B.C. Agricultural Drainage Manual

Chapter 11

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Prepared and Published by:

B.C. Ministry of Agriculture, Fisheries and Food

Printing Funded by:

Canada-British Columbia
Green Plan for Agriculture

1997 Issue

Canada-British Columbia
Green Plan for Agriculture

BRITISH COLUMBIA
Ministry of Agriculture,
Fisheries and Food

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The primary purpose of the B.C. Drainage Manual is to provide farmers as well as water management professionals and consultants with technical information on the design, installation and maintenance of agricultural drainage systems.

Individual chapters may rely on information that is presented in other chapters of the manual. There is a risk that downloading individual chapters may not present all of the required information in its entirety. A complete bound manual is available from the Irrigation Industry Association of BC.

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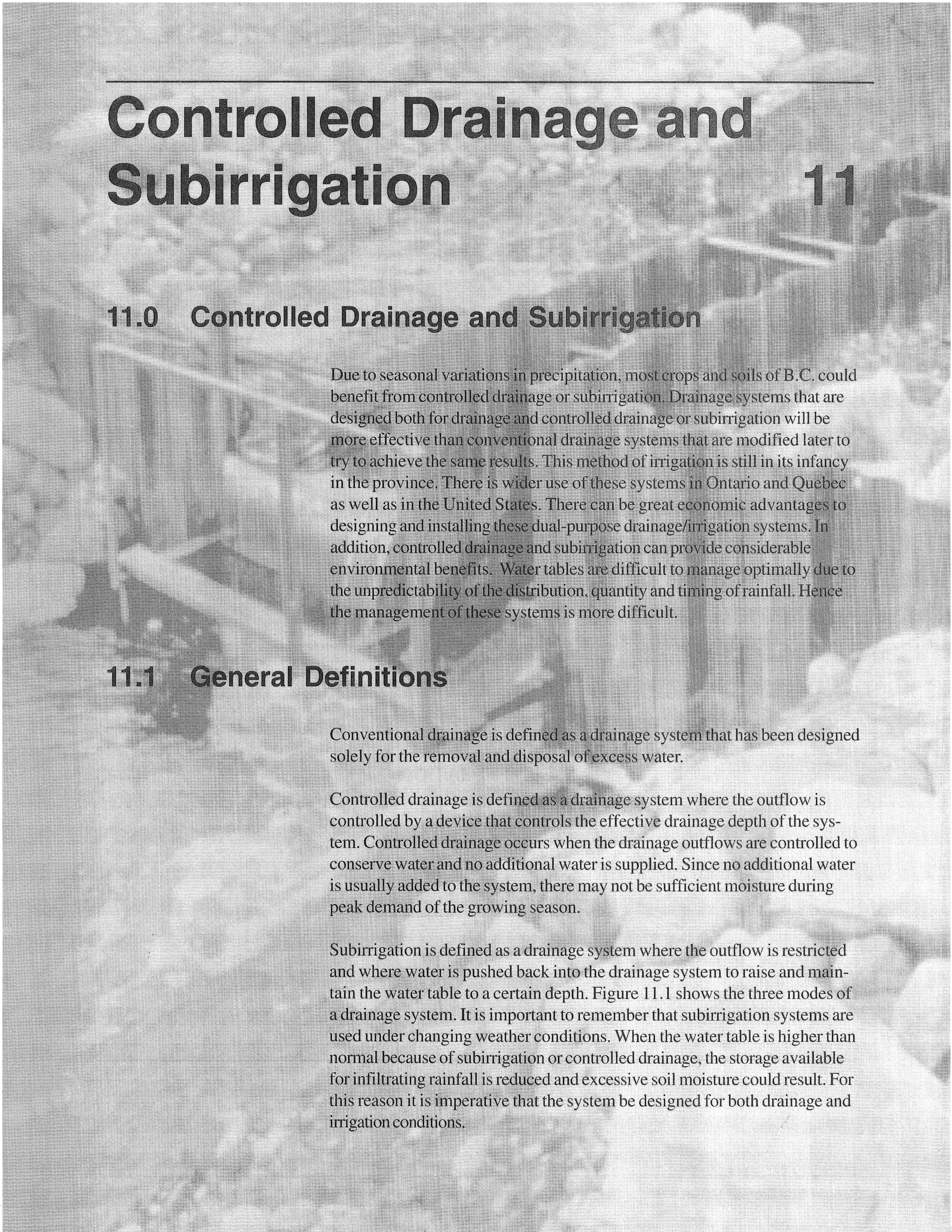


