BEST MANAGEMENT PRACTICES

Irrigation Management

REVISED EDITION, 2004

Canada

Ontario

CONVERSION TABLES

Lateral Pipe Requirements

LATERAL SPACING (feet)	(metres)	PIPE PER ACRE* (feet)	PIPE PER HECTARE* (metres)
20	6	2178	1667
30	9	1452	1111
40	12	1089	833
45	15	968	667
50	18	871	556
75	25	581	400
100	30	436	333

*** Main and submain requirements are not included.**

Metric Measurement Conversions

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
Length				
mm	millimetres	0.039	inches	in or ″
m	metres	3.281	feet	ft or ′
km	kilometres	0.621	miles	mi
Area				
m^2	square metres	10.764	square feet	ft^2
km^2	square kilometres	0.394	square miles	mi^2
ha	hectares	2.471	acre	ac
Volume				
L	litres	0.264	gallons	gal (US)
L	litres	0.220	gallons	gal (Imp)
L	litres	0.001	cubic metres	m^3
Rate				
L/s	litres per second	15.850	gallons per minute	gpm (US)
L/m	litres per minute	0.264	gallons per minute	gpm (US)
m^3/s	cubic metres per second	35.31	cubic feet per second	cfs
Other				
W	watts	0.00134	horsepower	hp
P	kilopascals	0.15	pounds/sq. in	p.s.i.

To convert from Imperial to metric units, divide by the number in column 3. For example, when you know inches, say 1.5, to find millimetres, divide 1.5 by .039 = 38.1 mm.

For a more complete set of metric measurement conversions, refer to OMAF Publication 75, *Guide to Weed Control.*

What is a Best Management Practice or "BMP"?

- a proven, practical and affordable approach to conserving soil, water and other natural resources in rural areas

Who decides what qualifies as a BMP?

- a team that represents many facets of agriculture and rural land ownership in Ontario, including farmers, researchers, natural resource managers, extension staff and agribusiness professionals

What is the BMP Series?

- innovative, award-winning, full-colour books presenting options that can be tailored to meet your particular environmental concern and circumstances
- current BMP titles are:
  Buffer Strips
  Farm Forestry and Habitat Management
  Field Crop Production
  Fish and Wildlife Habitat Management
  Horticultural Crops
  Integrated Pest Management
  Irrigation Management
  Livestock and Poultry Waste Management
  No-Till: Making It Work
  Nutrient Management
  Nutrient Management Planning
  Pesticide Storage, Handling and Application
  Soil Management
  Water Management
  Water Wells

How do I obtain a book?

- if you're an Ontario farmer, single copies of each title are available at no cost at your nearest Ontario Ministry of Agriculture and Food location
- to purchase single copies or bulk orders of all other titles, and to order complete sets of BMP books, please contact: Ontario Federation of Agriculture, Attn: Manager, BMP, 40 Eglinton Ave. E., 5th flr., Toronto, Ontario M4P 3B1. Phone: 416.485.3333
- for an on-line order form, go to: http://www.gov.on.ca/OMAF/english/products/best.html
- please note that prices vary per title and with quantity ordered

Table of Contents

1 INTRODUCTION

3 Benefits of Irrigation
5 Protecting Water Resources
6 Design, Materials and Management

8 WATER SOURCES

9 Types of Water Sources
17 Water Quality Concerns

19 LEGISLATION, POLICY AND PERMITS – WATER-TAKING AND LOW WATER RESPONSE

19 Permit To Take Water
21 Ontario Low Water Management
22 Some of the Legislation and Guidelines Protecting Water Resources

24 SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

24 Water Cycle
25 Water Balances: Rainfall and Crop Requirements
25 Soil Water
27 Crop Water Requirements
28 Irrigation Scheduling
29 Monitoring Soil Moisture
29 Types of Measurements
30 Feel Method
30 Tensiometer
33 Electrical Resistance
33 Time Domain Reflectrometry (TDR)
33 Neutron Moisture Meter
34 Placing the Measurement Units
35 Soil Moisture Measurement Tools (summary chart)
38 Using the Plant to Indicate Water Stress
39 Evapotranspiration
40 Irrigation Scheduling Using Evapotranspiration Data: The Water Balance Method
47 Scheduling by Computer
47 Considerations for Applying Irrigation Water

48 IRRIGATION SYSTEMS

49 Sprinkler Irrigation
50 Fixed Sprinkler Systems
55 Mobile Sprinkler Systems
61 Micro-Irrigation (also called drip or trickle)
64 Subsurface Drip Irrigation
65 Controlled Drainage/Sub-Irrigation
66 Controlled Drainage
67 Sub-Irrigation
68 Irrigation Prices: $ Per Acre
69 Irrigation Pumps
69 Centrifugal Pumps
70 Turbine Pumps
71 Power Sources
71 Electric Motors
72 Internal Combustion Engines
74 Hardware
74 Pipe
75 Pipe Connections
76 Sprinklers

77 BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

77 Water Efficiency
80 Managing Rate of Water Use
81 Fruit Crops
83 Tree Fruit and Grapes

Table of Contents

84 Berry Crops
86 Vegetable Crops
91 Tree Nut Crops
93 Tobacco
94 Field-Grown Nursery Stock
95 Container-Grown Nursery Stock
97 Sod

98 SPECIAL APPLICATIONS

98 Fertigation of Field Vegetables and Tree Fruit
103 Chemigation
105 Wind Erosion Control
106 Frost Protection of Berry Crops
107 Evaporative Cooling

109 ANALYZING THE COSTS AND BENEFITS

110 Worksheet 1: Water and Power Requirements
111 Worksheet 2: Annual Ownership, Repair and Maintenance Costs
113 Worksheet 3: Annual Operating Expenses
115 Worksheet 4: Cost/Benefit Summary
116 Worksheet 5: Break-Even Calculation
116 Repair, Maintenance and Expected Life

inside front cover
CONVERSION TABLES

inside back cover
IRRIGATION SCHEDULING WORKSHEET (photocopy for repeated use)

INTRODUCTION

Potentially high-value crops such as fruits, vegetables, tobacco, sod and nursery stock must be of top quality to win acceptance in the marketplace. Attaining quality requires timely management decisions – especially regarding crop production inputs.

Water, in the form of precipitation or irrigation, is one of the most critical crop inputs. Water must be supplied in sufficient quantity, of desired quality, when the crop needs it. But natural rainfall can be unpredictable. By controlling your crop's water supply, you are controlling an essential production variable. The importance of irrigation may increase in the coming years as a result of increased climate variability and fluctuation.

Beyond good soil management, irrigation is the best strategy available to meet your crop's water requirements when natural rainfall is inadequate. This book will help you plan and implement best management practices to fulfill water needs profitably, safely and in an environmentally responsible way.

Irrigation does not suit every operation. Its benefits must outweigh its costs. Consider the criteria on the next page before purchasing, modifying or simply assessing your irrigation system requirements.

Potatoes, whether for the table or processing, need irrigation to obtain high quality and yields.

A successful celery crop depends on irrigation.

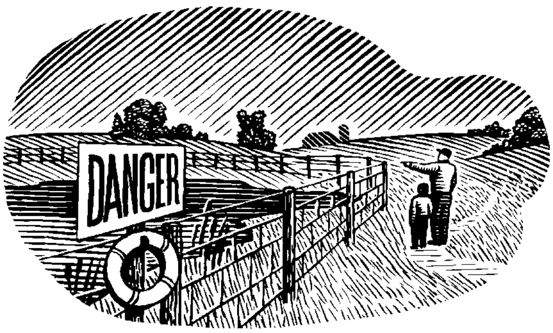
INTRODUCTION

IF YOU'RE CONSIDERING AN IRRIGATION SYSTEM

GENERAL CRITERIA	DETAILS
WATER QUALITY	• irrigation water should be free of contamination from pesticides (herbicides), heavy metals, organic solids, salts, nematode and other parasitic organisms • water should be of desirable temperature and pH
WATER QUANTITY	• sufficient volumes must be available on demand within reasonable distance • design should accommodate peak crop needs (for frost protection, design should be able to accommodate several consecutive nights' use) • strategy should be in place to recharge limited volumes of water
REGULATIONS & LEGAL CONSIDERATIONS	• these must be complied with before drawing water to irrigate • *Ontario Water Resources Act* requires a Permit To Take Water from a surface or ground water source, or a combination of both, if the amount exceeds 50,000 litres (10,000 Imp gal) per day
CAPITAL	• capital investment and operating costs can vary dramatically depending on system type, power sources, usage pattern, crop, field location and maintenance
LABOUR & MANAGEMENT	• irrigation systems demand differing degrees of input
ENVIRONMENTAL IMPACT	• irrigating should not jeopardize the water cycle of a fragile ecosystem, nor interfere with quantity or quality of flowing water for downstream users
SAFETY	• an irrigation pond poses a potential hazard, especially in areas where there is easy access • fencing should be provided, with Warning signs posted in high risk situations • certain irrigation systems may carry an inherently high risk while in use, because of high operating pressure or potentially dangerous electrical energy

Each system demands differing degrees of labour input.

With these considerations in mind, let's look at the reasons for choosing irrigation.



Where possible, irrigation ponds should be fenced and signed.

INTRODUCTION

BENEFITS OF IRRIGATION

ESTABLISHMENT

- recently transplanted or seeded crops require water for root establishment /germination, especially tree fruits and nuts, berry crops, grapes, nursery stock and field vegetables

GROWTH AND VIGOUR

- plants require water for all phases of growth, including cell division, cell elongation, photosynthesis and transpiration during the growing season – it is the process of transpiration that provides a cooling effect to the crop as it grows

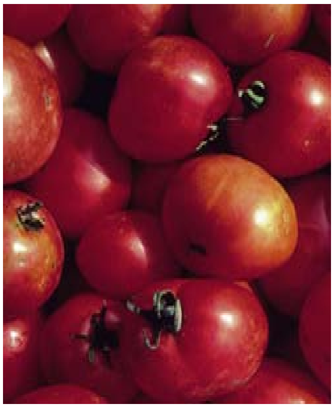
FLOWER-SETTING AND FRUIT DEVELOPMENT

- adequate water supply enhances fruit and flower bud formation (feathering in young trees), flowering, fruit set and fruit sizing

QUALITY

- the flavour, appearance and post-harvest attributes of certain fruits and vegetables can be improved with water-efficient irrigation in situations where rainfall or available soil water is limited. In some situations, some fruit and vegetable crops may not respond positively to irrigation water in terms of flavour or sugar development. (This may be cultivar- and soil type-specific.)

All crops require an adequate moisture supply for growth and development. Vegetative growth and early development are accelerated by irrigating and protecting this hazelnut or filbert planting.

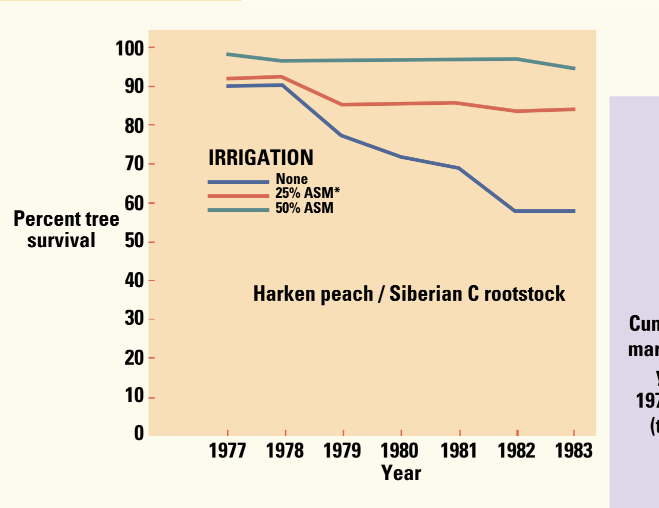


Most high-value crops require properly timed and adequate moisture supplies. Irrigating fresh-market tomatoes enhances size, volume and texture of produce in a dry year.

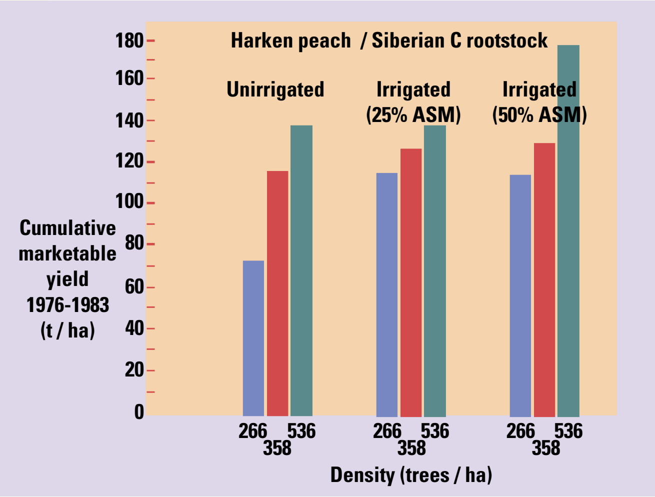
Reliable and healthy transplant stock is what the landscape industry requires. Irrigation can help.

INTRODUCTION

Irrigation helps a young peach orchard become established. Young trees need ample water for root development, shoot growth and fruit bud initiation. Overall, marketable yield is increased.



*ASM = Available Soil Moisture



SPECIAL APPLICATIONS

- ► evaporative cooling to ensure quality fruit and continued crop development under conditions of excessive heat, e.g., strawberry, nursery stock
- ► frost protection of high-value crops, e.g., vegetables and tobacco, fruit, asparagus and berries
- ► wind erosion protection of soil and crops in extreme conditions, e.g., vegetables and tobacco
- ► seedbed activation of direct-seeded vegetable crops, e.g., rutabaga, carrot
- ► chemigation and fertigation: crop protection materials and necessary nutrient treatments can be applied at a lower cost to the producer. Fertilizer treatments can be applied with precision, e.g., tree fruits, nursery stock, berry crops, vegetables.

Fertigation involves supplying water and nutrients at the same time. Compared to untreated checks, yield increases of up to 20% have been measured with the fertigation of high-value crops such as green peppers.

Irrigation can help you avoid losses of high-value crops. For example, frost damage on strawberries can be prevented with sprinkler irrigation during the bloom period. The blossom shown here is not freezing. As irrigation water is applied, it turns to clear ice, releasing a small amount of heat that prevents the blossom from freezing.

INTRODUCTION

PROTECTING WATER RESOURCES

Irrigation depends on reliable supplies of fresh, clean water from surface and/or ground water sources. You must be aware of potential impacts that your irrigation system has on the quantity and quality of ground and surface water.

SUMMARY OF ENVIRONMENTAL CONCERNS

CONCERN		ASK YOURSELF
QUALITY		• **is quality of irrigation water not used by the crop and returned to the hydrologic (water) cycle good enough for downstream users, and for reuse?** • **will water from deep ground water sources, which can contain impurities, have harmful surface water impacts?** • **is source water of reliable quality for intended use?**
QUANTITY	Sources	• **are you putting aquatic systems at risk?** ◦ large rivers and lakes within reach (< 2 km) can supply large amounts of water, while small watercourses and wetlands have limited supplies ◦ construction of dams, ponds and stream pumps to facilitate water-taking can disturb watercourses, and ultimately disrupt the aquatic ecosystem ◦ in some situations, a minimum suction screen size will prevent destruction of small fish ◦ ground water supplies may not be sustainable ◦ cumulative effect of several water-taking projects on a single ground or surface water source should be evaluated ◦ excessive taking from ground water may result in contaminants travelling from upper ground water to deeper aquifers ◦ stands of deeply rooted woody perennials such as apple orchards or natural woodlots can suffer from drastic changes in water table depth ◦ large ground water-takings can lower levels in wetlands, small streams, and in nearby wells
	Measuring Quantity	• **are you measuring and recording water quantity used according to conditions of your Permit To Take Water?** ◦ water used must be accurately recorded
	Equipment	• **are you maintaining and using equipment properly?** ◦ pressure gauges become unreliable if used for purposes other than irrigation, e.g., spreading liquid manure • **are you using the best available technology to conserve water?**
	Timing	• **can you time water-taking to ensure adequate flow remains?** ◦ time water applications for desired crop response ◦ take no more than 10% of flow from surface water sources, e.g., rivers, creeks, streams ◦ take surplus water only when impact on aquatic ecosystems and hydrology is minimal

INTRODUCTION

A large river like this one can be a suitable source of water. Wetlands and smaller watercourses are not as well suited to irrigation.

Taking large amounts of water from ground water can lower levels in wetlands, small streams and nearby wells.

DESIGN, MATERIALS AND MANAGEMENT

The main components of an irrigation system are design, materials and ongoing management.

Design must take into account your crop's needs and response along with the environmental concerns listed in the previous chart. Materials include power source, pumps, conduit pipes, emission points and monitoring devices. Ongoing management includes monitoring, record-keeping, scheduling and application.

Irrigation technology is improving, responding to growers' demands for more efficient systems. Newer systems meet crop needs with more efficient distribution of water. Gentler application methods help maintain soil structure, and also help to avoid surface compaction problems.

Irrigation can help growers service niche markets with more predictable volumes of high-quality produce.

Trickle irrigation systems can deliver water to where the crop needs it, efficiently and economically, as shown here with high-density apples on M9 rootstock.

INTRODUCTION

INDUSTRY STANDARDS FOR MEASUREMENT

Throughout this book, there's a mix of metric and Imperial measurements. Although convention calls for metric, irrigation presents a special case.

Most of the technology used – pumps, gauges, pipes and nozzles – is developed in the United States. Most measurements are in Imperial units, with the exception of flow rates (US gallons per minute – US gpm).

In this book, in many cases Imperial units will be presented first, followed by metric in brackets, e.g., 4-inch (100-mm) pipe. For water volumes and flow rates, we'll use acre inches and US gpm, with no metric conversions – to conform with industry standards.

For help with a variety of conversion factors, please see the inside front cover of this book.

WATER SOURCES

Be sure you know the recharge rate of your water supply – particularly during periods of greatest need and lowest supplies.

When you draw water for irrigation, you must ensure there are no long-term implications for the local environment, and no short-term interference with other uses. More specifically, you need to know:

- an estimate of how much water might be needed
- how continuous the supply is (or the recharge rate), especially during the time of need when conditions are the driest and supplies usually the lowest
- that the quality of water matches the needs of the crop to be irrigated
- how the location of the water supply impacts the design and cost of the system, i.e., horizontal distance and vertical lift
- the repercussions if adequate water isn't available
  - a shortage of water with micro-irrigation systems (also known as "drip" or "trickle") can be disastrous
  - running out of water while protecting a crop from frost can also be disastrous – e.g., small fruit or berry growers should have a water inventory capable of use for several consecutive nights of frost protection
- whether the amount of water you're taking is environmentally sustainable
  - effects on fish and fauna – a large suction inlet cuts down on water velocity entering the intake pipe, and allows fish to escape
  - effects on quality and quantity of water in adjacent bodies of water
  - effects on the water table.

Here are some calculations with conversions to help you estimate the volumes required:

1 acre inch of water =
3630 cu ft = 27,154 US gal = 22,610 Imp gal = 102,800 L

For example:
10 acres of land to be irrigated with 1½ inches (38 mm) of water

Volume required =
10 x 1.5 x 3630 = 54,450 cu ft of water = 339,150 Imp gal

Equivalent pond storage =
90 ft x 90 ft x 15 ft (27 m x 27 m x 4.6 m)

A 10 Imp gpm* well would take 23.5 days to pump sufficient water to cover this acreage.

To irrigate this field directly from a well in a 10-hour period would require a well with a pumping rating of greater than 565 Imp gpm.

A pump capable of delivering 1,200 US gpm can fill a 900 US gal tank in 45 seconds.

***gpm = gallons per minute**

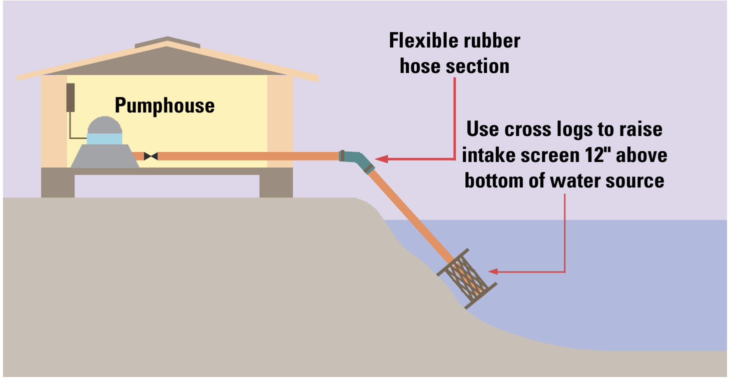
WATER SOURCES

TYPES OF WATER SOURCES

LAKES

- are an abundant source
- aren't always accessible and may require extra suction lift if elevation differs substantially from lake level to field
- can be used to replenish irrigation ponds
- are important habitats for fish and wildlife – try to keep impact to a minimum, i.e., keep fish out of water intakes
- offer, generally speaking, good water quality for irrigation
  - variables include water source feeding the lake, and events such as heavy rainfall and runoff at particular locations (such as the mouths of rivers)
  - monitor water quality during the irrigation season

Lakes can be an excellent source of water for irrigation.



An intake apparatus like this one helps reduce damage to aquatic life.

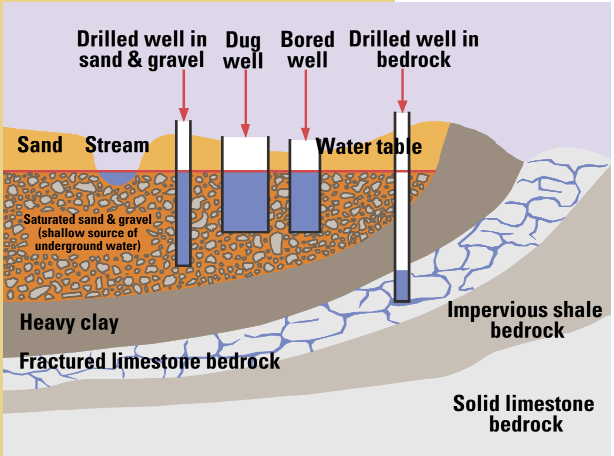
RIVERS AND STREAMS

- must be deep enough to pump from
- aren't always accessible and may require extra suction lift if elevation differs substantially from the surface of the water to the field
- contain sediment and other pollutants that can plug micro-irrigation systems
- are used by others: water-taking shouldn't interfere with their rights
- are important habitats for fish and wildlife: to minimize impact, take action such as keeping fish out of water intakes
- offer a range of water quality
  - variables include events such as heavy rainfall, as well as neighbouring land uses
  - even with regular monitoring, take extra caution with more sensitive irrigation applications (e.g., strawberries versus corn)
- can be used to replenish irrigation ponds but care must be taken to maintain flow

Rivers and streams are moderate to good sources. Low flow usually coincides with periods of crop need. Harvest water during or near times of peak flow.

WATER SOURCES

WATER WELLS



Dug and bored wells typically access shallow ground-water aquifers. Drilled wells access deeper aquifers, such as water-bearing rock formations.

- use shallow or deep aquifers
- can be dug, bored, drilled, or sand point
- will provide water, but not always at the rate or volumes needed
  - have it tested
  - pump it for at least 24 hours to determine drawdown and yield
- can be used to supplement pond storage
- may provide water that is too cold for irrigation
- can take enough water to drop water tables
  - irrigation from wells must not affect neighbouring ones
- provide water of the most reliable quality, often comparable to municipal water supplies
  - monitor the water quality during the irrigating season
  - avoid contamination through proper maintenance and the creation of a well protection zone to keep potential contaminants out of the well

PONDS

- offer a wide range of water quality, depending in part on water source that fills pond – ponds filled by rainfall or ground water usually provide better quality water
  - ensure water quality is sufficient for more sensitive irrigation applications (e.g., strawberries versus corn) – test regularly
  - create buffer zones around pond to prevent entry from runoff and other undesirable contaminants
  - if harvesting water from a stream or river after rain, avoid taking water during peak flow – peak flows tend to carry more sediments and contaminants

WATER SOURCES

FARM POND WATER CAPACITY

Water Surface Dimension Feet (metres)	Water Depth Feet (metres)	Capacity			
		Litres	US Gallons	Imp Gallons	Acre Inches
100 x 60 (30 x 20)	10 (3)	906,100	239,400	199,300	8.8
100 x 100 (30 x 30)	10 (3)	1,812,200	478,700	398,700	17.6
100 x 100 (30 x 30)	15 (4.5)	2,081,200	549,800	457,900	20.3
100 x 150 (30 x 45)	10 (3)	2,944,900	777,900	647,900	28.7
100 x 150 (30 x 45)	15 (4.5)	3,567,800	942,500	784,900	34.7
100 x 300 (30 x 90)	10 (3)	6,342,800	1,675,500	1,395,400	61.7
100 x 300 (30 x 90)	15 (4.5)	8,027,600	2,120,600	1,766,100	78.1
100 x 500 (30 x 150)	10 (3)	10,873,300	2,872,300	2,392,100	105.8
100 x 500 (30 x 150)	15 (4.5)	13,973,900	3,691,400	3,074,300	136.0

Based on pond measurement at water surface with side slopes of 2 (horizontal): 1 (vertical).

Conversions:
- 1000 litres = 1 cubic metre
- 3.785 litres = 1 gal (US)
- 4.546 litres = 1 gal (Imp)
- 28.32 litres = 1 cu ft water weighs 62.3 lbs
- 3.785 litres = 1 gal (US) water weighs 8.3 lbs
- 4.546 litres = 1 gal (Imp) water weighs 10 lbs

DUGOUT POND

CONSTRUCTION

- ▸ storage volume determined by how much is excavated
- ▸ side slopes 2:1 (horizontal:vertical) or flatter
- ▸ depth 10 feet (3 m) or more if possible (to help with weed control)
  - ▹ best source is where there's a shallow water table in a pervious soil

MAIN WATER SOURCES

Direct Rainfall

- ▸ not adequate to fill or replenish storage (approx. 39 in/yr [1,000 mm])

Ground Water

- ▸ can be a good source – must be identified by experience within the region, or dig a test hole and observe over one summer season to determine dependability (recharge rate and static water level)

WATER SOURCES

Tile Drainage System

- generally not adequate as a total supply unless it's tapped into a spring that continuously supplies water
- main supply of water is in the spring
- quality of water can be a concern depending on activities on the fields that the system services

Artesian Spring

- excellent source of water if quantity is adequate
- not very common to most of Ontario

Water Well

- can be a total or partial source of water if volumes are available to meet the need
- adds considerable cost to system if well has to be installed
- if pumped heavily, water level in neighbouring wells may be affected

Rivers, Streams, etc.

