distribute of nutrients. A schematic representation of the automation model is shown in Figure 8.1.

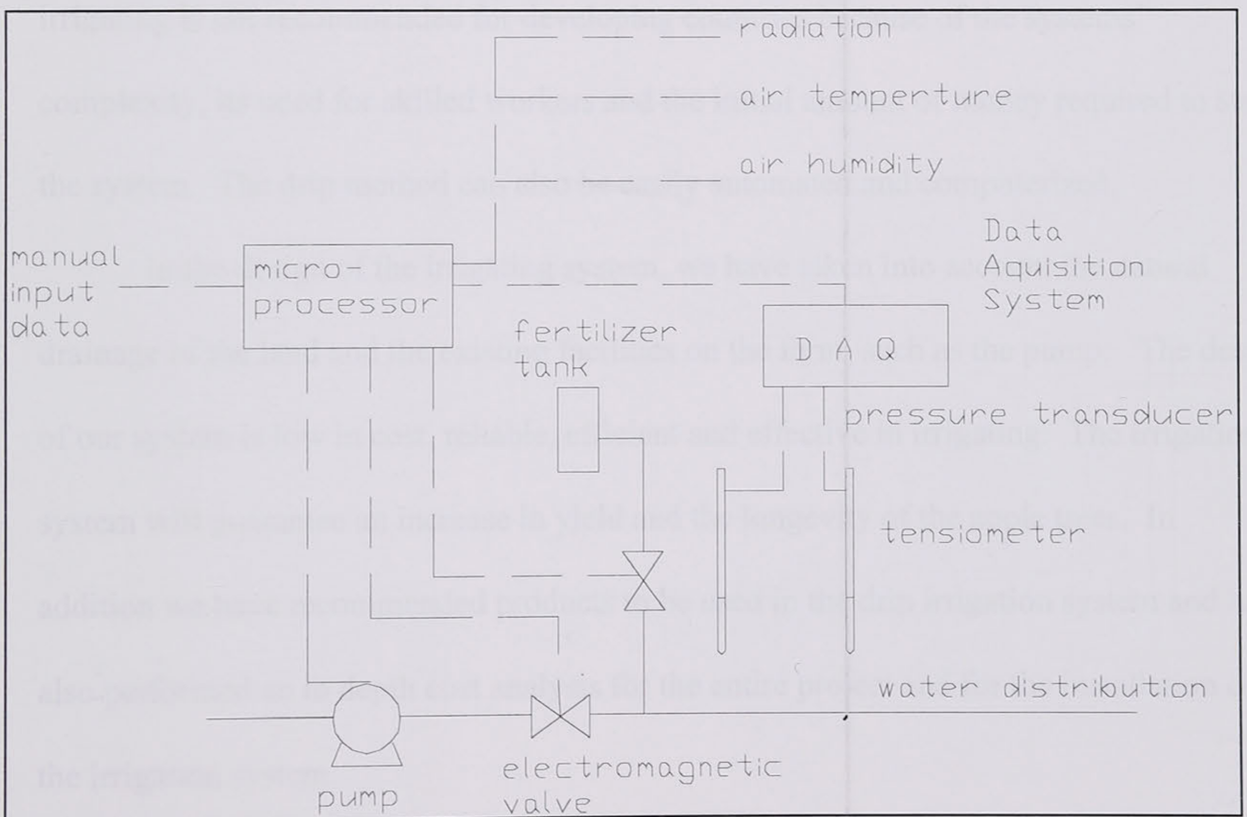


Fig. 8.1 - Schematic representation of the computer model

(IX)Conclusions

The aim of this project is to develop and design a drip irrigation system for an apple orchard. The orchard in question is located east of the Horticultural Center, which is located on the MacDonald Campus of McGill University. The soil of this orchard is a St.Bernard sandy loam. "Drip irrigation is characterized by the following features: (1) as water applied at low rates, (2) as water being applied over a long period of time, (3) as water is applied near or into the plant's root zone and (4) as water being applied by a low pressure delivery- system"[18]. In the comparison of drip irrigation to sprinkler and flood irrigation, we determine that drip has the greatest expenses, has the highest efficiency and is the most effective method of irrigating. In addition, the drip method of irrigating is not recommended for developing countries because of the systems' complexity, its need for skilled workers and the initial amount of money required to start the system. The drip method can also be easily automated and computerized.

In the design of the irrigating system, we have taken into account the natural drainage of the land and the existing facilities on the farm, such as the pump. The design of our system is low in cost, reliable, efficient and effective in irrigating. The irrigation system will guarantee an increase in yield and the longevity of the apple trees. In addition we have recommended products to be used in the drip irrigation system and have also performed an in depth cost analysis for the entire project and for the installation of the irrigation system.