Controlled Drainage and Subirrigation 11

11.0 Controlled Drainage and Subirrigation

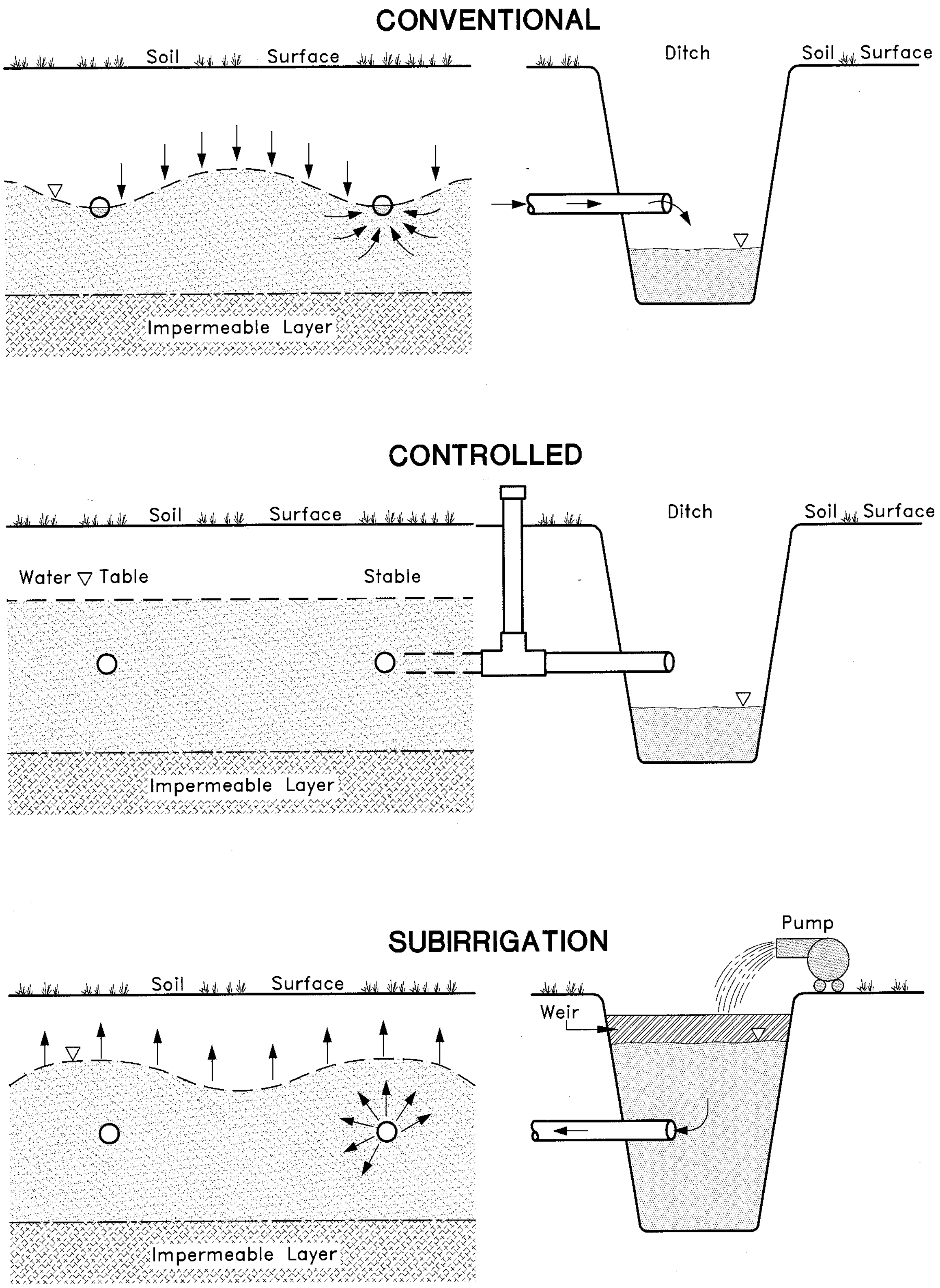
Due to seasonal variations in precipitation, most crops and soils of B.C. could benefit from controlled drainage or subirrigation. Drainage systems that are designed both for drainage and controlled drainage or subirrigation will be more effective than conventional drainage systems that are modified later to try to achieve the same results. This method of irrigation is still in its infancy in the province. There is wider use of these systems in Ontario and Quebec as well as in the United States. There can be great economic advantages to designing and installing these dual-purpose drainage/irrigation systems. In addition, controlled drainage and subirrigation can provide considerable environmental benefits. Water tables are difficult to manage optimally due to the unpredictability of the distribution, quantity and timing of rainfall. Hence the management of these systems is more difficult.

11.1 General Definitions

Conventional drainage is defined as a drainage system that has been designed solely for the removal and disposal of excess water.

Controlled drainage is defined as a drainage system where the outflow is controlled by a device that controls the effective drainage depth of the system. Controlled drainage occurs when the drainage outflows are controlled to conserve water and no additional water is supplied. Since no additional water is usually added to the system, there may not be sufficient moisture during peak demand of the growing season.

Subirrigation is defined as a drainage system where the outflow is restricted and where water is pushed back into the drainage system to raise and maintain the water table to a certain depth. Figure 11.1 shows the three modes of a drainage system. It is important to remember that subirrigation systems are used under changing weather conditions. When the water table is higher than normal because of subirrigation or controlled drainage, the storage available for infiltrating rainfall is reduced and excessive soil moisture could result. For this reason it is imperative that the system be designed for both drainage and irrigation conditions.



CONVENTIONAL

CONTROLLED

SUBIRRIGATION

Figure 11.1 Three modes of a drainage system

Advantages of subirrigation include:

- The system satisfies both drainage and irrigation needs,
- Less energy, labour and maintenance are needed than conventional irrigation,
- The operational cost is lower than for conventional irrigation systems,
- Evaporation is reduced and plants stay dry during water application, and
- Quality of drainage waters and water conservation can be improved.

Disadvantages of subirrigation are:

- Not all soils or topography are suitable,
- Cannot be used for frost protection, crop cooling, chemigation or fertigation.

11.2 Applicability

Not all field and soil characteristics are suitable for controlled drainage or subirrigation. Hilly, steep, or rolling terrain is generally not suited for controlled drainage or subirrigation. Before subirrigation is considered, the site should already require a conventional drainage system for a particular season during the year. **It is usually uneconomical to use subirrigation if only irrigation is required and there is no need for drainage.** This method of irrigation may not be appropriate for arid regions depending on the salt leaching requirements.

