

Chapter 10

COLLECTOR SIZING

Introduction

Collectors are the pipes that collect water from the laterals. They are also referred to as submains and mains. If the lateral pipes outlet to a collector that in turn outlets to another pipe, the first collector is called a submain and the final pipe that delivers the water to an outlet ditch or drainage pump is called the main.

Water table management systems consist of underground pipes that both drain water from the soil profile and transport water to the root zone during subirrigation. Therefore, water table management pipes may require two different flow capacities – for subsurface drainage and for subirrigation. Flow for these two conditions may be in opposite directions.

For Subsurface Drainage

A water table management system is first of all a subsurface drainage system. In the spring, the lateral and collector pipes remove water from the soil profile so field operations can be performed without damage to the soil structure. For this conventional subsurface drainage mode, the collector pipes are sized just as they would be if the system was only used for subsurface drainage. The designer selects an appropriate drainage coefficient, and uses the selected drainage coefficient and area served by the collector to determine the needed flow capacity of the collector in cfs. For the collector pipe grade and roughness, Manning's equation is solved to determine the diameter needed to transport that flow capacity with the pipe flowing full but not under pressure.

Manning's equation for pipe flow is

$$Q = \frac{1.49}{n} A \cdot R^{2/3} \cdot s^{1/2}$$

Where

Q is pipe discharge in cfs;

A is area of flow, in ft²;

R is flow hydraulic radius (flow area / wetted perimeter) in ft;

s is the bottom slope of the pipe in ft/ft; and

n is the Manning roughness coefficient for the pipe.

Charts to determine required flow capacity in cfs and pipe diameter in inches for both corrugated plastic pipe and smooth pipe (clay or concrete) are provided at the end of this chapter.

Drainage coefficients historically have been used to quantify the degree of drainage provided by subsurface drainage systems. A drainage coefficient is a rate of water removal (volume per unit area) from the soil profile expressed as a vertical depth of water to be removed in one day. In selecting the appropriate drainage coefficient for a given situation, the frequency, intensity, and duration of rainfall; the degree of surface drainage; the porosity; the hydraulic conductivity of the soil; and the sensitivity of the crop to water-logging all need to be considered. A minimum value of (3/8 in./day) is commonly used for field crops in humid-region mineral soils with good surface drainage and without surface water inlets. Typically the drainage coefficient is increased by 15 to 20% if surface drainage is poor. It is the opinion of the author that for water table management systems, the pipes should be able to discharge water at no less than 3/4 inch in 24 hours (Drainage Coefficient = 0.75 inch/day) and often should be even greater to be able to lower the water table in a timely manner when a large rain occurs while subirrigating as discussed in the following section.

Water Table Drawdown after Rain

Often, for a water table management system, subsurface drainage in the spring is not the most critical subsurface drainage requirement. The usual maximum needed rate of subsurface drainage is likely to be when the system is in subirrigation mode and a rainfall occurs that causes the water table to rise to near the surface of the field. When this happens, the crop roots are saturated and may be damaged if the water table is not quickly lowered to the depth it was when it began raining. For this condition, the required subsurface drainage rate often is greater than the drainage coefficient needed for conventional subsurface drainage design.

To determine an appropriate drainage coefficient for the situation just described, the system designer must consider the depth to the water table when the rain begins, the volume of free water the soil profile can hold in that depth, the hydraulics of that free water moving to the laterals, and the time limitations the roots can be saturated without damage. Obviously, to include all of these considerations in a formulation to determine the appropriate drainage coefficient is difficult. However, some simplifying assumptions can be made that allows us to develop a table that can be used to provide guidance for most conditions likely to be encountered.

Let's first assume that when it begins raining, the water table management system is in the subirrigation mode. Next, assume the rain event causes the water table to rise to the field surface, and fills all of the pores with water. This suggests that the volume of water to be removed by our system is the volume of free water contained within the depth of soil from the field surface to the water table depth when it begins raining. The volume of free water in the soil that needs to be removed is the difference in the soil-water volume at saturation and the soil-water volume at field capacity. Let's call this the drainable-soil water volume and give it units inch of water per inch of soil depth. Then the water to remove by the drainage system can be calculated by multiplying the drainable soil-water volume by the average depth to the water table. The following table provides values for drainable porosity, f , based upon soil texture.

Table 10-1. Saturated hydraulic conductivity (K) and drainable porosity (f) for soil by texture.

Soil Texture	K inches/hour	f
dense clay, not cracked and no bio-pores	0.003	0.01-0.02
clay loam and clay - poorly structured	0.03-0.3	0.02-0.04
very fine sandy loam	0.3-0.8	0.02-0.04
loam, clay loam, and clay - well structured	0.8-3.0	0.04-0.08
sandy loam and fine sand	1.5-5.0	0.15-0.20
medium sand	1.5-8.0	0.20-0.25
coarse gravelly sand	15-100	0.25-0.30

Finally, we will assume when it stops raining the system is put into the subsurface drainage mode and we know the maximum length of time we can take to lower the water table before the roots are damaged.

