ASAE EP480 FEB03
Design of Subsurface Drains in Humid Areas

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Design of Subsurface Drains in Humid Areas

Supersedes design sections of EP260, Design and Construction of Subsurface Drains in Humid Areas, adopted by ASAE 1952; EP480 developed by the ASAE Water Table Management in Humid Areas Committee; approved by the Soil and Water Division Standards Committee; adopted by ASAE March 1998; reaffirmed February 2003.

1 Purpose and scope

This Engineering Practice is intended as a guide to the design of subsurface drainage systems, particularly as a resource for developing detailed construction drawings and specifications for a specific drainage project. ASAE EP481 provides construction information that should be considered in the design process. This Engineering Practice is not directly applicable to the design of subsurface drains in irrigated semiarid and arid regions.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Engineering Practice. At the time of publication, the current editions were valid. All standards are subject to revision, and parties to agreements based on this Engineering Practice are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of currently valid standards.

ASAE EP369.1 DEC94, *Design of Agricultural Drainage Pumping Plants*
ASAE EP407.1 DEC96, *Agricultural Drainage Outlets–Open Channels*
ASAE EP481 MAR98, *Construction of Subsurface Drains in Humid Areas*
ASAE S268.4 DEC97, *Design, Layout, Construction, and Maintenance of Terrace Systems*
ASAE S526.1 MAR95, *Soil and Water Engineering Terminology*
ASTM C4-97, *Standard Specification for Clay Drain Tile and Perforated Clay Drain Tile*
ASTM C412-94, *Standard Specifications for Concrete Drain Tile*
ASTM C498-95, *Standard Specifications for Perforated Clay Drain Tile*
ASTM D698, *Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3, 600 kN-m/m^3)*
ASTM D2321-89, *Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications*
ASTM F405-97, *Standard Specification for Corrugated Polyethylene (PE) Tubing and Fittings*
ASTM F667-97, *Standard Specification for Large Diameter Corrugated Polyethylene Pipe and Fittings*

3 Definitions

For definitions, refer to ASAE S526.

4 Materials

4.1 Corrugated plastic tubing

4.1.1 Quality. Corrugated plastic tubing shall meet requirements specified by ASTM F405 and ASTM F667. Standard pipe, as designated by ASTM F405 and ASTM F667, is satisfactory for most agricultural drainage and can be specified for systems with prepared bedding at depths no shallower than 0.6 m (2 ft) in soils relatively free of rock. Heavy duty tubing, as designated in these same specifications, is recommended where the trench is classified as wide, narrow, and/or deep; where the trench cannot provide adequate side support; and in rocky soils. A narrow trench is defined as a trench with width at the top of the tubing less than twice the outside diameter of the tubing. A wide trench is defined as a trench with width at the top of the tubing equal to or greater than twice the outside diameter of the tubing. A deep trench has a depth exceeding 3.0 m (10 ft).

4.1.2 Temperature extremes will affect the material handling properties of corrugated plastic drain tubing as described by ASAE EP481.

4.2 Clay and concrete tile

4.2.1 Quality. Clay and concrete tile shall meet requirements specified by the appropriate ASTM standard. Quality classes for clay and concrete drain tile are designated in ASTM C4, ASTM C412, and ASTM C498.

4.2.2 Concrete and clay tile exposed to acid and sulfate conditions. Concrete tile installed in acid soils or sulfate soils shall be of the special quality class described in ASTM C412. Clay tile is acid resistant and not affected by exposure to sulfate soils.

4.2.3 Concrete and clay tile exposed to freezing and thawing action

4.2.3.1 Clay tile meeting the standard quality class requirements described in ASTM C4 is frost resistant.

4.2.3.2 Concrete tile meeting the standard quality class requirements described in ASTM C412 is frost resistant.

4.2.4 Quality class of drain tile. The quality class of a drain tile shall be specified to withstand the anticipated maximum soil and live loads to be imposed on the drain tile during the life of the system.

4.3 Other materials. Other pipe materials may be used only if their durability and capability to function equals or exceeds that of corrugated plastic tubing, and concrete and clay tile as previously specified.

4.4 Envelope/filters

4.4.1 Usually pipe drains installed in stable soils will give satisfactory performance without specific requirements for soil stabilization. However, unstable soil situations, such as fine sand and non-cohesive soil, require stabilizing. This is accomplished by specifying

- — an envelope/filter;
- — an aggregate stabilizing material; or
- — a geotextile stabilizing material.

Envelope/filter materials provide structural stability and improved hydraulic performance. Aggregate and geotextile stabilizing materials provide structural stability to the subsurface drain system and to a lesser extent improve the hydraulic performance of the system.

4.4.2 Conditions where envelope/filters, aggregate stabilizing materials, or geotextile stabilizing materials should be considered include:

- — soils that may fill the pipe drain, such as silt or sands with particles smaller than 0.5 mm (0.02 in.);
- — soils that do not provide a stable foundation, such as saturated sands in a ‘‘quick’’ condition;
- — soils that may limit water entry into the pipe drain by clogging perforations; and
- — soils containing rocks that may damage the pipe drain during or following installation.

4.4.3 Envelope/filters

4.4.3.1 Manufactured synthetic envelope/filter materials such as knitted polyester, spunbonded nylon, polypropylene fabric, fiberglass sheets or mat (borosilicate type), and other durable, nonbiodegradable materials are satisfactory in most soils. In areas where available soluble iron, manganese oxide, or other compounds may form deposits, the success of previous drainage applications using envelope/filter materials in that locale should be considered. Such deposits may seal the openings in the envelope/filter material and/or the pipe drain perforations and restrict water entry. For this reason, caution in the use of synthetic envelope/filter

Table 1 – Agricultural drain envelope/filter fabrics (current 1987)

A	B	C	D	E	F	G	H	I	J
Big "O" (polyester)	Knitted	112	29	23	N/A	7	75	N/A	30
Typar type 3401 (Polypropylene)	SB[1)]	60	24	21	150	4.6	57	5.9	20
Cerex type 25 (nylon)	SB[1)]	32	10	13	N/A	2.6	50	4.5	50

[1)] spunbonded

Key
(A) Fiber
(B) Process
(C) Weight (g/m^2)
(D) Flow (m^3/m^2·min)
(E) Grab tensile (kg); machine dir.
(F) Grab tensile transverse dir. (kg)
(G) Mullen burst (kg/cm^2)
(H) Elongation (%)
(I) Trapezoidal tear (kg)
(J) Equivalent opening size; US std. sieve

materials must be exercised. Table 1 provides the physical properties of commonly used synthetic envelope/filter fabrics intended for use in direct contact application on agricultural subsurface drains. The products described are commercially available and have been used in subsurface drain system installations. Their listing does not constitute an endorsement by ASAE.

4.4.3.2 Sand/gravel envelope/filter materials include combinations of sand, gravel, crushed stone, slag, and others. Design criteria for a sand/gravel envelope/filter follow:

The gradation of the sand-gravel used for envelope/filter will be based on the gradation of the base material of the native soil within the following limits:

— *D*15 shall be less than 7 times *d*85 but not less than 0.5 mm (0.02 in.);

— *D*15 shall be larger than 4 times *d*15;

— there shall be less than 5% of the envelope/filter material passing a No. 200 sieve; and

— the maximum size of the envelope/filter material shall be less than 35 mm (1.5 in.)

where:

D is the envelope/filter material, and

d is the base material, with the number following being the percent of sample by weight that is less than the particle diameter shown.

Pit run sand and gravel may meet these gradation limits.

4.4.4 If the aggregate stabilizing method is used, the aggregate materials should conform to the following gradation:

— 100% less than 38 mm (1.5 in.), with less than 30% passing a No. 60 sieve; and

— less than 5% passing a No. 200 sieve.