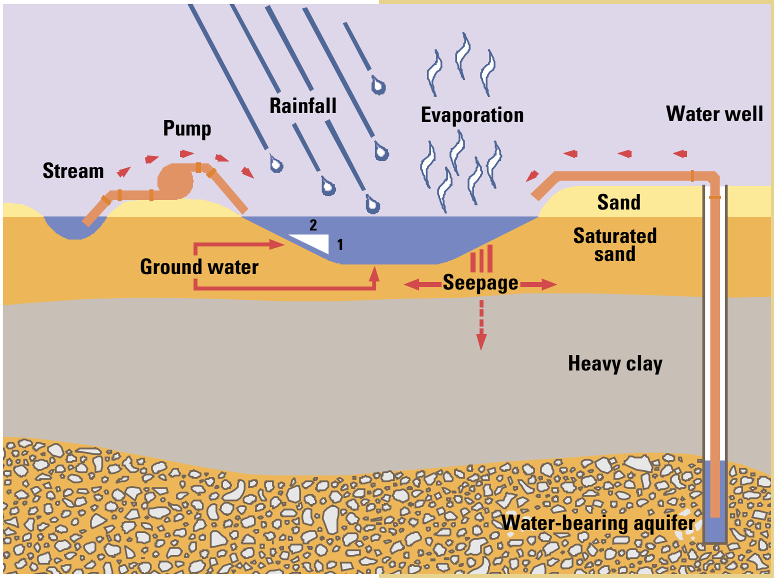
- excellent source of water if accessible and flows are adequate
- pond can be replenished by pumping water from stream into pond at a controlled rate so as not to affect other users and uses of stream, and at time of year that will have least impact (spring) – as a water user, you're required to maintain adequate water flow to maintain the basic functions of the ecosystem, e.g, fish habitat

PERMITS THAT MAY BE REQUIRED

- Permit To Take Water for > 50,000 litres (10,000 Imp gal) per day from Ontario Ministry of the Environment
- Permit to Construct from Conservation Authority if site is in the designated floodplain
- Permit to Construct from Ontario Ministry of Transportation if close to a highway
- Permit from Ontario Ministry of Natural Resources to build pond on a stream or river – permit for this use is seldom given
- Permit may be required within Niagara Escarpment Commission area

WATER SOURCES

Dugout ponds work best in poorly drained sandy soils when they can be replenished by ground water.



Dugouts can be replenished by many sources. From ground water, ponds can gain water from tile drainage, wells and ground water flow. Water can be pumped from lakes, rivers, streams and ponds. Ponds can also collect rainfall and snowmelt.

BYPASS POND

CONSTRUCTION

- storage volume is determined by how much is excavated
- side slopes are 2:1 (horizontal:vertical) or flatter
- depth is 10 feet (3 m)or more if possible (to help with weed control)
- locate adjacent to stream
- available space is sometimes limited if stream is located in valley

MAIN WATER SOURCES

Rivers, Streams, etc.

- excellent source of water if accessible and flows are adequate
- pond can be replenished by diverting water from stream into pond (through a diversion channel or pipe, at a controlled rate so as not to impact other users and uses of stream [< 10% of flow])
- you can select water with this system not only for quantity but also quality
  - after a storm, when water can be murky with sediment, etc., you can close diversion until water is cleaner
- for intermittent streams, pond needs to be sized bigger to give enough storage between runoff events
- bottom-draw outlets will release only deeper, cooler water, which benefits cool- and cold-water fish like salmon and trout

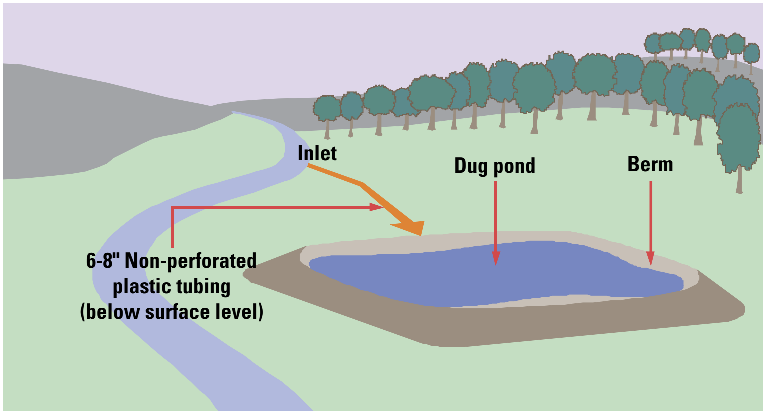
A bypass pond is created close to a stream by flowing water along a small channel. The channel enables a small portion of water (less than 10% of the flow) to flow from the stream or ditch to the pond.

WATER SOURCES

PERMITS THAT MAY BE REQUIRED

- Permit To Take Water for > 50,000 litres (10,000 Imp gal) per day from Ontario Ministry of the Environment (not only for irrigation but also to fill or refill pond)
- Permit To Construct from Conservation Authority if site is in the designated floodplain
- Permit To Construct from Ontario Ministry of Natural Resources
- a permit may be required within Niagara Escarpment Commission area
- a permit for a bypass pond may not be granted

Dammed watercourses are not bypass ponds. Dammed watercourses restrict fish migration.



A properly designed bypass pond can be replenished by diverting water (< 10% of flow) from a stream. Not all bypass ponds have outlets. If an outlet is included, it should be a bottom-draw outlet, as this will release only deeper, cooler water, which benefits cool- and cold-water fish like salmon and trout.

IMPOUNDMENT POND

An impoundment pond is formed by placing a dam across an intermittent stream, a draw or a valley – but not in a continuous-flow stream.

CONSTRUCTION

- a dam is built across an intermittent stream, a draw or a valley (but not in a continuous-flow stream)
  - involves specialized construction: layers of impervious soil are placed between two banks and compacted to form the dam
  - capable of holding back large volumes of water depending on the valley characteristics (slope, elevations, etc.)
- water is held back until it reaches a certain level, and excess water must be passed through an overflow device (spillway)
  - spillways can be made of concrete, steel or plastic, and must be sized according to the predicted flows
- the entire system must be designed according to sound engineering principles and built with equal attention – a failure could cause severe downstream damage
- can be very costly

WATER SOURCES

MAIN WATER SOURCES

Runoff

- runoff is the main source of water, and is prone to quality problems depending on the land activities in the runoff watershed
- runoff dams are dependent on surface runoff in the spring to fill; additional runoff in the summer isn't dependable enough for irrigation water
- the site must be of a soil type (preferably clay) to retain water, since the supply isn't dependable or continuous
- careful attention to site selection is important in attaining a healthy pond

Rivers, Streams, etc.

- excellent and dependable sources of water
- even though a dam usually can't be built across them, they can be used as a source of water by pumping into the pond if runoff is not adequate

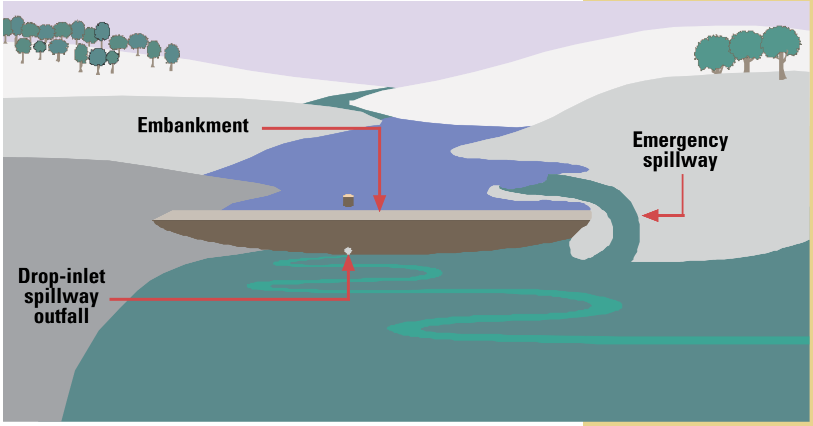
Note: dams on continuous-flow streams can cause serious problems to fish movement and habitat.

Approval for on-stream dams is rare because of the potential negative impacts.

Dams across ravine areas that don't have a stream in the bottom are the best option.

PERMITS THAT MAY BE REQUIRED

- Permit To Take Water, > 50,000 litres (10,000 Imp gal) per day from Ontario Ministry of the Environment
  - not only for irrigation but also to fill or refill pond
- Permit To Construct from Conservation Authority, if site is in the designated floodplain
- Permit to Construct from Ontario Ministry of Natural Resources
- Permit to Construct from Ontario Ministry of Transportation, if close to a highway



Impoundment ponds require a dam constructed of impervious layers, and a spillway to outlet excess water.

WATER SOURCES

SEEPAGE CONTROL – ALL POND TYPES

CLAY LINER

- line the pond with clay, 1–2 feet (0.3–0.6 m) thick, and compact; clay content should be greater than 30%
- trucking costs can be very expensive if clay isn't available nearby

BENTONITE

- a special kind of clay that expands 10–20 times its dry size when wetted
- when incorporated with the existing soil, bentonite can act as an excellent seepage reducer
- should not be considered equivalent to an impermeable liner

SYNTHETIC LINERS

- high- and low-density polyethylene, polyvinyl, hypalon and butyl rubber are examples of synthetic liners
- cost rises as durability and longevity increase
- prices of materials range from $0.75–$2.00 per square foot for most products used – costs could mount substantially with increased quality
- generally, the higher the price, the less site preparation required

Dugout ponds in drier medium-textured soils and drier coarse-textured soils may require artificial liners to reduce water loss.

ALGAE CONTROL IN IRRIGATION PONDS

A Permit to Purchase and/or Perform a Water Extermination must be obtained from Ontario Ministry of the Environment before a pesticide for control of aquatic weeds can be legally purchased and/or applied to surface water in Ontario (unless exempt).

An exemption from the permit requirement is made for "Agriculturists" who wish to treat a water body wholly confined within their property and where there is no outflow, at any time, beyond their property limits.

WATER SOURCES

WATER QUALITY CONCERNS

Water quality should always be of concern. The desired level of water quality will depend on crop type and resulting use. If you haven't already, you should:

- assess the importance of water quality for your operation
- test your water for *E. coli* or faecal coliforms, i.e., indicators of potential pathogens in the water
- protect your water source.

DESIRED IRRIGATION WATER QUALITY

CROP TYPE	DESIRED LEVEL OF WATER QUALITY
Not consumed, e.g., tobacco	•
Field crops	•
Consumed after cooking, e.g., sweet corn	••
Consumed raw where water is not applied to the food surface, e.g., tomatoes under drip irrigation	••
Consumed raw where water is applied in overhead irrigation e.g., bell peppers under sprinkler irrigation	•••
Consumed raw where water is applied in overhead irrigation and food surface is textured, allowing for water to remain trapped on the surface until eating (e.g., raspberries under sprinkler irrigation)	••••
Consumed raw, pick-your-own operation	••••

Legend – Quality

•	**Minimal**
••	**Medium**
•••	**High**
••••	**Very high**

WATER SOURCES

If you need high quality water, consider:

- ► changing to a water source with a high level of water quality
- ► buying an irrigation system where the water does not come in contact with the food product, such as a drip or subsurface drip system
- ► treating the water so that it adheres to Canadian Environmental Quality Guidelines for irrigation water, i.e., 100 faecal coliforms/100 ml; 1000 total coliforms/100 ml.

VARIABILITY OF WATER QUALITY FOR IRRIGATION

WATER SOURCE TYPE	VARIABILITY OF WATER QUALITY FROM THE TYPE OF SOURCE
River or stream	••••
Pond filled by stream, ditch or runoff	••••
Lake	•••
Pond filled by groundwater, spring or well	••
Well supplying directly to irrigation system	•
Municipal water supply	No variability

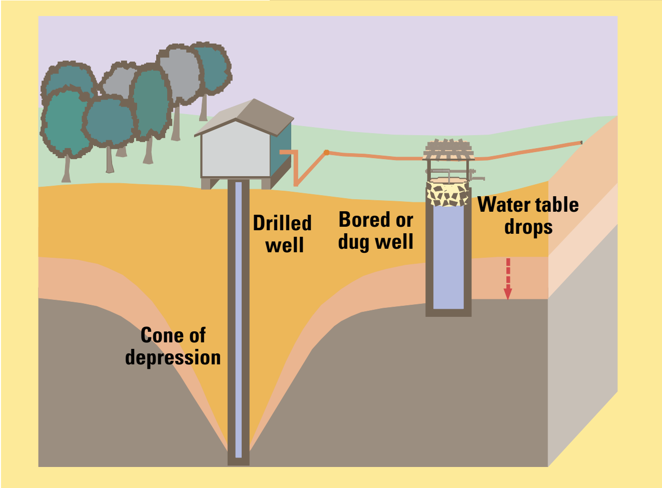
Legend – Variability

•	**Minimal**
••	**Moderate**
•••	**Medium**
••••	**High**

LEGISLATION, POLICY AND PERMITS – WATER-TAKING AND LOW WATER RESPONSE

To protect your rights and the rights of future water users, federal, provincial and local governments have created laws and guidelines that ensure an abundant supply of clean water.

Most of the water-related laws and guidelines that can directly influence the use of irrigation on your farm are listed at the end of this section. If you have concerns or questions regarding irrigation management on your property, be sure to contact relevant government agencies and be aware of bylaws in your area.



When large amounts of water are taken in a short period of time, a cone of depression is created in the area of deeper wells. This can cause neighbouring wells to run dry.

PERMIT TO TAKE WATER

A Permit To Take Water is required if you're taking in excess of 50,000 litres (10,000 Imp gal) per day for any use other than general household activities or livestock watering. The permit is issued under the *Ontario Water Resources Act.*

The permit's purpose is to ensure all water users and the aquatic environment get their fair share while protecting the resource. To make application for a permit, contact your local office of the Ontario Ministry of the Environment. See the blue pages of your telephone directory for the office nearest you.

If you plan to use greater than 50,000 litres per day from surface water, such as rivers, streams, creeks and irrigation ponds supplied by surface waters, **you will be required to provide the following information** with your application for a Permit To Take Water:

- the flow rate of the river, stream or creek (preferably measured during summer)
- a location map – see following page
- the estimated daily rate of water used
- the volume of water required for irrigation
- Global Positioning System (GPS) coordinates of withdrawal site if available
- a completed application form.

Note that the best management practice for replenishing ponds from surface water is to "harvest" the water during peak or high flow. This helps to prevent taking water from watercourses at lowest flows.

Harvest water during higher flows (during spring and/or after heavy rainfall) when withdrawals will have minimum impact on stream flow.

LEGISLATION, POLICY AND PERMITS – WATER-TAKING AND LOW WATER RESPONSE

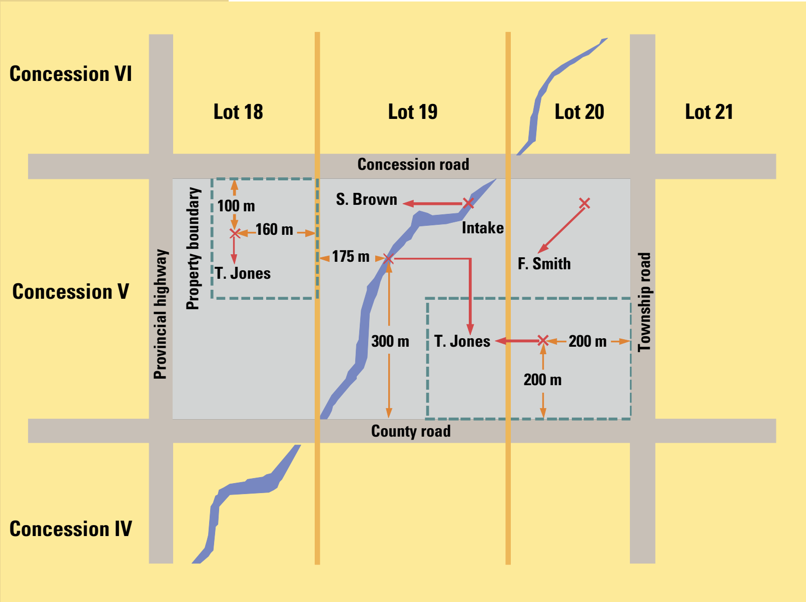
50,000 litres is equal to:

- **13,210 US gallons**
- **approximately ½ acre irrigated with 1 inch of water**
- **½ hectare irrigated with 10 mm of water**
- **a 500 US gpm irrigation gun operating for 26 minutes**
- **a 100 m^3/h irrigation gun operating for 30 minutes**
- **24 hours of lawn watering (at 7 Imp gpm)**

If you plan to use greater than 50,000 litres per day from ground water, either from a well, a pond replenished from a well or an excavated pond replenished directly by ground water, **you may be required to provide the following information** with your application for a Permit to Take Water:

- ► a completed Permit To Take Water application form
- ► GPS coordinates of withdrawal site if available
- ► a location map (see map below)
- ► water well records within the survey area
- ► details on pumping equipment and intake levels
- ► information on subsurface conditions, e.g., pits, drill holes or other excavations
- ► pumping test – indicate water level before and after maximum water-taking applied for and time taken for water level to recover.

The above information may be sufficient if ministry officials consider yours to be a low risk situation. Low risk means that there is minimal impact on surrounding users. If the taking is not deemed low risk, further information may be required by the Ontario Ministry of the Environment as determined by the specific situation.



Location maps for Permits To Take Water require general location (lot, concession, direction) as well as water supplies and wells within 0.3 miles (0.5 km) of your source of water. The map, together with estimates of water-taking and supply, will help in the assessment of potential impact on neighbouring users.

LEGISLATION, POLICY AND PERMITS – WATER-TAKING AND LOW WATER RESPONSE

ONTARIO LOW WATER MANAGEMENT

LOW WATER RESPONSE PLAN

The provincial Low Water Response program (developed in March 2000) outlines a process to address low water conditions during extended dry periods. This Ontario-wide approach enables a quick response during periods of low water conditions. Based on current legislation and regulations, it builds on existing relationships among the province, local government and agencies.

The Government of Ontario provides overall direction and coordinates policies. The province provides support where local declarations of extreme low water have been made. At the local level, conservation authorities bring together all the stakeholders (municipalities, ministries, farmers and other user groups) to plan strategies for dealing with low water.

The Ministry of Natural Resources leads the Low Water Response program at the provincial level. Staff from the Ministries of Natural Resources, Agriculture and Food, and Environment provide technical support and serve as advisors to the local Low Water Response teams.

There are three levels of low water response. At Level I, an information and education program is carried out. Everyone is encouraged to conserve water and decrease water use by 10%. Level II requires more conservation efforts with an additional 10% reduction in water use. At Level III, conditions have deteriorated to a point where the province is asked to implement regulations that allocate water use.

As an irrigator, you should consider:

- having representation on the Water Response Team
- ensuring you're included in the process of developing low water solutions and your interests are represented
- implementing more water-saving practices during low water in order to comply with the 10% reduction for Level I and an additional 10% reduction for Level II
- drawing water from a source other than streams during critical times.

LEGISLATION, POLICY AND PERMITS – WATER-TAKING AND LOW WATER RESPONSE

SOME OF THE LEGISLATION AND GUIDELINES PROTECTING WATER RESOURCES

LAW / GUIDELINE	GOVERNMENT AGENCY	GOAL	RELEVANCE TO LANDOWNER
COMMON LAW	Provincial Courts	• generally, to protect the rights of people	• all landowners bordering water are entitled to have water flow through in its natural state (this relates to both water quality and quantity)
CONSERVATION AUTHORITIES ACT	MNR, Local Conservation Authority	• to manage and conserve natural resources within watershed jurisdiction	• regulations may be in place controlling construction or the placement of fill adjacent to a watercourse
DRAINAGE ACT	OMAF	• to allow landowners to obtain an improved outlet for their land drainage	• general prohibition against the discharge of polluting substances into a drain • control of activities in or near a drain and connections to a drain
ENVIRONMENTAL PROTECTION ACT	MOE	• to protect Ontario's land, water and air resources from pollution	• contaminants are not allowed to be discharged into the environment in excess of regulatory limits
FISHERIES ACT	Fisheries and Oceans Canada and Environment Canada	• to protect fish and fisheries habitat	• prohibition of the harmful alteration, disruption or destruction of fish habitat • general prohibitions against discharging pollutants to a watercourse that would harm fish or fish habitat
LAKES AND RIVERS IMPROVEMENT ACT	MNR	• to ensure flow and water level characteristics of lakes and rivers are not altered to the point of disadvantaging other water users	• any work forwarding, holding back, or diverting water must receive prior approval from MNR
NUTRIENT MANAGEMENT ACT	OMAF and MOE	• to manage nutrients so as to enhance environmental protection and provide a sustainable future for agriculture and rural development	• standards for the management of nutrients by some livestock farms and others with livestock

LEGISLATION, POLICY AND PERMITS – WATER-TAKING AND LOW WATER RESPONSE

SOME OF THE LEGISLATION AND GUIDELINES PROTECTING WATER RESOURCES

LAW / GUIDELINE	GOVERNMENT AGENCY	GOAL	RELEVANCE TO LANDOWNER
ONTARIO WATER RESOURCES ACT	MOE	• to protect the quality and quantity of Ontario's surface and ground water resources	• general prohibitions against discharging pollutants to surface or ground water • permits are required for the taking of large amounts of surface or ground water, i.e., for irrigation
PESTICIDES ACT	MOE	• to protect Ontario's land and surface and ground water resources from damage due to improper use and storage of pesticides	• landowners involved in pesticide application as part of a business (farming) are required to take a Grower Pesticide Safety Course • regulations are set regarding pesticide storage., e.g., Warning sign identifying the storage site, proper ventilation, no floor drains, concrete impervious floors
PROVINCIAL POLICY STATEMENT, PLANNING ACT	MMAH	• to provide direction on matters of provincial interest for the wise use and protection of resources, including agriculture, natural heritage features and areas (wetlands and quality and quantity of ground and surface water)	• landowners should contact their municipalities regarding how these provincial interests impact their property
PUBLIC LANDS ACT	MNR	• to protect and perpetuate public lands and waters for the citizens of Ontario	• landowners must obtain work permits for any activity on shorelands adjacent to a navigable water • shorelands include public or private lands as well as areas that are seasonally inundated with water • the bed of a navigable water (below the high water mark) is considered to be public (Crown) land

MMAH = Ontario Ministry of Municipal Affairs and Housing
MNR = Ontario Ministry of Natural Resources
MOE = Ontario Ministry of the Environment
OMAF = Ontario Ministry of Agriculture and Food

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

To irrigate effectively, you need to know how much water your crop needs, and when it needs it.

The goal of irrigation is to provide a crop with the right amount of water, when the crop needs it for maximum crop response, at the lowest cost and with least impact on the environment.

To do this effectively, it's worth looking at some basic principles, such as:

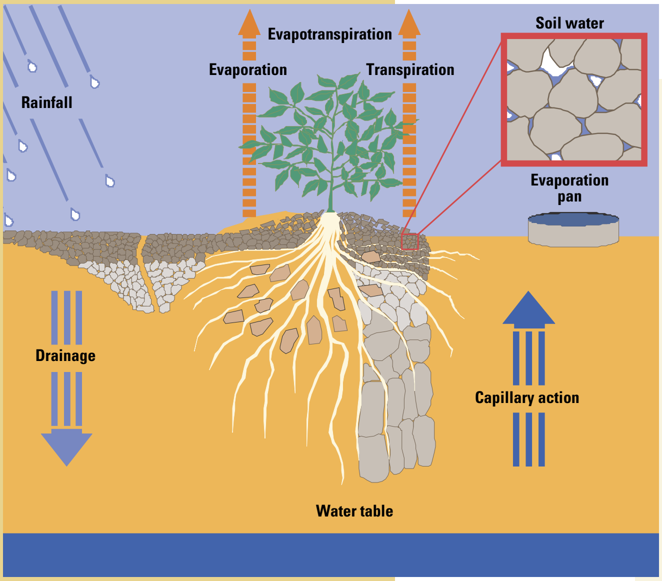
- how water flows through, over, and around your cropland
- how soils provide moisture to crops
- how much water crops require and when they need it
- how to estimate and schedule crop water requirements practically and at low cost.

This chapter explains:

- when to irrigate
- how much water your crop requires, using practical and accurate methods
- how to change the amount of water applied if soil types change across your farm
- how to account for rainfall when you estimate crop water needs.

WATER CYCLE

Knowing how water moves through cropland can help you use irrigation water more effectively and with less risk to water sources.



Water is added to cropland as snow, snowmelt and rain. In a typical field, most of this water will eventually be evaporated back to the atmosphere (66% from April to October). About 25% of it will run off the soil surface to streams, creeks, drains, lakes and ponds.

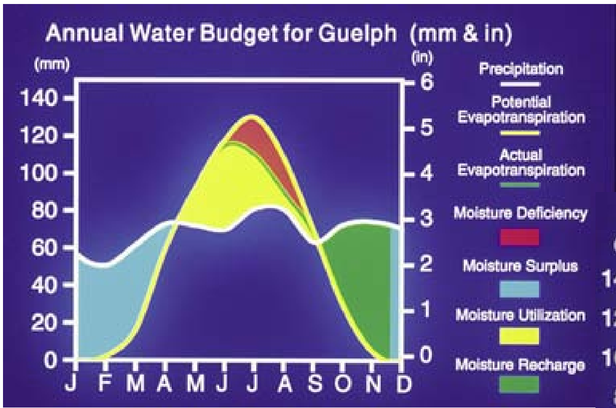
The remaining 9% of this will enter ("infiltrate") the soil. This soil water can flow through the soil to ground water, be stored as soil moisture, or is transpired by plants back to the atmosphere. The ground water will replenish the soil water table (shallow aquifers), percolate to deep aquifers, or flow back to surface waters such as streams and creeks.

Irrigation is applied to meet crop requirements just before the combination of evaporation and transpiration (evapotranspiration) exceeds the available soil moisture supplies. The fate of irrigation water, particularly with overhead sprinkler systems, is similar to that of falling precipitation (as described above). The fundamental difference is that water is taken from local surface or ground water sources. The risk to these resources is taking or wasting too much water when supplies are low.

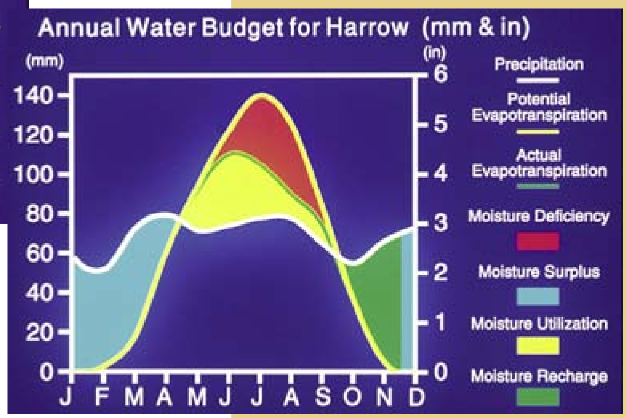
SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

WATER BALANCES: RAINFALL AND CROP REQUIREMENTS

Most of the province's irrigation occurs in Southern Ontario, where average annual precipitation ranges from about 26.0–40.2 inches (660–1020 mm). In Southwestern Ontario, crop water requirements may be 20–24 inches (500–600 mm) during the growing season, but precipitation during the same period averages only 12–16 inches (300–400 mm). This results in a water deficit for the crop in an average year. Unfortunately, years of below-average rainfall also occur, causing even greater moisture deficits.



The annual water budget for Guelph shows how water is supplied and used throughout the year. Guelph experiences a moisture deficit of up to 2 inches (50 mm) each year in July and August.



Note the extent of the moisture deficit: over 3 inches (75 mm) monthly each year for most of Harrow's growing season.

