Drainage
FACTSHEET

BRITISH COLUMBIA
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Controlled Drainage / Subirrigation

Due to seasonal variations in precipitation, some crops and soils of B.C. could benefit from controlled drainage or subirrigation. Significant economic advantages can be gained in designing and installing these dual-purpose water management systems. In addition controlled drainage and subirrigation can provide considerable environmental benefits. However, it is usually uneconomical to use subirrigation if only irrigation is required and there is no need for drainage.

Why Use Controlled Drainage / Subirrigation?

- To provide a system that satisfies both drainage and supplemental irrigation needs,
- to reduce water related stress, and thus increase crop yield,
- for operational cost savings, mainly in reduced energy consumption compared to conventional irrigation systems,
- to reduce fertilizer costs,
- to conserve water, the system takes advantage of rainfall events,
- to offer flexibility in managing drainage water,
- to protect the environment.

What is Controlled Drainage / Subirrigation?

Conventional subsurface drainage is designed solely for the purpose of removing excess water from the soil root zone, where controlled drainage or subirrigation uses control structures to control the water table level.

Controlled drainage occurs when a control structure is used to conserve water by reducing outflow. No additional water is added into the system.

Without rainfall or a high groundwater table a controlled drainage system would not store enough water in the soil to grow a crop over a long period of time. However, controlled drainage is able to store water in the soil to reduce short term stress. This type system is best for locations that have frequent rains.

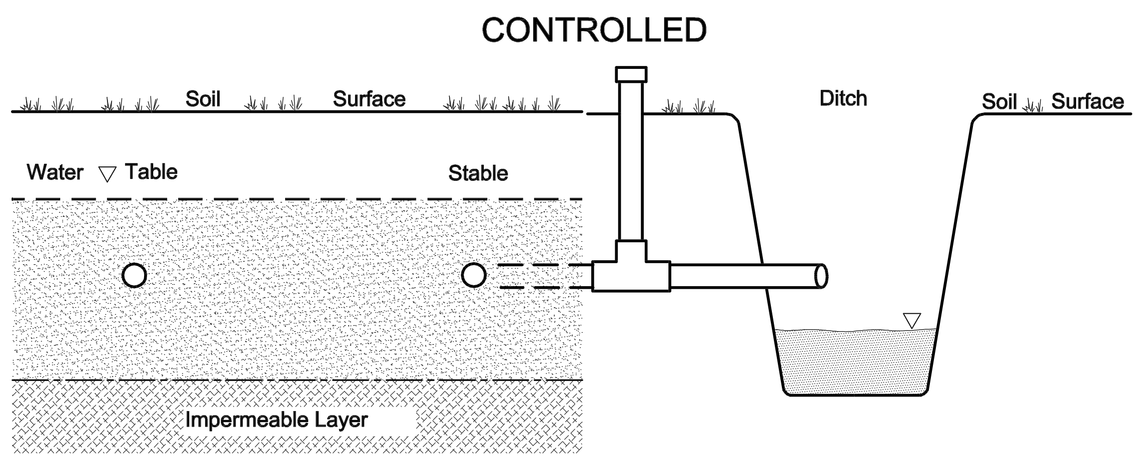

Figure 1 Controlled Drainage Diagram

With **subirrigation** water is pumped behind the controlled outlet where it moves back into the drain pipes raising the water level in the field.

Caution: when the water table is higher than normal because of subirrigation or controlled drainage, available soil water storage is reduced. Subsequent rainfall may result in excessive soil moisture. For this reason it is imperative that the system be designed for both drainage and irrigation conditions.

Subirrigation can **not** be used for fertilizer application. This could result in serious damage to the environment and the drainage system.