11.2.1 Topographic requirements

Potential sites for subirrigation should have the following topographic characteristics:

- The field should be preferably flat 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 300 mm, and
- The natural water table (before drainage) should be close to or above the drain depth.

11.2.2 Soil Requirements

Sites being considered for subirrigation should have the following soil characteristics:

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

11.3 Design

11.3.1 Water Table Design Depth

The water table design depth for subirrigation systems depends on the depth and distribution of plant roots and the rate at which the water can be transmitted upward from the water table to the plant. The distribution of a root system varies depending on plant species, stage of growth, fertility of the soil, barriers such as hardpans, and soil moisture during establishment. Generally, the root distribution through a soil profile is similar to Figure 11.2. The plant takes up 70% of its water and nutrients in the first half of its total rooting depth. This critical zone is called effective rooting depth or effective root zone.

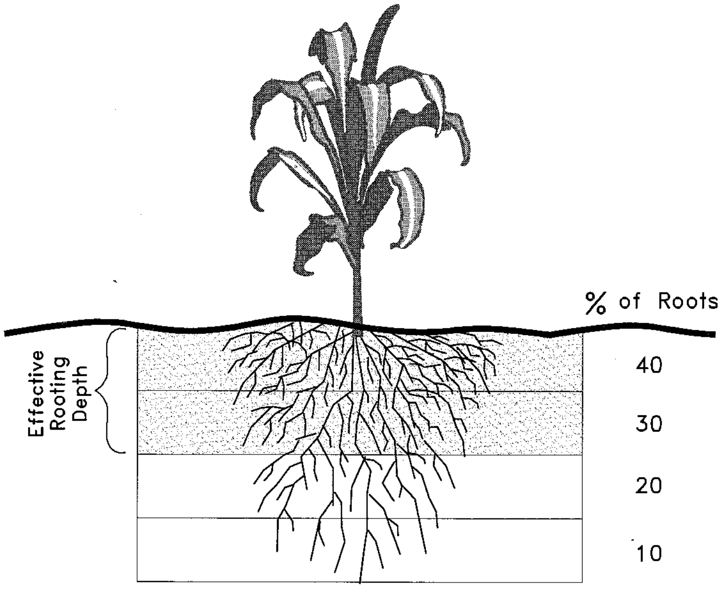


Figure 11.2 Water Table Design Depth

Normal effective rooting depths for various crops grown in deep, uniform, fertile and well drained soils are given in Table 11.1. These depths should be modified to reflect specific soil conditions. It is imperative that the moisture provided by subirrigation reaches the effective root depth.

During subirrigation, water is transmitted from the water table through the capillary zone to the plants root system. The thickness of the capillary zone is dependent on soil texture and the size, shape, distribution and continuity of pores within a soil. The thickness of the capillary zone can be estimated using Equation 3.1 (Chapter 3) which gives average capillary zone thicknesses for different soil textures. 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. A schematic view of the systems involved in conveying water for subirrigation are shown in Figure 11.3.

Table 11.1 Effective Rooting Depth of Mature Crops for Subirrigation System Design

30 cm	45- 60 cm	90 cm	120 cm
Celery	Beans	Brussels	Alfalfa
Clover (ladino)	Beets	Sprouts	Asparagus
Lettuce	Blueberries	Cereals	Blackberries
Onions	Broccoli	Clover (red)	Corn (field)
Radishes	Cabbages	Corn (sweet)	Grapes
Spinach	Carrots	Eggplant	Hops
	Celery	Kiwifruit	Loganberries
	Cucumbers	Peppers	Raspberries
	Pasture species	Squash	Sugar Beets
less than 30 cm	Peas	Pumpkin	
cranberries	Potatoes		
	Strawberries		