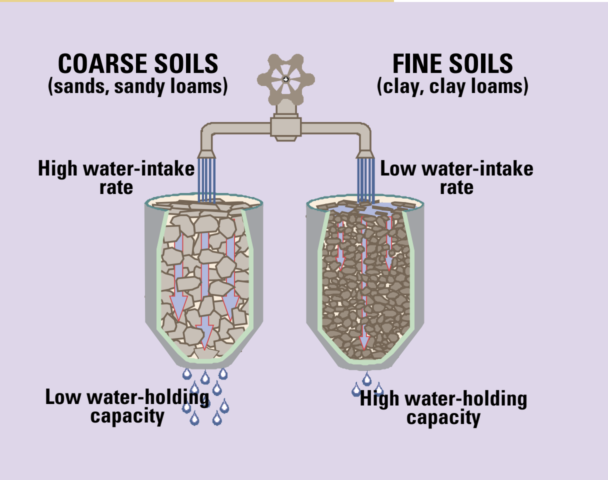
SOIL WATER

Each soil type and field have unique moisture characteristics that determine how much water is held and how available the water is for plant growth. Based on this information, you can determine how much and how frequently water should be applied. The two main characteristics explored here are **water intake rate** and **available water capacity.**

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

Water Intake Rate (or **infiltration rate**) – how fast the soil can absorb water

- the larger the soil particles, the faster the soil can absorb water
- water infiltrates coarse-textured soils faster than fine-textured ones
- good soil structure improves infiltration – soil aggregate formation and stability are key, especially in loams, silt loams and clays
- cover crops or crop residues can protect soil and slow runoff, increasing water intake rate and maintaining soil structure at the same time
- slope, soil compaction and tillage practices also affect speed of water movement into the soil
  - in heavier soils, some growers may chisel the trough between tilled rows to improve water infiltration
- the presence of macropores, such as those formed by earthworms, can have a very beneficial effect on water infiltration rates
- water applied faster than a soil's intake rate can result in ponding, leading to runoff, erosion and wasted irrigation water



Coarse-textured soils such as sands and gravels have high infiltration rates and contain the least amount of available water for plants when at field capacity. Fine-textured soils (clays) have low infiltration rates and have more available water for plants when at field capacity. However, medium-textured soils (loams) have the most available water for plants when at field capacity.

Available Water Capacity – the amount of water a soil can hold that is available to the crop

- soil texture determines how much water a soil can hold – what the crop can use is called **available soil water***, and the water bound to the soil but unavailable to the crop is called **bound water**
- coarse-textured soils hold less water, so that watering must be more frequent
- **field capacity** is the amount of water held in a soil after the excess has drained following a saturating rainfall
- the **permanent wilting point** is the amount of water held in the soil, below which plants wilt beyond recovery

For more information on soil water and the water cycle, see the Best Management Practices books, *Soil Management* and *Water Management*.

*Available soil water can be expressed as inches of available water per inch of soil (or millimetres of available water per metre of soil).

SOIL TYPE	RATE OF WATER MOVEMENT INTO SOIL	
	ON BARE SOIL	ON CROPPED SOIL
SAND	fast	fast
SILT LOAM	medium	fast
LOAM	medium	fast
CLAY LOAM	medium	medium
CLAY	slow	slow

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

CROP WATER REQUIREMENTS

The available water in the soil is used by a combination of plant transpiration and soil evaporation, i.e., **evapotranspiration (ET):**

- expressed as inches or millimetres of water used per day
- affected by temperature, light intensity, wind, humidity, crop cover and crop growth stage
- generally accepted ET values can be found in the chart on page 45, which lists ET for an average year
- more accurate maximum ET can be calculated using evaporation data from Environment Canada, a local weather station, or from on-site instrumentation

The **crop factor** is used to reflect water use by crop type and its growth stage. ET is multiplied by the crop factor and used for irrigation scheduling.

Crop factor:

- can be obtained from charts (see page 45)
- varies depending on the type of crop (crop species, annual vs. perennial) and the crop growth stage
  - for annual crops, the crop factor increases from emergence to 50–80% crop cover, remains at a maximum for 2–5 weeks, then decreases.

The moisture needed to supply the crop's ET needs is called the **crop water requirement:**

- water depleted from the soil by ET is normally replenished by rain, dew or irrigation in sufficient amounts to meet the crop's needs at any given time
- irrigation should maintain a minimum amount of available soil moisture – if water isn't applied until the crop is wilting, economic losses have already occurred, as yield and/or quality potential can be reduced
- frequency and depth of irrigation required vary, depending on soil characteristics, crop water requirements and rooting depth (see Table 2, page 41 for more details on rooting depth).

Weather stations estimate evapotranspiration using the open pan evaporation method, which measures the daily loss of water by evaporation. Since evaporation from an open-air water surface is faster on windy days, days with low humidity, and on hot, sunny days, ET would be correspondingly higher.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

IRRIGATION SCHEDULING

Irrigation scheduling is the process of planning and providing crops with the amount of water needed, when they need it. It involves monitoring, record-keeping, and calculations to determine field water capacity, losses and gains. Ultimately the producer compensates for net losses with irrigation. This system is based on known daily water losses by ET for various crops in different growth stages.

Scheduling can be done either by hand or on computer. Scheduling and a basic understanding of crop physiology can help ensure you use water only when it's needed. Scheduling should always be used, and especially so when water supplies are under stress.

Sampling for Field Variation
Soil texture and water-holding capacity can vary significantly within fields. Choose a representative area or areas to use for scheduling.

BENEFITS OF SCHEDULING

- increased yields and quality; better returns on investment of irrigation equipment
- more efficient use of water resources
- more efficient use of equipment, energy, management time and labour
- avoids delaying irrigation until moisture stress has occurred and damage to yield and quality is irreversible, i.e., optimizes application timing
- reduced possibility of excess water being applied – excess water may result in crop damage, leaching of nutrients or soil erosion

FACTORS IN SCHEDULING

- specific infiltration rates and available water-holding capacities of the various soil types need to be known
  - some calibration work may have to be done
  - you may have to measure the performance of the soil using known quantities of soil and water
- crop rooting depth – deeper-rooted crops will need less frequent but deeper irrigations than shallow-rooted crops
- the probability of rainfall – this affects frequency and amount of irrigation needed
- plant water requirements – this depends on crop type and growth stage

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

METHODS OF DETERMINING IRRIGATION NEED

The need for irrigation can be determined by a number of methods. These include: monitoring soil moisture levels, observing crop symptoms, and measuring or estimating plant transpiration and water evaporation (evapotranspiration).

The physical properties of your soils must be known to help make irrigation scheduling work effectively. The technician in this case is taking soil samples to measure water-holding capacity.

MONITORING SOIL MOISTURE

Soil moisture levels can be monitored to aid in scheduling irrigation events. A limit is set on the depletion of crop-available soil water in the crop rooting zone. For example, the field may be allowed to dry down to a pre-set level of 50% of crop-available water before irrigation is triggered. The allowable crop-available soil moisture will vary, depending on soil type and crop.

There may also be variations, depending on crop development or growth stage. Soil moisture may be allowed to drop lower as the growing season progresses and the critical periods of crop development pass.

Soil moisture can be measured in a number of ways, ranging from high-tech to very basic. High-tech techniques can be used in conjunction with basic techniques, and are particularly useful in refining feel-method skills. One particular method does not suit everyone. For some operations, it will be advantageous to use two or more methods. Experienced irrigators should consider using electronic methods to verify basic methods and confirm quality of moisture level assessment.

Read about different soil moisture monitoring methods in the next few pages and use the comparative chart on pages 35–37 to select the one most appropriate for your operation.

TYPES OF MEASUREMENTS

There are three types of soil moisture measurements.

- **gravimetric** – a measure of the weight of water held within a soil (g of water/g of dry soil). It's easily measured by weighing wet soil, drying it overnight, and weighing the dry soil. The difference is the weight of the water held by the soil. However, different soil types with the same weight will occupy a different volume and hold a different amount of water.
- **volumetric** – most commonly used method. Volumetric measures allow comparisons among soils of different types. The soil bulk density is multiplied against the gravimetric measure to determine the volumetric result. It's reported as ml/cm^3 or ml/L of soil or % volume of water per volume of soil.
- **soil water potential** – a measure of the difficulty in extracting water from soil. As soil dries, the pore size that is water-filled decreases, the water is held more tightly, and more energy is needed to remove it. Potential or soil water suction is measured in kilopascals.

Mulch maintains soil moisture content over a long period of time.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

FEEL METHOD

The feel method is commonly used by many to schedule irrigation. It involves a shovel or soil probe to obtain soil samples at the desired depth. The amount of moisture is estimated through the feel of the soil in the hands. While it's the quickest and simplest method, it does require experience, and due to its subjective nature, it's not especially accurate. It doesn't generate definitive numbers that can be compared.

The chart on page 31 has been used for some time as a guide in estimating soil moisture in soil samples. It relates soil appearance and feel to approximate soil moisture levels for specific soil textures. High organic matter content will influence the feel of a soil.

TENSIOMETER

This is a tensiometer, best suited for use in sandy soils.

A tensiometer measures **soil water tension** rather than soil water content. Soil water tension is what the plant must pull against in order to extract water from the soil. This method is more suited to sandy soils, for repeated measurements at the same location. Users must interpret soil moisture release curves to determine the amount of water to irrigate.

HOW IT WORKS

The tensiometer involves an airtight system consisting of a sealed tube, a vacuum gauge and a porous ceramic tip, which is initially filled with a prepared solution. The water tension in the soil pulls water out through the porous tip, until the tension (vacuum) in the tensiometer is equal to the water tension in the soil. The vacuum gauge measures this tension.

As the soil dries, more water is pulled out of the tube, and the vacuum in the tensiometer increases (measured in centibars). Irrigation is required when the soil water tension reaches a predetermined level for specific soil and crop conditions (e.g., about 50% crop-available soil water). After a rain or irrigation, which decreases soil water tension, water from the soil moves back into the tensiometer through the porous ceramic tip, causing a decrease in the vacuum gauge reading.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

"FEEL TESTING SOIL"

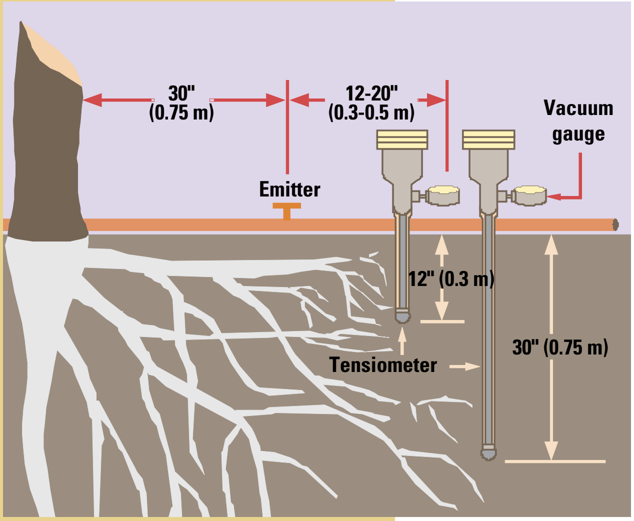
AVAILABLE MOISTURE IN SOIL	FEEL OR APPEARANCE OF SOIL – SOIL TEXTURE			
	Coarse (sands)	**Moderately coarse (sandy loams)**	**Medium (silt loams, loams)**	**Fine and very fine (clay, clay loams)**
0%	dry, loose and single-grained; flows through fingers	dry and loose; flows through fingers	hard clods that break into powder	hard, baked and cracked; has loose crumbs on surface in some places
50% OR LESS	appears to be dry; does not form a ball under pressure[1]	appears to be dry; does not form a ball under pressure[1]	somewhat crumbly but holds together under pressure	somewhat pliable; balls under pressure[1]
50-75%	appears to be dry; does not form a ball under pressure[1]	balls under pressure but seldom holds together	forms a ball under pressure; somewhat plastic; sticks slightly under pressure	forms a ball; ribbons out between thumb and forefinger
75% TO FIELD CAPACITY	sticks together slightly; may form a very weak ball under pressure	forms weak ball that breaks easily; does not stick	forms ball; very pliable; sticks readily if relatively high in clay	ribbons out between fingers easily; has a slick feeling
AT FIELD CAPACITY (100%)	on squeezing, no free water appears on soil but wet outline of ball is left on hand	same as for coarse-textured soils at field capacity	same as for coarse-textured soils at field capacity	same as for coarse-textured soils at field capacity
ABOVE FIELD CAPACITY	free water appears when soil is bounced in hand	free water is released with kneading	free water can be be squeezed out	puddles; free water forms on surface

[1]Ball is formed by squeezing a handful of soil very firmly.

Adapted from R.P. Harris and R.H. Coppock, eds., *Saving Water in Landscape Irrigation,* University of California, Div. of Agriculture Science leaflet 2976, 1978

Dry soils are loose or baked. At 100% moisture, a wet outline of water is left on the hand after squeezing.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE



Tensiometers are usually installed in pairs, one in the zone of maximum root activity and one below. They only measure soil water tension near the porous ceramic tip, not the amount of water in the soil. A reading of 10-20 centibars on the vacuum gauge indicates soils at or near field capacity.

INSTALLATION

Tensiometers are usually installed in pairs, one in the zone of maximum root activity and one just below this zone. The ceramic tip must be in contact with the soil for the water movement to occur, so it's important to ensure a snug fit that allows the ceramic tip to have maximum soil contact. Installation procedures should be followed carefully, as air leaks may develop. Temperature may affect the readings, and the instruments need to be monitored carefully after installation to ensure that they are de-aired by pumping and fluid levels are maintained.

LIMITATIONS

The vacuum gauge indicates soil water tension in the immediate vicinity of the porous ceramic tip, not the amount of water in the soil. Therefore, the measurements indicate when irrigation is required, but not how much water to apply.

The tensiometer can only measure tensions up to about 0.85 atmospheres or 85 centibars before the risk of air leaks develops. It's especially suited to sandier soil where much of the available soil water is held at tensions of less than 1 atmosphere. On clay soils, a reading of 70 or 80 centibars may mean that only 20% of the available soil moisture has been depleted. On sandy loam soils, a reading of half this amount may be interpreted as having lost more than 50% available soil moisture.

The system is portable, but stations, once established, are usually left for the season.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

ELECTRICAL RESISTANCE

Similar to the tensiometer, electrical resistance blocks measure soil water tension. In wet soils, water is drawn into the blocks, while the reverse is true in dry soils. Generally, once properly installed, this is an accurate and low-cost soil water measurement device with no maintenance.

The unit consists of a block of some material with fine pores and two wires embedded in the material. For a gypsum block, the more moist the block is, the less resistance to the electrical current flowing between the two wires. The newer ones are more robust and may have a meter that reads directly in kilopascals (kPa) and makes the soil temperature adjustment. Installation will vary with the equipment used. Check manufacturer's recommendation and specification listings.

TIME DOMAIN REFLECTROMETRY (TDR)

A TDR instrument works by sending a signal down wave guides or steel probes buried in the soil. The signal is reflected back to the TDR unit and the time taken for this is measured. The time taken is related to the dielectric of the soil. Soils typically have dielectric constants in the range of 2.0 to 4.0, while the dielectric constant of water is 78. Changes in the soil dielectric constant relates to changes in the water content of the soil. A similar method is involved in the Frequency Domain Reflectrometry or FDR.

Properly calibrated, this equipment gives very accurate results. In the past, the cost of TDR equipment restricted it to research or consultant use. Prices have come down considerably, but it's still most suited to the large-scale or intensive irrigator.

Installation will vary with the equipment used. Check manufacturer's recommendation and specification listings.

NEUTRON MOISTURE METER

The neutron moisture meter directly measures soil water content by emitting and detecting neutrons. When neutrons bounce off the hydrogen atoms in water, they return to the probe at a slower velocity. The number of returning slow neutrons indicates the water content of the soil, which can then be expressed as percent moisture or inches (millimetres) of water for a specific depth of soil. The instrument is used mostly in research work and by crop consultants.

C probe technology is another tool for measuring soil moisture. Its structure allows for measurements at a variety of depths, and offers a high degree of automation. However, careful siting of the probe is critical to ensure representative information of a field.

Until recently, use of the C probe was mostly limited to research trials due to the expense. But per unit costs have been coming down, and C probes are in use in a variety of large, intensive irrigation operations.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

PLACING THE MEASUREMENT UNITS

Once you've selected the soil moisture monitoring method, consider where the units need to be placed or the samples taken. Consider:

- how many areas will be monitored through the season – usually only one or two, depending on field size
- location of sample areas within the field – easy access for observation, but they need to be well within the field for an accurate measure of irrigation application, and outside of any non-representative areas, e.g., ditch spoil
- depth of equipment placement – it's often recommended that there be two depths (one at 30 cm or 1 ft.; the other at the bottom of the root zone for that crop type), so that the top one will capture the moisture status of the active root zone while the other will indicate if there is under-irrigation
- placement of units relative to the crop or drip emitters – usually in the plant row in the active root zone and about 30 cm (1 ft.) away from an emitter (maintaining a consistent distance from the emitter is important).

Neutron moisture meter

Time domain reflectometry

Electrical resistance

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

SOIL MOISTURE MEASUREMENT TOOLS

SOIL MOISTURE MEASUREMENT TOOL	SIMPLICITY OF USE	RELIABILITY	RANGE OF SOIL TYPES	EASE OF AUTOMATION	PORTABILITY	OBSERVATIONS	COST
FEEL METHOD measures soil water depletion	✓✓✓	✓	• All	• NA	• High	• Requires experience • Open to misinterpretation	• Operator time
SOIL SAMPLE (gravimetric) measures water content by mass	✓✓✓	✓✓	• All	• NA	• High	• Time-consuming and slow – lots of weighing, waiting and calculating • Highly variable, depending on sampling technique, temperature of drying etc.	• Operator time • Inexpensive
TENSIOMETER measures soil water tension	✓✓	✓✓	• Most, except clays	• Easy • Requires specialized unit and connections	• Low in season	• Indicates when irrigation is needed, but not how much • Successful operation depends on proper installation • Placement is important to avoid damage from field operations • High maintenance and regular checking of units needed • Soil type-dependent, i.e., most suited for sandy soils as tension can be too high in clay soils • If the sand is coarse, may require a special unit • An excellent tool to be used for calibrating the hand-feel method • A combination of tensiometers and the hand-feel method will give more reliable results with the ability to cover large areas	• $100 + per unit • Usually two units are installed at two different depths and the units stay in one site in the field for the season

Legend

✓✓✓ **Best**
✓✓ **Good**
✓ **Least**

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

SOIL MOISTURE MEASUREMENT TOOLS

SOIL MOISTURE MEASUREMENT TOOL	SIMPLICITY OF USE	RELIABILITY	RANGE OF SOIL TYPES	EASE OF AUTOMATION	PORTABILITY	OBSERVATIONS	COST
ELECTRICAL RESISTANCE BLOCKS e.g., watermarks, gypsum blocks measure soil water tension	✓✓✓	✓✓	• Most, except clays	• Easy • Requires datalogger/ connections	• Buried for crop season, but moveable from season to season	• Installation generally easy but depends on soil type • Requires some calibration with soil type • Sensitive to salt levels • Low maintenance • Low impact on field operations with appropriate placement • Less sensitive at high soil moisture • Lifespan ~3 years + • Readings are affected by soil temperature (1% per 0.6 °C) • An excellent tool to be used for calibrating the hand-feel method • A combination of electrical resistance blocks and the hand-feel method will give more reliable results with the ability to cover large areas	• Individual ER blocks – $40–50 • One meter ($300) can be used to measure many ER blocks • Similar to tensiometers – often two units at different depths
• TDR – TIME DOMAIN REFLECTRO-METRY • FDR – FREQUENCY DOMAIN REFLECTRO-METRY measure volumetric soil water	✓✓✓ • Depends upon unit used	✓✓✓	• All, but clay may pose some problems	• Easy	• High • May require an access tube previously placed in the soil	• Cost in the past has restricted use to researchers and large-scale irrigators • Depending on unit, may need calibration • Insertion under dry conditions may be difficult • FDR – sample volume 10 inches (25 cm) diameter around probe	• Cost has come down in recent years – $1000+

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

SOIL MOISTURE MEASUREMENT TOOLS

SOIL MOISTURE MEASUREMENT TOOL	SIMPLICITY OF USE	RELIABILITY	RANGE OF SOIL TYPES	EASE OF AUTOMATION	PORTABILITY	OBSERVATIONS	COST
NEUTRON MOISTURE METER measures moisture content	✓	✓✓✓	• All	• Unit usually too expensive	• High • Requires an access tube previously placed in the soil	• Suited to research • Uses a radioactive source of neutrons • Requires calibration	• High cost – in $1000s

Legend
✓✓✓ **Best**
✓✓ **Good**
✓ **Least**

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

USING THE PLANT TO INDICATE WATER STRESS

Using the plant as an indicator is difficult because once symptoms appear, the plant has usually already experienced a reduction in growth or damage to plant tissues, and economic damage has been done to the crop. However, a few methods have been developed to indicate the onset of plant water stress.

Although these methods may show that the plant needs water, they give no indication of how much. Also, they probably don't indicate the onset of water stress early enough for irrigation scheduling purposes.

VISUAL SYMPTOMS

Plant colour, plant wilting, leaf growth, fruit growth, and stem or trunk growth have been measured to determine when to irrigate.

LEAF TEMPERATURE

Leaf temperature tends to be higher for a stressed plant than for an unstressed plant. Temperature can be quickly measured using an infrared thermometer.

LEAF REFLECTANCE

Water-stressed leaves reflect less infrared light than the leaves of well-watered plants. Aerial infrared photography has been used to detect water stress in this way.

INSTRUMENTS

Instruments measure stomatal (leaf breathing pore) conductance and transpiration, which tend to decrease as water stress becomes more severe.

Using signs of water stress to schedule irrigation has obvious limitations. This peach orchard has suffered reduced tree size and possible damage to plant tissues due to a lack of water.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

EVAPOTRANSPIRATION

Irrigation can also be scheduled based on estimates of evapotranspiration – the total amount of water lost by **transpiration** from the crop canopy and **evaporation** from the soil. The water needed for **evapotranspiration** is the **crop water requirement.**

METHODS OF ESTIMATING EVAPOTRANSPIRATION

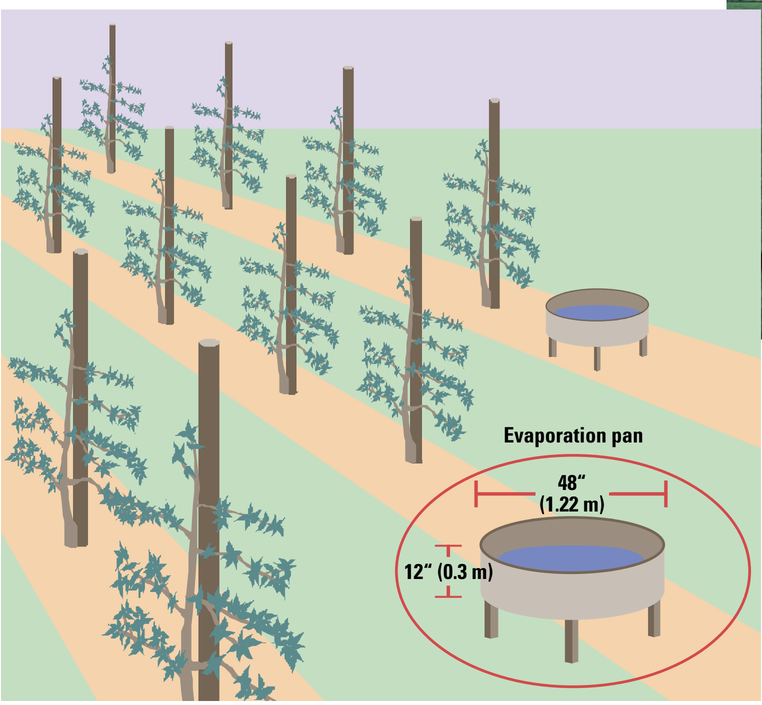
Pan Evaporation

▸ local weather stations may collect evaporation data

Modified Penman

▸ uses data on temperature, percent sunshine, relative humidity and wind velocity
▸ interprets air temperature and radiation data

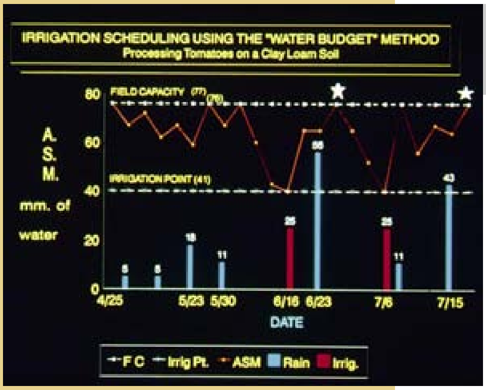
The method used depends on the availability of climate data. Not all data required are available everywhere. In all cases, the evapotranspiration value is multiplied by a crop factor that reflects percent ground cover as well as type of crop and crop growth stage.



The pan evaporation method provides a reasonable estimate of cropland evapotranspiration. To be most useful, pans should be placed close to the crop grown.

Weather stations estimate evapotranspiration using the open pan evaporation method, which measures the daily loss of water by evaporation. Since evaporation from a free water surface is faster on windy days, days with low humidity, and on hot, sunny days, ET would be correspondingly higher.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE



This graph illustrates rainfall dates and amounts, irrigation periods and available soil moisture contents over the growing season. Shown here are available soil moisture contents for processing tomatoes on clay loam soil over the growing season.

IRRIGATION SCHEDULING USING EVAPOTRANSPIRATION DATA: THE WATER BALANCE METHOD

With the help of evapotranspiration data, the water balance method can be used to schedule irrigation. The method is inexpensive, simple and relatively accurate. It assumes:

- soil water is a reservoir of available water
- field capacity is reached when reservoir is full (this is the amount of water held in the soil after the excess has drained following a saturating rainfall)
- crop water use (evapotranspiration) takes water out of the reservoir
- rainfall and irrigation add water to the reservoir.

The following example, using a tomato grower in Southwestern Ontario, might help you better understand the water balance method. Each step is described, illustrated, and corresponds to the irrigation scheduling worksheet on page 42.

Here is some essential information about the grower's operation:

Nearest weather station	**Windsor**
Soil texture	**sandy loam**
Crop	**tomato**
Soil-saturating rainfall	**June 19**
Irrigation system	**sprinkler.**

Table 1. RANGES IN AVAILABLE WATER CAPACITY FOR SOIL TEXTURES

SOIL TEXTURE	AVAILABLE WATER CAPACITY (inch of water/inch of soil = mm of water/mm of soil)	
	Range	**Average**
SANDS	0.05–0.08	0.065
LOAMY SAND	0.07–0.10	0.085
SANDY LOAM	0.09–0.12	0.11
LOAM	0.13–0.17	0.15
SILT LOAM	0.14–0.17	0.16
SILTY CLAY LOAM	0.15–0.20	0.18
CLAY LOAM	0.15–0.18	0.17
CLAY	0.15–0.17	0.16

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

Before you start:

Estimate the maximum amount of crop-available soil water in the root zone (field capacity).