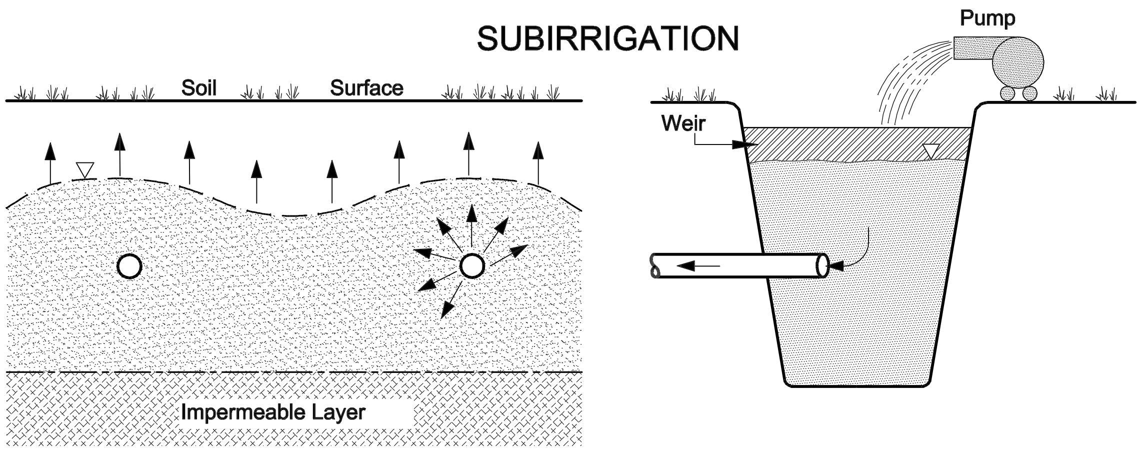

Figure 2 Subirrigation Diagram

Is Controlled Drainage / Subirrigation for Me?

Not all field and soil characteristics are suitable for controlled drainage or subirrigation. Hilly, steep, or rolling terrain is generally not suited.

Topographic Requirements

- The field should be level or have a constant slope that is less than 0.5%.
- The field surface should be uniform, where the difference in elevation between small depressions and bumps is no greater than 30 cm.
- The natural water table (before drainage) should be close to or above the drain depth.

> *Before subirrigation is considered, the site should already require conventional drainage*

Soil Requirements

- The soil profile should be uniform and relatively deep with a good hydraulic conductivity.
- An impermeable layer that is parallel to the surface of the soil is required. Ideally this surface should be no more than 3 m from the soil surface to limit percolation losses.

Water Supply Requirements
(for subirrigation only)

- Only water of reasonable quality should be used to sub-irrigate. The water should be free of sediments, chemical or biological compounds.
- The water supply should have adequate capacity to meet plant requirements use at peak water use and compensate for the water loss due to seepage.

Water Table Control Structures

Water table control structures are devices used in conjunction with a drainage system to maintain a higher than normal water table. The principle objective of a water table control structure is to slow the draw-down of the water table to enhance crop production. The control structure must have a capacity equal to the maximum drainage discharge and have a mechanism to adjust the water level. An overflow, automatic gate or control valve to lower the water table after heavy rainfalls is required. There are two main types of control structure: flashboard and a float type.

Flashboards

Small weirs or culverts can easily be modified to accept flashboards. This is an inexpensive system that can be homemade. However, the system is not automated and may require daily attention to operate at peak efficiency. All stop logs are removed for normal drainage mode.

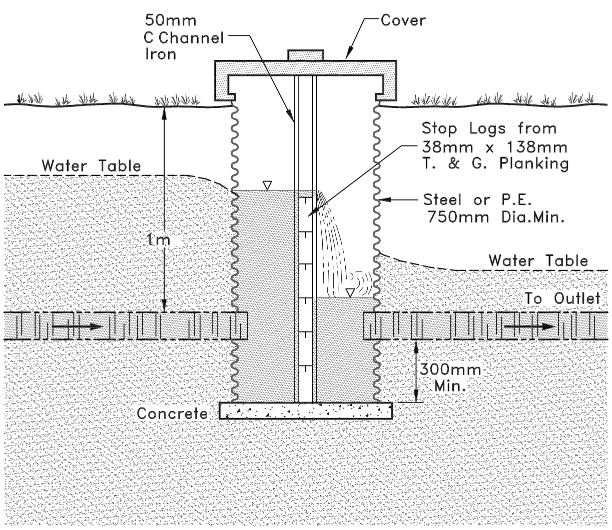

Figure 3 Flashboard Type

Float

The float type system is usually purchased as a prefabricated unit. In this system an adjustable float regulates the water level by raising a rubber control flap. When the water table recedes below the level of the float the valve closes. This system is more suitable for automation. The control flap apparatus can be removed for normal drainage mode.