Using these assumptions and allowing f to be a reasonable approximation for the drainable soil-water, the required drainage coefficient can be estimated by solving the

$$DC = \frac{f \cdot d_r}{dd_t}$$

equation:

Where

DC = Drainage Coefficient in inch/day;

f = drainable porosity, unitless,

d_r = effective depth of roots in feet; and

dd_t = time allowed to return water table to depth before start of rain, days.

To use the table, select the drainage coefficient from the table for the soil texture to be drained, and multiply that drainage coefficient by the effective rooting depth in feet and divide by the number of days the roots can remain saturated without damage. The following table provides some typical effective rooting depth estimates for various plants.

Table 10.2 Effective rooting Depths for various plant species.

crop	root depth inches
alfalfa	36 to 72
cabbage	18 to 24
carrot	18 to 24
corn	30 to 48
cucumber	18 to 24
field bean	12 to 24
lettuce	6 to 12
onion	12 to 18
pasture	18 to 36
peas	12 to 24
potato	18 to 24
small grain	24 to 36
soybean	18 to 24
strawberry	6 to 12
sugar beet	24 to 36
tomato	12 to 24

Source: Chapter 12 of the
Michigan Irrigation Guide
by M. L. Vitosh

Subirrigation

During subirrigation the direction of water flow reverses. Instead of the water flowing from the soil to the pipes, it must flow from the pipes to the soil and through the soil to the plants. Even though the direction is in reverse to drainage flow, the concept of a coefficient to describe the rate of that flow remains valid. Therefore, it makes sense to talk about an irrigation coefficient during subirrigation instead of a drainage coefficient used to describe subsurface drainage flow.

During subirrigation, the pipes need to have adequate capacity to deliver water to the root zone at a rate that is equal to the rate the plants will use the water, plus the rate of evaporation from the soil surface, plus the rate of water loss by seepage laterally around the perimeter of the field and vertically through the impermeable barrier. The rate of water use by the plants is called the evapotranspiration or consumptive use rate. The subirrigation system needs to be able to provide water at the peak rate during the growing season.

Some values for Michigan crops are provided by Table 10-3.

Table 10.3. Peak Daily and Total Seasonal Consumptive Water Use of Selected Plants in Michigan

Agricultural Crops	Peak Daily Use, inches/day	Total Season Use, Inches
alfalfa	0.22	26
pasture	0.22	24
small grains	0.18	14
sugar beets	0.20	20
field beans	0.18	12
corn	0.25	20
potatoes	0.20	18
field peas	0.18	9
tomatoes	0.17	17
tree fruit	0.18	20

Landscape Plants	Peak Daily Use, inches/day	Total Season Use, Inches
turfgrass	0.25	25
groundcover, annual flower beds, evergreens, perennials, shrubs < 4 ft., vines and fruit-bearing trees	0.25	25
mature shade trees	0.20	20
ornamental plants, native shrubs, and shrubs > 4 ft.	0.18	18
established native plants	0.10	10

source: Irrigation Principles and Practices, third edition;
by O. W. Israelsen and V. E. Hansen; Wiley and Sons, Inc., NY
by M. Vitosh and *Landscape Irrigation Design* by E. W. Rochester;
ASAE, St. Joseph, Mi.

Again, Manning's equation is used to determine the pipe size required to provide water to the subirrigated area at the peak daily use rate, plus an allowance for vertical and boundary seepage.

Manning's equation for pipe flow is

$$Q = \frac{1.49}{n} A \cdot R^{2/3} \cdot s^{1/2}$$

Where, as before,

Q is pipe discharge in cfs;

A is area of flow, in ft²;

R is flow hydraulic radius (flow area / wetted perimeter) in ft; and

n is the Manning roughness coefficient for the pipe.

However, the s term in Manning's equation is not the slope of the pipe for subirrigation. The s term is the slope of the energy grade line, which is approximately equal to the slope of the hydraulic grade line. A very good approximation for s is to subtract the elevation of the water table in the zone being fed by the pipe to be sized from the elevation of the water surface in the water table control device and then divide that difference by the length of the pipe that will transport the water. After s is calculated, Manning's equation is used to determine the pipe diameter that will provide Q equal to or greater than the peak daily use plus the seepage allowance.

The additional capacity needed for seepage loss varies with the texture of the soil and the water-tightness of the impermeable barrier. For fine-grained soils such as clay-loams, with a heavy blue-clay barrier, a increase of 10% has worked well. As the texture becomes coarser, seepage around the boundary will increase. For a smaller field such as 40 acres with a sandy texture, a 25-30% increase in capacity may be needed. For larger fields, the perimeter to area ratio is reduced and it may be possible to reduce the % increase needed for seepage.