Appendix A

Topography map of the field and the design of the Drip Irrigation System

Appendix B

Soil Profile along the Main Pipe and Flush Pipe

Soil Profile along the Main pipe

Position	Horizontal Distance	G.S. Elevation	Pipe-bottom Elevation	Depth to pipe bottom	Slope
W.S.	0.000	49.125	49.125	0.000	
EB1	5.000	49.125	49.125	0.000	
EB2	5.000	49.125	48.625	0.500	0.016
EB3	26.420	49.536	49.036	0.500	0.035
R1	27.270	49.536	49.066	0.470	
R2	32.270	49.756	49.242	0.514	
R3	37.270	49.792	49.417	0.375	
R4	42.270	50.031	49.593	0.438	
R5	47.270	50.191	49.769	0.422	
R6	52.270	50.530	49.945	0.585	
R7	57.270	50.655	50.121	0.534	
EB4	58.270	50.655	50.156	0.499	
EB5	58.270	50.655	50.655	0.000	
F.V.	59.270	50.655	50.655	0.000	

Soil Profile along the Flush Pipe (located at the top part of the field)

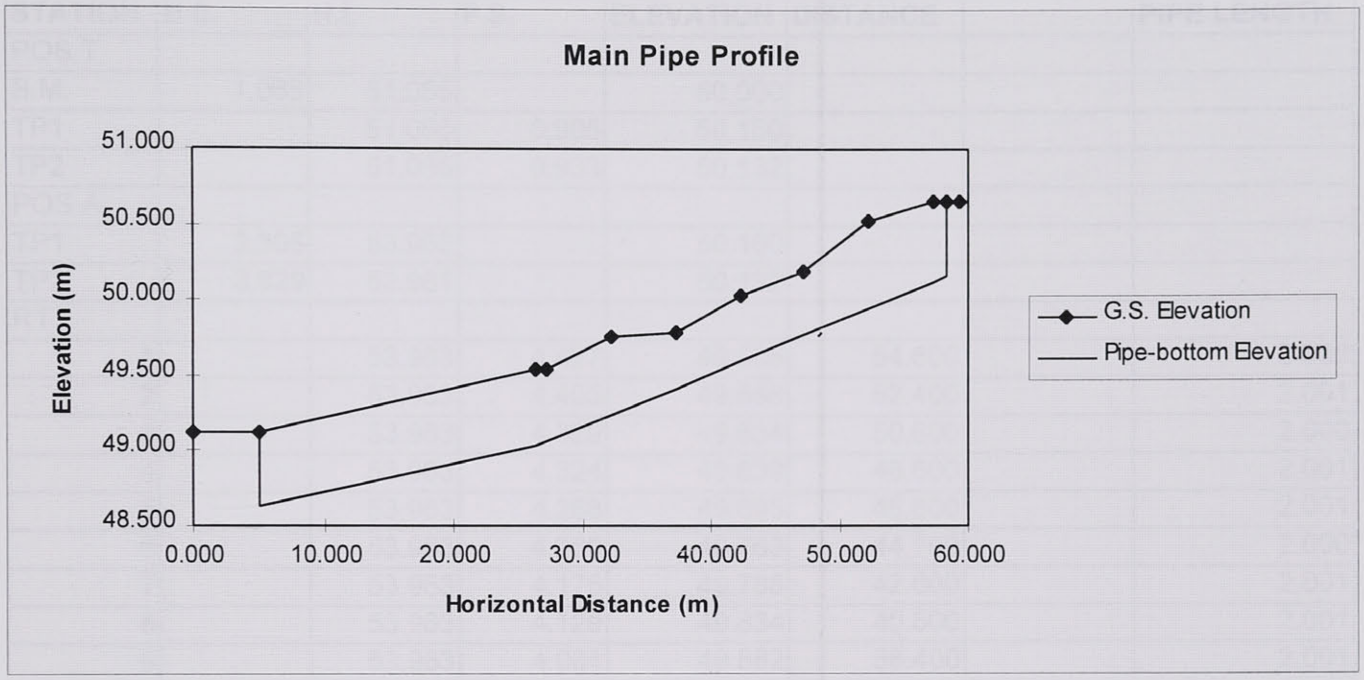
Position	Horizontal Distance	G.S. Elevation	Pipe-bottom Elevation	Depth to pipe bottom	Slope
R1	0.000	52.100	51.600	0.500	0.034
R2	5.000	52.503	51.770	0.733	
R3	10.000	52.588	51.940	0.648	
R4	15.000	52.919	52.110	0.809	
R5	20.000	52.976	52.280	0.696	
R6	25.000	53.140	52.450	0.690	
R7	30.000	53.160	52.620	0.540	
EB1	31.000	53.160	52.654	0.506	
EB2	31.000	53.160	53.160	0.000	
F.V.	32.000	53.160	53.160	0.000	