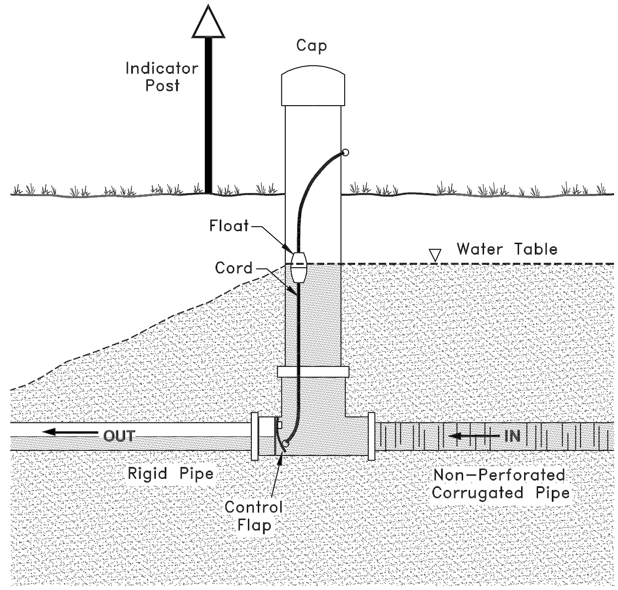

Figure 4 Float Type

Controlled Drainage / Subirrigation System Design

Factors to consider when designing a system are rooting depth, crop tolerance to water stress, soil water holding capacity, hydraulic conductivity and location of layers in the soil profile.

First determine if the site is suitable. To do this obtain or produce a topographic map with elevations, locations of valleys and ridges, field slopes, high points and low points. Laser leveling may be necessary to remove some high and low points. Divide the field into zones of uniform surface elevation. This will allow the water table to be kept at a constant depth below the soil surface.

Water Table Depth

The water table depth is the most difficult part of designing an effective subirrigation system. Fortunately the water table depths can be adjusted after the system is built.

The design depth of the water table for subirrigation is a balance between the effective rooting depth, the capillary zone thickness and the upward flux. A schematic view of the systems involved in conveying water for subirrigation is shown in Figure 5. The rate that water can be transmitted depends on the potential evapotranspiration (PET) and the depth of the water table.

rule of thumb

Some experienced designers have suggested using a design depth of 0.6 m for clay based soils and 0.450 m for lighter soils.

The plant takes up 70% of its water and nutrients in the first half of its total rooting depth. This is the effective rooting depth. It is imperative that the moisture provided by subirrigation reach this zone.

EXAMPLE: Water Table Depth

The PET rate for Abbotsford is 4.5 mm/day. From Figure A-1 on page 9 we can determine that 4.5 mm/day can be supplied by the upward flux of a fine sandy loam if the water table is 1 m below the effective root depth. The information from Figure A-1 should be used with caution. The graph does not represent the mixture of soil conditions that commonly occur in fields. Determining upward flux rates for soil is very difficult.

Evapotranspiration rates greater than the upward flux could not be sustained on a steady state basis. If the water table was 0.25 m deeper, the upward flux could only satisfy an upward flux of 2 mm/day. Since the PET rate is 4.5 mm/day there is a 2.5 mm/day deficit. This would result in water stress to the crop. As this example illustrates, the water table depth is critical to the success of a subirrigation system.