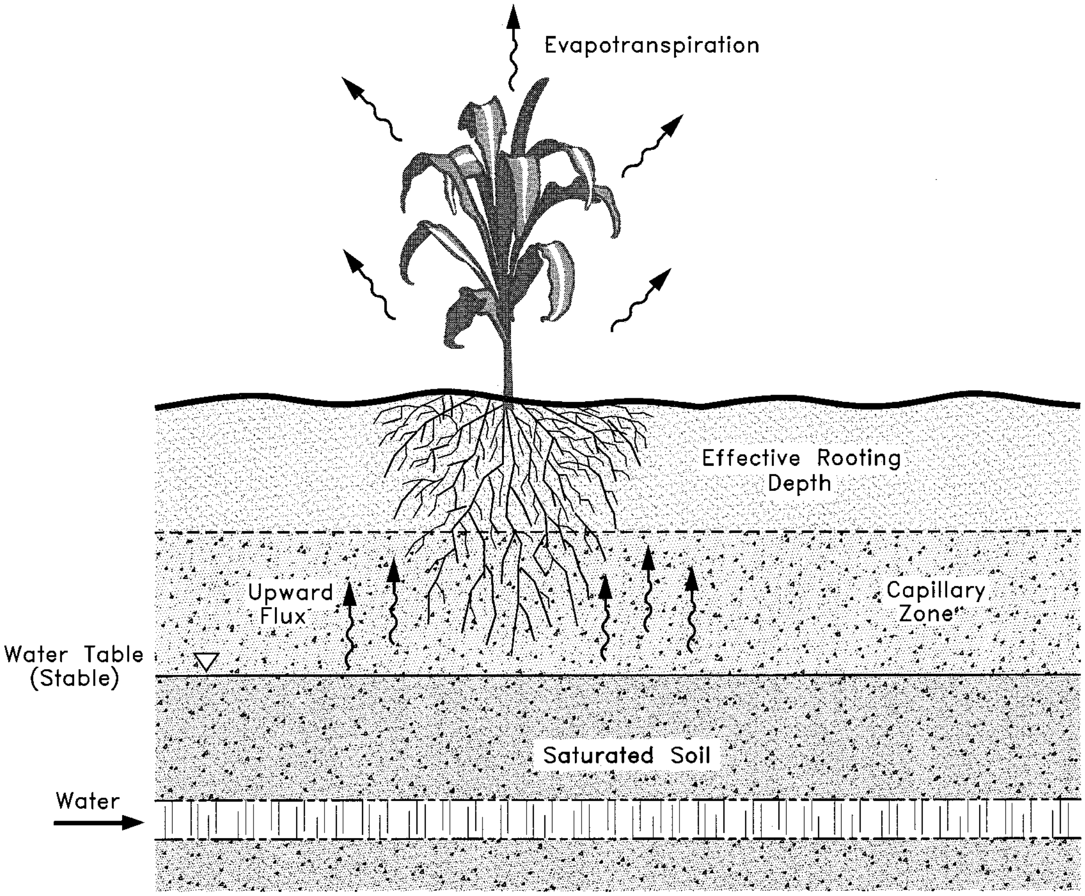


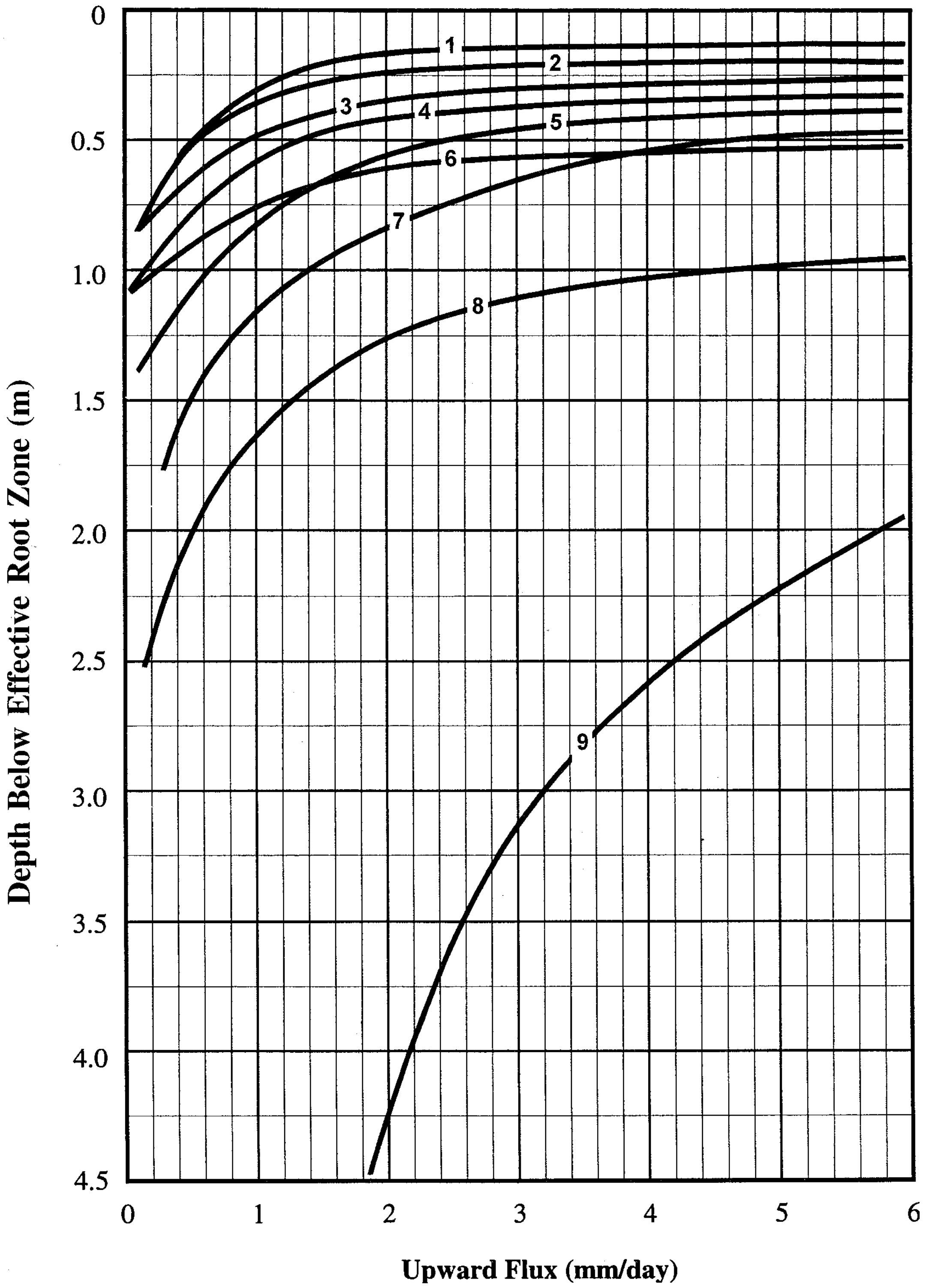
Figure 11.3 Water Table Design Depth

Upward flux is dependent on the unsaturated hydraulic conductivity, the soil pressure head at the boundary (bottom of effective root zone) and the water table depth. The actual rate of upward flux also depends on the potential evapotranspiration which influences the boundary conditions. Potential evapotranspiration is mostly dependent on relative humidity, radiation, wind and temperature. Peak evapotranspiration rates for different locations in B.C. are given in Table 11.2. For steady state conditions, the upward flux is constant. Upward flux values are very variable and cannot be measured in the field. Expensive laboratory tests are required to determine the upward flux value for a soil sample. General relationships between upward flux and water table depth are shown for different types of soil in Figure 11.4. Since these values are not site specific they should only be used as a general guide. Judgement and local experience will have to be used to select an appropriate upward flux value.