Note: All no. in ***m***

where:
EB(#) = ELBOWS
F.V. = FLUSH VALVE

Appendix C

Graphical Representation of the Main Pipe and Flush Pipe Profiles



Appendix D

Surveying Data of the Apple Orchard

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
POS.T							
B.M.	1.065	51.065		50.000			
TP1		51.065	0.905	50.160			
TP2		51.065	0.933	50.132			
POS.A							
TP1	3.805	53.965		50.160			
TP2	3.829	53.961		50.132			
R1							
1		53.963	4.427	49.536	54.600		2.000
2		53.963	4.405	49.558	52.400		2.001
3		53.963	4.329	49.634	50.600		2.000
4		53.963	4.324	49.639	48.600		2.001
5		53.963	4.268	49.695	46.600		2.001
6		53.963	4.200	49.763	44.700		2.000
7		53.963	4.175	49.788	42.600		2.001
8		53.963	4.129	49.834	40.500		2.001
9		53.963	4.081	49.882	38.400		2.001
10		53.963	4.006	49.957	36.500		2.006
11		53.963	3.852	50.111	34.500		2.002
12		53.963	3.771	50.192	32.400		2.002
13		53.963	3.693	50.270	30.500		2.004
14		53.963	3.567	50.396	28.400		2.002
15		53.963	3.489	50.474	26.300		2.003
16		53.963	3.372	50.591	24.200		2.004
17		53.963	3.252	50.711	22.300		2.003
18		53.963	3.150	50.813	20.300		2.004
19		53.963	3.023	50.940	18.300		2.003
20		53.963	2.918	51.045	16.300		2.004
21		53.963	2.787	51.176	14.400		2.004
22		53.963	2.665	51.298	12.500		2.003
23		53.963	2.561	51.402	10.600		2.005
24		53.963	2.418	51.545	8.400		2.008
25		53.963	2.235	51.728	6.400		2.011
26		53.963	2.029	51.934	4.300		2.007
27		53.963	1.863	52.100	2.700		
						Total length	52.079
ULC		53.963	1.045	52.918	5.100		
TP3		53.963	0.786	53.177			
TP4		53.963	0.817	53.146			

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
POS. B							
TP3	1.135	54.312		53.177			
TP4	1.167	54.313		53.146			
R2							
27		54.313	1.810	52.503			2.004
26		54.313	1.944	52.369			2.005
25		54.313	2.092	52.221			2.005
24		54.313	2.234	52.079			2.004
23		54.313	2.355	51.958			2.003
22		54.313	2.458	51.855			2.003
21		54.313	2.569	51.744			2.004
20		54.313	2.703	51.610			2.004
19		54.313	2.830	51.483			2.005
18		54.313	2.967	51.346			2.006
17		54.313	3.120	51.193			2.005
16		54.313	3.268	51.045			2.003
15		54.313	3.382	50.931			2.004
14		54.313	3.510	50.803			2.004
13		54.313	3.632	50.681			2.002
12		54.313	3.730	50.583			2.005
11		54.313	3.870	50.443			2.001
10		54.313	3.920	50.393			2.003
9		54.313	4.037	50.276			2.002
8		54.313	4.117	50.196			2.002
7		54.313	4.215	50.098			2.001
6		54.313	4.278	50.035			2.002
5		54.313	4.362	49.951			2.001
4		54.313	4.415	49.898			2.001
3		54.313	4.464	49.849			2.001
2		54.313	4.540	49.773			2.000
1		54.313	4.557	49.756			
						Total Length	52.081