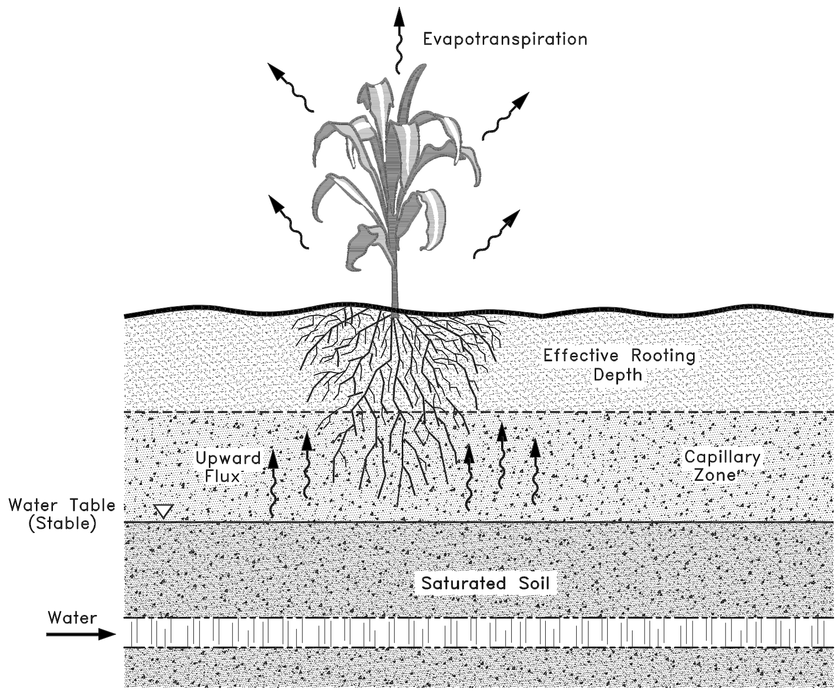

Figure 5 Water Table Design Depth

Drain Spacing for Subirrigation

Note: drain spacing needs to be calculated for drainage mode before proceeding with subirrigation drain spacing selection.

Normally only a parallel lateral system should be used for subirrigation. The spacing between laterals should be based on soil characteristics, drain depths, crop rooting depth and the plant's tolerance to water stress. The limiting factor is the time required to raise the water table to the desired level at mid spacing. Larger drain spacing means the system will be slower to respond and the system will need more intensive management.

Generally, the narrower that the drain spacing is, the better the control of the water table. Selection of the most cost effective system calls for determination of the optimum drain spacing for the selected crops to be grown.

rule of thumb

A rough estimate for drain spacing required for effective subirrigation is approximately 65% of the spacing required for adequate drainage.

Water Requirements

The system must have adequate capacity to meet required plant use and compensate for the water loss due to seepage. When the water table is raised during subirrigation the hydraulic head in the field is higher than surrounding areas, water is lost through lateral seepage and to a lesser degree deep percolation. The amount of seepage is dependent on the hydraulic conductivity of the soil, depth to restricting layers, and the soil and water table conditions along the boundaries on the field to be subirrigated.

rule of thumb

Typically maximum water application efficiency varies from 0.9 for clay loam and clays to 0.75 for other soils. For subirrigation water requirements can be roughly estimated at 0.6 to 0.9 l/s per hectare.

Size of Pipes

The hydraulic grade and the size of pipe, especially collectors, must be determined for both irrigation and drainage modes. In drainage mode the pipe diameter increases in size toward the outlet. For subirrigation the diameter of mains, collectors and laterals may be uniform or larger at the upstream end. The size of the pipes must be adequate to raise the water table to the desired elevation during subirrigation. If the water table needs to be raised during the growing season the water supply may have to be 1.5 times the daily design evapotranspiration rate.

Installation of Control Structures

The number of control structures will depend on the number of zones required to keep the water table within 30 cm of the desired level. Usually they are placed at the lowest elevation on the collector ditch of the section being control. The following recommendations should be followed during installation:

- For new drainage systems, the collector pipes should be two lateral spacings away from a ditch or water course that is deeper than the design water table level.
- If a large dynamic head is expected or the distance from a deep ditch is less than two lateral spacings, a non-perforated collector pipe should be used.
- All pipe should be non-perforated and joints sealed around the control structure for a distance of one lateral spacing.
- Backfill material around the control structure should be stone free and well compacted.
- The control structure should always have a cover or cap and be locked in areas accessible by the public.

Operation and Management

A well managed water table ensures the crop will receive the full benefit of a controlled drainage or subirrigation system.

It is necessary to operate the system for both irrigation and drainage during the growing season. Water tables are difficult to manage optimally due to the unpredictability of the distribution, quantity and timing of rainfall. When the water table is raised for purposes of subirrigation the storage available to infiltrating rainfall is reduced and conditions of excessive soil water may result. Being aware of, and using weather events, may conserve water by taking advantage of rainfall and storing the water for later use. If conserving water is not a concern the water table can be maintained at a constant level and excess water from minor rainfall events will be drained naturally from the soil. For significant rainfall events or an extended duration of rainfall the system should be changed to drainage mode to quickly remove the excess water.

Water Table Management

Management decisions include;

- when to raise and lower the control structure,
- what height to maintain the weir in the control structure,
- when to add water.

- **Raising and Lowering the Control Structure**

In areas where supplemental water is not available or water prices are high, controlled drainage would be the recommended operation. It is best, in this situation, to raise the weir soon after planting to conserve as much water as possible. The depth of the water table should still be maintained low enough so prolonged saturation of the root zone does not occur and root development is not hindered.