Aggregate stabilizing materials meeting these gradation limits are commonly available from ready-mix concrete plants and are designated as fine aggregate for concrete mixtures.

4.4.5 Geotextile stabilizing materials include both woven and nonwoven fabrics. Applications include ground stabilization, drainage, separation of dissimilar soils, filtration of influent, and as an underlayment for aggregate stabilization and asphalt surfacing. The physical properties of the geotextile and the surrounding soils must be evaluated for the application intended. For stabilization of base material, the geotextile shall line the perimeter of the granular backfill. Figure 1 illustrates how geotextile may be installed in a narrow trench to stabilize the subgrade and trench walls.

5 Design

5.1 Field investigations. The objectives of a subsurface drain system are to lower shallow water tables and remove excess water from the root zone soil profile. This allows agricultural field operations to take place in a timely manner and prevents crop damage from excess soil water. Successful achievement of these objectives requires the consideration of the following factors when developing the field layout of a subsurface drain system.

5.1.1 Topography of site and direction and amount of surface flow. Pipe drains should, where possible, be installed approximately perpendicular to the direction of surface flow to provide the maximum opportunity for interception. To improve trafficability, consideration should be given to performing agricultural operations at right angles to the direction of the pipe drain system laterals.

5.1.2 Accessibility of outlet. The location, depth, and legal status of the outlet must be considered to ensure that the layout will function efficiently and within local regulations.

5.1.3 Soil profiles. Design depth and spacing of pipe drains are affected by the soil profile.

5.1.4 Existing subsurface drain system. If the newly designed system must be connected to an existing system, then the two systems shall be compatible in terms of life and drainage capability. Diameter and layout of the existing system may suggest the best method of layout for extension or improvement of the system.

5.1.5 Point and external sources of water, such as springs or artesian wells, may require other special design considerations.

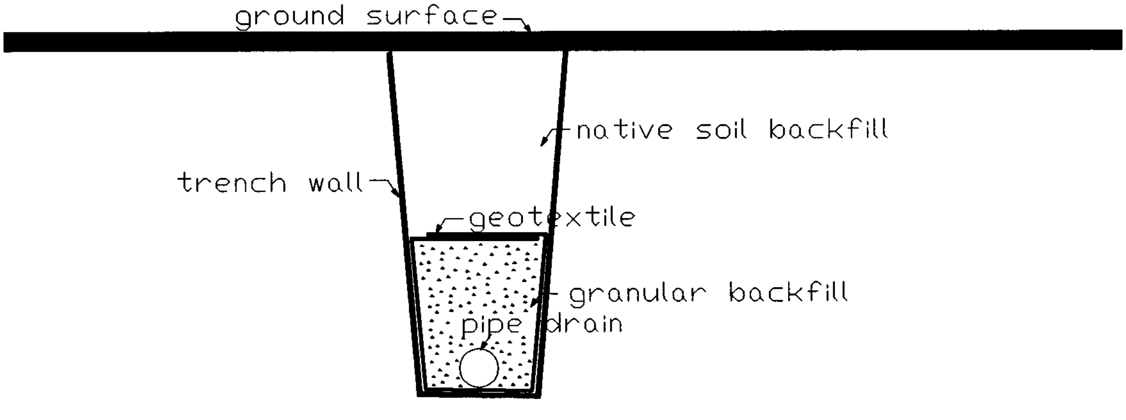


Figure 1 – Schematic showing use of geotextile to stabilize trench subgrade and walls

Table 2 – Typical lateral spacings in various soils for pipe drains buried approximately 1.2 m (4 ft)

Soil	Permeability	Lateral spacing, m (ft)
Clay and clay loam soils	Very slow	9-20 (30-70)
Silt and silty	Slow to moderately slow	18-30 (60-100)
Sandy loam soils	Moderate to rapid	30-90 (100-300)
Muck		15-60 (50-200)

5.1.6 Utilities. Minimal crossings of the utility right-of-way are preferable to multiple crossings.

5.1.7 History of cropping patterns. The ability of crops to tolerate water in the root zone shall be considered.

5.1.8 Trees or other permanent vegetation may interfere with operation and maintenance of the system.

5.1.9 Economics. If the client chooses not to install a comprehensive subsurface drain system at the time of initial planning, consideration should be given to installing pipe drain system mains and laterals in a manner that allows later expansion efficiently and economically.

5.2 Adequacy of drainage system outlet

5.2.1 Open channel. An open channel, such as a ditch, stream, or creek, may be used as a drainage system gravity flow outlet if the channel has adequate depth and flow capacity so that functioning of the drainage system is not impaired. The outlet ditch shall have adequate depth to ensure that the flow line (invert) of the drainage system outlet pipe is at least 0.3 m (1 ft) above normal low water flow in the ditch. An open channel that submerges the drainage system outlet for long periods of time following frequent rainfalls shall not be used as a gravity flow outlet. Procedures provided by ASAE EP407 shall be used to design drainage outlet channels or to determine the capacity of open channels to be used as outlets.

5.2.2 Existing pipe outlet. Where an existing outlet pipe is used as a part of a proposed system, it shall be in good operating condition, of adequate depth for good drainage, and have sufficient hydraulic capacity. If the existing outlet pipe does not have sufficient capacity to accommodate the additional flow, either an additional outlet pipe for the new system or a new outlet pipe, large enough to handle both systems, shall be designed.

5.2.3 Pump outlet. When a gravity outlet for the subsurface drain system is not available or suitable, the drain system outflow shall be pumped. The pump outlet shall be designed in accordance with ASAE EP369.

5.3 Spacing

5.3.1 When the pipe drain system consists of mains and laterals, the spacing between laterals shall be based on soil type and saturated hydraulic conductivity, pipe drain depth, crops to be grown, and degree of surface drainage provided. Local drainage guides may provide specific lateral spacing recommendations. Experience in draining similar soils and conditions should be considered.

5.3.2 When local drainage guides are not available, the general recommendations in table 2 may be used as a guide for pipe drain system laterals placed approximately 1.2 m (4 ft) deep.

5.3.3 An alternative method of determining pipe drain system lateral spacing for humid area drainage is by application of the Hooghoudt equation (equation 1). The Hooghoudt equation assumes steady state flow and may be used for multilayered soils. Equation parameters are shown in Fig. 2. The equation provides acceptable lateral spacing for typical agricultural drainage needs.

$$L^2 = \frac{4K_e(2\ d_e\ h + h^2)}{dc} \qquad (1)$$

where

L is spacing between laterals, m;

K_e is effective saturated lateral hydraulic conductivity for soil profile, m/d;

$$= \frac{K_1T_1 + K_2T_2\ \ldots\ K_nT_n}{T_1 + T_2 + \ldots\ T_n} \qquad (2)$$

K_n is coefficient of permeability for layers K_1 through K_n of a heterogeneous soil profile, m/d; and

T_n is thickness of layers T_1 through T_n, m;

h is water table height above the laterals midway between laterals, m;

dc is drainage rate, m/d; and

d_e is equivalent depth of impermeable layer below the pipe drain center, m (Skaggs and Tabrizi, 1986).