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
POS. B							
R3							
1		54.313	4.521	49.792			2.001
2		54.313	4.475	49.838			2.001
3		54.313	4.402	49.911			2.002
4		54.313	4.322	49.991			2.002
5		54.313	4.240	50.073			2.002
6		54.313	4.162	50.151			2.002
7		54.313	4.076	50.237			2.001
8		54.313	3.999	50.314			2.003
9		54.313	3.895	50.418			2.004
10		54.313	3.771	50.542			2.004
11		54.313	3.637	50.676			2.002
12		54.313	3.556	50.757			2.004
13		54.313	3.437	50.876			2.002
14		54.313	3.338	50.975			2.005
15		54.313	3.190	51.123			2.003
16		54.313	3.075	51.238			2.006
17		54.313	2.923	51.390			2.004
18		54.313	2.795	51.518			2.005
19		54.313	2.655	51.658			2.003
20		54.313	2.543	51.770			2.005
21		54.313	2.398	51.915			2.004
22		54.313	2.276	52.037			2.002
23		54.313	2.189	52.124			2.007
24		54.313	2.016	52.297			2.000
25		54.313	1.984	52.329			2.007
26		54.313	1.821	52.492			2.002
27		54.313	1.725	52.588			
						Total length	52.083
TP5		54.313	0.844	53.469			
TP6		54.313	0.872	53.441			

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
POS. C							
TP5	1.161	54.631		53.469			
TP6	1.190	54.631		53.441			
R4							
27		54.631	1.712	52.919			2.004
26		54.631	1.831	52.800			2.002
25		54.631	1.909	52.722			2.002
24		54.631	1.995	52.636			2.001
23		54.631	2.049	52.582			2.001
22		54.631	2.102	52.529			2.001
21		54.631	2.154	52.477			2.002
20		54.631	2.232	52.399			2.004
19		54.631	2.351	52.280			2.005
18		54.631	2.489	52.142			2.005
17		54.631	2.631	52.000			2.005
16		54.631	2.770	51.861			2.004
15		54.631	2.895	51.736			2.004
14		54.631	3.019	51.612			2.008
13		54.631	3.193	51.438			2.007
12		54.631	3.362	51.269			2.003
11		54.631	3.469	51.162			2.008
10		54.631	3.651	50.980			2.004
9		54.631	3.784	50.847			2.003
8		54.631	3.897	50.734			2.003
7		54.631	4.014	50.617			2.003
6		54.631	4.115	50.516			2.002
5		54.631	4.209	50.422			2.003
4		54.631	4.312	50.319			2.004
3		54.631	4.435	50.196			2.002
2		54.631	4.522	50.109			2.002
1		54.631	4.600	50.031			
						Total length	52.088

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
R5							
1		54.631	4.440	50.191			2.002
2		54.631	4.349	50.282			2.003
3		54.631	4.240	50.391			2.004
4		54.631	4.120	50.511			2.004
5		54.631	4.000	50.631			2.003
6		54.631	3.895	50.736			2.004
7		54.631	3.769	50.862			2.004
8		54.631	3.640	50.991			2.004
9		54.631	3.519	51.112			2.004
10		54.631	3.386	51.245			2.000
11		54.631	3.349	51.282			2.014
12		54.631	3.113	51.518			2.008
13		54.631	2.932	51.699			2.003
14		54.631	2.819	51.812			2.003
15		54.631	2.711	51.920			2.003
16		54.631	2.597	52.034			2.005
17		54.631	2.455	52.176			2.005
18		54.631	2.320	52.311			2.004
19		54.631	2.199	52.432			2.003
20		54.631	2.086	52.545			2.002
21		54.631	2.003	52.628			2.000
22		54.631	1.965	52.666			2.001
23		54.631	1.900	52.731			2.000
24		54.631	1.879	52.752			2.000
25		54.631	1.835	52.796			2.002
26		54.631	1.738	52.893			2.002
27		54.631	1.655	52.976			
						Total length	52.087
TP7		54.631	0.944	53.687			
TP8		54.631	0.977	53.654			

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
POS. D							
TP7	1.128	54.815		53.687			
TP8	1.161	54.815		53.654			
R6							
27		54.815	1.675	53.140			2.002
26		54.815	1.761	53.054			2.000
25		54.815	1.798	53.017			2.000
24		54.815	1.830	52.985			2.000
23		54.815	1.868	52.947			2.000
22		54.815	1.870	52.945			2.000
21		54.815	1.871	52.944			2.002
20		54.815	1.959	52.856			2.001
19		54.815	2.026	52.789			2.002
18		54.815	2.113	52.702			2.001
17		54.815	2.179	52.636			2.004
16		54.815	2.311	52.504			2.002
15		54.815	2.405	52.410			2.004
14		54.815	2.539	52.276			2.005
13		54.815	2.680	52.135			2.001
12		54.815	2.734	52.081			2.008
11		54.815	2.912	51.903			2.006
10		54.815	3.063	51.752			2.006
9		54.815	3.223	51.592			2.004
8		54.815	3.344	51.471			2.005
7		54.815	3.480	51.335			2.004
6		54.815	3.613	51.202			2.007
5		54.815	3.785	51.030			2.005
4		54.815	3.931	50.884			2.004
3		54.815	4.052	50.763			2.004
2		54.815	4.186	50.629			2.002
1		54.815	4.285	50.530			
						Total length	52.082