Conserving water could reduce associated pumping costs, but may increase the risk of early wet stress and discourage root development. The risk of raising the structure too soon or too high can be reduced by increasing the sensitivity of the system. A float type control structure will open the flap automatically when the water table is above the desired level and close the drain system once the desired water table level is reached.

- **Weir Height**

The water table level should be higher for shallow-rooted crops or for sandy soils. Keeping accurate records over several years of system operation may be needed to determine the best settings for the control structure. The records should include information on the control levels, wet and dry stress to plants and weather data.

- **Adding Water/Irrigating**

It is important that the soil not dry out too much before starting subirrigation. The soil hydraulic conductivity decreases as the soil dries and the volume of water per unit rise of water table is increased. This means the drier the soil is, the longer it will take for the water to reach the crop roots. Pumps should be shut off during rainfall events.

There are two approaches to adding water to the system: constant water table management verses varying water table level. For either method the water table should be maintained at the greatest depth that will adequately supply water to the crop. Maintaining a constant water table is usually the preferred option, as it requires less time to manage.

In constant water table management the water table should not fluctuate more than 3 cm through out the season. The greatest challenge is finding the optimum depth. The best way to achieve the goal of a constant water table is to use a float switch attached to a pump. The float switch will automatically turn the pump on if the water level drops too low.

In variable water table management the depth of the water table rises to a desired level and then is allowed to recede to a lower level. The pump is then turned on until the maximum desired water level reached. This method describes controlled drainage and is not subirrigation.

Management methods require the water table to be monitored. This may be accomplished manually, but is time consuming. Automated systems with floats or water level control switches on pumps reduce the time required to operate the system. An automated system's expense may be justified if the increase in yield can pay for the higher initial capital cost. Refer to the section on Economics for more information.

Monitoring

During the first year after installation, water table observation wells and soil tensiometers should be installed and monitored to determine the relationship between water table depth and available soil moisture for a particular site.

Manual control requires at least daily checking and operation of the pump and/or water control structure. Water levels change more rapidly above the drain than at midway between drains. It is advisable to have inspection wells midway between the drains for each soil type and each water control structure.

Water Table Observation Wells

Observation wells allow the farmer to monitor the water table to determine if the system is operating as desired. Information from observation wells should be added to the records being kept for the control structure settings.

The information can be used to determine the response time of the water table. In this case monitor how long it takes for the water table to rise. Also collect water table information when the system is in drainage mode. During most of the season weekly observations may be adequate.

Monitoring wells can be easily assembled using 1" PVC with 3 mm holes drilled every 2.5 cm of the length below the ground. A filter material should be used to prevent entry of soil material. Wells should be installed vertically to a depth of at least 30 cm below the desired water table elevation in the growing season.

Soil Moisture

Monitoring the soil moisture with tensiometers will indicate whether or not the crop is receiving adequate water. The Irrigation Scheduling Factsheet produced by the Ministry of Agriculture and Food contains information on soil moisture measurement techniques.

Irrigation Scheduling

The key to irrigation scheduling for subirrigation is to provide adequate water for the root zone while not restricting plant root development. Prior to spring tillage and seeding the water table should be lowered to about 0.75 to 1.0 m below the soil surface. After seeding the water table should be raised high enough to moisten the seed bed through capillary action. The water table is then lowered gradually as the root system develops. It is important not to have the water table too high during this period. The roots must be allowed to develop to their full depth, to reduce the chance of water stress later in the season. For the remainder of the growing season the water table should be maintained at a constant depth.

The management of the system during the growing season must take into account heavy or frequent rainfall events and the possible need to drain excess water from the soil profile. If the water table rises more than 0.15 m above the desired level of the water table control structure should be lowered or the system should be put in to drainage mode. Before harvest the water table should be lowered to 0.75 to 1.0 m below the soil surface to provide for good trafficability. The water table should be dropped slowly (0.3 m in 24 hours) to prevent the draw down of sediment or pollutants into the drains. Following harvest the system should be operated in subsurface drainage mode. Figure 6 illustrates the changing water table profile over time.