Total crop-available soil water in the root zone at field capacity:

= available water capacity of the soil texture (Table 1 on page 40) x crop rooting depth (Table 2 below)

= 0.11 mm/mm x 300 mm = 0.11 in/in x 12 inch

= 33 mm = 1.32 inch

Enter CROP-AVAILABLE SOIL WATER at Field Capacity on the worksheet on page 42.

Establish allowable soil water depletion in the root zone (irrigation point).

Allowable soil water depletion (irrigation point):
= 50% crop-available soil water

= 33 mm x 50% = 1.32 inch x 50%

= 16.5 mm = 0.66 inch

Enter IRRIGATION POINT (50% CROP-AVAILABLE SOIL WATER) on the worksheet.

(For this example we will use metric, as millimetres are used to record rainfall and predict ET.)

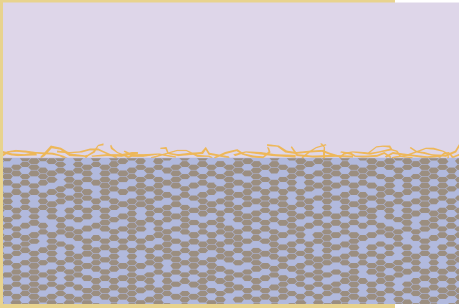
Table 2. CROP ROOTING DEPTH – HORTICULTURAL CROPS

CROP	DEPTH TO IRRIGATE mm (inches)
BEANS, CABBAGE, CELERY, CUCUMBERS, LETTUCE, MELONS, ONIONS, PEAS, RADISHES, TOMATOES, POTATOES	300 (12)
APPLES	900 (36)
CHERRIES	750 (30)
GRAPES	900 (36)
PEACHES	750 (30)
PEARS	750 (30)
RASPBERRIES	600 (24)
STRAWBERRIES	300 (12)

Table 2a. CROP ROOTING DEPTH – COMMON FIELD CROPS

CROP	DEPTH TO IRRIGATE mm (inches)
CORN	600 (24)
SOYBEANS, WHITEBEANS, TOBACCO, FIELD PEAS	300 (12)

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE



STEP 1 From the example on the previous page, fill in the CROP-AVAILABLE SOIL WATER and IRRIGATION POINT on the Irrigation Scheduling Worksheet. Select a starting date. In this example, a soil-saturating rainfall occurred on June 19. June 20 will be used as the starting date. Enter this date on the first line of the crop in column 1 of the worksheet. Enter the starting value of available soil water (in this case 33.0, crop-available soil water at field capacity) in the SOIL WATER BALANCE (start) column (7).

IRRIGATION SCHEDULING WORKSHEET

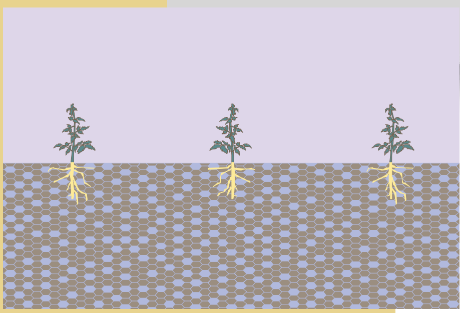
Field: ____________________ Crop: Tomatoes

CROP-AVAILABLE SOIL WATER at Field Capacity: 33 mm

IRRIGATION POINT at 50% Crop-Available Soil Water: 16.9 mm

Column (1)	(2)		(3)		(4)	(5)	(6)	(7)	(8)
DATE	CROP FACTOR	X	ET mm	=	ADJUSTED ET mm	RAINFALL mm	IRRIGATION mm	SOIL WATER BALANCE (START) mm	SOIL WATER BALANCE (END) mm
June 20	0.7	X	4.2	=	2.9			33.0	30.1
June 21	0.7	X	4.2	=	2.9	20		30.1	33.0
June 22	0.7	X	4.2	=	2.9			33.0	30.1
June 23	0.7	X	4.2	=	2.9			30.1	27.2
June 24	0.7	X	4.2	=	2.9			27.2	24.3
June 25	0.7	X	4.9	=	3.4			24.3	20.9
June 26	0.7	X	4.9	=	3.4			20.9	17.5
June 27	0.7	X	4.9	=	3.4		18.9	17.5	33.0
June 28	0.7	X	4.9	=	3.4			33.0	29.6
June 29	0.7	X	4.9	=	3.4			29.6	26.2
June 30	0.7	X	4.9	=	3.4	5		26.2	27.8
July 1	0.7	X	4.9	=	3.4			27.8	24.4

A blank copy of this worksheet has been provided on the inside back cover for you to photocopy and use.



STEP 2 Choose the CROP FACTOR for each day from Table 3 or 4. The crop factor is an estimate of the percent of the soil covered by plant foliage and is used with the Evapotranspiration (ET) value (see Table 5) to estimate daily water use by the crop. In the example above, the tomatoes have had a 1st flower. From Table 3, we know the crop factor is 0.7 after 1st flower. See column 2 above. As the plants grow, the crop factors change.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

Table 3. CROP FACTORS FOR VEGETABLES

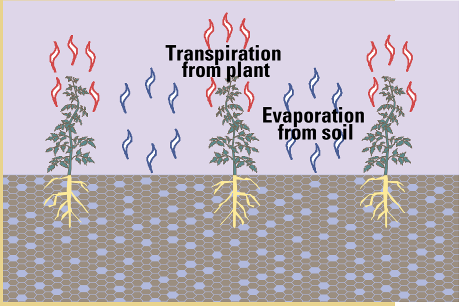
BARE SOIL	0.2	
CABBAGE, CAULIFLOWER	0.4 0.7 1.0	from seeding or transplanting to start of heading from start of heading to full row fill remainder of crop
SWEET CORN	0.4 0.7 1.0	from seeding to 1st showing of tassel in whorl 1st tassel to silking remainder of crop
TOMATOES, POTATOES, PEPPERS	0.4 0.7 0.7 0.7 1.0	from seeding or transplanting to 1st flower from 1st flower to maximum row fill (TOMATOES) from 1st flower to tuber sizing (POTATOES) from 1st flower to fruit sizing (PEPPERS) remainder of crop

Table 4. CROP FACTORS FOR FRUIT TREES
will vary with crop type and planting density

MONTH	PERMANENT SOD WITH HERBICIDE STRIP		CLEAN CULTIVATION PLUS COVER CROP	
	Non-bearing	**Mature**	**Non-bearing**	**Mature**
APRIL	0.2	0.2	0.2	0.2
MAY	0.3	0.3	0.3	0.3
JUNE (1–15)	0.3	0.4	0.3	0.4
JUNE (16–30)	0.5	0.6	0.4	0.5
JULY	0.6	1.0	0.5	0.65
AUGUST	0.6	1.0	0.5	0.65
SEPTEMBER	0.5	0.95	0.3	0.5

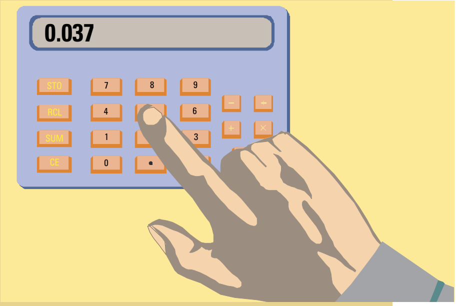
Non-bearing trees (ages 1-4 years); mature trees (age > 4 years)

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE



STEP 3

Enter the EVAPOTRANSPIRATION (ET) value for each day from Table 5, or from another reliable source of ET data. Examples are entered in column 3 of the worksheet.

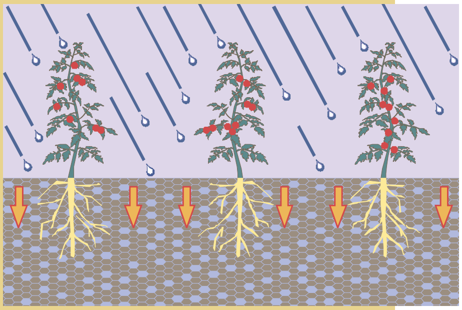


STEP 4

Calculate the adjusted ET for each day = ET x crop factor
For June 20:

= 4.2 mm x 0.7 = 0.17 inch x 0.7
= 2.9 mm = 0.12 inch

Enter this value in the ADJUSTED ET column for June 20. See column 4 of the worksheet.



STEP 5

Record the daily RAINFALL or IRRIGATION amounts for each day. Have rain gauges in the field to measure rainfall. With overhead irrigation they may also be used to confirm the amount of irrigation water applied. If surface runoff occurs, use only 75% of the total rainfall if heavy rainfall occurs within a short time period.

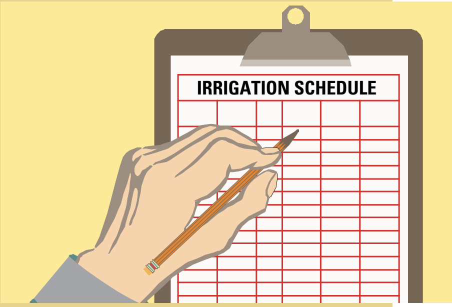
In this example, rain fell on June 21 and June 30. See column 5 of the worksheet.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

Table 5. AVERAGE MAXIMUM DAILY ET VALUES (mm)

Month	Date	Windsor	Ridgetown	London	Simcoe	Vineland	Toronto	Mt. Forest	Trenton	Ottawa	North Bay	Thunder Bay
MAY	7	2.1	2.2	2.4	2.8	2.0	2.3	3.0	2.1	3.0	2.7	2.4
	14	3.5	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.7	3.1	3.1
	21	3.6	3.8	3.9	4.6	3.2	3.9	4.0	3.6	4.2	3.3	3.3
	28	4.1	4.0	3.7	4.9	3.3	3.8	3.3	3.3	3.5	2.9	3.7
JUNE	4	4.2	4.3	4.1	4.8	3.9	4.3	4.5	4.3	4.6	3.9	4.0
	11	4.3	4.2	4.2	5.2	4.4	4.2	3.8	4.1	4.6	4.1	4.1
	18	4.2	4.3	4.1	5.4	4.3	4.4	4.5	4.0	4.6	3.9	4.1
	25	4.9	4.7	4.5	5.5	5.3	4.6	5.2	4.8	4.5	4.0	4.9
JULY	2	4.6	4.7	4.9	5.3	4.7	4.5	5.3	4.5	4.7	4.1	4.3
	9	5.4	5.2	4.5	5.5	5.2	4.9	5.1	5.1	5.0	4.2	4.7
	16	4.9	4.9	4.4	5.0	4.8	4.7	4.8	4.4	4.3	4.0	4.8
	23	4.7	4.6	4.4	5.6	4.4	4.8	4.5	4.5	4.9	4.0	5.1
	30	4.8	4.2	4.3	5.1	3.3	3.9	4.7	4.2	4.5	3.7	4.5
AUG	6	4.8	4.7	4.2	4.6	4.3	4.5	4.8	4.1	4.3	3.6	4.0
	13	3.6	3.8	3.5	4.5	3.3	3.6	3.2	3.3	3.2	2.6	4.2
	20	3.4	3.0	3.6	3.5	3.2	3.2	3.7	3.4	3.4	2.6	2.8
	27	3.5	3.3	3.5	4.3	3.3	3.4	3.5	3.0	3.1	2.4	2.7
SEPT	3	3.5	3.2	3.4	4.5	3.2	3.3	3.3	3.2	3.5	2.7	2.8
	10	3.3	3.4	2.8	3.9	2.7	3.0	3.4	2.6	2.4	2.5	2.3
	17	2.4	2.4	2.3	3.0	2.5	2.7	2.2	1.7	1.3	1.0	1.6
	24	2.3	2.4	2.3	2.9	2.2	1.6	1.7	1.7	1.9	0.7	1.1

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE



STEP 6

Calculate the daily SOIL WATER BALANCE.
= Soil Water Balance (start) – adjusted ET + rainfall + irrigation
For June 20:

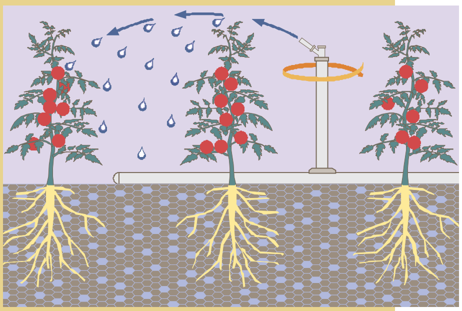
= 33 mm – 2.9 mm + 0 mm + 0 mm = 1.32 inch – 0.11 inch + 0 inch + 0 inch

= 30.1 mm = 1.21 inch

Enter this value in the SOIL WATER BALANCE (end) column for June 20.
Carry this over to the SOIL WATER BALANCE (start) column for June 21.

On June 21, the soil water balance adds up to 47.2 mm (1.86 in). The soil water balance cannot be greater than the crop-available soil water. When this occurs, enter the value for crop-available soil water (33 mm or 1.32 in). See column 8 of the worksheet.

Continue this calculation for each day of the growing season.



STEP 7

Irrigate when the soil water balance drops to the irrigation point (50% crop-available soil water). In this example, the soil water balance drops to 17.5 mm (0.69 in) to trigger an irrigation. On June 27, the grower irrigates to 100% of crop-available soil water (33 mm or 1.32 in). Since this grower uses sprinkler irrigation, a 75% irrigation efficiency is assumed, and the amount of water required is adjusted upwards by dividing by 0.75.

Water required:

= 100% crop-available soil water + adjusted ET – Soil Water Balance (start)

= 33 mm + 3.4 mm – 17.5 mm = 1.32 inch + 0.13 – 0.69 inch

= 18.9 mm = 0.76 inch

Assume 75% irrigation efficiency for sprinkler irrigation:

= Water required ÷ 0.75

= 18.9 mm ÷ 0.75 = 0.76 inch ÷ 0.75

= 25.2 mm = 1.01 inch

Record the water required in the IRRIGATION column. On the irrigation date, the SOIL WATER BALANCE (end) should be entered as 100% of crop-available soil water.

With monitoring and simple calculations, irrigation scheduling can make irrigations more timely, precise and less wasteful.

SCHEDULING: KNOWING WHEN AND HOW MUCH TO IRRIGATE

SCHEDULING BY COMPUTER

In some areas and in some crops, computer programs are being used to schedule irrigation. Data such as crop information, rainfall, previous irrigation and water monitoring equipment (e.g., tensiometer readings) are used to calculate the water balance for a particular crop and determine the need for irrigation. The computer may be used to turn irrigation on and off for automated systems (applicable to drip, centre pivots and permanent sprinkler systems). The Ontario Ministry of Agriculture and Food continues to evaluate the available irrigation scheduling programs and equipment and their suitability.

Most crops have certain growth stages, during which drought stress can severely reduce yield and/or quality. While adequate moisture is desirable at all growth stages, irrigation is especially important during the critical growth periods.

CONSIDERATIONS FOR APPLYING IRRIGATION WATER

Avoid wasting water during application. Be aware of the water intake rate of the soil. This is the rate at which water infiltrates the soil and it determines how much water to apply per hour. Applying water at a higher rate than the soil can absorb will lead to runoff. Table 6 below lists the maximum rate of water to apply per hour for various soil textures. Coarse-textured soils have a higher water intake rate than fine-textured soils. Rain or irrigation gauges should be placed in the field to help you determine how much irrigation water (overhead only) you've applied. These gauges will also help you track rainfall amounts, which will aid in irrigation scheduling.

Using simple monitoring methods and calculations, scheduling can make irrigation more timely and precise and less wasteful.

TABLE 6. RANGES OF INTAKE RATE FOR SOIL TEXTURES

SOIL TYPE	INTAKE RATE (in/hr)		INTAKE RATE (mm/hr)	
	Range	Average	Range	Average
SANDS	0.5–1.0	0.70	12–25	18
LOAMY SAND	0.3–0.8	0.55	7–20	14
SANDY LOAM	0.3–0.8	0.55	7–20	14
LOAM	0.3–0.8	0.55	7–20	14
SILT LOAM	0.2–0.3	0.25	4–8	6
SILTY CLAY LOAM	0.2–0.3	0.25	4–8	6
CLAY LOAM	0.2–0.3	0.25	4–8	6
CLAY	0.1–0.25	0.20	2–6	4

IRRIGATION SYSTEMS

Probably the most fundamental best management practice for irrigation is choosing the right system. This requires more than grower experience. Your irrigation system should be designed by experts.

An irrigation system has some form of the following components:

- water source
- power source
- pumps
- conduit pipe
- filtration
- emission points, e.g., sprinklers
- water-efficient hardware.

All components must be suitably matched.

In this chapter, components of irrigation systems will be described and evaluated to help you choose the best system for your operation.

The main principle of irrigation is quite simple: to provide the root zone of your crop with usable amounts of water during periods of need. This is accomplished by delivering irrigation water to a field and then distributing it within the field. In Ontario, three methods are used for the in-field distribution of irrigation water:

- sprinkler irrigation – spraying the water over the entire soil surface of the field
- micro-irrigation (trickle, drip) – piping the water directly and only applying the water to the soil around each plant
- sub-irrigation – piping water into the soil below the root zone.

The techniques of each system are quite different and have inherent advantages and disadvantages.

For all systems, some prefiltration of water is required. The level of filtration will vary depending on system type and design.

FOOD SAFETY AND DIFFERENT IRRIGATION SYSTEM TYPES

If irrigation water becomes contaminated, it could potentially contaminate the produce. This risk is higher for irrigation systems where the water is sprayed over the plants and comes in contact with the produce, i.e., most types of sprinkler irrigation. You can greatly reduce the risk of contamination by applying water in such a way that it does not directly contact the produce, i.e., micro-irrigation and sub-irrigation. The decision of what type of system to choose will depend on the product being grown. Crops that are not consumed, are used for feed or are processed are considered lower risk. Crops that are consumed raw, especially those that go directly to the table or that may be difficult to clean, are considered high risk.

IRRIGATION SYSTEMS

This diesel-powered pump on a pad is drawing water from a pond.

A conduit pipe carries water to the field.

All systems have emission points – in this case, a big gun irrigation distributor.

SPRINKLER IRRIGATION

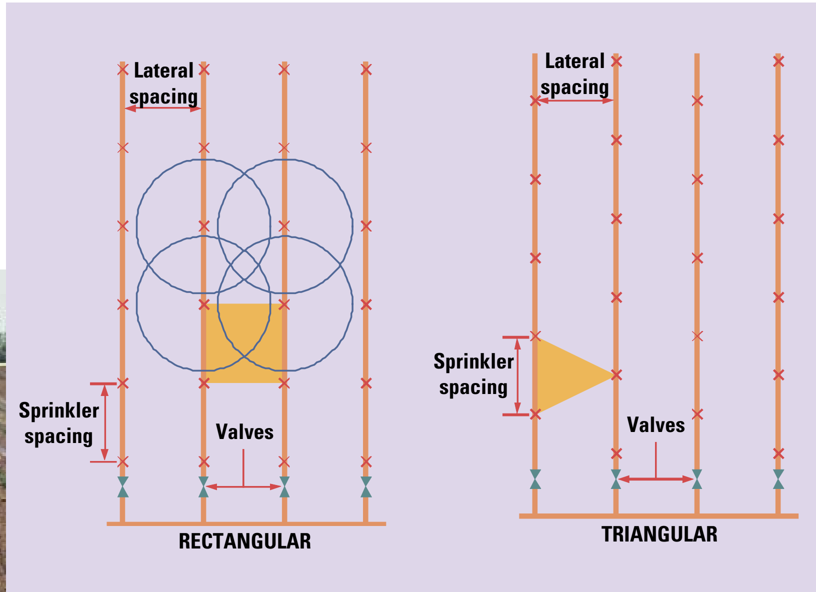
Design & Hardware

- network of pipes transmits water to all areas of the field to be irrigated
- irrigation pipe transmits water from the pump to the nozzles for application to the desired site
- pipes can be located on or below the ground surface and must be properly sized
- pipe material is aluminum, PVC, polyethylene, steel or concrete, and comes in many sizes
- sprinkler head is the component that evenly distributes the water over the field surface
- special heads are available for only a part-circle application
- in all systems, a proper design is required to match the water supply, the pump, the piping and all sprinklers at the proper spacing, in order to achieve the desired application rate and evenness of distribution

IRRIGATION SYSTEMS

How It Works

- water is distributed in a circular pattern
- a 50% overlap of application is usually required to get an even distribution of water
- water is applied in the form of an aerial spray, either above or below the crop canopy
- entire cropland surface receives intermittent applications of water
- has been used on a variety of crops in Ontario for over 50 years



In sprinkler irrigation systems, sprinklers are laid out in a square or triangle. The water is applied in a circular pattern.

Here is an example of a hand-move portable system.

FIXED SPRINKLER SYSTEMS

HAND-MOVE PORTABLE SYSTEM

Design & Hardware

- a network of evenly spaced lateral pipe (aluminum 2–6 inches diameter [50–150 mm]) fed by a movable main trunk line
- sprinklers are evenly spaced along the lateral lines (usually 50% overlap of coverage)
- rate of application is determined by the sprinklers that are used – minimum: 0.1 in/hr; maximum: 2.0 in/hr (2.5–50 mm)
- volume of application depends on how long the system is operated in one position: lower-rate sprinklers for a longer period of time or higher-rate sprinklers for a shorter period of time
- main trunk line must be small enough to move by hand – this can be a limiting factor on how much area can be irrigated at any one time
- pump size and power requirements can be kept low by irrigating in zones

IRRIGATION SYSTEMS

How It Works

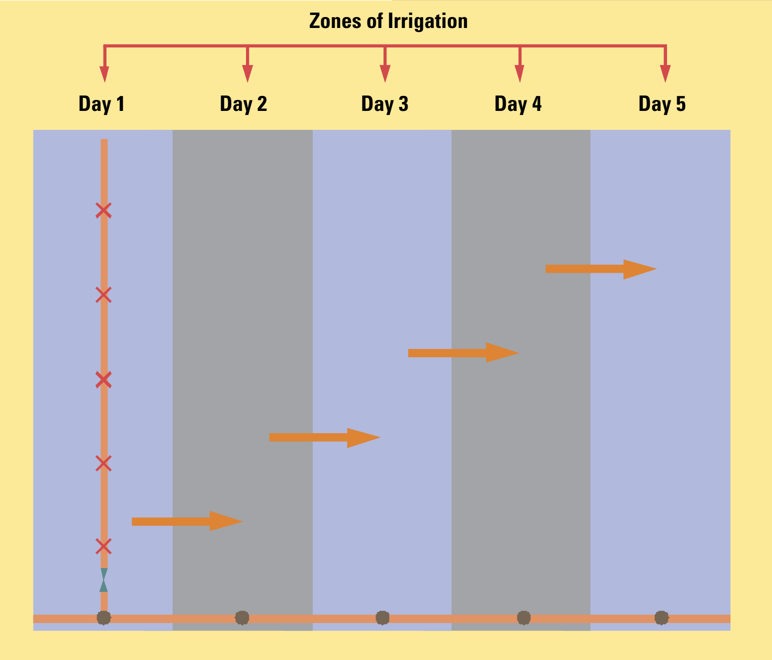
- each irrigation set waters a section of the field
- size of average single system: 1–40 acres (0.5–16 ha)
- after a section of the field is watered with a predetermined amount, the system is moved by hand to the next section to be irrigated
- the system is usually moved every few hours and can be operated 24 hours a day
- after a certain number of days, the entire field is then irrigated and the cycle is started again
- the number of moves is a balance of how many times the system can be moved, the area to be irrigated, over what period of time, and the coverage area of the system
- system is very portable – entire system can be moved from field to field or farm to farm as long as there is a water supply available
- primarily for horticultural crops, especially vegetables

Capital & Labour

- initial capital cost is usually the lowest of any sprinkler system; labour requirements are the highest
- labour: 0.5–1.5 hr/acre-irrigated (1.25–3.75 hr/ha)

Advantages (+) & Disadvantages (–)

\+ can be low initial capital cost
\+ flexible use system
\+ can be used for frost protection
– gets in the way of tillage
– very high labour requirement
– washes crop protection materials off leaf and fruit in orchard crops unless low-trajectory system used
– some crop damage usually results from moving lines
– can be a food safety risk, since water contacts produce, and lower-quality irrigation water could potentially contaminate it



Hand-move systems are designed with a network of evenly spaced lateral pipes and main line to irrigate one section of a field at a time.

IRRIGATION SYSTEMS

SEMI-PERMANENT SYSTEM (main supply lines buried)

Design & Hardware

- very similar to the hand-move portable system, except that the water is delivered to the system through a permanent main line that's usually buried
- valves project to the surface and the lateral lines are attached, thus eliminating the need to move the main line, as the laterals are moved to different sections of the field
- water application rates vary, 0.1–2.0 in/hr (2.5–50 mm/hr)
- as larger set areas are irrigated, the pump size and power requirements increase as well

How It Works

- system allows for larger areas to be irrigated in one set, since the main trunk line is not hand-moved and size isn't a limiting factor
- less portable – only areas serviced by the buried trunk main can be irrigated
- primarily for vegetable and other horticultural crops

Semi-permanent systems are identical to hand-move portable ones, except that the main lines are buried.

Capital & Labour

- the initial capital cost usually increases because of the buried main line – but cost is still moderate if the field is irrigated in sections
- very high capital cost if entire field is irrigated at one time (solid-set is not moved)
- labour requirements are lower than hand-move but still high because the laterals have to be moved after each irrigation – more coverage, larger trunk main, fewer sets, fewer moves, less labour, more capital cost

Advantages (+) & Disadvantages (–)

\+ the main trunk line is buried and presents less obstruction to travelling or tilling the fields
\+ can provide frost protection
– can be a food safety risk, since water contacts produce, and lower-quality irrigation water could potentially contaminate it

Hydrants that project to the surface can be used with semi-permanent systems and trickle systems, like the one shown here. Buried main lines don't obstruct traffic as much, and require less labour.

IRRIGATION SYSTEMS

SOLID-SET PERMANENT SYSTEM

Design & Hardware

- ► similar network of pipe and sprinklers to hand-move system
- ► pipes may be buried or put on the surface in the spring (buried pipes will obstruct traffic less)
- ► sufficient pipe and sprinklers are required to cover entire field
- ► pump and power requirements are generally high – pumping requirements may be reduced if the field is irrigated in segments using valves

How It Works

- ► no pipes are moved
- ► entire field can be irrigated at the same time or in sequence, allowing for flexibility in the rates and volumes applied, e.g., smaller volumes can be applied more frequently

Capital & Labour

- ► highest initial capital cost
- ► not portable
- ► labour requirements are low
- ► operation needs to be scheduled and the system requires maintenance

Advantages (+) & Disadvantages (–)

+ entire field can be irrigated at the same time or in sequence – beneficial for frost protection, evaporative cooling and chemigation
+ do not have to move any pipe – less labour
+ water efficiency – when properly scheduled, smaller volumes can be applied as needed
– highest initial capital cost
– can be a food safety risk, since water contacts produce, and lower-quality irrigation water could potentially contaminate it

Initial capital costs for solid-set systems are very high, but labour requirements are very low.