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE		PIPE LENGTH
R7							
1		54.815	4.160	50.655			2.003
2		54.815	4.047	50.768			2.004
3		54.815	3.917	50.898			2.002
4		54.815	3.819	50.996			2.007
5		54.815	3.655	51.160			2.006
6		54.815	3.495	51.320			2.006
7		54.815	3.335	51.480			2.005
8		54.815	3.189	51.626			2.005
9		54.815	3.045	51.770			2.003
10		54.815	2.935	51.880			2.006
11		54.815	2.784	52.031			2.014
12		54.815	2.549	52.266			2.001
13		54.815	2.498	52.317			2.002
14		54.815	2.411	52.404			2.003
15		54.815	2.294	52.521			2.004
16		54.815	2.172	52.643			2.001
17		54.815	2.095	52.720			2.003
18		54.815	1.985	52.830			2.001
19		54.815	1.922	52.893			2.001
20		54.815	1.875	52.940			2.000
21		54.815	1.865	52.950			2.001
22		54.815	1.819	52.996			2.000
23		54.815	1.810	53.005			2.000
24		54.815	1.793	53.022			2.000
25		54.815	1.750	53.065			2.000
26		54.815	1.753	53.062			2.002
27		54.815	1.655	53.160			
						Total length	52.082
URC		54.815	1.435	53.380			

STATION	B.S.	H.I.	F.S.	ELEVATION	DISTANCE
POS. E					
B.M.	0.892	50.892		50.000	21.000
W.S.		50.892	1.767	49.125	20.400
LRC		50.892	0.351	50.541	32.500
R1-1		50.892	1.405	49.487	8.500

Appendix E

Soil Grain Size Analysis by Sieve Method

Objective:

To determine the grain size distribution and the soil type. The soil is from the Horticulture Center of MacDonald Campus, of McGill University.

Apparatus:

1. A set of sieves with different opening sizes.
2. A sieve shaker.
3. An electronic weighing device.

Procedure:

1. 10 soil samples were collected from the field in depths of 30 cm and depth of 60 cm. These samples were attain with the use of a soil auger.
2. Put all 10 samples in oven to evaporate all the moisture content in the soil.
3. Weigh all 10 samples
4. Stack the set sieves with smaller openings on the bottom. Add the bottom pan and soil sample.
5. Set the assembled sieve set in the shaker and shake for a minimum of 10 minutes.
6. Take the sieve set apart and weigh each sieve with its contents, making sure to include the pan.

Results

The fraction of soil type in each size range is the mass retained in each sieve divided by the total weight of the soil. The percent finer is the total soil mass which has passed through a particular sieve, what was captured on sieves of smaller opening sizes and what was on the bottom pan, divided by the total weight of the soil and multiplied by 100%. The grain size distribution can be classified on the USDA triangular soil texture chart.

Data Table

Soil particle analysis

Sample	Weight(g)
1	297.01
2	396.93
3	352.56
4	397.80
5	370.86
6	374.87
7	519.29
8	413.26
9	336.73
10	495.80

Grain Size Distribution

Sample	>1.7mm	>1.0mm	>0.84mm	>0.295mm	>0.045mm	>0.000045mm	<0.000045mm	Total weight(g)
1	92.91	44.03	14.37	57.51	10.19	53.03	24.97	297.0
2	120.00	58.16	18.04	76.97	14.48	75.85	33.43	396.9
3	63.80	35.22	11.50	66.60	19.13	121.32	34.99	352.5
4	85.35	40.29	12.15	67.32	19.50	148.27	24.92	397.8
5	82.37	41.48	15.18	84.17	21.11	108.03	18.52	370.8
6	71.24	36.32	12.92	67.53	17.36	150.56	18.94	374.8
7	114.28	45.66	15.29	86.09	28.63	203.37	25.97	519.2
8	85.25	38.71	13.23	72.11	23.26	163.54	17.16	413.2
9	41.48	27.79	9.36	56.07	21.39	176.63	4.01	336.7
10	103.37	37.08	10.48	54.38	22.01	244.60	23.88	495.8