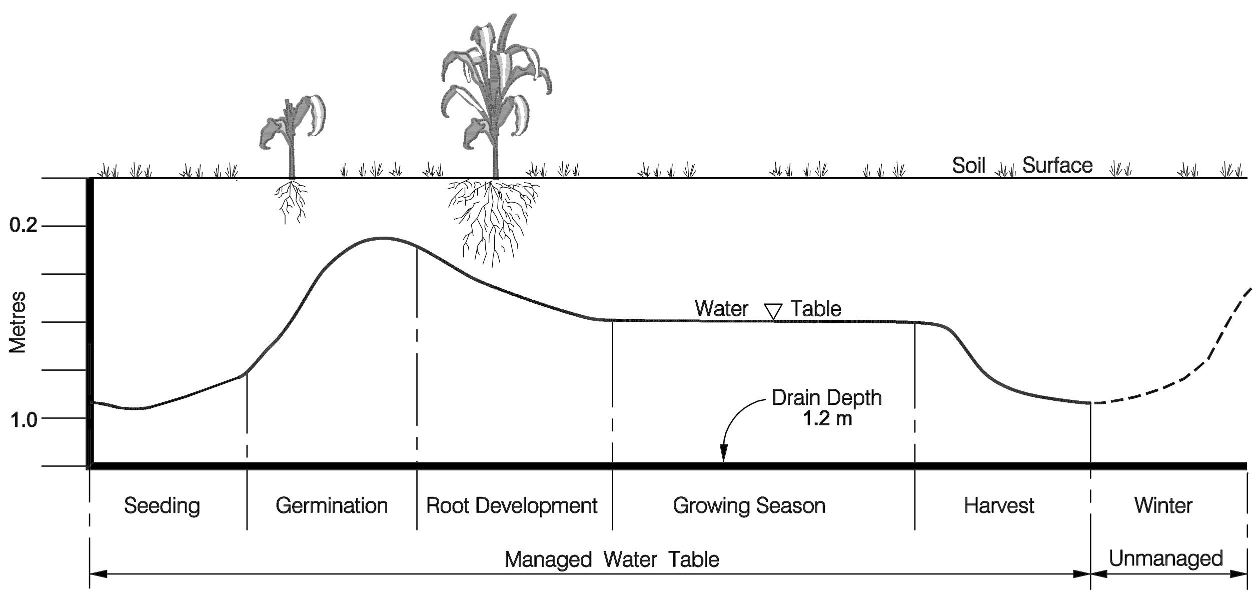

Figure 6 Managing the Water table depth for plant development

***Note:** appropriate depths for specific crops should be calculated.*

Economics

A subirrigation or controlled drainage system has a higher initial cost than a conventional drainage system. It also has the potential for higher yields, less varied yield results and a lower operational cost than what would be expected for separate irrigation and drainage systems.

An important consideration *is 'will the return from the system justify the cost'*? For example: for a control area of 20 acres the cost of a water control structure is approximately $500 or $25/acre. Depending on the value of the crop and the amount of yield increase, from the reduced plant water stress and increased uniformity in the field soil moisture, the cost of installing the system could be quickly recovered. For lower value crops, and drainage systems that require extensive retrofitting, the cost of installing a controlled drainage system may not be justified.

Also, the initial cost verses the time available to operate the system should be considered. It is less expensive to install a system that is more labor intensive to manage, however, the time may not be available to operate the system properly and the results will be less than optimal. Unlike conventional drainage systems, controlled drainage or subirrigation systems require more attention to properly manage the water table level. This includes removing or replacing flashboards, turning pumps on or off and monitoring the water table level. Installing an automated system would significantly decrease the amount of time spent managing the system. Automation would also reduce the variability in management and produce better results and higher yields more consistently.

Environmental Benefits

Many studies have shown that water table management systems can improve drainage water quality. Controlled drainage has been recognized as a best management practice (BMP). Unlike many other BMP's controlled drainage benefits water quality as well as crop productivity. Controlling the drainage rate on a subsurface system can reduce nitrates leaving the site by up to 50% compared to conventional drainage. This is achieved by three mechanisms; nitrates are retained in the soil matrix for future plant uptake, higher soil moisture slows the nitrification process and denitrification occurs before the nitrates leach.

Controlled drainage also improves the off-site water quality in terms of herbicides, pesticides, sediments and other nutrients. In controlled drainage systems the volume of water released to surface water is reduced. This reduces the amount of nutrients and sediments released into other water courses.