IRRIGATION SYSTEMS

FIXED-VOLUME GUN HAND-MOVE SYSTEM

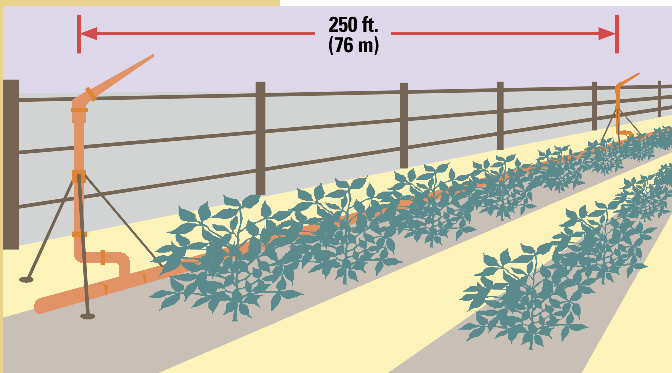
Design & Hardware

- water is supplied by aluminum and rigid or flexible plastic pipe
- makes use of high-volume sprinklers (guns) capable of discharging 50–1000 gpm under operating pressures of 40–130 psi
- nozzles range from 0.5–2.0 inches (12–50 mm) in diameter; water can be projected up to 250 feet (75 m)
- application rates are high: minimum: 0.25 in/hr; maximum: 2.0 in/hr (6–50 mm/hr)
- pump size and power requirements are generally high

How It Works

- water is projected quite high, and distribution evenness can be greatly affected by wind
- one setting can irrigate up to 4.5 acres (2 ha)
- size of average single system: 20–40 acres (8–16 ha)
- guns are moved by hand from setting to setting, or they are mounted on trailers and moved with a tractor
- system is similar to conventional sprinkler except there are fewer sprinkler positions and line positions
- system is very portable and can be moved from field to field wherever there is water supply
- normally used in potatoes, tobacco and nursery stock

Large-diameter, crushable (lay-flat) hose can be used on laneways and access roads. The hose can be driven over without damaging the system.



High-volume guns fixed to aluminum pipe can project water up to 250 feet (76 m).

Stationary guns mounted on wheeled frames are also used in the fixed-volume gun hand-move system. Such systems require supervision to avoid runoff on sloping land.

IRRIGATION SYSTEMS

Capital & Labour

▸ initial capital cost is moderate

▸ labour requirements are moderate (0.5–1.0 hr/ac/irrigation, sometimes > 1 hr/ac/irrigation [1.25–2.5 hr/ha/irrigation]) – but management requirements are moderate to high, as there's a steady requirement for attention and frequent resetting of guns due to high application rates

Advantages (+) & Disadvantages (–)

+ easy to use, easy to maintain
– easy to mismanage – system has some labour requirements
– can lead to runoff and erosion on sloped land
– can cause compaction (surface crusting)
– guns are more subject to wind disrupting the coverage pattern
– not recommended for frost protection
– can be a food safety risk, since water contacts produce, and lower-quality irrigation water could potentially contaminate it

MOBILE SPRINKLER SYSTEMS

TRAVELLING GUN SYSTEM

Design & Hardware

▸ uses the high-volume gun sprinkler technology mounted on a trailer or a sled

▸ water supplied by a flexible plastic hose attached directly to pump, or flexible plastic hose connected to an aluminum main supply line

▸ only part-circle gun sprinklers are used for two reasons: better uniformity of water application, and so that the trailer or sled doesn't have to be pulled through wetted soil

▸ application rates are high: minimum: 0.25 in/hr; maximum: 2.0 in/hr (6–50 mm/hr)

▸ volume of water applied per acre can be adjusted by the travel speed of the sled or trailer, giving some flexibility

▸ pump size and power requirements are generally high

▸ booster pump may be required at gun to maintain adequate operating pressure

A reel device pulls a mounted gun down the field – irrigating as it goes.

IRRIGATION SYSTEM

SAFETY

Low-pressure systems (< 50 psi) are inherently safer and also consume less energy. The risk of injury is greater with high-pressure systems (> 80 psi) because of blown lines, line jumping, guns flipping, etc.

How It Works

- one unit can irrigate approximately 1 ac/hr with 1 inch of water (41,603 L/ha/hr) – many nozzle sizes are available
- size of average single system: 3–140 acres (1–57 ha)
- moved to each location by tractor
- trailer or sled is pulled down the field by a winching device (cable) or reel device (plastic pipe), irrigating the field as it moves
- after each pass of the field, the unit is moved to the next position
- very portable
- suitable for irrigating high- and low-growing crops – commonly used on tobacco, sod, potatoes, tomatoes, tree fruits and grapes
- best suited to flatter ground

Capital & Labour

- initial capital cost is moderately high
- labour requirements are low: 0.1–0.3 hr/ac/irrigation (.25–.75 hr/ha/irrigation)
- entails steady supervision – emergency "kill" switches on the pumping unit are a must

Advantages (+) & Disadvantages (–)

+ easy to use and maintain under ideal management
– easy to mismanage as mechanics are more complex
– can lead to runoff or erosion on sloped land
– can cause compaction
– subject to wind disruption of coverage pattern
– not generally used for frost protection
– limited distance due to capability of travelling reels
– can be a food safety risk, since water contacts produce, and lower-quality irrigation water could potentially contaminate it

IRRIGATION SYSTEMS

LOW-PRESSURE BOOM TRAVELLER SYSTEM

Design & Hardware

- similar to the travelling gun system except the gun is replaced by a boom
- also similar in design to a field sprayer equipped with sprayer nozzles
- booms range in width, 40–235 feet (16–72 m)

The low-pressure boom traveller system is similar to a travelling gun, except that the gun is replaced by a boom with low-pressure nozzles.

How It Works

- application volume is varied by the speed of the reel
- works under low horsepower (10–50 hp)
- application rates are high
- one unit can irrigate approximately 0.2 ac/hr – 0.9 ac/hr with 1 inch of water

Capital & Labour

- moderate capital cost – considerable drop in capital cost per acre if used on large acreages
- labour requirements are low
- supervision is necessary to prevent runoff

Advantages (+) & Disadvantages (–)

\+ can be used on delicate crops (e.g., spinach) because it delivers fine droplets
\+ not significantly affected by wind because delivery is close to the ground
\+ by using drag hose or sock attachments, water is less likely to come into contact with the produce, thus reducing food safety risks associated with irrigating with lower quality water
– works best on soils with high infiltration rates (sandy soils)
– requires supervision or runoff will occur
– limited strip width of 40–235 feet (16–72 m)
– limited distance due to capacity of travelling reels
– not useful for frost protection
– food safety risks – unless a drag hose or sock is used, water contacts produce, and lower-quality irrigation water could potentially contaminate the produce

Low-pressure spray nozzles apply fine droplets, making this system useful for delicate crops.

IRRIGATION SYSTEM

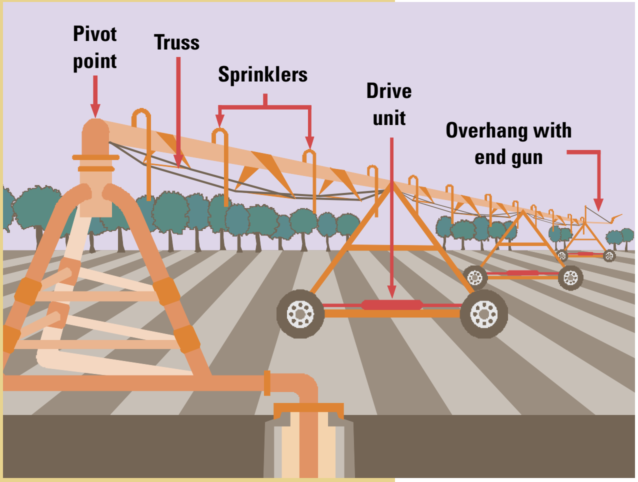
CENTRE PIVOT SYSTEM

Design & Hardware

- system consists of a single lateral, supported by trusses and towers on wheels, with one end anchored to a fixed pivot centre
  - lateral can extend 375–2000 feet (15–600 m)
- other end is free to move in a circle about the pivot
- can use normal mid- to low-pressure impact, high-pressure gun, drop tubes and/or low-pressure spray sprinklers either on top of or below the lateral
- water application rates: minimum: 0.2 in/hr; maximum: 10 in/hr (5–250 mm/hr)
- tower supports are 120–200 feet (35–60 m) apart and are driven by electric, hydraulic (water or oil), or air-pressure energy
  - speed of rotation is usually electronically controlled
- pump size and power requirements are usually high due to large application area
- low-pressure nozzles reduce the requirement for power and pump size

How It Works

- water is fed into the lateral through the centre pivot and distributed from the lateral by sprinklers (high- or mid-pressure), or low-pressure spray nozzles
- a 1600-ft. (490-m) lateral can irrigate an area of 195 acres (80 ha) in one setting
- size of average single system: 7–500 acres (3–200 ha)
- application rate increases toward the outer end of lateral because more area must be covered, and is determined by the sprinkler selection
- in order to get uniform application volumes, sprinklers along lateral are either:
  - evenly spaced along lateral, but are sized to give a higher volume output from each successive sprinkler as the distance from the sprinkler increases, or
  - the same size but spaced closer together as the distance from pivot increases
- gun can be placed at the end to irrigate the corners
- low-pressure drop nozzles are more water-efficient than high-projectile sprinklers/guns
- total irrigation application dependent on the speed of travel, which is variable – one rotation usually completed within 24 hours
- suitable for potatoes, onions and other vegetables



A centre pivot system consists of a single lateral supported by wheeled towers and trusses. It moves about in a circle from a fixed pivot and is fed pumped water.

IRRIGATION SYSTEM

Capital & Labour

- ► initial capital cost is high
- ► very low labour requirements: 0.05–0.15 hr/ac/irrigation (0.13–0.38 hr/ha/irrigation)

Advantages (+) & Disadvantages (–)

+ can function effectively on rolling ground
+ easy to use and maintain once system is understood
+ very low labour requirements (high level of automatic control)
+ good range of application rates available
+ system type suited for both larger and smaller areas
+ a low-pressure nozzle increases water use efficiency; sprinklers/guns are less efficient
+ can be automated
+ can be equipped to shut off from remote location
– high capital cost
– can be moved, but better suited to one location
– large flow rates are used
– large reservoirs of water needed
– crop rotation must be carefully planned
– very high power requirements are often needed
– cannot protect from frost
– will not irrigate corners of field unless special devices are attached to end of lateral line that engage in the corners of the field only
– system is portable and can be towed from farm to farm – but it's not an easy move unless it's in the same field (2–4 hours)
– can be a food safety risk, since water contacts produce, and lower-quality irrigation water could potentially contaminate it

This is an older centre pivot, which consumes more energy because of its high-pressure sprinklers.

Irrigation systems with low-pressure drop tubes offer greater water efficiency.

IRRIGATION SYSTEMS

LATERAL MOVE SYSTEM

The lateral move system is mechanically similar to the centre pivot, except that it moves sideways across a field in line, irrigating a rectangular section.

Design & Hardware

- very similar mechanical construction to the centre pivot, except that entire elevated lateral moves across the field in line, and irrigates a rectangular section
- water is delivered to the system by a flexible hose or by use of an open ditch
- all types of sprinklers can be used in the design
- typical water application rates: minimum: 0.2 in/hr; maximum: 2 in/hr (5–50 mm/hr)
- application rate is the same from one end of the system to the other
- speed of each drive unit electronically controlled to keep in line
- lateral can extend up to 2,600 feet (800 m)
- pump size and power requirements are high because of large area usually irrigated (low compared to travelling gun system)

How It Works

- total application is controlled by travel speed of lateral (variable control)
- best suited for irrigation of large acreage: size of average single system is 80–500 acres (32–200 ha)
- system is somewhat portable on the smaller units between adjacent farms, but it isn't an easy move
- suitable for potatoes and strawberries (where frost protection is not required)

Lateral move systems have a high initial capital cost, but don't require much labour.

Capital & Labour

- initial capital costs are high
- very low labour requirements: 0.05–0.15 hr/ac/irrigation (0.13–0.38 hr/ha)

Advantages (+) & Disadvantages (–)

+ very low labour
+ good range of application rates available
+ by using drag hose or sock attachments, water is less likely to come into contact with the produce, thus reducing food safety risks associated with irrigating with lower quality water
+ easy to use once system is understood (high-tech electronic controls)
– high capital cost
– generally for one field location
– cannot provide frost protection

IRRIGATION SYSTEMS

MICRO-IRRIGATION *(also called drip or trickle)*

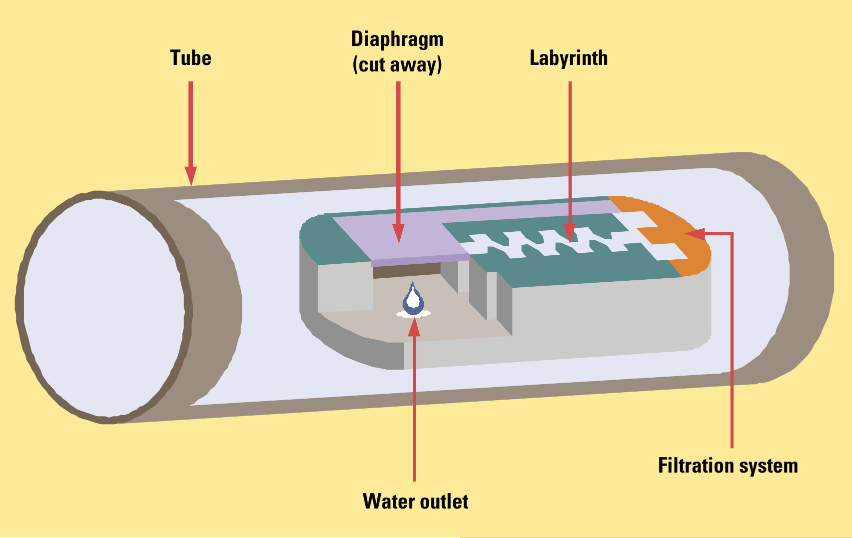
This is a drip emitter, which provides a point source for water discharge.

This spray emitter has no moving parts and can be inserted into the line.

Shown above is a tape system, where emitters are usually built into the seam of the hose.

Design & Hardware

- a network of evenly spaced lateral lines (polyethylene $^3/_8$ – 1.5 inch diameter [10 mm–38 mm]) fed by sub-mains and main trunk lines
- emitters (the equivalent of sprinklers in other systems) may be evenly spaced along the lines to irrigate a continuous row (8–24 inches apart [200–600 mm]) or grouped near each plant (e.g., for orchards)
- emitters may be in line or offset
- systems require filtration units to provide clean water and avoid emitter plugging
- systems generally require pressure regulators at the head of the sub-mains
- pumps are smaller, less power is required, less energy is used, and the water conveyance lines are smaller
- a high level of design is imperative for this system to operate properly, especially on rolling terrain – pressure-compensating emitters can largely overcome the challenge presented by uneven terrain and long runs: the emitter will deliver more volume by opening up when pressure is reduced and less volume by closing down as pressure is increased, resulting in a uniform flow rate



In-line emitters like this can be designed with pressure-compensating features that help maintain the same discharge rates throughout an irrigated field. Pressure-compensating emitters deliver the same flow rate over a wide range of line pressure. This overcomes the problem of slope and distance from the pump.

IRRIGATION SYSTEMS

Drip irrigation provides a small wetting pattern above the rooting zone. Below soil level, the wetting zone fans out.

Systems

- there are three main categories:
  - **tape**: thin-walled hose with the discharge system built into the seam of the hose or manufactured inside the hose (wall thickness 0.004– 0.020 inches [.10–.50 mm])
  - **drip emitter**: thicker hose with emitters plugged in or manufactured inside the hose to provide a point source for water discharge
  - **spray emitter**: thick hose with emitters plugged in that distribute water by means of a spray pattern (diameter of throw is less than 10 feet [3 m])
- microsprinklers are not considered in the same category as the above micro-irrigation techniques
  - provide water to the entire soil area instead of just the plant root zone
  - can be distinguished by having a moving part such as a spinner or other device to increase the diameter of throw
  - higher flow rates >25 US gph (>100 Lph)
- older systems supplied water almost on a 24-hour basis during times of need (low pressure/very low flows); newer systems use higher flow rates, and can apply the desired amount of water in 4–8 hours on a daily basis
- higher flow rates reduce emitter clogging problems (larger orifices) and field can be irrigated in sections or zones, thereby reducing the pump sizes
- a 3 hp electric pump is capable of supplying the power to irrigate an extensive orchard planting – by breaking the planting into zones holding approximately 1,000 trees/zone, the pump feeds approximately 2.5 acres (1 ha) of planting at a time
- clean water is a must for emitters to function properly, and to reduce maintenance requirements – filtration systems are needed

Filters

- there are three main types:
  - **screen**
  - **disk**
  - **sand**
- choice of filter type should be based on water quality and emitter orifice size
- filters must be back-flushed to keep them clean and operating properly – this backflushing may be automated or done manually
- filters are classed by the size of the openings of their mesh, which is called "mesh equivalent"
  - e.g., 100 mesh equivalent = 0.1520 mm; 200 mesh equivalent = 0.0740 mm
  - a minimum of 80 mesh screen must be used for any trickle irrigation system

Note: disk filtration systems are often mounted on a mini-trailer for easy portability

IRRIGATION SYSTEMS

FILTER TYPES

FILTRATION TYPE	PORTABILITY (able to move it between sites)	ABILITY TO DEAL WITH HIGH LEVELS OF ORGANIC PARTICLES	ABILITY TO HAVE AUTOMATED BACKFLUSH
SCREEN FILTER	Yes	Low	Yes
DISK FILTER	Yes	High	Yes
SAND FILTER	No	High	Yes

Screen filter

Sand filter

Disk filter

How It Works

- system supplies a small amount of water (1/2–2 US gal/hr [2–8 L/hr]) near the base of each plant – the amount of water is controlled by the length of time the system runs
- system components can be downsized because water is delivered on a more continuous basis (usually on a daily basis when needed) and only the rooting areas are watered (not between the rows)
- used most commonly for fruit trees, berry crops, vegetable and ornamentals

Capital & Labour

- very low labour requirements once the system is in place
- labour is required to ensure that emitters are not plugged and equipment operates properly

IRRIGATION SYSTEMS

Advantages (+) & Disadvantages (–)

+ based on the concept of preventing rather than relieving moisture stress – crop response is good
+ very low labour
+ easily automated
+ water-efficient: can reduce water usage by one-third to one-half compared to overhead systems
+ can be used for fertigation
+ can be applied on windy days or during spraying operations
+ can be functioning without interruption of harvest operation
+ foliage is not wetted – reduces disease problems for some crops and does not remove crop protection materials from leaf canopy or maturing fruit
+ operating costs are relatively low
+ weed problems are reduced since only crop rows are irrigated
+ water does not come into contact with the produce and therefore the food safety risk associated with lower quality water is reduced
– water supplies must be dependable
– cannot be used for frost protection
– crop could suffer badly if irrigation is interrupted during a dry period
– occasional rodent damage
– may present a problem where tillage or mowing devices are used near crop row – line can get tangled in equipment

SUBSURFACE DRIP IRRIGATION

Design & Hardware

► the same as regular drip irrigation, except that in this case lateral lines are buried (see details on page 61)
► burial depth for lines will depend on crop rooting depth and soil type
► it's important to install lateral lines with emitter orifice pointing up

Drip tape can go above and below ground. Here you can see the wetting pattern from a subsurface drip irrigation tape.

IRRIGATION SYSTEMS

How It Works

- ▸ system supplies water directly to the plant roots, beneath the soil surface
- ▸ system supplies a small amount of water on a frequent basis (usually daily)
- ▸ **root intrusion**
  - ▷ irrigation applications must be frequent to avoid root intrusion
  - ▷ deficit irrigation is not appropriate for subsurface drip irrigation systems, since it may lead to roots intruding into emitters
  - ▷ in woody plantations, irrigation must continue throughout growing season even after harvest, as roots are still growing, and if irrigation is stopped, the roots may aggressively seek water and move into the emitters
  - ▷ to prevent root intrusion, use acid flushing or emitters designed to prevent the entry of roots
  - ▷ once root intrusion occurs, the system must be replaced

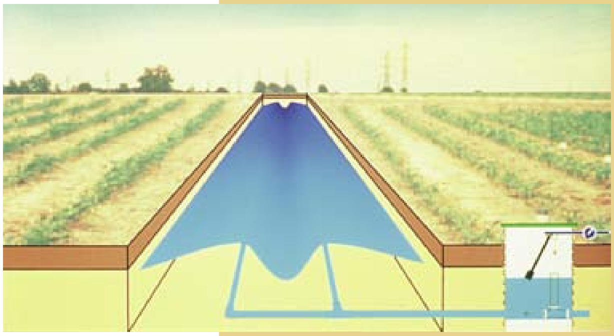
Advantages (+) & Disadvantages (–)

+ less water evaporation from soil surface
+ no interference with crop operations even during irrigation event
+ wets a larger soil volume, reducing deep percolation
+ reduces animal damage to laterals
– potential for root intrusion
– potential for lateral lines to become pinched, restricting water flow
– difficult to monitor system since it is buried and not visible
– must rely on pressure gauges and flow meters to make sure the system is working as designed
– do not install in areas where compaction or high traffic will collapse the lines

CONTROLLED DRAINAGE / SUB-IRRIGATION

A subsurface irrigation system uses the existing tile drainage network to maintain, raise or lower the water table height. The concept is to keep the water table near the bottom of the root zone.

By capillary action, water is made available in the area of the roots. Two systems may be used to assist in the management of the water table: controlled drainage and sub-irrigation.



With controlled drainage (no water added) or sub-irrigation (water added), the water table level is controlled so that water can be drawn up the root zone by capillary action.

IRRIGATION SYSTEMS

CONTROLLED DRAINAGE

Design & Hardware

- flow-level control devices are installed at the outlets of the tile or at strategic points of the subsurface drainage system (e.g., rubber flap valve)
  - flow control devices are kept open to allow drainage during spring melt and frequently during planting
  - flow control devices will be kept open for drainage (i.e., in spring) and are closed for the rest of the growing season, unless it rains enough to require drainage
- tiles are typically 30–36 inches (750–900 mm) below the ground surface, and will draw the water table down to that depth
- when flow control devices are activated, the water table will only be lowered to a depth of 16–18 inches (400–450 mm) just below the primary root zone
- site requirements:
  - field must be systematically tile drained
  - best suited to fields that are relatively flat
  - higher sloping fields can be done, but additional cost and management are required
  - must have an impervious layer at or near the depth of the tile system; otherwise, the water table drops too quickly for any benefit to be realized – may require a careful study of the soil horizons

How It Works

- not a true irrigation system
- delays the need for irrigation by making better use of the water before it drains from the soil
- manages the function of a subsurface drainage system
  - subsurface drainage system is designed to remove gravitational water from the soil, so that the water table is lowered to a depth for optimum growing conditions
  - even after attaining the desired water table depth, excess water is removed until the water table is lowered to the depth of the drainage system
- by using controlled drainage techniques, some of this water normally removed by conventional drainage could be used as a source to replenish the root-zone moisture content (through capillary action)
- the system simply controls how far the water table is drawn down by the drainage system
- water isn't added: it extends the time period before irrigation or rain is required

IRRIGATION SYSTEMS

SUB-IRRIGATION

Design & Hardware

- site requirements
  - imperative that an impervious layer of soil be at or below the tile depth in order to retard the downward movement of the water
  - if this layer doesn't exist, the water table level cannot be maintained and benefits will not be gained
  - soils with a naturally high water table are also suitable; naturally well-drained soils are not suitable
  - flat or low-sloped fields are best for this system
  - test holes need to be dug throughout the field to identify the soil profile and the impervious layer

How It Works

- functions the same as controlled drainage system, except that water is added to the system to maintain the water just below the primary root zone
- tile system provides the path for water to drain in the spring and for water to be reintroduced to the soil to maintain the water table during the growing season
- depending on the water source, water is pumped into the tile system or provided by gravity
- water can be put into the tile at the high or low end

Advantages (+) & Disadvantages (–)

\+ low maintenance and low labour
\+ doesn't impede the tillage and surface operations of the field
\+ research has shown additional benefits from sub-irrigation systems besides yield increases: more efficient use of nitrogen (less loss to ground or surface water), and reduction in deep percolation of pesticides
\+ water doesn't contact the produce, thereby reducing food safety risks associated with irrigating with lower quality water
– on sloping fields, it may be necessary to divide the field into sections
– in retrofit situations, a good knowledge of the existing drainage system is required (location, slopes, depths etc.)
– not suitable for frost protection
– must have adequate water supply

This commercially available sub-irrigation unit will help control the amount of irrigation water supplied to the drainage system.

IRRIGATION SYSTEMS

IRRIGATION PRICES: $ PER ACRE

IRRIGATION SYSTEM	15 ACRES	50 ACRES	100 ACRES
HAND-MOVE PORTABLE	1540 3 moves 5 ac. irrigated/move	980 5 moves 10 ac. irrigated/move	N/A
SEMI-PERMANENT	1575	865	N/A
SOLID-SET	3580	3250	3070
FIXED-VOLUME GUN, HAND-MOVE	2100	1440 48 moves of gun	900 84 moves of gun
TRAVELLING GUN	1985	900	700
TRAVELLER WITH BOOM	3000 7 moves	1715 5 moves	915 9 moves
CENTRE PIVOT	N/A	890 incl. generator	750 incl. generator
MICRO PIVOT	1575 no generator incl.	860 mobile pivot, 2 circles	N/A
LATERAL MOVE	N/A	1240 micro lateral	990 large lateral
All pivots and laterals are subjected to the size and shape of field. Power is required to drive pivots or laterals. Generators may or may not be included in price: see above.			
DRIP/MICRO IRRIGATION	**15 ACRES**	**50 ACRES**	**100 ACRES**
DISPOSABLE TAPE/THIN WALL	1078 (230/ac/yr to replace tape)	822/ac (219/ac/yr to replace tape)	750/ac (219/ac/yr to replace tape)
HEAVY WALL/PERMANENT DRIP TUBING (15-year life on drip tube)	3040	2550	2325

Assumptions: All pricing based on close water supply and minimal suction lift. Fields are relatively flat and shaped such that main supply lines are minimal.

Power supply not included.

To convert to costs per hectare, multiply cost by 2.48.

IRRIGATION SYSTEMS

IRRIGATION PUMPS

A major component of any irrigation system is the pump. Water must be delivered to all sprinklers or emitters at the proper pressure and flow rate. The pump and motor must be adequately matched to perform the desired function. A proper match will ensure an economical system that can save you dollars on maintenance and operation.

Each irrigation pump has unique flow characteristics that vary with pump rpm and operating pressure. The pump must be matched to the total irrigation flow rate and the total dynamic head:

- total irrigation flow rate at any one time – determined by flow rate from the maximum number of sprinklers or emitters that operate at the same time
- total dynamic head developed by the system
  - $H = h_p + h_f + h_s + h_e$ (h_p = pressure head; h_f = friction head; h_s = static suction head; h_e = static discharge head).

The brake horsepower required by an irrigation pump can be calculated from:

- H.P. = $(Q \times H) / (3960 \times E)$
  - H.P. = Brake horsepower required by system; Q = Design flow rate of system (US gpm); H = Total dynamic head (ft); E = Pump efficiency (% in decimal form).

Pump efficiency can be obtained from a Pump Performance Curve. This curve indicates how the pump performs at different pumping rates, rpm speed, and different resistant forces (H). The higher the efficiency, the more energy that is transferred to the water for movement.