Table 11.2 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	4.0
Northern Okanagan	4.5
Kootenay	4.5
Cariboo	7.0
Southern Okanagan	7.0
Central Okanagan	6.0

For example, from Table 11.2, the peak evapotranspiration (PET) rate for Upper Fraser Valley is 4.5 mm/day. From Figure 11.4, it can be estimated that 4.5 mm/day can be supplied by the upward flux of a fine silty loam if the water table is 1 m below the effective root depth. Smaller evapotranspiration rates can also be supplied by the water table at this level. However, greater evapotranspiration rates may not be sustained on a steady state basis from a water table of this depth. Furthermore, if the water table was 0.25 m deeper (1.25 m from the effective root depth on Figure 11.4) the upward flux may only satisfy an upward flux of 2 mm/day. Since the PET rate is 4.5 mm/day this creates a 2.5 mm/day deficit. This deficit could either increase the suction at the upper boundary and possibly increase the upward flux or the evapotranspiration rate will be limited to the rate of the upward flux. This could 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 11.4 indicates upward flux rates for different soil textures.



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

Adapted From: Doorenbos and Pruitt, 1977.

Figure 11.4 Upward Flux vs. Water Depth for Different Soils

The effective root depth should not be in direct contact with the water table. In order to maintain the proper oxygen and water balance in the effective root depth, a layer of soil must separate both of them. The design depth of the water table for subirrigation is therefore a balance between the effective rooting depth, the capillary zone thickness and the upward flux.

The water table design depth is the most difficult part of designing an effective subirrigation system. Fortunately, water table depths can be changed or adjusted after the system is built. As a general rule of thumb, some experienced designer have suggested using a design water table depth of 600 mm for clay based soils and 450 mm for lighter soils. These values will need to be readjusted following the installation and operation of the system.

After the system is installed, it is imperative that the water table variations and soil moisture levels be monitored to fine tune the design. 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.

11.3.2 Drain Spacing for Subsurface Irrigation

It is important to remember that usually subirrigation is only economically feasible when drainage is required. Hence, drain spacing will have to be designed for both drainage and subirrigation mode. **Drain spacing needs to be calculated for drainage mode as in Section 10.1.4 (Chapter 10) before proceeding with subirrigation drain spacing selection.**

Normally, only parallel lateral systems are suitable for subirrigation. The spacing between laterals should be based on soil characteristics, drain depths, effective rooting depth, tolerance to water stress and upward flux. The limiting factor is often the time required to raise the water table at mid-spacing. Generally, the narrower the spacing is, the better the control of the water table. However, selection of the most cost effective system calls for determination of the optimum drain spacing for both drainage and subirrigation for the selected crops to be grown. A rough estimate for drain spacing required for effective subirrigation is approximately 65% of the spacing required for adequate drainage.

There are two main types of drainage theories to calculate drain spacing for subirrigation mode: steady state and non-steady state. In the more realistic non-steady state theories, different parameters vary with time. In general, the more sophisticated computer drainage models use non-steady state theories. These methods are more precise but because of their large data collection requirements (like historical rainfall data) and elaborate calculations, their use is usually only justified for large projects. Software like DRAINMOD and Sidedesign have been used for the design of large subirrigation systems. For field size projects, spacing for subirrigation mode can be calculated using a steady state equation. In this case, spacing is usually calculated using a variation of Hooghoudt's equation that combines peak evapotranspiration rates.

The equation can be expressed as:

$$S^2 = \frac{4K\left(2h_0 - \frac{h_0 M}{D}\right)}{ET} \qquad \textbf{(EQ 11.1)}$$

where

S = spacing between drain lateral, m

K = effective horizontal hydraulic conductivity, m/day

ho = Yo + de, distance from the water level over the drain to the equivalent impermeable layer, m

- Yo = depth from the water table level over the drain to the centre of the drain, m
- de = equivalent depth of the impermeable layer below the drain centre, m

D = depth from water level over the drain to the actual impermeable layer, m

M = difference in water level as measured over the drain and midway between the drain, m