For $0 < d/L < 0.3$:

$$d_e = \frac{L}{1 + d/L[8/\pi * \ln(h/re) - 3.4]}. \qquad (3)$$

For $d/L \geqslant 0.3$:

$$d_e = \frac{L}{8[\ln(L/re) - 1.15]} \qquad (4)$$

where:

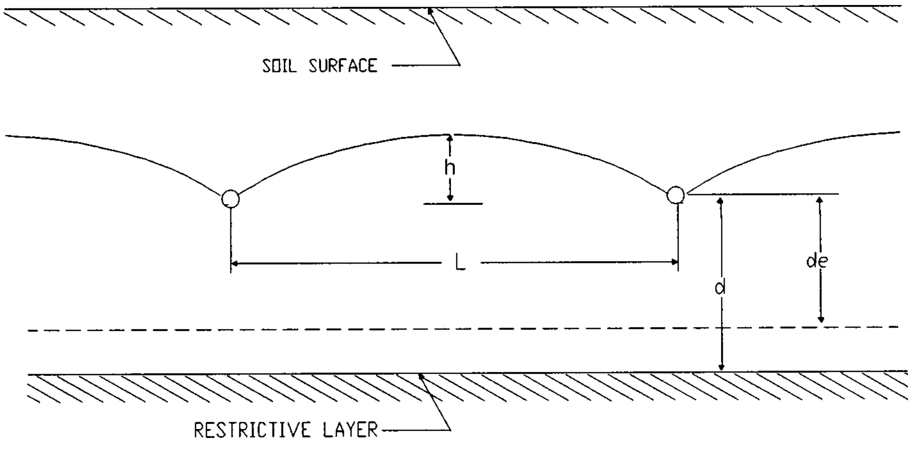


Figure 2 – Typical cross section of pipe drain system laterals defining Hooghoudt equation variables

Table 3 – Effective corrugated plastic tubing radius, r_e

Drain	Outside diameter, mm (in.)	r_e, mm (in.)
Corrugated1)	89 (3.5)	10.0 (0.39)
Corrugated1)	114 (4.5)	15.1 (0.59)
Corrugated with synthetic envelope/filter	114 (4.5)	40.0 (1.57)
Corrugated1)	140 (5.5)	10.3 (0.40)
Corrugated1)	165 (6.5)	14.7 (0.58)
Clay-1.59 mm (0.06 in.) between joints	127 (5.0)	3.0 (0.12)
Clay-3.18 mm (0.13 in.) between joints	127 (5.0)	4.8 (0.19)
Corrugated plastic surrounded by gravel envelope/filter with square cross section of length 2*a* on each side	2*a*	11.77*a* (0.463*a*)

1)Based on five rows of slots with total open area 1.5% to 2% of the wall area.

NOTE – Table 3 values are from the Drainmod Reference Report (Skaggs, 1980) as revised by Mohammad and Skaggs (1983).

r_e is effective corrugated plastic tubing radius to account for head loss through drain openings, m (table 3); and

d is actual depth of impermeable layer below the pipe drain center, m.

5.4 Minimum depth

5.4.1 Mineral soils

5.4.1.1 It is desirable, for drainage purposes, that pipe drain system lateral inverts be placed at a depth of 0.9 to 1.2 m (3 to 4 ft). This may be reduced, with appropriate lateral spacing reduction, under the following conditions:

- where extremely low hydraulic conductivity soil, unstable soil, or large stones exist at the desirable pipe drain depth;
- where a layer of extremely low hydraulic conductivity soil exists above the desired pipe drain depth;
- in depressed or impounded areas; and
- where the outlet depth is limited.

5.4.1.2 The minimum cover to protect a properly installed pipe drain from excessive deflection or damage by heavy machinery is 0.6 m (2 ft) for 75 to 150 mm (3 to 6 in.) diameter pipe drains and 0.8 m (2.5 ft) for 200 mm (8 in.) and larger diameter pipe drains. In non-agricultural areas not subject to vehicular traffic, minimum covers may be reduced to 0.3 m (1 ft) with class IA fill material placed in the trench and uniformly placed about the pipe; class IB and class II fill compacted to 85% standard proctor density; or class III fill compacted to 95% or greater standard proctor density. Fill class definitions are given by ASTM D2321. Standard proctor density is the maximum dry unit weight of soil compacted at optimum moisture content, as obtained by laboratory tests in accordance with ASTM D698. Minimum cover may need to be increased to accommodate the tillage practices expected.

Table 4 – Minimum grade, %

Inside diameter of pipe, mm (in.)	Pipes not subjected to fine sand or silt1)		Pipes subjected to fine sand or silt2)	
	Clay/conc.	Corr. plastic	Clay/conc.	Corr. plastic
75 (3)	0.08	0.10	0.60	0.81
100 (4)	0.05	0.07	0.41	0.55
125 (5)	0.04	0.05	0.30	0.41
150 (6)	0.03	0.04	0.24	0.32

1)Grades provide a minimum cleaning velocity of 0.15 m/s (0.5 ft/s)
2)Grades provide a minimum cleaning velocity of 0.42 m/s (1.4 ft/s)

Table 5 – Maximum velocity without protective measures

Soil texture	m/s (ft/s)
Sand and sandy loam	1.1 (3.5)
Silt and silt loam	1.5 (5.0)
Silty clay loam	1.8 (6.0)
Clay and clay loam	2.1 (7.0)
Coarse sand or gravel	2.7 (9.0)

5.4.2 Organic soils

5.4.2.1 Organic soils should not be subsurface drained before initial subsidence has occurred. To hasten initial subsidence and stabilize the soil strata at design pipe drain depth and permit installation at design grades, temporary pipe or open drains can be installed to remove free water and the area allowed to stand or be partially cultivated for a period of 3 to 5 years. Subsidence due to oxidation, compaction, shrinkage, and wind erosion will likely continue after the initial stage and decrease with time to approximately 25 mm (1 in.) per year.

5.4.2.2 For organic soil, controlled drainage should be considered. Controlled drainage is achieved by installing water table level control structures at the outlet and within the pipe drain system mains as dictated by main length and gradient. Experimental data show that the subsidence rate increases proportionally to the average depth to the water table during the growing season. If controlled drainage is not provided to minimize subsidence, the recommended minimum depth of cover is 0.9 m (3 ft).

5.4.3 Pipe drains that cross grassed waterways, cross lined or unlined channels, or are otherwise located such that minimum cover cannot be obtained, shall consist of heavy-duty pipe installed in a gravel envelope/filter or high-strength non-perforated pipe such as Schedule 40 polyvinyl chloride (PVC) or equivalent-strength steel.

5.5 Grade

5.5.1 Minimum grade

5.5.1.1 For nearly level areas, the pipe drain grade shall be as steep as practical without sacrificing adequate depth. Recommended minimum pipe drain grades are shown in table 4.

5.5.1.2 For grades less than recommended, the designer shall consider the following.

5.5.1.2.1 The system has a free outlet so back-water conditions will not further reduce velocities.

5.5.1.2.2 Sediment traps and cleanout systems are provided on lines of pipe drains at or near the minimum slopes.

5.5.1.2.3 The entire system is protected from sedimentation by the use of envelope/filters suitable to prevent entry of base soil material into the subsurface drain system.

Table 6 – Drainage coefficient (no surface water admitted directly into the pipe drain)

Soil	Field crops mm/d (in./d)	Truck crops mm/d (in./d)
Mineral	10–13 $(\frac{3}{8}–\frac{1}{2})$	13–19 $(\frac{1}{2}–\frac{3}{4})$
Organic	13–19 $(\frac{1}{2}–\frac{3}{4})$	19–38 $(\frac{3}{4}–1\frac{1}{2})$

Table 7 – Drainage coefficient (surface water admitted directly into the pipe drain)

Soil	Blind inlets mm/d (in./d)	Open inlets mm/d (in./d)
Mineral		
Field crops	13–19 ($\frac{1}{2}$–$\frac{3}{4}$)	13–25 ($\frac{1}{2}$–1)
Truck crops	19–25 ($\frac{3}{4}$–1)	25–38 (1–1$\frac{1}{2}$)
Organic		
Field crops	19–25 ($\frac{3}{4}$–1)	25–38 (1–1$\frac{1}{2}$)
Truck crops	38–51 (1$\frac{1}{2}$–2)	51–102 (2–4)

Table 9 – Design Manning roughness coefficients

Type of conduit	Nominal pipe diameter, mm (in.)	Manning value, *n*
Corrugated plastic tubing	75–150 (3–6)	0.015
	200 (8)	0.016
	250 (10)	0.017
	250–300 (12–15)	0.018
	>300 (>15)	0.020
Clay or concrete tile	to 1200 (to 48)	0.013
Corrugated metal pipe	75–750 (3–30)	0.025
Smooth wall pipe (tongue and groove or bell/spigot joints)	75–750 (3–30)	0.012

5.5.1.2.4 Breathers and relief wells are provided for venting and assuring full hydraulic operation.

5.5.2 Maximum grade

5.5.2.1 Short pipe drain system laterals not subject to pressure flow may be installed on grades up to 5%. On long pipe drain system mains and laterals, the maximum permissible velocity, without providing protective measures, shall not exceed table 5 values.