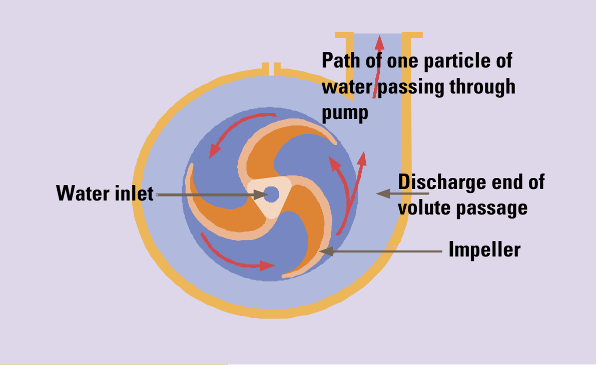
Obtain expert advice when selecting a pump.

CENTRIFUGAL PUMPS

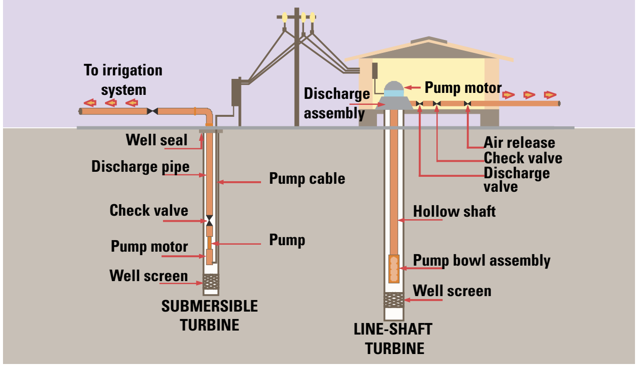
- most common type of pump
- water generally enters the side of the impeller and is spun out by centrifugal force to the outside of the impeller
- should be selected and operated at or close to its **best efficiency point** (BEP), as fuel efficiency will drop
- try to select pumps that have a BEP of 65% or better
- shouldn't be operated at less than 80% of its BEP
- should be located as close to water elevation as possible to minimize vertical suction lift
- water is easier to push up rather than raise by suction

IRRIGATION SYSTEMS

- ► used with surface water sources, e.g., ponds, streams
- ► when used with water sources free of silt or sand, this pump gives many years of dependable service
- ► can be used with many types of power and power transfer systems, i.e., electric, gas, diesel, power takeoff, etc.
- ► can be used over a wide range of speeds; suitable for low volumes at high pressure (frost control) or higher volumes at lower pressure (irrigation)



In a centrifugal pump, the water enters the side of the impeller and is spun out to the outside of the impeller.



The submersible pump is most often used in smaller diameter wells with static water levels. The line-shaft turbine pump is better suited to wells with fluctuating head situations.

TURBINE PUMPS

SUBMERSIBLE TURBINE

- ► usually used when pumping from wells with a static water level below 15 feet (4.5 m)
- ► most often used in smaller diameter wells
- ► pump and motor located below static water level in well
- ► water must be clean of silt and sand
- ► electrically powered
- ► mainly used for small volumes

LINE-SHAFT TURBINE PUMPS

- ► used in water wells or wells connected to another supply such as a river
- ► capable of pumping high volumes of water
- ► often used for high total dynamic head (H) situations or fluctuating head situations
- ► power supply is at the top of well, and different types can be used, e.g., electrical, internal combustion engines
- ► pump is located in the well below the static water level
- ► can operate with less clean water (water that is not crystal-clear)
- ► higher priced

IRRIGATION SYSTEMS

POWER SOURCES

ELECTRIC MOTORS

Advantages (+) & Disadvantages (–)

+ very efficient (85–90%)
+ very dependable and low maintenance
+ if power is readily available, they require less initial cost than internal combustion engines
+ if 3-phase power is available, there are additional savings on motor cost, especially on larger-size motors; however, demand charges apply monthly
+ have a long life expectancy (20–30 years)
+ wide range of sizes available and easy to match the need
+ quiet and clean
+ easy to automate
+ very useful for micro-irrigation (trickle)
– not a very portable power source – power sources are usually fixed locations
– they run at a fixed speed, which doesn't allow for changing pumping rate if that is required (unless equipped with a variable speed drive)
– if power isn't readily available, the initial cost may exceed that of internal combustion engines
– higher capital cost

Additional Information

If the power requirements exceed 10 hp, special soft-start motors are required to operate on a single-phase service. These are more costly than conventional motors.

Another option is a 3-phase motor, if that type of power supply is available. Three-phase motors can be used with a single-phase service, but a phase converter must be added ahead of the motor, increasing the cost of the installation.

If you're considering larger systems, you should contact the local hydro utility to ensure that the access lines have an adequate electrical power supply. Line surge charges may be encountered, adding to operating costs if large motors are required. Consult with a knowledgeable electrician for more options.

This 3 hp electrical pump is used to supply water to a trickle irrigation system.

IRRIGATION SYSTEMS

INTERNAL COMBUSTION ENGINES

Advantages (+) & Disadvantages (–)

+ very portable
+ speed can be adjusted to alter the pumping rate for different requirements, e.g., very high speed for big guns
+ large power requirements can be provided more easily
+ can make dual use of existing power supplies, e.g., tractor
– higher maintenance required, e.g., oil changes, tuneups
– less motor size availability
– shorter life
– higher initial cost
– if a tractor is used to drive pump, tractor isn't available for other farming functions
– if tractor is used to drive pump, the motor life is being decreased but other tractor functions are not being affected – in high use situations, a dedicated motor should be used
– Murphy safety switches are essential to eliminate chance of motor meltdown
– noisy and emit fumes
– need to be refuelled

Additional Information

There are safety features that should be installed to protect internal combustion engines:

▸ low irrigation-pressure shutoff
▸ low oil-pressure shutoff
▸ high-temperature engine-water shutoff.

Tractor PTO pumps make good use of existing power sources.

Fixed pumps are very portable and can be adjusted to alter pumping rate for different requirements.

IRRIGATION SYSTEMS

Direct drive (dedicated use) or PTO systems may be used, as can diesel or gasoline engines. Diesel engines are longer lasting, and have a higher capital cost and lower energy cost than gasoline engines. There has been some interest in the use of natural gas as a fuel source because it costs much less than gasoline. Engines running on natural gas can have a long life expectancy and have a good record for engine starts in cold conditions.

POWER REQUIREMENTS

Water Horsepower (WHP)	=	The actual energy delivered to the water by the pump (hp)
WHP	=	Q x H/3960
Where Q	=	Design flow rate of system (US gpm)
Where H	=	Total dynamic head (ft)

WATER HORSEPOWER PER UNIT OF FUEL

FUEL	WATER HORSEPOWER HOURS PER UNIT OF FUEL
GASOLINE	2.14 per litre
DIESEL	2.9 per litre
ELECTRICITY	0.885 per kilowatt-hour

FUEL COST COMPARISON

FUEL	TO PRODUCE 10 WHP HOURS	COST PER UNIT OF FUEL ($)	TOTAL COST ($)
GASOLINE	4.67 litres	90	4.20
DIESEL	3.44 litres	80	2.75
ELECTRICITY	11.29 kw-hrs	0.11	1.24

Note: This chart only deals with the fuel costs. It uses average efficiency rates of the motors for each fuel. It does not take into account the costs of installation, the purchase price, maintenance, or the life expectancy.

IRRIGATION SYSTEMS

HARDWARE

Selecting the right hardware is part of choosing and designing an effective irrigation system. Irrigation hardware includes pipes, pipe connections, sprinklers and nozzles. The types of irrigation hardware are presented in the following section to help you choose those most suitable to your irrigation system and crop operation.

PIPE

ALUMINUM

- size range: 2–8-inch diameter (50–200 mm); 30-ft length (9.1 m) most common
- approximate weights: 3-inch diameter, 30–40 lb/30-ft section (75 mm, 13.6–18.1 kg/ 9.1 m); 8-inch diameter, 100 lbs/30-ft section (200 mm, 45.4 kg/9.1 m)
- life expectancy is very good (50 years+)
- used for above ground applications only (not suitable for underground use due to corrosion)
- fertigation can reduce the life of the pipe

PLASTIC

- size range: .5–10-inch diameter (12.7–254 mm) most common; larger sizes are available; 20-ft length (6.1 m) most common
- weighs more than aluminum of equivalent diameter
- mainly used for underground applications (main line distribution system)
- excellent resistance to chemical deterioration
- new products developing for plastic pipe aboveground uses; currently only 3-inch (75 mm) available
- life expectancy is 25–30 years
  - durabilty is unknown, especially in cold weather
  - plastic becomes more brittle with cold temperatures and exposure to sunlight
- suitable for fertigation

IRRIGATION SYSTEMS

PIPE CONNECTIONS

Several types are available. The two main types are: knob and latch, and ball and socket.

KNOB AND LATCH

- when pump is shut off, water can drain from line due to design of gasket
- when pipes are disconnected, water can drain out for moving purposes – this makes moving pipes less difficult

BALL AND SOCKET

- able to go around some bends and still maintain seal
- when pump shuts off, line remains pressurized
- when sections are disconnected, pipes remain full of water and therefore pipe is heavy to move
- newer types avoid this problem by a method of breaking the seal to let water escape

One of the advantages of a knob and latch connection is that water can drain from disconnected pipes easily – making moves less difficult.

Leaky connections waste water. Monitor and repair your pipe connections.

IRRIGATION SYSTEMS

Big-volume guns are very versatile and will move large volumes of water quickly to a crop in need. Low labour requirements make this system very attractive to potential users.

Low-pressure nozzles are used extensively on travelling booms.

A travelling boom with drag hoses and socks applies water directly to soil surface. In this case, water does not contact surface of the product, thereby minimizing plant disease, food safety risks, and evaporation.

SPRINKLERS

MATERIAL

PLASTIC

- approximately 30% less cost than conventional brass sprinklers
- not feasible to repair: wear out, throw away
- are being used in specialty applications, e.g., ginseng (low-trajectory sprinkler under shade canopy)

BRASS

- guns
- majority of sprinklers are brass
- can be repaired – nozzles can be replaced as they wear
- very durable and long life expectancy
- they can be one- or two-directional
  - one-directional is good for frost protection: reduces water volume
  - two-directional is good for uniformity of application, short and long distance

LOW-PRESSURE NOZZLES

- based on the principle of water projection onto a cone deflector, creating the spray pattern
- the deflector may be fixed or rotated by the water to create an even, circular pattern
- used extensively on travelling boom, centre pivot or lateral move system
- droplet size created is much smaller than traditional sprinklers
- spray projection distance is much shorter than for traditional sprinklers
- require lower pressure to operate than traditional sprinklers
- can result in significant water savings if used in conjunction with drop tubes that bring the water application closer to the soil surface, thereby decreasing the evaporation losses
- the nozzle size determines the flow at different pressures
- the deflectors determine the spray pattern
- spray pattern options include wobblers, nutators, low drift nozzles, spray heads, quad sprays, rotators, spinners, accelerators, bubblers, fertigators, aerators etc.
- made of plastic, some may have brass or rubber parts

DRAG HOSE / DRAG SOCK

- can be used for Low Energy Precision Application (LEPA)
- hoses replace sprinklers on travelling boom and lateral move
- water is delivered directly to the ground surface between each or alternate rows
- hose is dragged along the soil surface applying water between the crop rows, and the flow rate is controlled by a nozzle
- plastic sock may be used at the end of the hose to disperse water on soil surface

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

In this chapter, we look at more specific needs of different kinds of irrigated crops, including:

- ▸ fruits
- ▸ tree nuts
- ▸ nursery stock
- ▸ vegetables
- ▸ tobacco
- ▸ sod.

The charts on pages 81–97 present practices that increase crop productivity and quality and, where technology is available, save water.

First, we'll look at ways of making optimal use of water resources.

WATER EFFICIENCY

Here are some general best management practices for most crop operations using irrigation:

get required permits

- ▸ get a Permit To Take Water from the Ministry of the Environment and keep it up to date
- ▸ keep records of the water used for irrigation

match crop to suit soil conditions

- ▸ choose a crop that's right for your soil, so crops with high water needs are grown on soils with high water-holding capacity

build healthy soils – you want water to infiltrate and be available for crop use

- ▸ build organic matter (manure, green manure, compost, cover crops): your soil's structure will improve and the amount of water available to your crop will increase
  - ▷ a 0.5% increase in soil organic matter can result in as much as a 12% increase in the soil water-holding ability of sandy loam soil
- ▸ avoid compaction: don't work wet land, especially fine-textured soils
- ▸ reduce tillage: less tillage means less drying and less organic matter loss
  - ▷ with reduced tillage and higher organic matter, more macropores will develop, which will make it easier for water to enter the soil (macropores may be formed by earthworms or old root channels)
- ▸ use conservation tillage equipment to keep more residue on the surface
- ▸ use conservation tillage equipment to maintain a rough surface, which encourages snow trapping and water infiltration
- ▸ take a look at the Best Management Practices book or CD-ROM, *Soil Management*, for more suggestions on building healthy soils

Build your soil's organic matter: add manure and compost, or grow plowdowns.

Save water: choose precision irrigation systems with a high degree of distribution uniformity (such as trickle irrigation).

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

irrigate efficiently

- ▸ harvest and store water from watercourses during peak flows, or from ground water when water table is high
- ▸ sprinkle-irrigate when winds are less than 3 mph (5 km/hr)
- ▸ try new irrigation methods that bring water application closer to soil surface in order to reduce evaporation losses and wind effects
- ▸ choose drip irrigation next time you upgrade
- ▸ design the system to reduce friction losses to pressure when pumping water – friction losses are lower with larger-diameter mains
- ▸ apply the right amount of water when the crop needs it – use a technique to measure soil moisture (see page 29 for methods of determining irrigation need)
- ▸ use irrigation scheduling and take into account weather forecast information
- ▸ avoid irrigating during the heat of the day
- ▸ make use of rain gauges to measure how much and how evenly water is being applied
- ▸ match application rate to the rate at which it will soak into the soil (and avoid runoff)
- ▸ maintain your irrigation equipment for optimal performance
  - ▹ fix leaking pipes
  - ▹ replace worn-out nozzles – consider replacing nozzles with new water-efficient technology, e.g. low-pressure nozzles

This large reservoir stores water for the growing season. It is filled with water pumped from drainage ditches during the winter and spring, and is gradually emptied over summer months.

Many growers now use boom systems, which minimize water loss from evaporation and wind.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

reduce water loss from crops and soil (evapotranspiration)

- plant windbreaks or wind strips to slow drying winds
- plant perennials into chemically killed sod
- use dwarf grasses between orchards and nursery crops
- schedule short-season crops for spring or fall
- manage crop residues to reduce runoff, increase infiltration and so that they can act like a mulch
- space plants to cover soil surface quickly
- use plastic or organic mulches
- ensure a weed-free period (1–6 weeks for most crops is needed to maximize yield)
- mow sod and cover crops regularly
- reduce tillage to reduce soil water loss
- in some circumstances, try shallow tillage to reduce the upward movement of soil water and create a dry soil mulch layer that can reduce soil evaporation, e.g., vegetables on muck soils.

A straw mulch and grass clippings are used to reduce soil evaporation losses in this high-density apple orchard. Weed suppression in the tree row is an added benefit.

Finally, when considering whether to irrigate, you should weigh the increased costs and potential benefits.

Cost/benefit is directly related to soil type, site location (climate), crop, planting density, and plant-training system. For example, a strawberry grower in a climatically preferred region with soils that have good moisture-holding capacity may choose to go without a system. Drought and frost losses totalling a few thousand dollars in one out of four years may be acceptable compared to an investment of $50,000–$100,000 for an irrigation system.

If, however, soils have low moisture-holding capacity, frost damage is common or crop value is very high, the cost of an irrigation system will be low compared to the benefits it may provide in ensuring an excellent crop year after year. See pages 109–116 to calculate the cost/benefit of an irrigation system for your operation.

Use plastic mulches to save water. These mulches will also accelerate plant growth and development by warming soils earlier in the year. Added benefits include reduced fertilizer leaching, and shedding of water away from root zones in excessively rainy conditions.

Newly established orchard trees need irrigation.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

MANAGING RATE OF WATER USE

Total available water is of course important. However, the rate of withdrawal may be even more important, especially if you are withdrawing from a watercourse. Consider these steps to help you ensure water is available when you need it:

- construct a pond to reduce pumping rate from watercourse
  - fill pond gradually at a low-flow rate; irrigate from pond at a high-flow rate
- construct a pond to provide water storage, i.e., store water when it's plentiful (in the spring or after a large rain) for use during water shortages in the growing season
- pump at a low-flow rate from many different water sources (watercourse and well) to fill a pond – the pond is used as a water reservoir, enabling you to irrigate from the pond at a high-flow rate
- irrigate less acreage at a time
  - e.g., with a solid-set system, irrigate the area in zones
  - breaking the irrigated area into two zones will reduce your rate of water withdrawal by 50%
- schedule water-takings with neighbours (see sketch below)
  - e.g., if four farmers all irrigate from the same water course at 500 gpm, the total rate of water withdrawal from the creek is 2000 gpm
  - if each neighbour takes a turn to irrigate, the total rate of water withdrawal from the creek will be 500 gpm
  - water scheduling may mean some people irrigate during the day, which is less efficient – other options may be to irrigate alternate days
  - talk to your neighbours and see what is possible for your situation
- consider nozzles that operate at a lower flow rate.

2000 gpm	All four farms withdrawing.
1500 gpm (75%)	Three of four farms withdrawing.
1000 gpm (50%)	Two of four farms withdrawing at one time.
500 gpm (25%)	Only one farm withdrawing at one time.

Scheduling water-taking reduces the impact of irrigation on local water levels. This is particularly important when withdrawing water from creeks or small lakes.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

For best management practices for specific crops, find your crops in the charts that follow. They summarize some of the documented benefits of irrigation. Crops appear in this order:

- fruit crops
- tree fruit and grapes
- berry crops
- vegetable crops
- tree nut crops
- tobacco
- field-grown nursery stock
- container-grown nursery stock
- sod.

FRUIT CROPS

Rooting depth to 3–4′ (0.9 –1.2 m)

AMOUNT OF WATER REQUIRED: – up to 8 Imp gal/mature tree/day (36.4 L/day) during July and August
– approx. 1" (25 mm) every 14 days to maintain 50–100% available soil moisture
– approx. 1" (25 mm) every week during July & Aug.

Irrigation scheduling may help you determine how much water to apply, and how often.

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
APPLES low to medium density on vigorous or semi-vigorous root systems 💧💧 high-density systems (M26, M9 root stocks or equivalent) 💧💧💧	• increased fruit size and yield • more fruit bud initiation • less biennial bearing • reduces probability of bitter pit • improved quality • better growth and development of nursery stock • moderation of June drop • better production of new unsuberized roots, which are responsible for nutrient uptake • better tree establishment	• May–September • bloom through cell division stage • fruit bud initiation (June) • fruit swell (August–September)	• trickle • travelling gun • fixed-volume gun	• more important on fully dwarfing rootstock • use short wettings or trickle irrigation to avoid scab and fireblight spread • uniform soil moisture may reduce bitterpit • moderate to excessive summer pruning under drought conditions (without irrigation) may have a negative effect on crop volume and finish • do not root prune on droughty soils unless irrigation is available – the added stress may also affect winter hardiness • light summer pruning reduces whole canopy transpiration • organic mulches help conserve water

Under average growing conditions, adding fertilizer materials to irrigation water using the technique of "fertigation" has shown no appreciable extra benefit in high-density apple culture in northeastern North America.

High-density apple systems are quite suitable to trickle irrigation. Note the added benefits of mulch for water conservation. A nematode-resistant dwarf perennial rye sod is between tree rows.

code:
- 💧 **seldom expect response**
- 💧💧 **some response 30–60% of time**
- 💧💧💧 **expect response most years (75%)**
- 💧💧💧💧 **expect response 9 years out of 10**

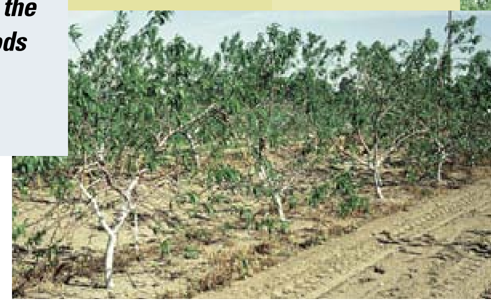
BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

FRUIT CROPS

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
PEACHES & NECTARINES 💧💧💧💧	• less thinning needed • fewer split pits with with regular irrigation • less stress to tree, therefore less winter injury • increased marketable yield • improved stand establishment	• May–September • pit hardening through fruit swell	• travelling gun • trickle • fixed-volume gun	• maintain 50% available soil water • irrigation is critical if sod is established between rows • longer tree life is expected from season-long irrigation • use trickle or low risers to avoid spread of brown rot and bacterial spot
PEARS 💧💧💧	• larger fruit and yields • more fruit bud initiation • less biennial bearing • increased growth • more critical in high-density systems • improved stand establishment • increased quality	• May–September • fruit bud initiation (July) • fruit swell (July–September)	• travelling gun • trickle • fixed-volume gun	• overhead irrigation may wash psylla residue off, but may help spread fireblight (less risk of fireblight with trickle), scab and leaf spot disease • avoid excessive growth with balanced nutrition • more critical in high-density systems

Consider using a low-trajectory sprinkler system (under canopy) or sled to avoid washing crop protection materials from the tree canopy and to reduce wetting periods that encourage disease.

Incidence of split pits in peach can be reduced with regular irrigation.



These peaches, which were grown on sandy soil with no sod strips or irrigation, show reduced vigour compared with those shown in the photo on the right.

Shown here is the same cultivar (Garnet Beauty) with sod strips and irrigation. Note the overall improvement in vigour and vegetative growth.

code:

- 💧 **seldom expect response**
- 💧💧 **some response 30–60% of time**
- 💧💧💧 **expect response most years (75%)**
- 💧💧💧💧 **expect response 9 years out of 10**

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

TREE FRUIT AND GRAPES

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
PLUMS	• larger fruit • reduces the probability of heat spot and gummosis • reduced winter injury • improved stand establishment • improved yield	• May–September • pit hardening through fruit swell	• travelling gun • trickle • fixed-volume gun	• use short wetting to reduce spread of brown rot with overhead irrigation • regular and uniform irrigation may reduce gummosis • thin crop for maximum response
CHERRIES	• larger fruit • healthier trees • better recovery after mechanical harvest for sour cherries • rapid tree establishment – critical for new dwarfing rootstocks like the Gisela series	• May–September • pit hardening through fruit swell	• travelling gun • trickle • fixed-volume gun	• no overhead irrigation after fruit colour to avoid splitting and brown rot (can use trickle irrigation) • use short wettings to avoid leaf spot infections with overhead • irrigate soon after mechanical harvest if under stress from dry conditions
APRICOTS	• larger fruit • less thinning required • reduced winter injury due to less stress on trees	• May–September • pit hardening through fruit swell	• travelling gun • trickle • fixed-volume gun	• greater risk of spreading brown rot and bacterial spot with overhead than with trickle
GRAPES	• larger berry size • increased vine growth • increased yield in some years • increased sugar content during very dry years when leaf function may be limited • improved vineyard establishment	• berry set through to ripening period (veraison) • avoid irrigation after this period to maintain sugar levels and reduce probability of late growth and winter injury	• trickle • travelling gun	• more response on heavy clays, very coarse soils and shallow light soils • greater berry size response in labrusca table and juice grapes • timely pesticide application is important when using overhead irrigation to reduce disease spread, e.g., downy mildew • well-pruned vinifera vines with small crops have a lower risk of water stress

Avoid sweet cherry cracking – do not sprinkle-irrigate after fruit colour. Water absorption leading to cracking takes place primarily through the skin of the ripe cherry.

Gummosis (heat spot) of plum can be more prevalent under dry growing conditions.

In tree fruit crops, maximum growth response to irrigation can be expected in the first five years after planting.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

BERRY CROPS

Berry Crops: Rooting depth of 1-2.5' (0.3-0.8 m)
AMOUNT OF WATER REQUIRED: – approx. 1–2" (25-50 mm) per week
Irrigation scheduling may help you determine how much water to apply, and how often.

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
LOWBUSH BLUEBERRIES	• plant vigour and health • larger fruit • increased yields • increased root growth • improved quality	• bloom (frost protection) • berry sizing through harvest • post-mowing (renovation)	• hand-move portable • solid-set	• avoid wet plants overnight
HIGHBUSH BLUEBERRIES	• plant vigour and health • larger fruit • increased yields • improved quality	• May–September • bloom • berry sizing	• solid-set • travelling gun • trickle	• avoid wet plants overnight • irrigation critical for establishment and growth • requires 2" (50 mm)/week during fruit development • use a maximum 4 Imp gal/day (18 L/day) per bush • ensure entire root mass is irrigated by wetting greater soil volume
RASPBERRIES	• larger fruit • taller canes • increased yield • more root growth • annual production • less winter injury • frost protection for fall-bearing cultivars	• bloom • fruit sizing through harvest • primocane growth	• trickle • solid-set • travelling gun	• avoid wet plants overnight • high moisture requirements • keep irrigation off primocanes to reduce disease • overhead irrigation can be used for frost protection in spring with summer-fruiting cultivars or fall with fall-bearing cultivars

Drip (i.e., trickle or micro-) irrigation will help yield larger blueberries. Highbush blueberries are very responsive to irrigation. By using a drip system, plant foliage is not wetted and cultural practices can be carried out while the irrigation system is running.

Drip irrigation is water-efficient, but doesn't provide frost protection to berry plants in bloom.

code:
- **seldom expect response**
- **some response 30–60% of time**
- **expect response most years (75%)**
- **expect response 9 years out of 10**

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

BERRY CROPS

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
STRAW-BERRIES 💧💧💧💧	• larger fruit • increased yields • frost protection • regrowth after renovation • evaporative cooling • improved quality	• bloom (frost protection) • fruit sizing • post-renovation	• hand-move portable • solid-set • travelling gun • trickle	• avoid wet plants overnight to prevent fruit rot • very responsive to irrigation • avoid leaching on sandy soil • maintain available soil moisture above 50% (do not exceed 100%) • irrigation for frost protection can increase the incidence of bacterial angular leaf spot • strawberries are only responsive up until first fruit colour – don't use water during last half of harvest • irrigation is critical after renovation
OTHER BUSH BERRIES 💧💧💧	• larger fruit • larger bushes • increased yields • improved quality	• bloom • fruit sizing through harvest	• hand-move portable • travelling gun • trickle	• avoid wet plants overnight to prevent fruit rot • very responsive to irrigation • avoid leaching on sandy soil • maintain available soil moisture above 50% (do not exceed 100%)

GENERAL NOTES ON IRRIGATION FOR ALL FRUIT

Irrigation improves plant establishment, nutrient use, bearing area and plant health. It can also be used for frost control (sprinkler) and fertigation.

Overhead irrigation is recommended for frost protection and evaporative cooling. Trickle irrigation is more suitable for fertigation than overhead sprinklers, and will cause fewer infections of scab, fireblight, brown rot, Botrytis fruit rot, etc. Some measure of frost protection may be gained from under-canopy, low-trajectory sprinkler irrigation systems. They are probably best suited for high-density plantings not taller than 6.5 feet (2 m), but have not been fully evaluated in Ontario.