ET = Peak evapotranspiration rate, m/day

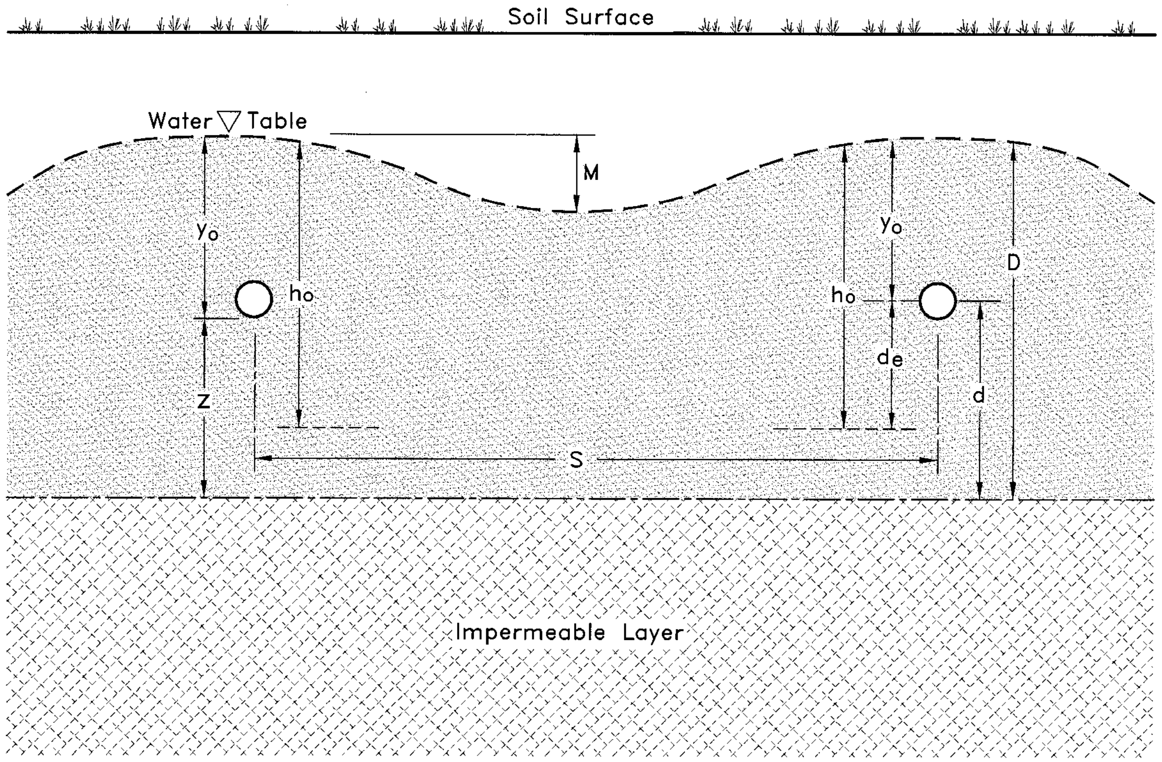


Figure 11.5 Subirrigation Spacing Variables

11.3.3 Water Requirements

Without a proper water supply, subsurface irrigation is infeasible. The most important design component of a subirrigation system is the water supply. This system must have adequate capacity to meet required plant use and compensate for the water loss due to seepage.

Water requirements can be roughly estimated at 0.6 to 0.9 L/s per hectare. When the water table is raised above the surrounding regional water table during subirrigation, the hydraulic head created in the field creates side seepage losses. Deep percolation losses can also be increased but usually to a lesser degree. The severity of side seep losses will depend on boundary conditions (i.e. ditches, roads, slopes), hydraulic conductivity, depth and location of impermeable layers. A system must be designed to compensate for these losses.

11.3.4 Size of Pipes

The hydraulic grade and the size of pipe, especially collectors, must be determined for both irrigation and drainage modes. In conventional drainage, the collector size increases towards the outlet as the system is required to carry more water. This is illustrated in Figure 11.6. For subirrigation where water is added at the top of the system (inlet A), the collector size decreases towards the lower end since it has to convey less water as it is approaching the outlet. The size must be calculated for both modes and the largest pipe size must always be selected for each section. When the water is added from the bottom end of the system (inlet B), the collector size will usually be the same size as the one calculated for the drainage mode provided the ET rate is smaller than half the drainage coefficient. However, the gradient of the pipe is negative (i.e. the grade is rising), and gravity flow cannot occur. The system must provide the necessary hydraulic head to compensate for the grade gained, as well as the friction along the pipe.

The size of the pipes must be adequate to raise the water table to the desired elevation during subirrigation. Water supply may have to be 1.5 times the daily design evapotranspiration rate if the water table needs to be raised during the growing season. The friction loss of a collector with multiple laterals can be calculated using different methods. A conservative and simple approach would be to compute the head loss as though the inlet flow (maximum flow rate) ran the full length of the collector. For more detailed design, a multiple outlet factor should be applied to the friction loss of the collector to compensate for the reduced flow along its length. Friction losses for corrugated polyethylene pipes under gravity flow can be calculated using Figure 11.7.