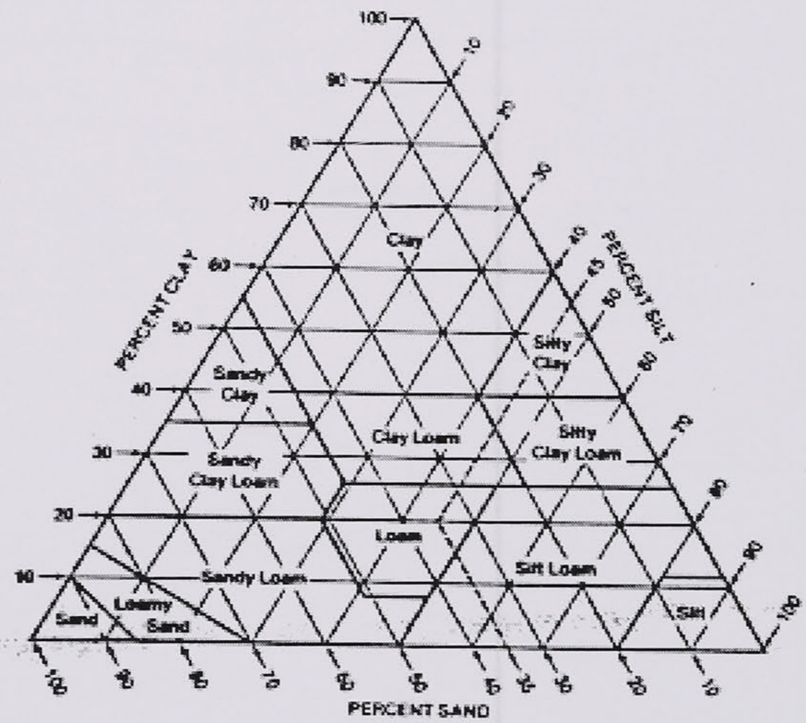
Percentage Grain Size Distribution

Sample	%sand	%silt	%clay
1	70.31	21.29	8.41
2	68.82	22.76	8.42
3	50.24	39.84	9.92
4	51.56	42.17	6.26
5	60.18	34.82	4.99
6	50.15	44.79	5.05
7	50.32	44.68	5.00
8	50.65	45.20	4.15
9	40.00	58.81	1.19
10	41.41	53.77	4.82
Average->	**53.36**	**40.81**	**5.82**

USDA triangular soil texture chart

By plotting the percentage particle distribution on the USDA triangular soil texture chart we determine the percent of:

Sand	=	53.36%
Silt	=	40.81%
Clay	=	5.82%



USDA soil textural triangle.

Conclusion:

From the soil texture triangle, we determine that the soil collected from the field is sandy loam. Using a soil map of the Ste-Anne-de-Belleuve area, we found that the soil type for the on the apple orchard is St. Bernard sandy loam.

Appendix F

OPERATION MANUAL

Operation Manual

Drip Irrigation Components:

Component	Quantity	Product Number
Main Line	61 meters	PPC-100-100
Flush Line	34 meter	PPC-100-100
Lateral Drip Hoses	1 row = 56.2 meter total = 400 meter	PPC-50
Drippers/Emitters	378 drippers	DDP-305
Main Valves	1	69-900
Flush Valves	2	68-200
L - Elbow	1	806-010
T - Elbow	1	801-130
Filter	1	FIL-100
Pressure Gage	1	790-101
Hole puncher	2	HP125

In the installation of the drip irrigation system it is essential to flush the drip system. It is necessary to flush the drip system at several times during installation in order to keep the lines clean and free from dirt. Stakes should be pounded into the ground, marking the site thus preventing hoses from being knocked around and from breaking. After the entire site has been marked, determine the location of the emitters, and the placement on the drip hoses.

In the apple orchard, we determined that we would lay the drip hose and emitters on the surface of the soil. Once the main line and laterals have been laid, each line and valves should be kept open in order to flush the lines. Once flushing has been completed the lines should be closed off one at time working down the slope. After all of the emitters are punched into the line, all of the valves should be then be reopened and the lines flushed once again for three to five minutes, this will test the entire system for leaks. The valves should also be closed in sequence from the highest to the lowest slope. After the installation has been completed the system should then be allowed to run and each emitter inspected carefully.