5.5.2.2 Pipe drain system mains that collect flow from laterals and/or other drainage systems with combined peak flows in excess of the capacity of the main may be subject to pressure flow. To avoid pressure flow, either increase the diameter of the main to reduce velocities to the limits shown in table 5 or provide relief wells.

5.5.2.3 Relief wells relieve water pressure that might otherwise cause the pipe drain to blow out or rupture. Relief wells are located at points in the pipe drain where pressure flow may occur for short periods of time, such as at the bottom of a steep grade or downstream of surface inlets. If the capacity of the pipe drain on a flat grade following a steeper grade is such that the hydraulic grade line will be near or above the soil surface under full flow, a relief well should be installed to prevent a blowout. A relief well is constructed by placing a tee connection in the line and fitting a pipe vertically into the tee. The vertical pipe shall extend 0.3 m (1 ft) above the soil surface unless provisions have been made in the design for it to also serve as a surface inlet. The exposed end of the vertical pipe shall be covered with heavy wire mesh or grating to exclude trash and animals. The vertical pipe diameter shall be equal to or greater than the diameter of the pipe drain where installed.

5.5.2.4 A breather at the top of a steep grade may be needed along with a relief well at the bottom. The need for a breather is determined by the velocities in the pipe drain, the soil in which the pipe drain is laid, and the capacity of the pipe drain below the steep grade with respect to the velocity in the steep grade.

5.6 Rate of water removal (drainage coefficient)

5.6.1 The drainage coefficient is the rate of water removal (volume per unit area) expressed as a vertical depth of water to be removed in 24 h. The frequency, intensity, and duration of rainfall, the degree of surface drainage, and the porosity and hydraulic conductivity of the soil shall be considered. The requirement for rapid removal of excess water due to sensitivity of the crop to water-logging shall also be considered in selecting the design drainage coefficient. A minimum value of 10 mm/d (3/8 in./d) 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.

Table 8 – Interceptor pipe drain inflow rates

Soil	Inflow rate	
	300 m of pipe, m^3/s	1000 ft of pipe, ft^3/s
Coarse sand-gravel	0.004–0.028	0.15–1.00
Sandy loam	0.002–0.007	0.07–0.25
Silt loam	0.001–0.003	0.04–0.10
Clay and clay loam	0.0006–0.006	0.02–0.20

5.6.2 For functioning drainage systems, the actual drainage coefficient can be calculated from measured values of midpoint water table depth, pipe drain system lateral spacing and length, and measured discharge using equation 1. The drainage coefficient can also be estimated by comparing the rate of water table drop at the midpoint between laterals to the drainable porosity of the soil.

5.6.3 In lieu of field measured drainage coefficients or local experience, the drainage coefficients provided by tables 6 and 7 should be used.

5.6.3.1 Table 6 applies to agricultural land in which the surface water drainage is provided by the topography and/or surface drainage practices such as field ditches, land smoothing, bedding, and diversions.

5.6.3.2 Table 7 applies to subsurface drain systems that include surface water inlets to admit surface water.

5.6.3.3 Figure 3 relates drainage coefficient to area drained and full-flow pipe drain discharge capacity.

5.6.4 Interception of seepage

5.6.4.1 Hillside seepage is intercepted and removed by placing the pipe drain partly within the impervious or slowly permeable layer and across the path of flow. Borings are made to locate restricting layers. The design flow shall be based on an estimate of the actual seepage flow as determined by field investigations. Flow capacities from table 8 may be used if actual field data are unavailable.

5.6.4.2 Measured or estimated inflow rates for interceptor pipe drains on sloping land should be increased by 10% for slopes between 2% and 5%, by 20% for slopes between 5% and 12%, and 30% for slopes greater than 12%.

5.6.4.3 Discharge from flowing springs or surface flow entering through a surface inlet shall be added to the hillside seepage discharge. Such flow may be measured or estimated.

5.7 Drainage area. The selected drainage coefficient shall be applied to the actual drainage area according to the following.

5.7.1 Where surface water is not admitted directly to the subsurface drain system through inlets, the design drainage coefficient applies only to the area to be drained. An exception is if the runoff from an upland watershed spreads over the area to be drained, adding an additional amount of infiltration. If the runoff from this upland watershed cannot be diverted from or channeled through the area to be drained, the drainage coefficient shall be applied to the entire contributing watershed area.

5.7.2 If surface water is admitted directly to the subsurface drain system through surface inlets, the entire watershed draining to the surface inlet