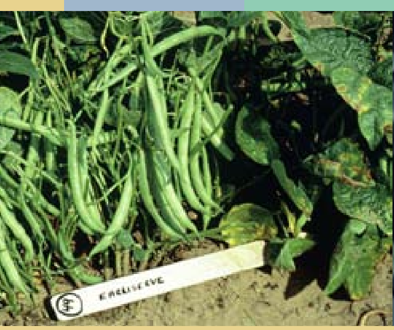
See pages 106–107 for more information on the ice encapsulation method of frost control.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

VEGETABLE CROPS

Shallow-rooted Vegetables: rooting depth of 1–2' (0.3–0.6 m) in most soils
AMOUNT OF WATER REQUIRED: – approx. 1" (25 mm) per week during vegetative growth
– approx. 1.5–2" (40–50 mm) per week during critical periods
Irrigation scheduling will help determine how much to water to apply and how often.

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
BEANS Snap, Lima 💧💧	• straighter, better quality pods	• flowering, pod set	• hand-move portable • fixed-volume gun • travelling gun • low-pressure boom	• improper irrigation can promote mould • avoid excessive irrigation during flowering • avoid watering in the evening • allow foliage to dry before night to discourage diseases
BEET (red) 💧💧💧	• better quality, better-shaped roots • improved seed germination	• stand establishment • root enlargement	• hand-move portable • fixed-volume gun • travelling gun • low-pressure boom	• uniform moisture required at all growth stages
COLE CROPS e.g., Broccoli, Brussels Sprouts, Cabbage, Cauliflower, Rutabaga 💧💧💧	• larger head size, quality • prevention of premature heading (buttoning) of cauliflower • prevents tipburn of cabbage	• head formation and enlargement	• hand-move portable • fixed-volume gun • travelling gun • low-pressure boom	• rutabaga seedbeds can be irrigated to stimulate germination if soil moisture is lacking • excess irrigation may cause head splitting in cabbage, head-rot in cauliflower and broccoli • boron may be applied through irrigation if required • frequent irrigation is required for cauliflower grown in warm months to prevent buttoning



Irrigation will yield straighter and larger pods in beans.

Irrigation can produce higher quality, larger heads.

Plan irrigation carefully. Excess water can promote head-rot in broccoli and cauliflower.

code:
💧 seldom expect response
💧💧 some response 30–60% of time
💧💧💧 expect response most years (75%)
💧💧💧💧 expect response 9 years out of 10

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

VEGETABLE CROPS

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
CARROT 💧💧💧💧	• seed germination • better quality, longer roots	• root enlargement	• fixed-volume gun • travelling gun • low-pressure boom • sub-irrigation	• high moisture requirement • uniformity is important, as excess moisture causes cracking and short roots
CELERY 💧💧💧💧	• celery is very susceptible to drought at all stages • drought causes blackheart (calcium-related breakdown of the centre of the plant) and buttoning	• crop establishment to harvest	• hand-move portable • travelling gun • low-pressure boom	• celery shouldn't be grown without irrigation • requires approx 2" (50 mm) weekly
CUCUMBER Muskmelon Zucchini 💧💧💧	• larger fruit • less crooked fruit • better quality • less hollow heart	• flowering • fruit set • fruit sizing	• hand-move portable • fixed-volume gun • travelling gun • trickle	• fertigation may be used with trickle to improve yield • plastic mulch may be used for maximum moisture retention and increased soil temperature
GARLIC on coarse-textured soils 💧💧💧💧	• better quality, larger cloves	• vegetative growth, bulbing	• hand-move portable • fixed-volume gun • travelling gun	• requires 1–2" (25–50 mm) weekly, especially in hot weather • avoid watering in the evening to reduce disease development • avoid watering shortly before harvest as excess water may discolour the bulb papers
LETTUCE 💧💧💧💧	• improved germination of direct-seeded lettuce	• head formation and sizing	• hand-move portable • low-pressure boom	• irrigation important for seeded lettuce, especially in hot weather • avoid watering in the evening, allow foliage to dry before night to reduce disease development
ONION 💧💧💧	• larger bulbs • more single centres	• bulbing and enlargement	• hand-move portable • travelling gun • sub-irrigation	• requires 1–2" (25–50 mm) weekly • excess water as the bulbs mature will result in thick necks, immature bulbs, and storage problems – decrease moisture supply gradually as bulbs mature

Cucumber crispness can be improved with irrigation.

Celery requires irrigation immediately after transplanting and throughout the season. Irrigation should be done in the early morning to reduce the spread of disease.

Both sprinklers and irrigation guns are appropriate for onions. Irrigation of onions may be necessary on shallow muck or mineral soils.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

VEGETABLE CROPS

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
PEPPER & EGGPLANT 💧💧💧	• larger fruit, better quality, less sunscald and blossom-end rot • higher yield	• flowering • fruit set • fruit sizing	• hand-move portable • fixed-volume gun • travelling gun • trickle	• fertigation may be used with trickle to improve yield • plastic mulch may be used for maximum moisture retention and increased soil temperature • frequent light irrigation is best for these shallow-rooted crops • over-irrigation may promote root disease
POTATO 💧💧💧💧	• better sizing, better chipping quality, prevention of hollow-heart • higher yield	• tuber formation and enlargement • from tuber initiation to marketable-size potatoes requires a minimum of 1" of water per week	• centre pivot • lateral move • fixed-volume gun • travelling gun • low-pressure boom	• irrigation may reduce soil temperature and improve tuber set in hot weather • excess irrigation causes cracking and hollow-heart

Tuber set can be improved in hot weather with irrigation.

This photo shows placement of drip irrigation tape between rows of peppers. In this case the tape is buried slightly, with the emitter facing up.

Irrigation will produce potatoes that are bigger, and have better chipping quality and less hollow-heart.

code:
💧 seldom expect response
💧💧 some response 30–60% of time
💧💧💧 expect response most years (75%)
💧💧💧💧 expect response 9 years out of 10

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

VEGETABLE CROPS

Medium-rooted Vegetables: rooting depth of 1–2.5' (0.3–0.8 m) in most soils

AMOUNT OF WATER REQUIRED: – approx 1" (25 mm) every 10 days during vegetative growth
– approx 1.5–2" (40–50 mm) every 10 days during critical periods

Irrigation scheduling will help determine how much to water to apply and how often.

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES /CONSIDERATIONS
TOMATO (Fresh Market)	• larger fruit, better quality, less blossom-end rot, less cracking, higher yield	• flowering, fruit set, fruit sizing	• hand-move portable • fixed-volume gun • travelling gun • trickle	• fertigation may be used with trickle to improve yield • plastic mulch may be used for maximum moisture retention and increased soil temperature
TOMATO (Processing)	• larger fruit, better quality, less blossom-end rot, less cracking, higher yield	• flowering, fruit set, fruit sizing	• travelling gun • low-pressure boom • trickle	• research has shown a benefit of irrigation for processing tomatoes on a range of soil types from sand to clay loam • fertigation may be used with trickle irrigation to improve yield

Chemically killed rye windstrips will reduce erosion and moisture loss in processing tomato production.

Flowering is a critical period for the irrigation of fresh-market tomatoes.

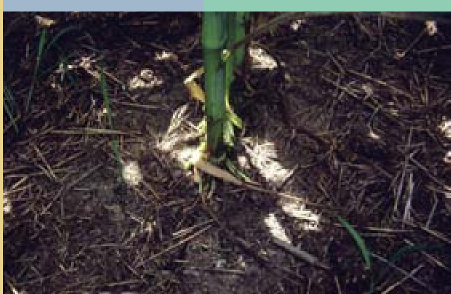
These tomatoes show signs of blossom-end rot (BER). This disorder occurs when insufficient moisture is available to transport calcium to the developing fruit. Properly scheduled irrigation reduces the incidence of BER.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

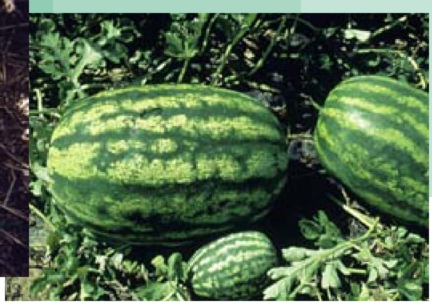
VEGETABLE CROPS

Deep-rooted Vegetables: rooting depth of 2.0–3.5' (0.6–1.1 m) in most soils
AMOUNT OF WATER REQUIRED: – approx 2" (50 mm) every 14 days
Irrigation scheduling will help determine how much to water to apply and how often.

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
ASPARAGUS 💧	• improved seed germination and seedling establishment • irrigation sometimes used to control wind-induced abrasion	• stand establishment – limited response in mature asparagus	• travelling gun • fixed-volume gun	• very deep-rooted crop; limited response in mature asparagus • irrigation can be used for frost control in spring • irrigation sometimes used after harvest is complete during periods of very dry growing conditions
SWEET CORN 💧💧	• better pollination, fewer blank kernels, better tip-fill	• tasselling, pollination, ear filling	• travelling gun	• irrigation promotes good tipfill • maximum 2–3 irrigations required in very dry years
SWEET POTATO 💧💧	• greater yield, quality and tuber size • irrigation sometimes used to control wind-induced abrasion • improves plant survival	• early August into early September	• travelling gun • hand-move portable	• sweet potato is known for high drought tolerance
WATERMELON Pumpkin Squash (winter) 💧💧	• larger fruit, better fruit shape	• flowering, fruit set, fruit sizing	• hand-move portable • fixed-volume gun • travelling gun	• deep-rooted crops respond to irrigation during very dry conditions • summer squash may show a more definite response pattern as it is a medium-rooted crop • transplanted pumpkins and squash develop medium-root systems and will require more frequent irrigation (1-1.5" per week during fruit bulking, depending on soil type)



Residue management in sweet corn reduces soil erosion and helps retain moisture.



Irrigation will increase the fruit size of deep-rooted crops such as watermelon.

code:
💧 **seldom expect response**
💧💧 **some response 30–60% of time**
💧💧💧 **expect response most years (75%)**
💧💧💧💧 **expect response 9 years out of 10**

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

TREE NUT CROPS

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
FILBERT / HAZELNUT	• accelerated tree establishment • increased precocity • more vigorous bloom, better nut fill, higher yields, larger nuts	• 6 weeks post-bloom • nut fill from mid-July to mid-August	• trickle • fixed-volume gun • travelling gun	• irrigation is necessary on annual basis • sufficient water must be used to wet entire rooting zone • irrigation is most important in planting establishment to promote adequate root development
HEARTNUT & SWEET CHESTNUT	• accelerated tree growth and improved yields • better nut size	• nut fill mid-August to mid-September	• trickle • fixed-volume gun • travelling gun	• heartnut may require irrigation on an annual basis, depending on soil type • chestnut requires irrigation every year on coarse-textured soils • chestnut flowers very late (June) and must develop the bulk of crop volume over a very short time

Chestnuts will need irrigation every year on sandy and gravelly soils.

Heartnuts fill in mid-August to mid-September on the tree. Irrigation can be important at this time. This heartnut has started to germinate in the nursery seedbed. Half the shell has been removed.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

TREE NUT CROPS

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
WALNUTS & PECANS	• accelerates tree growth and development • improves yields • better quality nuts, larger size • spring frost protection	• mid-July to mid-August for walnut • mid-August to 1st week October for pecan	• trickle • fixed-volume gun • travelling gun	• excessive irrigation may promote root and crown disease, depending on rootstock • soil moisture regime must be adequate for good tree performance • under severe stress, walnut cannot produce or maintain foliage or fruit • Carpathian, black walnut and pecan are the most drought-resistant nut trees – on average, irrigation will produce a noticeable economic advantage one year in three

Note: Micro sprinklers will distribute the water over a larger surface area, requiring fewer emitters for large mature trees.

This picture shows a filbert and pecan orchard in September 1990, the year of its planting.

Here is the same orchard 34 months later, having benefitted from a trickle irrigation system.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

TOBACCO

BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	AMOUNT PER APPLICATION	APPLICATION RATES	BEST MANAGEMENT PRACTICES / CONSIDERATIONS
• improves quality • increases yield	• in order of importance: 1. just prior to topping and until the tip leaves have fully grown out 2. rapid vegetative stage of growth starting in late June and until July before topping 3. during harvest, especially when higher rates of nitrogen fertilizer have been used	• travelling gun • solid set • fixed-volume gun • travelling boom • lateral move	• 0.75–1.5" (20–40 mm) • amount depends primarily on the soil's initial moisture content and its maximum water-holding capacity	• 0.25–0.5" (7.5 –12.0 mm)/hr • when guns are used, nozzle sizes should be between 1–1.25" (25–31.8 mm) and operated between 550–560 kPa (80–94.5 psi)	• soil moisture must be maintained at or above 60% of field capacity • irrigation can be done anytime during day or night, but will be more efficient at night since less water is lost through evaporation and usually there is very little wind

For optimum growth, tobacco soils must be maintained at or above 60% of field capacity.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

FIELD-GROWN NURSERY STOCK

TYPE OF STOCK	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	AMOUNT OF WATER	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES/ CONSIDERATIONS
SEEDBEDS	• improves germination	• during germination and growth until root system is established	• 0.5–1" (12.5–25.0 mm) per week, maintain near field capacity	• hand-move portable • semi-permanent • solid-set	• keep soil moist during seedling germination
LINER BEDS & ROWS 7" (180 mm) rooting depth	• improves transplant establishment • increases plant size	• after transplanting until root system is established • during dry periods with young nursery stock	• 0.5–1" (12.5–25.0 mm) per week, maintain near field capacity	• hand-move portable • semi-permanent • solid-set • travelling gun	• irrigate budding understock prior to budding • irrigate post planting • irrigate when soils are at 50–70% of field capacity
CALIPER TREES	• improves transplant establishment	• after transplanting until established	• 0.5–1" (12.5–25.0 mm) per week, maintain near field capacity	• hand-move portable • travelling gun • trickle	• irrigate post-planting

Irrigation improves germination rates in seedbeds.

Caliper trees require irrigation post-planting.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

CONTAINER-GROWN NURSERY STOCK

TYPE OF STOCK	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES/ CONSIDERATIONS
CONTAINER-GROWN SEEDLINGS	• improves seedling germination • maintains uniform and vigorous growth	• daily for newly potted plants, every 1–2 days after rooting out into media • essential for seedling establishment and growth	• hand-move portable • semi-permanent • solid-set • low-pressure boom • mist lines • hand watering	• good for a greenhouse or an enclosed production area • requires careful judgement and experience • ensure even coverage of water: each cavity must receive the same amount of water • water must have low salts and be free of disease organisms • plants vary in response to watering • covering cavity with grit will help conserve moisture • amount depends on medium, temperature and plant

Drip irrigation maintains rapid and vigorous growth in container-grown stock.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

CONTAINER-GROWN NURSERY STOCK

TYPE OF STOCK	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES/ CONSIDERATIONS
NEWLY POTTED & ESTABLISHED CONTAINER STOCK	• helps nutrient uptake from control-release fertilizers • evaporative cooling of plants • maintains rapid and vigorous growth of established stock	• following transplanting until liner establishment • in the fall prior to covering polyhouses • can be used to leach when total salt readings exceed 3.5 mS/cm • daily for newly potted plants, every 1–2 days after rooting out into media • during growth throughout the growing season	• trickle or drip • solid-set	• good for container sizes of 1–5 Imp gal (4.5–22.7 L) • overhead irrigation is inefficient – only 15–55% of water reaches the media **To improve efficiency:** • offsetting spacing of containers is more efficient than square spacing • group plants according to their water requirements, pot size, rate of growth and age • shift plants into larger containers before plants have reached their maximum canopy size, instead of spacing containers • use control release fertilizers • consider pulse irrigation – using an automated system, water is applied in regularly timed intervals, e.g., a cycle may consist of 4 intervals on for 15 minutes, and then off for 30 minutes – this allows water to percolate through the pot (uses 30% less water)

Overhead irrigation is used for container stock. To make it more effective, group plants according to their water requirements, pot size, rate of growth and age.

BEST MANAGEMENT PRACTICES FOR CROP PRODUCTION

CONTAINER-GROWN NURSERY STOCK

CROP	BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES/ CONSIDERATIONS
CONTAINER-GROWN NURSERY STOCK	• maintains rapid and vigorous growth • reduces or eliminates transplant shock	• daily during growing season	• solid-set • trickle or drip	• consider drip system for containers larger than 5 Imp gal (22.7 L) • trickle uses 75% less water than overhead irrigation system • requires an automated system capable of delivering 0.16–0.33 Imp gal (.75–1.5 L) per 2 gal container per day
PROPAGATION OF NURSERY STOCK	• prevents cuttings from dehydration	• until cuttings are rooted	• solid-set • intermittent mist lines	• keep water on the leaves to maintain evaporative cooling • requires a time clock or electronic leaf, interval adjusted to crop requirements

Irrigation prevents cuttings from dehydration in propagation beds.

SOD

BENEFITS OF IRRIGATION	CRITICAL IRRIGATION PERIODS	COMMONLY USED SYSTEMS	BEST MANAGEMENT PRACTICES /CONSIDERATIONS
• brings turf out of dormancy to allow sod to be harvested • moistens root zone prior to harvest	• mid-summer	• centre pivot • lateral move • travelling gun • travelling boom	• rooting depth: 4–8" (100–200 mm) • excess irrigation during evening or night can promote disease • to minimize evaporation losses, avoid irrigating during the heat of the day and during periods of high winds

Sod crops require irrigation to ensure vigour.

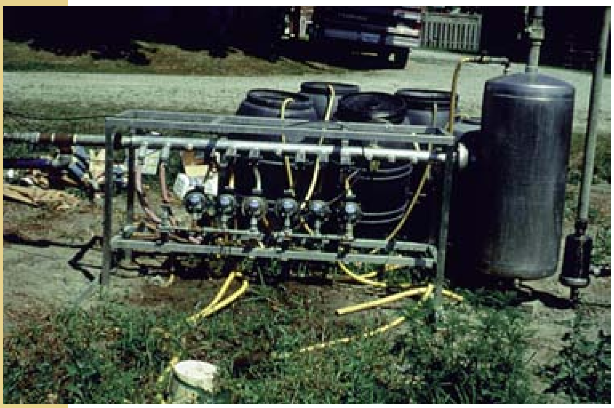
SPECIAL APPLICATIONS

Supplying water for crop use is not the only useful function of an irrigation system. It can also be used to apply crop protection materials to high-value crops. Frosts, sand-blasting and excessive heat can be controlled in some situations. Also, in selected crops, productivity can be increased and quality improved by applying crop nutrients with irrigation water through "fertigation". Fertigation is normally done using drip (also known as micro-irrigation or trickle) systems.

This chapter presents best management practices for special applications of irrigation. These include fertigation, chemigation, evaporative cooling, wind erosion control and frost protection. All of them require careful management to ensure effectiveness, water efficiency and protection of the environment.

FERTIGATION OF FIELD VEGETABLES AND TREE FRUIT

Drip irrigation and fertigation are relatively new practices for fruit and vegetable growers in Ontario. They provide a very efficient method of applying irrigation water and nutrients, and can be used to increase yield and quality of certain fruit and vegetable crops.



Drip irrigation and fertigation can be used to increase yield and quality of horticultural crops.

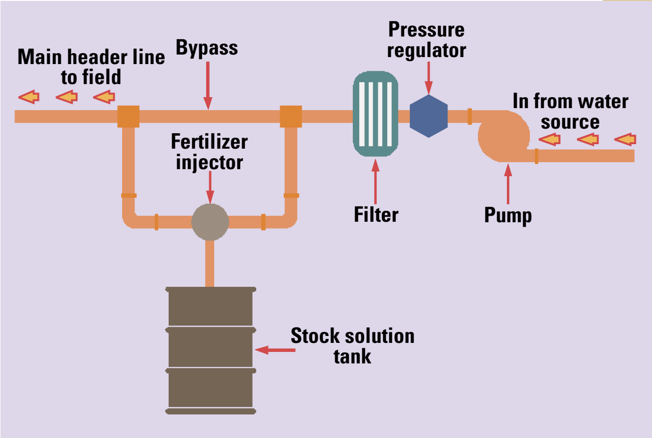
SPECIAL APPLICATIONS

FERTIGATION SYSTEM DESIGN

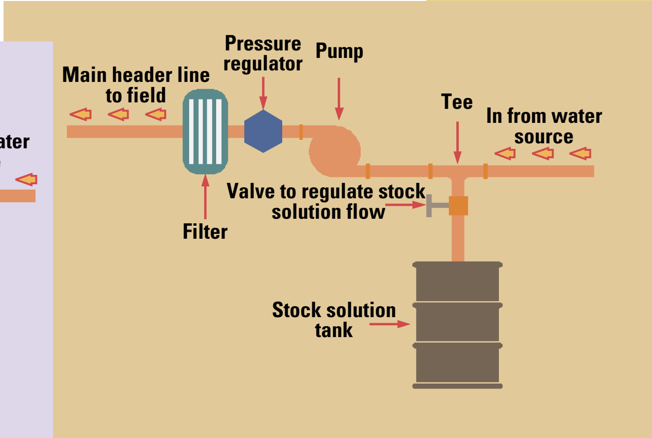
There are many systems available to inject fertilizer solutions into irrigation water. The most accurate is a fertilizer injector (e.g., Anderson, Dosatron, Amiad etc.) that injects the stock fertilizer solution into the irrigation water at a pre-set ratio.

An alternative method is to **install a tee** on the suction side of the irrigation pump, with a hose leading to the fertilizer stock tank. The flow of fertilizer solution into the system is regulated with a tap or gate-valve. This setup isn't as accurate as a fertilizer injector, but is less expensive and should be accurate enough for most field situations.

An anti-backflow device such as a check valve prevents contaminated water from being drawn back into your water source.



The fertilizer injector is the most accurate of fertigation systems. With the main filter before the fertilizer injector, this system requires extra filters at the inlet of each zone or group of zones.



Installing a tee is less expensive, and is usually on the suction side of the irrigation pump. It functions in a fashion similar to a fertilizer injector.

FERTILIZER STOCK SOLUTIONS

Stock solutions are the concentrated fertilizer solutions that are injected into the drip irrigation system. To prepare the fertilizer stock solution:

▸ calibrate the system to determine how much stock solution is injected over the desired injection period – in most cases an injection period of approximately 1 hour is sufficient

The required amount of fertilizer must be totally dissolved in the volume of water in the stock solution tank before injection.

SPECIAL APPLICATIONS

A solubility ratio of 1:1 means 1 kg of fertilizer will dissolve in 1 L of water (1 L water = 1 kg).

TRY THE JAR TEST

When mixing fertilizer products, it's a good idea to try the "jar test" to make sure that there is no incompatibility between the fertilizers. (An incompatibility means that precipitates may form and emitter plugging may occur.) To do a jar test, put some of the fertilizer solution into a jar of irrigation water. If there's a potential incompatibility between your fertilizer choices, a precipitate or milkiness will occur within one or two hours. If there's cloudiness, emitter plugging may occur. Be sure to wear protective clothing and eye protection when performing any jar test.

▸ determine how much fertilizer material must be added to the stock solution to deliver the desired rates of nutrients on the land area to be fertigated – see the table on page 101 for suggested fertigation rates for vegetable crops

(The required amount of fertilizer must be soluble in the volume of stock solution to be injected. Solubility ratios, i.e., weight of fertilizer that can be dissolved in a given weight of water, are given in the table below. If the fertilizer required cannot be dissolved in the water volume, more water must be added, and the solution must be injected over a longer period of time.)

▸ use only 100% water-soluble dry fertilizers when using dry fertilizer sources

▸ fertilizer materials may be mixed together in one stock solution tank, or separate solutions may be prepared for each fertilizer material and injected with a multi-head fertilizer injector. Soluble fertilizers 20–5–20 or similar analyses may be used, but are considerably more expensive. DO NOT mix fertilizer solutions containing calcium with solutions containing phosphates or sulphates, as these can precipitate out and plug emitters.

FERTILIZER MATERIALS RECOMMENDED FOR PREPARATION OF STOCK SOLUTIONS FOR INJECTION THROUGH DRIP IRRIGATION

FERTILIZER MATERIAL	% ACTUAL NITROGEN	% POTASH (K_2O)	SOLUBILITY RATIO OF SOLUTE:WATER
AMMONIUM NITRATE	34	0	1:1
CALCIUM NITRATE	15	0	1:1
POTASSIUM NITRATE	13	44	1:4
POTASSIUM SULPHATE	0	50	1:15

SPECIAL APPLICATIONS

FERTILIZER REQUIREMENTS FOR VEGETABLES

Usually part of the nutrient requirement of the crop is soil-applied prior to planting, and the remainder is injected through the drip system. Scheduling of nutrient injection is done according to crop demand. Low rates of nutrients are applied when the crop is small, and increasing rates are applied during the period of rapid growth and fruit development.

Soil testing should be used to determine phosphate and potash requirements. All the phosphate should be applied prior to planting.

Approximately 30–50% of the nitrogen and potash requirement is broadcast prior to planting, and the remainder is injected through the drip irrigation system, according to the schedules in the table below.

RECOMMENDED FERTIGATION RATES FOR VEGETABLE CROPS GROWN ON SAND TO SANDY-LOAM SOIL TYPES

RATES OF ACTUAL N AND K_2O (kg/ha/week)

GROWTH STAGE	TOMATOES	PEPPERS	CUCUMBERS & OTHER VINE CROPS
VEGETATIVE GROWTH TO BLOSSOM	2.5*	3 – 5	3 – 5
FRUIT SET TO FRUIT SIZING	5.0	7 – 10	7 – 10
HARVEST	2.5	3 – 5	3 – 5

*** 2.5 kg/ha/week of each of N and K_2O**
To convert to lbs/ac, multiply kg/ha by 0.9.

FERTILIZER REQUIREMENTS FOR TREE FRUIT

General recommendations for fertilizing tree fruits are given in Ontario Ministry of Agriculture and Food Publication 360, *Fruit Production Recommendations.*

With fertigation, instead of applying the required amount of N as a single banded application around the drip line of each tree or in the herbicide strip, one-third of the nitrogen requirement per tree is injected as a single dose in early April before the trees leaf out. This is done to stimulate early vegetative growth in the spring. Active root growth starts before any obvious bud movement in the tree canopy.

SPECIAL APPLICATIONS

Total recommended rates of nitrogen and potassium applied as dry fertilizer can be reduced by about 50% with fertigation. This method of feeding orchard trees should be carefully monitored by leaf analysis.

The remaining two-thirds of the nitrogen requirement is applied in equal amounts with each irrigation in May and mid-June. Apply nitrogen after mid-June to slow vegetative growth and promote hardening-off for winter.

When applying potassium (K) using fertigation, instead of applying the total requirement per tree as a single banded application in the spring, K is injected in equal amounts with each irrigation in July and August. The delayed application of K relative to N is to enhance fruit colour, winter hardiness, tree growth and disease resistance during the latter half of the growing season.