Operating parameters:

1. Overall operating pressure: 162.74 kPa
2. Average lateral pressure: 145.0 kPa
3. Total discharge rate: 0.346 L/s
4. Discharge rate at each emitter: 3.47 L/h
5. number of hours of operation: 8 hours
6. number of emitters or drippers per tree: 2

General Maintenance

Daily

1. Check coupling & closure gaskets under pressure.
2. Check the system operation pressure.

Weekly

1. Check flow meter to maintain proper flow rate.

Monthly

1. Clean the filter.
2. Valve lubrication.

Quarterly

1. Inspect pipe connection.
2. Chlorine treatment.

Seasonal Shut Down

1. Valve lubrication.
2. inspect valve internal components.
3. Chlorine treatment.
4. Acid treatment.

Cleaning the system when clogging occurs

The most common causes of clogging of a drip irrigation system are the precipitation of calcium carbonate ($CaCO_3$), iron oxide (Fe_2O_3), bacterial slimes and algae growths. Use of the acidification for calcium and iron precipitates ,and chlorination for bacterial and algae are the most effective treatments when clogging occurs.

General Treatment Procedures for Calcium and Iron clogging

1. Determine the flow rate of the emitter.
2. Determine the pressure at the first and last emitters of the lateral.
3. Inject water that acidified to pH $_2$ to the line.
4. Check pH at ends of lines.
5. Adjust the injection rate until the entire system has reached the correct pH.
6. After injecting the acidified water for 60 minutes, stop the injection and shut down the system for 24 hours.
7. Flush the entire system.

General Procedure for Chlorinating

1. Inject chlorine a point before the filter.
2. Calculate the volume of chlorine to be injected.
3. Injection should occur when the system is running.
4. Determine the chlorine level at the drip emitter on the nearest lateral using a chlorine test kit.
5. Adjust the injection rate.
6. Repeat steps 4 and 5 until the chlorine level have reached 10 to 20 mg/L.
7. Shut the system down, leave for 24 hours.
8. Flush the entire system.

In cold weather the system should be taken in inside or if not removed during the winter months, must therefore be flushed prior to the onset of cold weather. Steps of sequential flushing are the same as those used in the initial installation.

Appendix G

Cost Analysis

Area of the field = 2000 m^2 (0.2 hectares)

Accessories Cost

Accessories Summary

	Length(m)	Diameter(mm)	Qty.	Part No.	Cost
Main Pipe	65	25.4	1	PPC-100-100	
Flush Pipe	34	25.4	1	PPC-100-100	
Total	**99**				395.59
Connection pipe	0.5	12.7	14	PPC-50	
Total	**7**				
Fitting					
L-Elbow		25.4	8	806-010	6
T-Elbow		25.4 to 12.7	14	801-130	6
(Main-Lateral)					
Lateral:					
R1 (row 1)	58	12.7	1	PPC-050	
R2	58	12.7	1	PPC-050	
R3	58	12.7	1	PPC-050	
R4	58	12.7	1	PPC-050	
R5	58	12.7	1	PPC-050	
R6	58	12.7	1	PPC-050	
R7	58	12.7	1	PPC-050	
Total	**406**				556.44
Dripper/ Emitters			400	DPP-305	108.88
Flush Valve		25.4	2	68-200	15.12
Filter			1	FIL-100	34.26
Pressure gage			1	790-101	56.23
Main Valve (pressure adjustable)			1	69-900	23.55
Hole puncher			2	HP125	38.4
				Total	**1240.47**

Total Accessories Cost

	1240.47
GST	86.83
PST	86.27
TOTAL	**1413.57**

Note: All price and part no. based on the 1996 Catalogue from :

Distribution Viking
5897, Chemin Saint-Francois, Ville St-Laurent
Quebec H4S 1B6

Cost of Installation:

Consulting Cost: (Waived)

Surveying the field = ($500.00)

Soil Analysis = ($200.00)

Design = $150/hour x 30 hours

= ($4,500.00)

Supervising the construction = $150/hour x 8 hours

= ($1,200)

Labor Cost (including equipment):

@$85.00 / hours x 40 hours = $3,400.00

Total Cost of the Drip Irrigation System

= ($6,400.00) + 3,400 .00 + 1,413.57

= <u>$4,813.57</u>

Appendix H

References:

Schwab, Glenn O., Fangmeier, Delmar D., Elliot, William J., and Frevert, Richard K. Soil and Water Conservation Engineering . New York: John Wiley an Sons Inc. 1993.

Jensen, M.E., ed. Design and Operation of Farm Irrigation Systems. Michigan: James A. Basselman, 1980.

Hinz, Frost, Sneed and Schiltz., ed. Irrigation. Maryland: The Irrigation Association, 1983.

Balogh, J. and Gergely, I. Basic Aspects of Trickling Irrigation. Budapest, 1985.

Nakayama, F.S., Bucks, D.A. Trickle Irrigation of Crop Production. Tokyo: Elsevier, 1986.