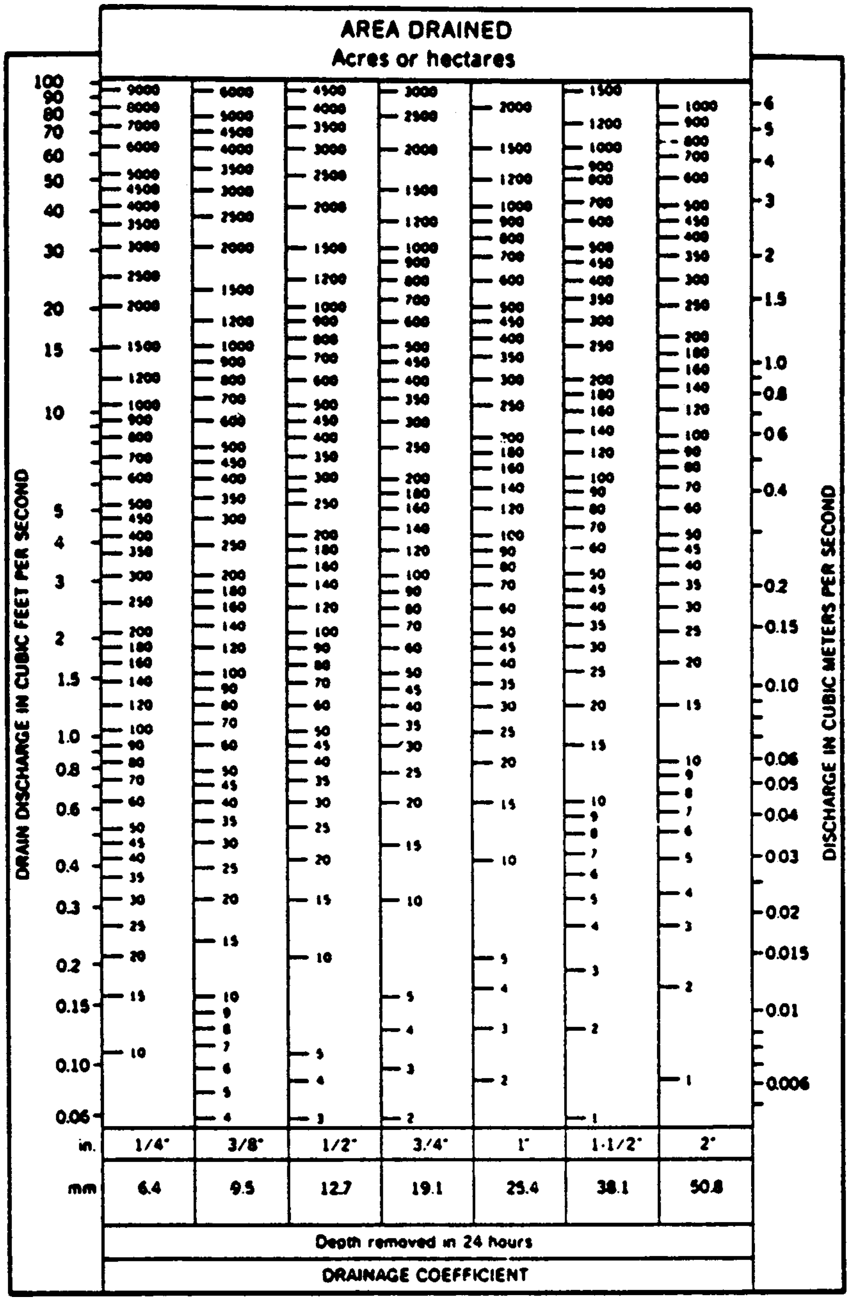


Figure 3 – Chart that relates drainage coefficient to required drainage rates; use hectares for cubic meters per second and acres for cubic feet per second

shall be used as the contributing area. The area may be reduced if a portion of the runoff impounded at the surface water inlet does not contribute to the subsurface drainage system flow.

5.8 Capacity of pipe drain system mains and laterals

5.8.1 Pipe drain capacity is the product of the nominal cross-sectional area of the pipe drain and the velocity of flow. The continuity and Manning equations are used to calculate pipe drain discharge:

$$Q = AV \tag{5}$$

$$V = \frac{C_v R^{2/3} \cdot s^{1/2}}{n} \tag{6}$$

where:

Q is discharge, m^3/s (ft^3/s);

C_v = 1.00 for Q in m^3/s and 1.49 for Q in ft^3/s;

V is velocity, m/s (1/1.49 · ft/s);

A is cross-section of pipe flow, m^2 (ft^2);

R is hydraulic radius of the pipe, m (ft);

s is slope of the pipe, m/m (ft/ft); and

n is Manning′s roughness coefficient, unitless (table 9).

5.8.2 Figure 3 provides the discharge required for a given drainage area at the selected drainage coefficient. With this discharge and the grade of the pipe drain, the required diameter of clay or concrete tile can be determined from figure 4. Figure 5 provides the required diameter for

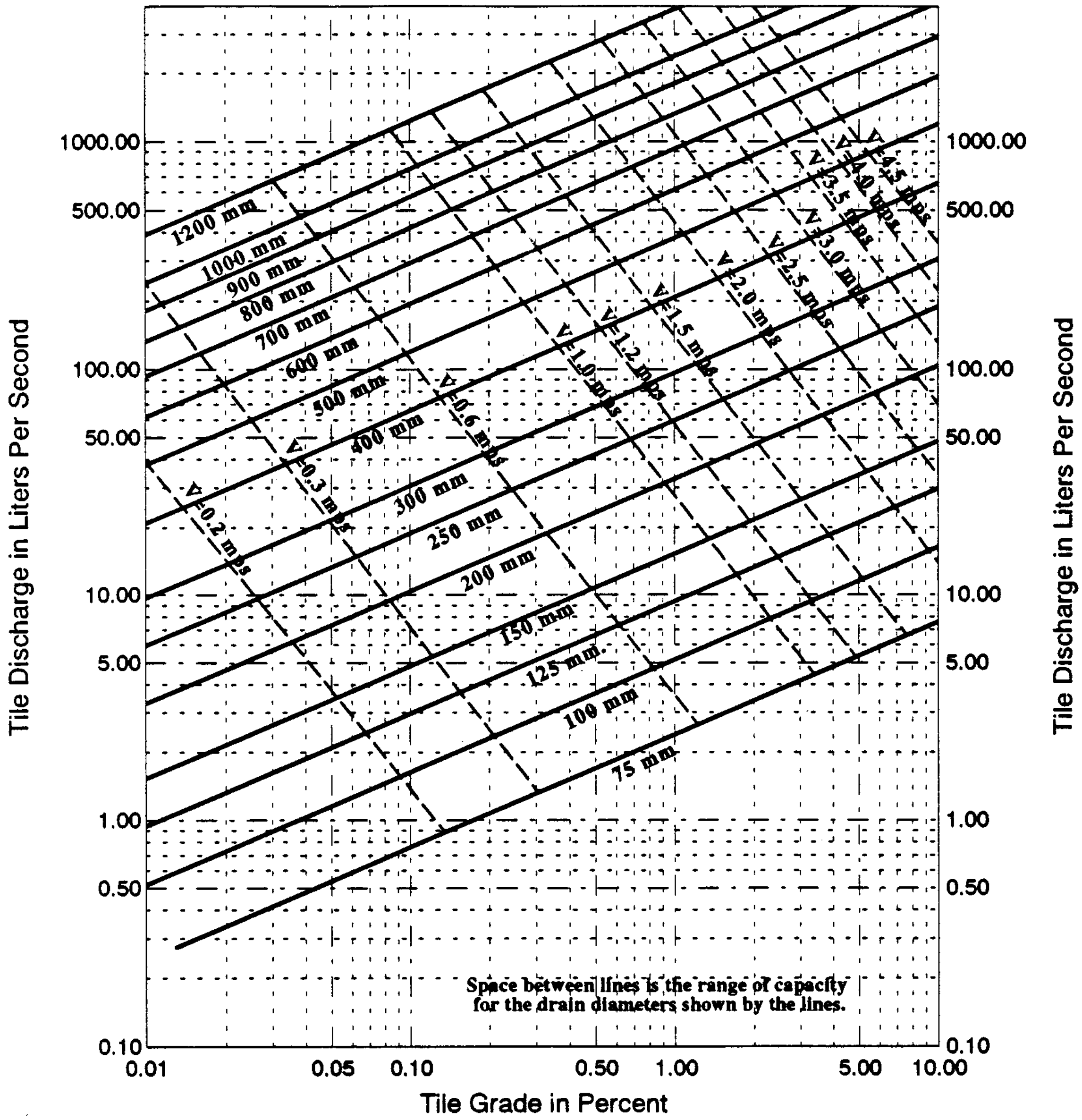


Figure 4(a) – Chart (metric) for determining the required size of clay and concrete tile (Manning's $n = 0.013$); pipe drain grade is unit vertical rise divided by unit horizontal length of pipe drain multiplied by 100

corrugated plastic drain tubing. Figures 4 and 5 assume full pipe flow with the hydraulic grade line parallel to the invert of the pipe drain.

5.8.3 Figures 3 to 5 are used as follows:

- Select the appropriate drainage coefficient column in figure 3;
- Find the number of hectares or acres to be drained;
- Project a horizontal line to determine the discharge (note: multiply cubic meters per second by 1000 to convert to liters per second);
- Select figure 4a, 4b, 5a, or 5b and project a horizontal line through discharge until it intersects the vertical line representing the pipe drain grade shown at the bottom of the figure;
- Record the diameter shown in the space between diagonal solid lines where the point of intersection occurs as at the pipe drain diameter needed.

Figures 4a, 4b, 5a, and 5b also provide the velocity of flow in the pipe drain at the design flow.

5.9 Minimum pipe drain diameter. The minimum pipe drain diameter is determined as follows.

5.9.1 The hydraulic capacity of the pipe drain at the design grade shall be equal to or greater than the rate required by application of the appropriate drainage coefficient.

5.9.2 For pipe drains to be installed at the minimum grade provided by clause 5.5.1, the pipe drain diameter shall be 75 mm (3 in.) or greater. For flatter grades and/or less stable mineral soils, the pipe drain diameter shall be 100 mm (4 in.) diameter pipe drain or greater.