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Appendix: Technical Information and Equations

Design Considerations

Capillary zone thickness

During subirrigation water is transmitted from the water table through the capillary zone to the plant's root system, see Figure 5. The thickness of the capillary zone can be estimated using the following equation:

$$Hc = 0.3/d$$

Where:

Hc = capillary rise, cm
d = average size of soil particle in centimeters, cm

Example: Sandy loam, particle size 0.06 mm (0.006 cm), the capillary rise would be about 50 cm.

The capillary zone thickness can be used to estimate the depth required between the bottom of the effective root zone and the water table.

Upward flux

The rate that water can be transmitted upward from the water table through the capillary zone to the plant effective root zone is called the upward flux. Figure A.1 indicates the general relationship between upward flux and water table depth. This graph should be used with caution and is for reference purposes only.

1. Heavy clay
2. Loamy sand
3. Clay
4. Peat
5. Clay
6. Loamy sand with humus
7. Sandy loam
8. Fine sandy loam
9. Very fine sandy loam

The rate of upward flux is dependent on the potential evapotranspiration and the depth of the water table. The upward flux decreases as the water table drops. Potential peak evapotranspiration (PET) for locations in BC are

Table A.1 Design Evapotranspiration (ET Rates)

Location	Peak ET (mm/day)
Delta	5.0
Central Fraser Valley	4.0
Upper Fraser Valley	4.5
Central Vancouver Island	5.0
Saanich Peninsula	5.0
Northern Okanagan	5.0
Kooteney, Creston area	5.0
Cariboo	5.5
Southern Okanagan	7.0
Central Okanagan	6.0

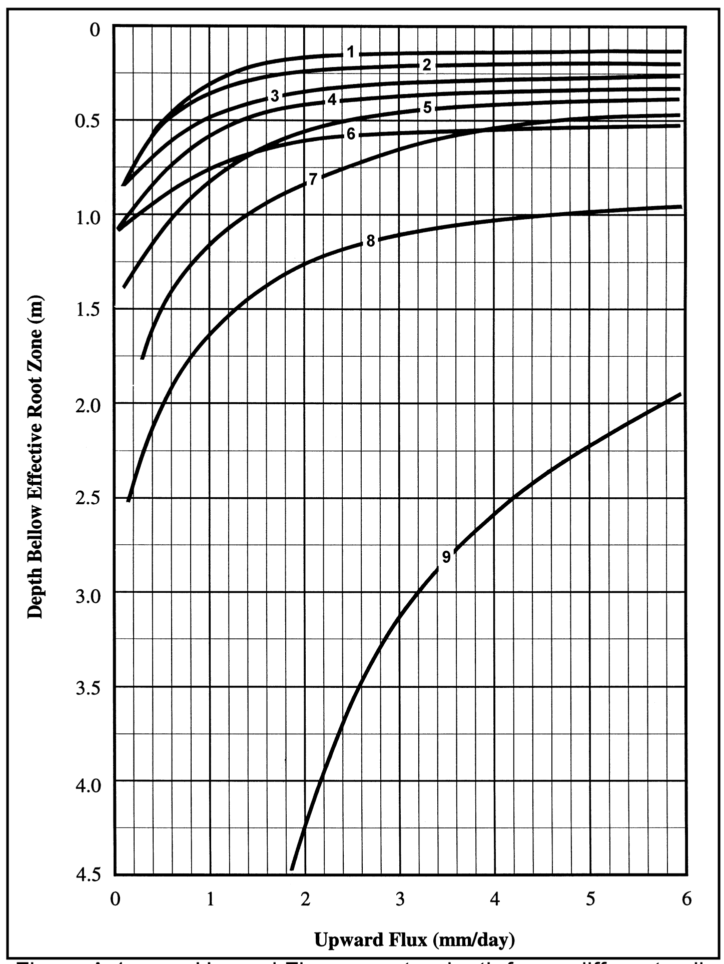

Figure A.1 Upward Flux vs. water depth for different soils.

given in Table A.1. The example in the Controlled Drainage / Subirrigation Design Section illustrates the importance of water table depth in relation to the PET. If the upward flux is less than the PET the system will not be able to provide adequate water to the crop.

Size of Drain Pipe

The hydraulic grade and the size of pipe, especially collectors, **must** be determined for both irrigation and drainage modes. The largest pipe size determined must be selected for each reach, see Figure A.2.

When the water is added from the bottom end of the system, the collector size will usually be the same size as the one calculated for the drainage mode, provided that the ET rate is smaller than half the drainage coefficient. However, if the grade of the pipe is rising, and gravity flow can not occur the system must provide the necessary head to compensate for the grade gained, as well as the friction along the pipe.