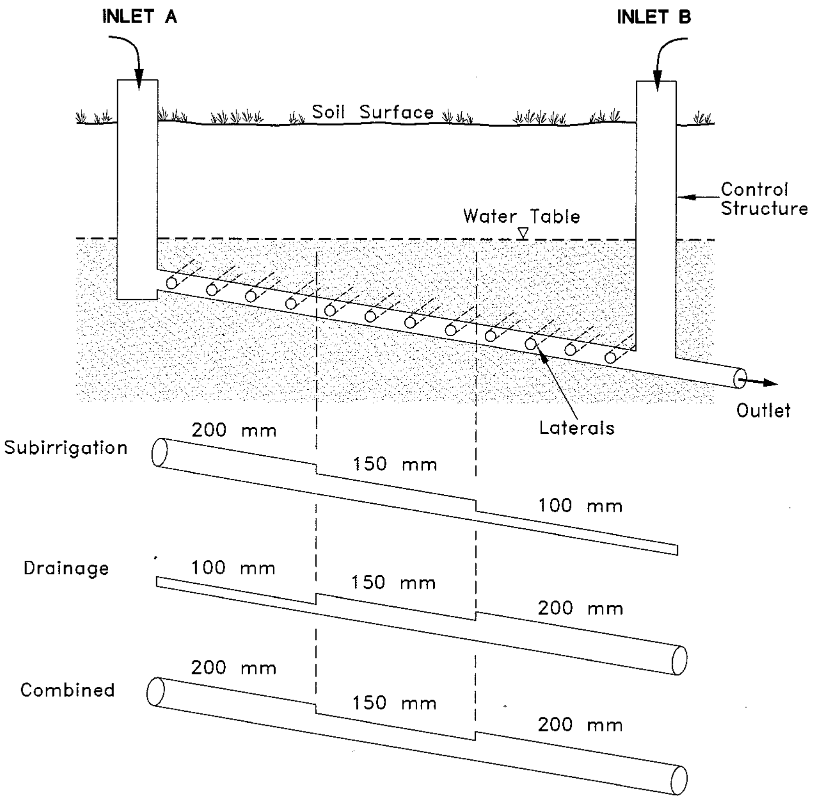


Figure 11.6 Pipe Sizing

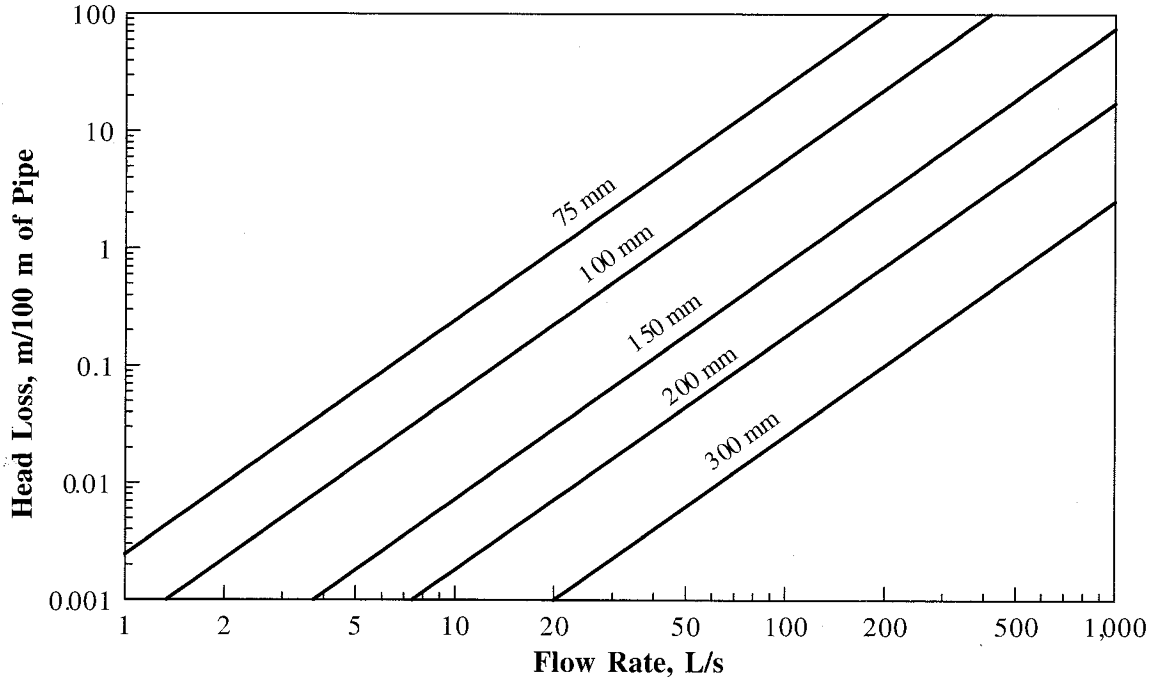


Figure 11.7 Head Losses for Corrugated Polyethylene Pipe

11.3.5 Water Quality

Only water of reasonable quality should be used for subirrigation. The water should be free of sediment, chemical or biological compounds. Subirrigation cannot be used for fertilizer or chemical injection, this could result in serious damage to the environment and the drainage system. Excess sodium in irrigation water relative to calcium and magnesium or relative to the total soluble salt content can adversely affect soil structure, reduce permeability and soil aeration for clay soils. The Sodium Absorption Ratio (SAR) should be determined if potential problems are suspected. Generally, clay soils with an electrical conductivity of less than 400 microhm/cm can tolerate water which has an SAR that is lower than 10. Refer to the Canadian Water Quality Guidelines for further details.

11.4 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 in the field for controlled drainage and subirrigation. They must have the capacity equal to the maximum drainage discharge and have a mechanism to adjust the water level. They also need an overflow or automatic gate or control valve to lower the water table after heavy rainfall. The principal objective of a water table control structure is to slow down the draw-down of the water table to enhance crop production.

Depending on the system layout and the automation level desired, different types of control structures can be installed. The simplest approach for controlled drainage or subirrigation is to control the water level of the outlet ditch. This can be done with small weirs or culverts modified to accept flashboards. This method is inexpensive but automation and precise water table control is difficult.

Although there can be many different specific designs, there are two main types of control structure: flashboard and a float type.

For the flashboard type, a section of culvert is modified by welding two "C" channel irons on the inside facing each other. Stop logs made from tongue and groove planking can be inserted to adjust the level of the effective outlet. All stop logs are removed for normal drainage mode. This type of system cannot be automated but its main advantage is that it can be easily "home made" with readily available materials.

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. The water level in the riser pipe is equal to the water table level in the field. 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.