5.9.3 In organic soils, the pipe drain diameter shall be 125 mm (5 in.) or greater.

5.10 Loading

5.10.1 Concrete and clay tile shall be specified so that loadings do not exceed the average minimum crushing strength of the pipe.

5.10.2 Concrete and clay tile loads may be determined from equations provided by Marston (1930). See table 10 for the application of those equations.

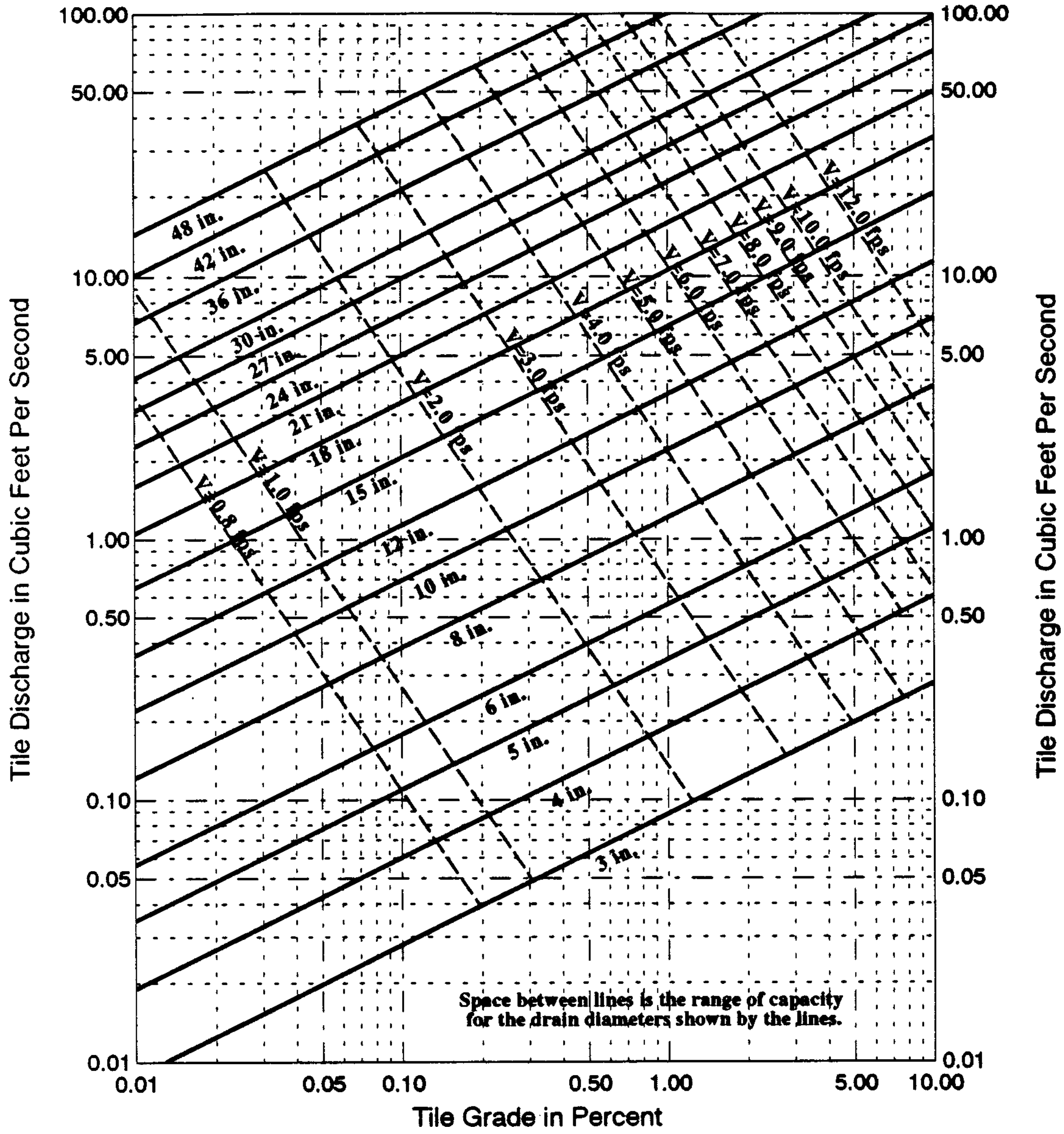


Figure 4(b) – Chart (inch-pound) for determining the required size of clay and concrete tile (Manning's $n = 0.013$); pipe drain grade is unit vertical rise divided by unit horizontal length of pipe drain multiplied by 100

5.10.3 Corrugated plastic tubing

5.10.3.1 Corrugated plastic tubing shall be specified to withstand loadings such that excessive deflection of the pipe drain wall does not occur.

5.10.3.2 Corrugated plastic tubing designs should limit deflection to not more than 20% of the pipe drain nominal diameter.

5.10.3.3 Soil loads and live loads on corrugated plastic tubing to be installed under projecting conditions (defined as tubing installed at a depth in natural ground less than the outside diameter of the tubing) or in wide trenches (defined in clause 4.1.1) shall be equal to or greater than the values given by table 10.

5.10.3.4 For corrugated plastic tubing to be installed in a trench not wider than two times its outside diameter and backfilled with earth, the design load shall be calculated as follows (Spangler and Handy, 1973):

$$W_c = C_d w B_c B_d \tag{7}$$

where:

W_c is drain load, kg/m;
C_d is load coefficient;
w is soil density, kg/m^3;
B_c is tubing outside diameter, m; and
B_d is trench width, m.

The load carrying capacity of corrugated plastic tubing may be calculated by the modified Iowa formula (Spangler and Handy, 1973) as follows:

$$W_c = \frac{93.16y(EI/r^3 + 0.061E')}{D_1 K} \tag{8}$$

where:

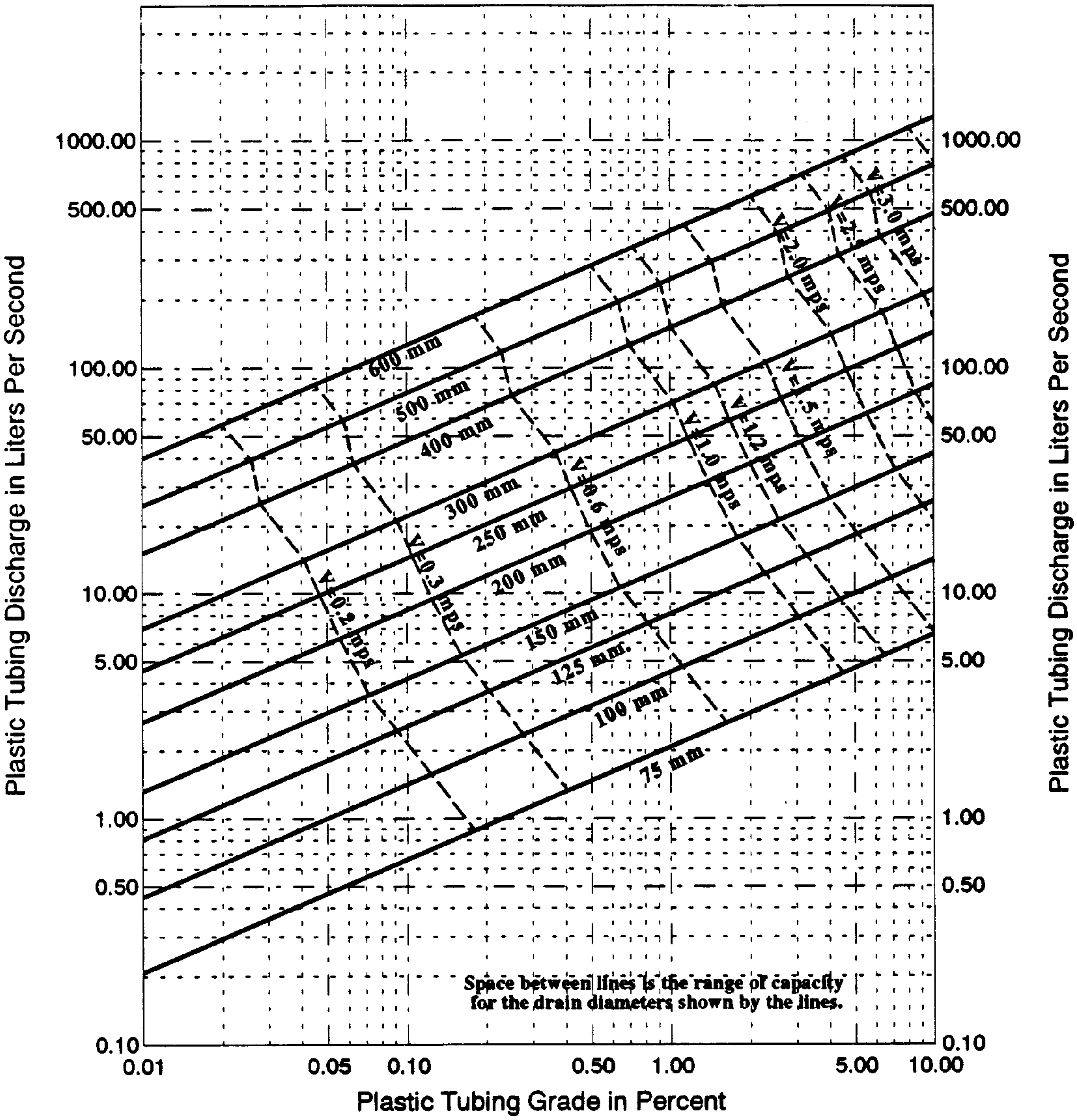


Figure 5(a) – Chart (metric) for determining the required size of corrugated plastic tubing using Manning's *n* values provided by table 9; pipe drain grade is unit vertical rise divided by unit horizontal length of pipe drain multiplied by 100

W_c is supporting strength, kg/m length;

y is allowable vertical deflection, m;

D_1 is deflection lag factor (usually 3.4);

K is bedding factor (use 0.096 for 90° groove angle or fitted circular groove);

EI/r^3 is pipe stiffness in kN/m^2 from parallel plate test at 20% deflection; and

E' is modulus of soil reaction, kN/m^2.

NOTE: 1 kg/m^2 = 0.0098 kN/m^2
= 0.0098 kPa
= 0.001422 lbf/in.^{2}

Fenemor et al. (1979) found equation 8 using $D_1 = 3.4$ and E'=345 kN/m^2, and tubing stiffness at 20% deflection gave reasonable results that agreed with field measured deflections. Recommended maximum depths for corrugated plastic tubing buried in fine-grained soils with 20% deflection, using equation 8, are provided by table 11.

5.10.4 Other loading requirements

5.10.4.1 Trench width. The width of the trench at the top of the pipe drain greatly affects the ability of the pipe to resist soil and traffic loading. A typical cross section showing the design trench requirements should be included in the construction plans. The design trench width should be adequate to provide clearance for joining the pipe drain in the trench with standard fittings and provide bedding conditions suitable to support the load on the pipe drain. As a minimum, the trench width should equal the pipe drain outside diameter plus 150 mm (6 in.) for open trenches and 100 mm (4 in.) for plowed installation. Maximum trench widths at the top of the pipe drain should not exceed trench width values provided by table 11. Compacted blinding or granular envelope/filter should be used to attain adequate pipe drain support when the trench width is 300 mm (12 in.) greater than the pipe drain diameter.

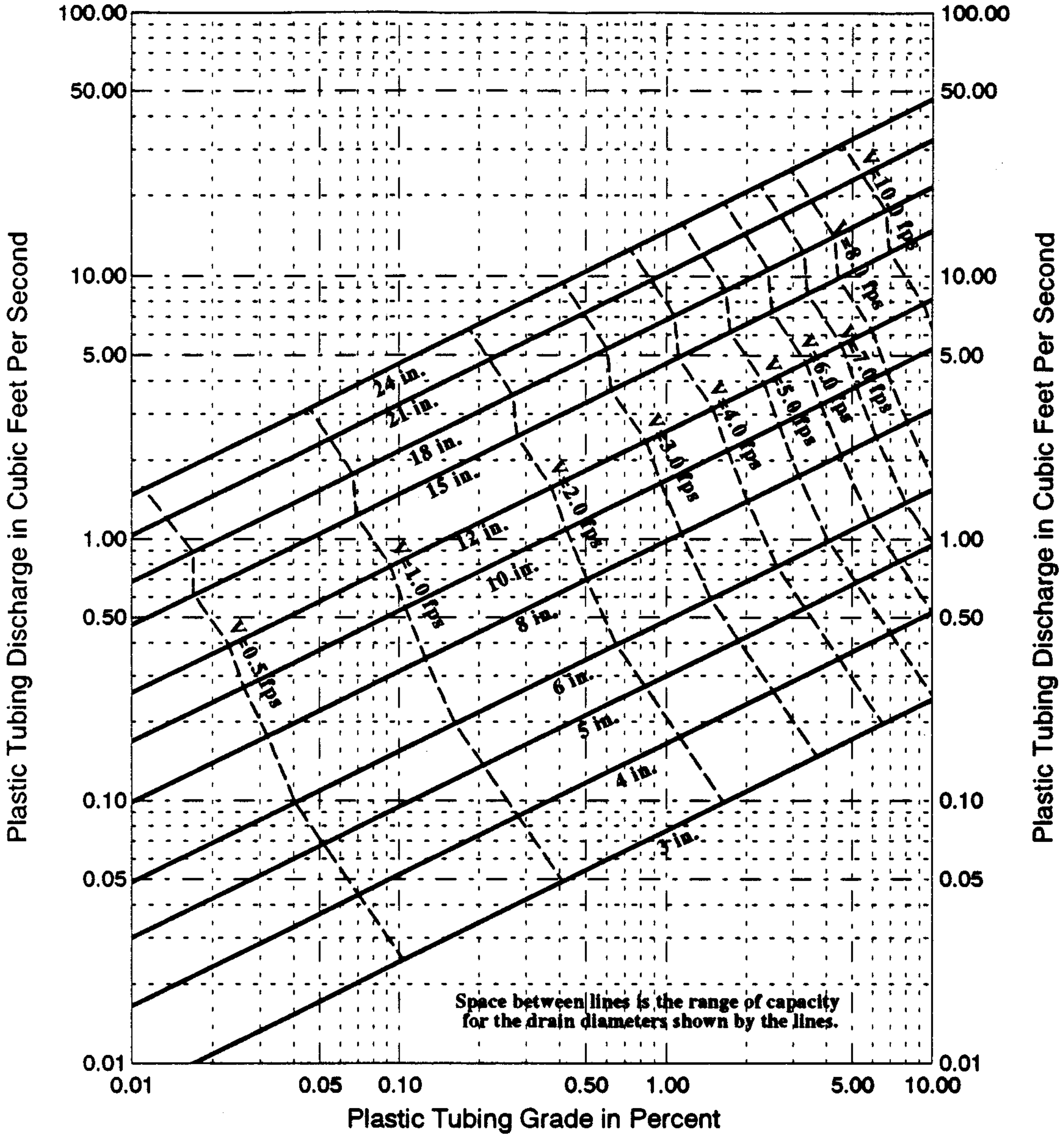


Figure 5(b) – Chart (inch-pound) for determining the required size of corrugated plastic tubing using Manning's *n* values provided by table 9; pipe drain grade is vertical rise divided by horizontal length of pipe drain multiplied by 100

5.10.4.2 Bedding

5.10.4.2.1 Corrugated plastic tubing. The load-bearing capability of corrugated plastic tubing is highly dependent upon its bedding. The required bedding section shall be specified and shown by the construction plans. Bedding by forming the trench bottom shall conform to figure 6a, 6b, or 6c. Bedding to be provided by a granular envelope/filter support shall be in accordance with figure 7a or 7b. A V-groove bottom (figure 6a) is appropriate for 75 to 150 mm (3 to 6 in.) tubing. The groove provides side and bottom support to the pipe and a means of controlling alignment during installation. Void space under the tubing assists with load bearing but may cause undermining by erosion on some grades and in some soils. If undermining is a possibility and for 200 mm (8 in.) or larger diameter tubing, the bottom of the trench may be shaped to closely fit the tubing cross section with a trapezoidal or circular shape as shown by figures 6b and 6c.