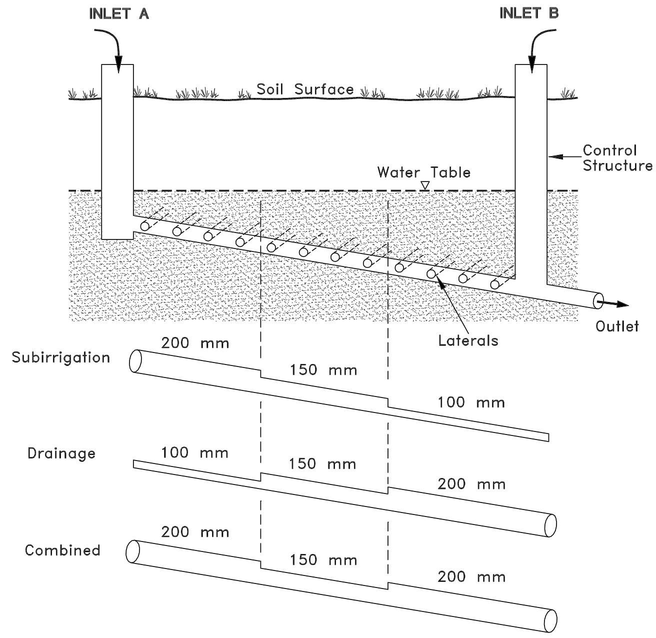

Figure A.2 Pipe Sizing

Friction Losses

A conservative and simple approach to calculate the friction loss of a collector with multiple laterals is to compute the loss as though the maximum flow rate ran the full length of the collector. For a more detailed design, a multiple outlet factor should be applied to the friction loss of the collector. The friction loss is calculated reducing the flow along the collector length Figure A.3 shows head losses for corrugated polyethylene pipes under gravity flow.

Note that the friction loss for perforated pipes is different than for non-perforated collectors, this should be taken into account when calculating friction losses.

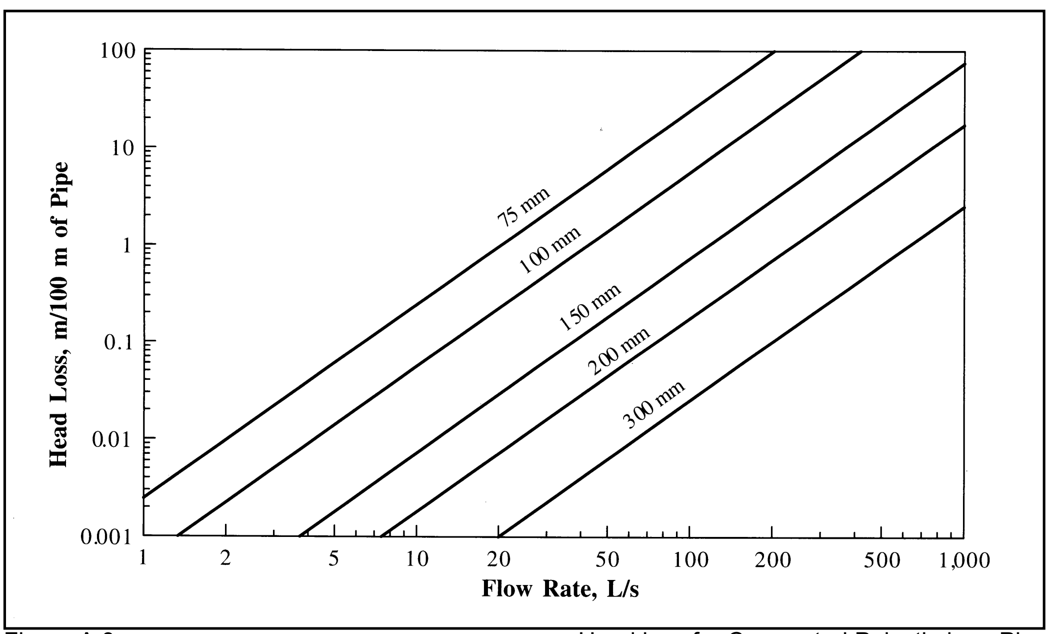

Figure A.3 Head loss for Corrugated Polyethylene Pipe

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