Design Charts

To assist in solving Manning's equation, the solution has been graphed various ways. The first chart provides a graph that converts drainage or subirrigation coefficients in inches/day to cfs based upon the acres of area being drained or irrigated. The following two charts (one for plastic tubing, the other for clay and concrete tile), relates the pipe diameter and pipe slope or hydraulic grade line slope to capacity in cfs. These charts can be used for sizing the pipes for both subsurface drainage and subirrigation by selecting the appropriate value for s .

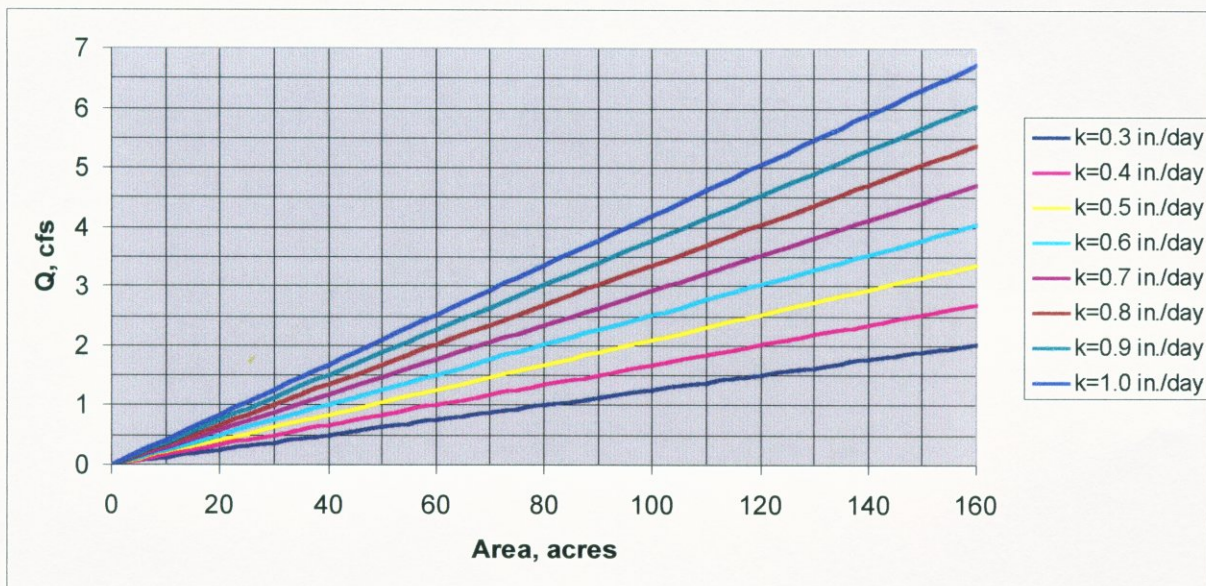


Figure 10-1. Chart of discharge versus area for various rates in inches/day.

Table 11-1 Peak evapotranspiration by day and total evapotranspiration by season for the lower peninsula of Michigan.

Agricultural Crops	Peak Daily Use, inches/day	Total Season Use, Inches
alfalfa	0.22	26
pasture	0.22	24
small grains	0.18	14
sugar beets	0.20	20
field beans	0.18	12
corn	0.25	20
potatoes	0.20	18
field peas	0.18	9
tomatoes	0.17	17
tree fruit	0.18	20

Landscape Plants	Peak Daily Use, inches/day	Total Season Use, Inches
turfgrass	0.25	25
groundcover, annual flower beds, evergreens, perennials, shrubs < 4 ft., vines and fruit-bearing trees	0.25	25
mature shade trees	0.20	20
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ASAE, St. Joseph, Mi.

For surface water sources, it is very important that the system designer be sure that the water needed is available during the time of the growing season when the crops will be at maximum water use rate, and rain is least likely to falling. A drainage ditch with lots of flow in the spring is not a suitable source if it is nearly dry during August.

Volume of Water Supply

For groundwater and flowing water surface sources, the volume of water will likely be sufficient to meet the irrigation demand over the season. For lakes and ponds this may not be the case. The lake or pond must have enough water volume to sustain the irrigation over much of the growing season. That volume can be estimated by multiplying the season irrigation needs by the area to be irrigated. The season irrigation needs can be found from cooperative extension sources and is usually given in inches and represents evapotranspiration minus expected rainfall. Another way to determine the volume of water needed is to multiply the irrigation supply flow rate by the duration of irrigation each day by the number of days likely to be irrigated.

The volume of water needed must be compared to the volume of water available. This is difficult to do because an unknown volume of water will evaporate from the lake or pond and an unknown volume of water may be added to the volume by runoff or by recharge. A conservative