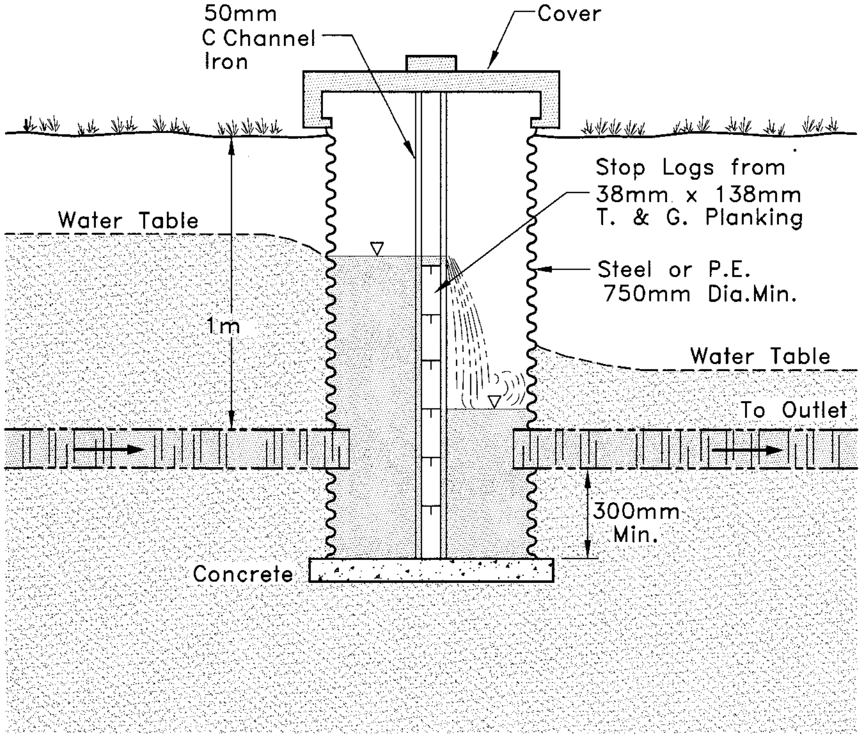


Figure 11.8 Flasboard Type Design

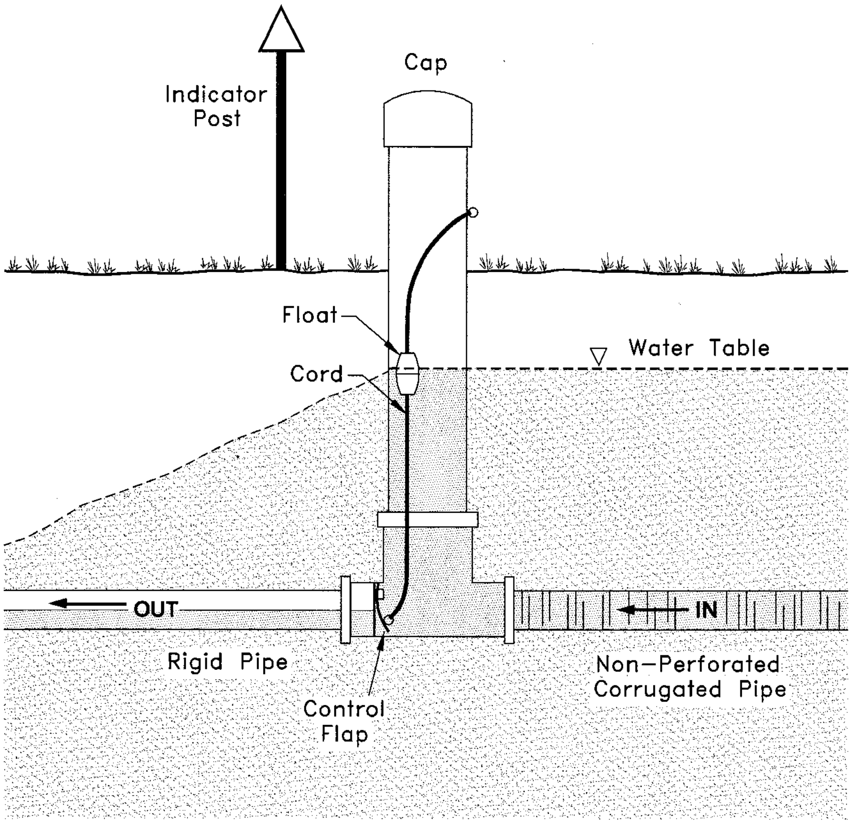


Figure 11.9 Float Type Design

11.4.1 Installation

Careful planning is required for the placement of water table control structures. The number of control structures needed will depend on the number of influence zones required to keep the water table within 30 cm of the desired elevation. Usually, these devices are placed at the lowest elevation on the collector ditch of the section to control. The following recommendations should be followed during installation:

- For new drainage systems, the collector pipes should be two spacings from a ditch or watercourse 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 spacings, a non-perforated collector pipe should be used.
- All pipes should be non-perforated and joints sealed around the control structure for a distance of one spacing.
- Backfill material around the control structure should be stone free and well compacted.
- The control structure should always have a cover or cap. These should always be locked in accessible areas.

When preparing a plan, in addition to requirements of Section 8.3.3, the following information should be provided:

- Zones of influence of each control structure should be clearly indicated.
- The area of each zone of influence should be indicated to help the owner decide on the economic feasibility of the subirrigation project.
- Type of water table control structures.
- Location of the control structures.
- Design water table depth for the crops grown.
- Pump rates and specifications.

11.5 Environmental Benefits

Many studies have shown that water table management systems can improve drainage water quality. Controlled drainage has been designated by many authorities as a Best Management Practice (BMP). Unlike many other BMPs, controlled drainage benefits water quality as well as productivity. In general, most water table management strategies that improve production also have a positive effect on water quality.