Shown here is a fertigation system with pump, filters and nurse tank. Fertigation systems may be used with trickle irrigation systems to more effectively apply fertilizers to crops. However, for apple and peach crops, evidence to date indicates fertigation offers no significant nutritional advantage over dry granular fertilizers applied in the spring at bud break.

Phosphorous (P) is not applied in the irrigation water because Ontario orchards normally don't show a demonstrated need for fertilization with P. Magnesium (Mg) and calcium (Ca) are best applied as foliar sprays if needed, rather than through trickle irrigation. Micronutrients (e.g., boron, manganese, iron, zinc) for tree fruits only need to be applied when deficiency is confirmed by leaf analysis or visible symptoms. Foliar sprays for the element or elements that are deficient is the best way of correcting a deficiency in micronutrients. Micronutrients are not applied via fertigation.

CAUTION

Soil acidification may occur below the emitters where an ammonium nitrogen source is used. Soil acidification does not occur with nitrate–nitrogen sources. This is therefore a preferred nitrogen source for fertigation of tree fruits. At lower soil pH (pH less than 4), manganese and aluminum can be absorbed and become phytotoxic. This results in stunted growth, and reduced fruit yields and quality.

FERTIGATION SCHEDULING FOR VEGETABLES AND TREE FRUIT

The timing of fertigation in relation to tree growth and crop development was described for application of N and K in the previous section. Each fertigation application should be part of a normally scheduled irrigation, and is best conducted near the end of each irrigation cycle to avoid leaching of nutrients below the main rooting zone. The lines must be flushed immediately after each fertigation to prevent plugging of the emitters.

SPECIAL APPLICATIONS

Remember:

- proper irrigation scheduling is important with fertigation to prevent fertilizer leaching
- tensiometers may be used to indicate when drip irrigation is required – for more information on tensiometers, see page 30
  - frequencies of fertigation can vary – low rates of fertilizer may be injected every 2–3 days, or higher rates every 7–14 days
- frequent injections (every 2–3 days) are recommended on sandy soils that don't retain moisture and nutrients well
- drip irrigation systems need to be thoroughly checked for leaks and to be sure all emitters are working before fertigation
- the system should have enough capacity to apply the required amount of fertilizer in a relatively short period of time
  - this is important during rainy periods when irrigation isn't required but fertilizer is still needed
  - after fertilizer injection is completed, it's important to run the drip system for a while to flush the fertilizer out of the emitters – otherwise, plugging of the emitters may result

CHEMIGATION

Chemigation – the application of chemicals using irrigation technology – can be useful for cranberries and greenhouse vegetables. Only approved products (as stated on chemical label) should be used for chemigation.

Applying herbicides and pesticides in minute concentrations can save you time and money. **However, it must be done with skill and caution, in compliance with laws and only with chemicals that are registered for this use.** The main environmental concern is contaminated water entering a water source or ground water in the event of a spill or equipment malfunction.

Chemigation can be useful if you have a solid-set low-volume sprinkler irrigation system.

HARDWARE

- spring-loaded check valve on pressure-side of pump to prevent backflow if pump stops
- foot valve to prevent backflow of water once it has entered pickup line from pond
- water source must be a pond that doesn't have any outflow, and does not operate directly from a municipal water supply system, water well, river or stream
- anti-backflow device should also be used
- only solid-set, low-volume sprinkler-type setups using 1/8, 1/10, 1/12 inch nozzles, applying water in a uniform, even pattern over a field, are eligible for chemigation

SPECIAL APPLICATIONS

CALIBRATION

Before applying chemicals, you must calibrate the irrigation system.

The goal of the following procedure is to calculate (E), which is the total elapsed time.

1. Turn on pump and charge the system so that all sprinklers are operating correctly, and fix all leaks.
2. Fill the chemical tank with predetermined volume of water, e.g., 40 Imp gal (200 L).
3. Mix in a marker dye.
4. Mark the time (a) and open the suction line valve to allow chemical pickup.
5. Watch the first nozzle to see when dye appears; mark time (b).
6. Continue to operate, observe when last nozzle shows dye; mark time (c) .
7. Continue to siphon chemical until it's all gone.
8. Watch first sprinkler and see when water is clear (free of dye); mark time (d).
9. Observe when last nozzle is free of dye; mark time (e).
10. Note the time for one full revolution of the sprinkler (f).
11. Take note of pressure setting at pump (p).

Total elapsed time (early-season application of insecticide & fungicide): E = e – a

Total elapsed time (insecticide and fungicide applied from bloom to harvest and herbicide applied at any time): E = f – a

Pressure: p

APPLYING CHEMICALS

Remember to calibrate your system before using chemicals (see previous procedure).

1. Use the same pressure (p) that was used during the calibration for all chemical applications.
2. Use preset volume of water in chemical tank (same volume as used for calibration, 40 Imp. gal [200 L]).
3. Know how much area is to be covered (# acres = A).
4. Check rate (r) of chemical from label (mass / acre).
5. Multiply the area by the rate, (A) x (r) to get amount of chemical required for whole patch. This will vary for each pesticide used, e.g., 12 acres at 3 pounds per acre = 12 ac x 3 lb/ac = 36 lb (6 hectares at 2 kilograms per hectare = 6 ha x 2 kg/ha = 12 kg).
6. Always dissolve pesticide in chemical tank thoroughly and keep it stirred up to prevent settling out.
7. Wear all appropriate safety equipment such as gloves, coveralls, mask, etc. when handling products.

SPECIAL APPLICATIONS

8. Turn on system and check that all nozzles are working correctly.
9. Turn on suction line valve to start chemical uptake. Mark time carefully.
10. Continue to chemigate for a total elapsed time E.
    - For early-season sprays of insecticide and fungicide: stop the system at E = e – a.
    - Insecticide and fungicide applied from bloom to harvest and herbicide applied at any time: stop the system at E = f – a (one extra sprinkler rotation is needed to "wash" pesticide down into the canopy).
11. If a blowout or other problem develops during chemigation, turn off suction-line valve to chemical tank, then shut down the pump – use appropriate safety gear if repairs are required in treated area, or on pipes containing chemical product.

SAFETY

- pick a low-wind "perfect" spraying time for chemigation – often early morning is appropriate
- don't allow anyone nearby or in the field while chemigating
- follow re-entry requirements and days to harvest as stated on the chemical label

If irrigation is to be carried out, do the chemigation at the end of the cycle.

Best management practices such as grass wind strips, cover crops, residue management, and windbreaks are your best bets for effective control of wind erosion.

WIND EROSION CONTROL

Many highly productive horticultural soils are prone to wind erosion. Dry loose soil is easily moved by wind.

Irrigation can provide some short-term emergency wind erosion control – or the final piece in an erosion control system. Water applied in advance of the wind event will help to hold soil. The success of this practice depends on:

- soil type
- amount of water applied (before and during windstorm)
- drying ability of the wind (relative humidity)
- duration of the wind event.

This practice is best used in combination with other measures, such as residue management, grass wind strips or windbreaks.

Irrigation for wind erosion control is considered an emergency response only. To be effective, it must be started before the wind event occurs.

SPECIAL APPLICATIONS

If left unchecked, frost can eliminate the early bloom in strawberry. Early blossoms are capable of producing the largest berries in the field.

Dew point affects how quickly the temperature drops. Frost injury can occur before frost forms on the surface if the dewpoint is below freezing. Cloudy ice means that not enough water is being applied. Ice should be clear, not cloudy.

FROST PROTECTION OF BERRY CROPS

REQUIREMENTS

- solid-set sprinkler irrigation system that gives total, even coverage
- nozzles that apply enough water for frost protection but do not flood the field. Usual size is from 1⁄8 to 5⁄32 inch (4 mm) at wind speeds of 0–1.25 km/hr. A rate of .15 inches (4 mm) of water per hour is adequate to carry protection down to -6.7° C (20° F). Recommended rates of application vary .10–.15 inches per hour (2.5–4 mm).
- adequate supply of water
- properly calibrated thermometers that are placed in the coldest spots in the field. An ideal system would involve the use of underground cables connected to thermistors in the field, joined to frost monitoring units with an alarm system set up to the house.

TIMING

Open strawberry blossoms will freeze at around -0.5° C (31° F) over a period of several hours. Unopen blossoms (balloon bud) will freeze at -2.2° C (28° F) over a period of several hours. Unprotected blossoms can withstand colder temperatures but only for a short time. Buds that are tight can take -5.5° C (22° F).

The alarm system should be set at somewhere around 1.1° C (34° F) to allow time for starting up the pump and getting the system going. It's important when temperatures are below freezing to watch that the sprinkler heads do not freeze and stop rotating.

The irrigation system, once it's running for frost protection, should continue to be run until the ice begins to melt. Some growers feel safer with the ice encapsulation method if the ice is completely melted before shutting down. However, this isn't necessary unless there is some fruit ripening.

PROBLEMS

- if winds are above 10 mph (16 km/hr), then poor coverage can result in some buds being frozen
- the higher the wind speed, the more water required per hour because of evaporation and potential freezing damage from the effects of evaporative cooling
- at a wind speed of 16 km/hr, to get protection down to -6.7° C (20° F), the required rate of water application/hr is 20 mm (.78 inch)
- using irrigation for frost protection leads to wet soils, which may favour the development of red stele and other root rots

SPECIAL APPLICATIONS

WARNING: ORCHARD CROPS AND OTHER FRUIT CROPS
(ice encapsulation method of frost control)

Do not apply overhead low-volume sprinkler irrigation (.10" per hour [2.5 mm/hr]) in an attempt to protect from frost injury with wind velocities > 5 mph (8 km/hr). The effect of evaporative cooling resulting from air moving over a thin layer of moisture on leaf or floral parts is enough to cause severe freezing damage at temperatures around the freezing mark. Most sprinkler irrigation systems set up for frost protection may not deliver sufficient water volume to overcome this potential problem. Make sure that adequate volumes of water are stored for a worst-case scenario of several nights' usage. With wind velocities of < 5 mph (8 km/hr), a rate of water application of .15 inch (4 mm) per hour is considered to be adequate to carry protection down to -6.7° C (20° F).

EVAPORATIVE COOLING

Hot dry weather can reduce fruit set and potential size of the fruit (e.g., strawberries). When water evaporates from the plant surface, it cools and can help to overcome these two problems. Water used for evaporative cooling should be of high quality, since the produce will be harvested soon afterwards.

The principle of evaporative cooling involves the use of a thin layer of water on the surface of the tissue. As the water evaporates from the surface of leaf or fruit tissues, it carries heat away from the plant.

Used properly, this process can:

- reduce plant temperature – important in leaf growth and runnering
- reduce the soil temperature
- reduce the fruit temperature
  - reduce ripening rate
  - help increase shelf life of fruit.

For evaporative cooling, use low application rates, i.e., 2 mm/hr. Evaporative cooling should be done in such a way that the plants will dry off before nightfall, thereby reducing the chance of increased disease development.

Evaporative cooling should be used when air temperatures are above 29° C (84° F) with low humidity and with some wind. It's not as effective if relative humidities are high or it is calm. Under ideal conditions, evaporative cooling can reduce temperatures by as much as 9° C (16° F).

Honeybees improve the seed number in developing fruit, and have a positive influence on yield. They won't work during an irrigation cycle.

SPECIAL APPLICATIONS

REQUIREMENTS

- solid-set irrigation system is desirable
- colder water will have an advantage over warmer water in reducing the effect of heat in the planting
- nozzle size
  - ⅛– ¼ inch
  - smaller size may be desirable for evaporative cooling of entire area at one time because application rates are lower
  - the smaller sizes are also useful for frost protection, but require that the irrigation system run longer for irrigation purposes
- proper timing
  - should be applied once the temperatures reach 29° C (84° F) as measured by a sheltered thermometer in the field
  - the irrigation should be run approximately 15 minutes and shut down
  - this can be repeated if the temperatures should again reach 29° C (84° F)
  - don't apply water past 3:00 pm to allow the foliage to dry before nightfall

PROBLEMS

- increased costs
- possible pollination problems – bees don't like to work during irrigation
- possible increase in disease problems (Botrytis fruit rot, leather rot, black root rot, verticillium and red steele) – see Ontario Ministry of Agriculture and Food Publication 360, *Fruit Production Recommendations* for further details
- evaporative cooling must be done with low application rates (i.e., 2 mm/hr) to avoid nutrient leaching
  - with high application rates and prolonged usage, nutrient leaching is enhanced

ANALYZING THE COSTS AND BENEFITS

Prior to investing in an irrigation system, an analysis of the financial factors should be made. In other words, will an investment in an irrigation system provide the desired returns? This chapter provides a method to calculate the potential financial gain (loss) with the purchase and use of an irrigation system. The methodology is to estimate the annual costs and annual returns from the purchase and use of a specific system.

The analysis is completed on an annual basis. The annual cost for equipment that is used for more than one year is determined by spreading its net cost over its expected use period. For example, a pump purchased for $12,000, expected to be used for five years and then sold for $2,000, would have a net cost of $10,000. The annual cost would be $2,000 (i.e., $10,000 ÷ 5).

The cost/benefit analysis should be completed on a specific system. Before beginning, you should have a good knowledge of the component and installation costs of the system. In addition, an estimate of operating expenses such as fuel, labour, maintenance, etc. will be required.

On the benefits side, the potential benefits of this irrigation system for crops on your farm will need to be determined.

The actual cost/benefit calculations are completed using five worksheets. The worksheet titles include:

Worksheet 1:	Water and Power Requirements
Worksheet 2:	Annual Ownership, Repair and Maintenance Costs
Worksheet 3:	Annual Operating Expenses
Worksheet 4:	Cost/Benefit Summary
Worksheet 5:	Break-even Calculation

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 1: WATER AND POWER REQUIREMENTS

This general description worksheet is used to record and determine information required in other worksheets. It calculates the total amount of water required for a season. This is then used to calculate the number of hours the system will operate during the year. For systems using a tractor or engine as a power source, the total fuel needed for one season is determined by the amount of fuel you estimate your power source will use in one hour of operation and the total annual hours of operation.

The pumping rate is the US gallons of water per hour that can be irrigated by the system being evaluated. The pumping rate may need to be adjusted from the rate specified for factors such as water depth and distance to the field.

1) Acres to be irrigated . . . . ____________

2) Average gross inches per acre applied annually . . . . ____________

3) Total acre inches applied annually ______ × ______ . . . .= ____________
(line 1) (line 2)

4) Pumping rate (US gallons per hour) . . . . ____________

5) Operating hours per year $\frac{27154^{1} \times \text{line 3}}{\text{(line 4)}}$ . . . .= ____________

6) Energy Requirements

a) Stationary pump or tractor ____________ × ____________ = ____________
(line 5) litres of fuel per hour of use

b) Electric motor ____________ × ____________ = ____________
(line 5) kW: hydro/hour

[1] 27, 154 US gallons (22, 610 Imp gal) are required to put one gross inch of water on one acre of land.

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 2: ANNUAL OWNERSHIP, REPAIR AND MAINTENANCE COSTS

Worksheet 2 can be used to calculate the average annual cost of purchasing, owning and maintaining the irrigation system.

The purchase price of many components is available from the supplier or can be estimated if the equipment to be purchased is used. The expected use period is the number of years you expect to use that component. If you will keep that item until it's no longer useful, the expected useful life can be estimated using the information on page 116. If you plan to trade or sell the item, the expected use period is the number of years you intend to use it. The salvage value is an estimate of the item's value at the end of its expected use period.

An annual interest expense is charged to reflect the interest cost of owning the irrigation system. It's calculated on the average value of your investment during the expected use period. The interest rate selected should be based on interest on savings, or cost of borrowing, or a combination of both.

Average annual repair and maintenance expenses can be estimated and placed in the last column. These expenses can be estimated based on a percentage of the purchase price (see page 116).

If a tractor is used as the power source, only the percentage of the purchase price of the tractor should be listed on Worksheet 2. For example, the total annual hours of use of a tractor is 1,000 hours. Of the 1,000 hours, 400 will be for irrigation. On Worksheet 2, only 40% of the tractor's purchase price should be listed.

For many irrigation systems, especially drip systems, there are "one-time" installation expenses. Some of these expenses could include: electrical hook-up, burying lines, installing drip hose in orchards, etc. These expenses should be included in the installation section of this worksheet and the expense averaged over the expected use period.

In the "Other" row, space is provided for any components or costs you require that are not listed in the worksheet.

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 2: ANNUAL OWNERSHIP, REPAIR AND MAINTENANCE COSTS

System Component	Purchase Price ($)	Expected Use Period (yrs.)	Salvage Value ($)	Annual Depreciation[1] ($)	Annual Interest[2] ($)	Repair & Maintenance[3] (% purchase price)	Annual R & M[4] ($)
Water Source							
Intake							
Pump							
Pipes & Fittings							
Power Source (electric motor, stationary engine, tractor)							
Sprinkler							
Trailer							
Filtration System							
Installation							
Other: Name ________ Name ________							
TOTALS							

[1] $\frac{\text{(Purchase Price - Salvage Value)}}{\text{Expected Use Period (yrs)}}$

[2] $\frac{\text{(Purchase Price + Salvage Value)}}{2} \times \text{Interest Rate}$

[3] See table on page 116.

[4] Purchase Price × Repair & Maintenance (% purchase price)

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 3: ANNUAL OPERATING EXPENSES

All costs not included in Worksheet 2 should be included in this worksheet.

To complete this worksheet, the amount of labour per hour required to operate the system is needed. Total labour costs are then calculated based on the labour required per hour and total hours of operation. For example, if it is estimated that 1.2 people are required to operate the system and the system is to be operated 400 hours in a season, the total labour required is 480 hours. If the one person is hired full-time to operate the system, a charge of 400 hours will be calculated for hired labour. If the farm manager provides the one-fifth of an hour, a charge for 80 hours of manager labour is calculated. An additional labour charge should be included for the time spent by the farm manager to manage the irrigation system.

The harvesting and marketing costs are only for additional costs incurred for extra yield attributed to irrigation. The marketing costs would include items such as fuel, containers, labour for extra deliveries, etc. If more than one crop is to be irrigated, these calculations may have to be completed separately for each crop.

Each spring and fall, there may be costs associated with either the setup and/or takedown of the system. An estimate of these costs (including labour) should be included in the setup (takedown) section of Worksheet 3.

The miscellaneous expense should include all other expenses not easily attributed to the irrigation system. Items here could include fuel used in trucks and tractors while operating the system, storage, additional insurance, etc. The cost of extra fertilizer could be included if the irrigation system is used to provide nutrients to the crop.

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 3: ANNUAL OPERATING EXPENSES

FUEL (tractor or stationary engine)

_________ × __________ × _____ =__________

operating hours per year × **litres of fuel per hour** × **$ per litre**

HYDRO (electric pump)

_________ × __________ × _____ =__________

operating hours per year × **kW per hour** × **$ per kW**

LABOUR

a) hired _________ × _________ × _____ =__________

labour required per hour of operation × **operating hours per year** × **hourly wage**

b) owner _________ × _________ × _____ =__________

labour required per hour of operation × **operating hours per year** × **hourly rate**

c) management _________ × _____ =__________

management hours per year × **hourly rate**

HARVESTING (additional yield)

_________ × _________ × _____ =__________

additional yield (units/acre) × **harvest cost per unit** × **acres**

MARKETING

_________ × _________ × _____ =__________

additional yield (units/acre) × **marketing cost per unit** × **acres**

ANNUAL SETUP (TAKEDOWN) COST =__________

MISCELLANEOUS =__________

TOTAL OPERATING EXPENSES . . . .=__________

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 4: COST/BENEFIT SUMMARY

The benefits section determines the annual estimated additional revenue or cost savings from the use of irrigation. The use of irrigation could improve quality, result in an earlier harvest, etc. If these result in a higher expected price, this should be included in the benefits calculation. The Additional Price calculation on Worksheet 4 is therefore for the increase in price (if any) you expect to receive if the crop were irrigated. The Other Benefits include any other annual cost savings and/or revenue increases that can be expected once a crop is irrigated.

Annual costs calculated on other worksheets are summarized below the benefits.

The Increase (decrease) in expected annual Net Farm Income results by subtracting Total Costs from Total Benefits.

A positive result indicates that, based on your calculations, the addition and use of an irrigation system should increase the annual returns for your farm.

Benefits

Increased Yield	___________	×	$_________	×	_____		=____________
	additional yield (units/acre)		**price ($ per unit)**		**acres**		
Additional Price	___________	×	$_________	×	_____		=____________
	total yield (units/acre)		**increase in price ($ per unit)**		**acres**		

Other Benefits . . . .=____________

TOTAL BENEFITS (a) . . . .=____________

Costs

Depreciation (from Worksheet 2)	___________
Interest (from Worksheet 2)	___________
Repair & Maintenance (from Worksheet 2)	___________
Operating (from Worksheet 3)	___________

TOTAL COSTS (b) . . . .=____________

INCREASE (decrease) Net Farm Income (a – b) . . . .=____________

ANALYZING THE COSTS AND BENEFITS

WORKSHEET 5: BREAK-EVEN CALCULATION

Once the net increase (decrease) in net income is determined, further calculations can be completed to determine the break-even yield increase. For example, an apple grower could determine his/her annual irrigation costs per acre to be $375. In addition, he/she expects to average $125 per bin after harvesting and marketing costs. The break-even increase in yield for this irrigation system is 3 bins ($375 ÷ $125) per acre.

Break-Even Calculation

a) Total cost of irrigation (from Worksheet 4) = ____________
b) Total acres irrigated = ____________
c) Irrigation cost per acre (a ÷ b) = ____________
d) Price per unit of produce = ____________
e) Break-even: yield increase (c ÷ d) = ____________

REPAIR, MAINTENANCE AND EXPECTED LIFE

	Repair & Maintenance % of Purchase Price	Average Expected Life (years)
Water Sources		
Well	0.5	25
Pond	0.5	15
Intakes		
Concrete structure	0.5	20
Suction line screens	10.0	5
Pumps		
Turbine – Bowls	6.0	7
– Columns	4.0	20
Centrifugal	4.0	15
Submersible	4.0	15
Power Source		
Diesel	5.0	15
Gasoline	5.0	9
Propane	5.0	14
Electrical Wiring	1.0	25
Pipe and Tubing		
Steel: coated, lined and buried	0.5	40
coated and buried	0.8	20
coated and surface	1.5	12
Aluminum: surface	2.0	15
PVC: buried	0.5	40
Sprinklers	5.0	8
Tractors	7.5	15
Pipe Trailer	2.0	15

The values listed in this chart are general averages. They should be used only as a guide to estimate repair, maintenance and average expected use for your system components.

IRRIGATION SCHEDULING WORKSHEET (photocopy for repeated use)

Field: ______________________ Crop: _______________________

CROP-AVAILABLE SOIL WATER at Field Capacity: ________mm

IRRIGATION POINT at 50% Crop-Available Soil Water: ________mm

Column (1)	(2)		(3)		(4)	(5)	(6)	(7)	(8)
DATE	CROP FACTOR	X	ET mm	=	ADJUSTED ET mm	RAINFALL mm	IRRIGATION mm	SOIL WATER BALANCE (START) mm	SOIL WATER BALANCE (END) mm

Acknowledgements

First Edition, 1995

The Best Management Practices project was originally funded by Agriculture and Agri-Food Canada through Green Plan, managed by the Ontario Federation of Agriculture, and supported by the Ontario Ministry of Agriculture and Food.

BMP Steering Committee: Cecil Bradley, Ontario Federation of Agriculture; Mike Hicknell, Agriculture and Agri-Food Canada; Len Senyshyn, Ontario Ministry of Agriculture and Food

Task Team: Ontario Ministry of Agriculture and Food – John Gardner (Chair), Leslie Huffman, Jim Myslik, Chris Kessel, Peter Mantel, Bill Ingratta, Ted Taylor; Agriculture and Agri-Food Canada – Richard Layne, Chin Tan, Ron Garton; Ontario Ministry of the Environment – Murray Blackie; Ontario Fruit & Vegetable Growers Association – John Jaques

Technical Coordinator: Ted Taylor, Ontario Ministry of Agriculture and Food

Technical Authority: J.P. Myslik, P.Eng., Ontario Ministry of Agriculture and Food

2nd Edition, 2004

BMP Manager: David Armitage, Ontario Federation of Agriculture

Acknowledgements to: Ontario Ministry of Agriculture and Food – Christoph Kessel, Anne Verhallen, Pam Fisher, John Gardner, Janice LeBoeuf, Kristen Callow, Eugenia Banks, Elaine Roddy, Ken Slingerland, Jennifer Llewelleyn, Sandra Jones, Leslie Huffman, Denise Beaton, Pam Charbonneau; University of Guelph – John Cline; Vanden Bussche Irrigation

Technical Coordinator: Elin Gwyn, Ontario Ministry of Agriculture and Food

Technical Authority: J.P. Myslik, P.Eng., Rebecca Shortt, P.Eng., and Anne Verhallen, Ontario Ministry of Agriculture and Food

Photography: Many of the photographs were supplied by OMAF Staff and by Vanden Bussche Irrigation. Others have been provided by contributors in Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia and Newfoundland.

Editor: Alison Lane

Graphic Designer: Neglia Design Inc.

Illustrator: David Rouleau, Ontario Ministry of Agriculture and Food

For More Information

In Print

B. C. Frost Protection Guide, Ted W. Van der Gulik and Rick J. Williams. British Columbia Ministry of Agriculture and Fisheries and the Irrigation Industry Association, 1988

B. C. Trickle Irrigation Manual, Ted W. Van der Gulik. British Columbia Ministry of Agriculture and Fisheries and the Irrigation Industry Association, 1999

Best Management Practices: Water Management. Agriculture and Agri-Food Canada, 1994

Best Management Practices: Water Wells (rev. ed.). Agriculture and Agri-Food Canada, 2003

Fertigation, C. Burt, K. O'Connor and T. Ruehr. Training and Research Center, California Polytechnic State University, 1998

How to Prepare for Irrigation During Water Shortages, J. P. Myslik. Ontario Ministry of Agriculture and Food, FS 99-023/1999

Irrigating Vegetable Crops, A. Verhallen and E. Roddy. Ontario Ministry of Agriculture and Food Infosheet

Irrigation Insights from the National Program for Irrigation Research and Development. Land and Water Australia, ISBN 0 642 760551

Irrigation Scheduling For Fruit Crops, C. S. Tan and R. E. C. Layne. Agriculture and Agri-Food Canada, FS 90-069/1990

Irrigation Scheduling for Tomatoes – Water Budget Approach, C.S. Tan. Agriculture and Agri-Food Canada, FS 90-049

Knotts Handbook for Vegetable Growers (4th ed.), Oscar A. Lorenz. Wiley-Interscience, 1996

Modern Fruit Science, Norman F. Childers. Horticultural Publications, 1996

Strawberry Production Guide, Northeast Regional Engineering Service. Cooperative Extension, Ithaca, NRAES-88

On the Web

Ontario Ministry of Agriculture and Food website – www.omaf.gov.on.ca

Ontario Ministry of the Environment website on Permit to Take Water, see: www.ene.gov.on.ca/envision/gp/3151e.pdf

Ontario Ministry of Natural Resources website on Ontario Low Water Response Program, see: www.mnr.gov.on.ca/mnr/water/publications.html

First edition, 1995; Revised edition, 2004

ISBN 0-7778-4497-4

Canada