Karmeli, David. Trickle Irrigation Design. California: Rain Bird Manufacturing and Corporation, 1982.

Gurjar, Ram Kumar. Geographical Perspectives on Irrigation. India: Rawat Publications, 1990.

Hoffman , G.J., Howell, T.A., and Solomon, K.H., e.d. Management of Farm Irrigation Systems. Michigan: Technical Publication, 1990.

Oomen, Wolf and Jobin. Health and Irrigation. The Netherlands: ILRI pub., 1990.

Worthingrton, E.Barton,. e.d. Arid Land Irrigation in Developing Countries, Environmental Problems and Effects. New York: Pergamon Press, 1977.

Use of Remote Sensing Techniques in Irrigation and Drainage. Italy: Food and agriculture Organization of the United Nations, 1995.

A compilation of Trickle Irrigation of Papers. Michigan: ASAE, 1978-1979.

Drip/Trickle Irrigation in Action, vol. 1. California: ASAE, 1985

Drip/Trickle Irrigation in Action, vol. 2. California: ASAE, 1985

Clark, Ga., Maynard, D.N., and Stanley, C.D. Drip -Irrigation Management for Watermelon in a Humid Region. Applied Engineering Agriculture: ASAE, 1996.

Landscape Irrigation Products, 1995-1996 Catalog. Rainbird.

Cuenca, R.H. Irrigation System Design: An Engineering Approach. NJ: Prentice Hall, 1989.

Appendix I

Footnotes

[1] Hinz, Frost, Sneed and Schiltz., ed. Irrigation. Maryland: The Irrigation Association, 1983.

[2] Hinz, Frost, Sneed and Schiltz., ed. Irrigation. Maryland: The Irrigation Association, 1983.

[3] Jensen, M.E., ed. Design and Operation of Farm Irrigation Systems. Michigan: James A.Basselman, 1980.

[4] Jensen, M.E., ed. Design and Operation of Farm Irrigation Systems. Michigan: James A.Basselman, 1980.

[5] Balogh, J. and Gergely, I. Basic Aspects of Trickling Irrigation. Budapest, 1985. Editor

[6] Balogh, J. and Gergely, I. Basic Aspects of Trickling Irrigation. Budapest, 1985.

[7] Balogh, J. and Gergely, I. Basic Aspects of Trickling Irrigation. Budapest, 1985.

[8] Schwab, Glenn O., Fangmeier, Delmar D., Elliot, William J., and Frevert, Richard K. Soil and Water Conservation Engineering . New York: John Wiley an Sons Inc. 1993.

[9] Schwab, Glenn O., Fangmeier, Delmar D., Elliot, William J., and Frevert, Richard K. Soil and Water Conservation Engineering . New York: John Wiley an Sons Inc. 1993.

[10] Hoffman , G.J., Howell, T.A., and Solomon, K.H., e.d. Management of Farm Irrigation Systems. Michigan: Technical Publication, 1990.

[11] Clark, Ga., Maynard, D.N., and Stanley, C.D. Drip -Irrigation Management for Watermelon in a Humid Region. Applied Engineering Agriculture: ASAE, 1996

[12] Clark, Ga., Maynard, D.N., and Stanley, C.D. Drip -Irrigation Management for Watermelon in a Humid Region. Applied Engineering Agriculture: ASAE, 1996

[13] Worthingrton, E.Barton,. e.d. Arid Land Irrigation in Developing Countries, Environmental Problems and Effects. New York: Pergamon Press, 1977

[14] Use of Remote Sensing Techniques in Irrigation and Drainage. Italy: Food and agriculture Organization of the United Nations, 1995.

[15] Drip/Trickle Irrigation in Action, vol. 1. California: ASAE, 1985

[16] Drip/Trickle Irrigation in Action, vol. 1. California: ASAE, 1985

[17] Worthingrton, E.Barton,. e.d. Arid Land Irrigation in Developing Countries, Environmental Problems and Effects. New York: Pergamon Press, 1977

[18] Worthingrton, E.Barton,. e.d. Arid Land Irrigation in Developing Countries, Environmental Problems and Effects. New York: Pergamon Press, 1977

[19] Karmeli, David. Trickle Irrigation Design. California: Rain Bird Manufacturing and Corporation, 1982.

[20] Karmeli, David. Trickle Irrigation Design. California: Rain Bird Manufacturing and Corporation, 1982.

[21] Drip/Trickle Irrigation in Action, vol. 2. California: ASAE, 1985

[22] Drip/Trickle Irrigation in Action, vol. 2. California: ASAE, 1985