5.10.4.2.2 Clay and concrete tile. Bedding for clay and concrete tile shall be specified to fit the lower part of the drain tile as shown by figure

Table 10 – Percent of wheel loads transmitted to pipe drains

Depth of backfill over top of pipe m (ft)	Trench width at top of pipe drain, m (ft)						
	0.3 (1)	0.9 (3)	0.6 (2)	1.2 (4)	1.5 (5)	1.8 (6)	2.1 (7)
0.3 (1)	17.0[2]	26.0[2]	28.6[2]	29.7[2]	29.9[2]	30.2[2]	30.3
0.6 (2)	8.3	14.2	18.3	20.7	21.8	22.7	23.0
0.9 (3)	4.3	8.3	11.3	13.5	14.8	15.8	16.7
1.2 (4)	2.5	5.2	7.2	9.0	10.3	11.5	12.3
1.5 (5)	1.7	3.3	5.0	6.3	7.3	8.3	9.0
1.8 (6)[1]	1.0	2.3	3.7	4.7	5.5	6.2	7.0

[1] Live loads transmitted are essentially negligible below 1.8 m (6 ft).

[2] The data include the percent of both live and impact load that is transmitted to 0.3 m (1 ft) of pipe drain.

Table 11 – Maximum trench depths for corrugated plastic tubing buried in loose, fine-textured soils[1]; m (ft)

Normal pipe diameter, mm (in.)	ASTM Quality	Trench width at top of tubing, m (in.)			
		0.3 (12)	0.4 (16)	0.6 (24)	0.8 (32) or more
		m (ft)	m (ft)	m (ft)	m (ft)
100 (4)	Heavy Duty	a (a)[2]	3.0 (9.8)	2.1 (6.9)	1.9 (6.2)
	Standard	3.9 (12.8)	2.1 (6.9)	1.7 (5.6)	1.6 (5.2)
150 (6)	Heavy Duty	a (a)[2]	2.9 (9.5)	2.0 (6.6)	1.9 (6.2)
	Standard	3.1 (10.2)	2.1 (6.9)	1.7 (5.6)	1.6 (5.2)
200 (8)	Heavy Duty	a (a)[2]	3.0 (9.8)	2.1 (6.9)	1.9 (6.2)
	Standard	–	2.2 (7.3)	1.7 (5.6)	1.6 (5.2)
250 (10)	Heavy Duty	–	2.8 (9.2)	2.0 (6.6)	1.9 (6.2)
300 (12)	Heavy Duty	–	–	2.0 (6.6)	1.9 (6.2)
380 (15)	Heavy Duty	–	–	2.1 (6.9)	1.9 (6.2)

[1] Assumptions: E'=345 kN/m^2 (50 psi); $D1$ = 3.4; K = 0.096 (90x@ bedding angle); w = 1750 kg/m^3 (109 lb/ft^3); y = 1.1 x minimum pipe stiffness 124 kN/m^2 (18 psi) at 20% deflection.

[2] Any depth is permissible for this or less width.

NOTE – Differences in commercial tubing among manufacturers, including corrugation design and pipe stiffness, may change the assumptions. Assumptions about soil conditions will also affect depth. Therefore, maximum depths may be more or less than stated above. The above depths are based on limited research and should be used *with caution*. Consultation with the manufacturer is recommended should consideration of greater fill heights be required or if unusual soil conditions are anticipated.

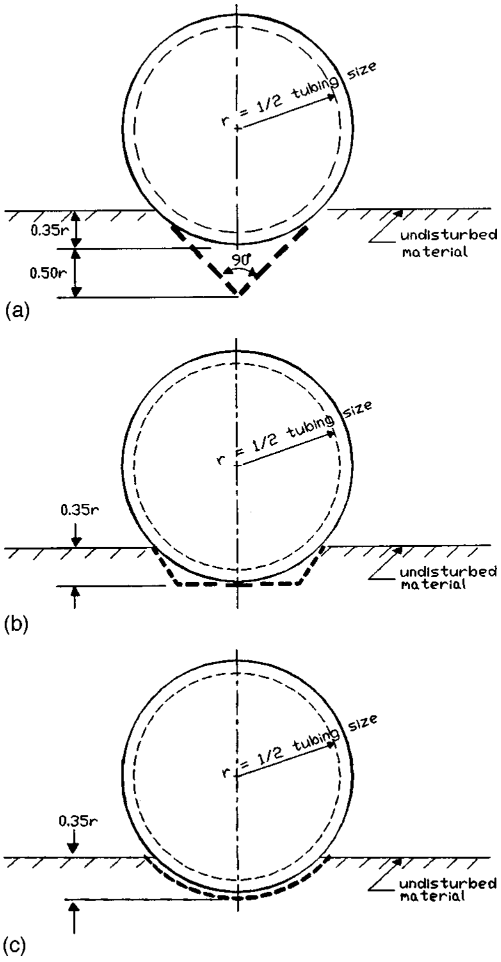


Figure 6 – (a) Formed trench bottom dimension for a 90° V groove. (b) Formed trench bottom dimension for a trapezoidal groove; note that trapezoid side slopes are tangent to the corrugated plastic tubing perimeter. (c) Formed trench bottom dimensions for circular shaped bedding cross section

8. Trenchers and plows with a finishing shoe provide an acceptable trench bottom. For flat trench bottoms without granular envelope/filters, such as from backhoe excavation, the final trench bottom will require forming with the use of hand tools.

5.10.4.3 To reduce soil load on pipe drains in deep or wide trenches, the trench may be excavated to the section shown by figure 9. The width of the trench measured at the top of the pipe drain (dimension *B* in figure 9) may be used to determine the soil load.

5.10.4.4 Live load calculations shall be added to the soil load when determining class of pipe drain and type of bedding. Table 10 provides the percent of wheel loads transmitted to the pipe.

5.11 Outlet protection

5.11.1 Pipe drains that discharge into an open channel shall have an outlet end that is rigid and non-perforated. The exposed portion of the drain outlet shall be protected against weather, animals, and anticipated traffic and shall be fitted with a rodent guard.

5.11.1.1 Outlet pipes shall be a minimum of 3.0 m (10 ft) of continuous rigid pipe. At least two-thirds of the outlet pipe length shall be embedded in the channel bank with the overhanging length discharging near the intersection of the sloping side of the channel with the channel bottom. When the placement of a pipe projecting into the channel may cause a serious ice jam or be damaged by floating ice or debris, the end of the pipe shall be flush with the channel bank with rock placed around the pipe outlet to prevent channel bank erosion. Corrugated plastic tubing shall not be used as an outlet pipe unless the tubing is nonperforated and is buried and protected by a head wall.

5.11.1.2 Surface runoff shall be diverted to enter the outlet channel through an erosion-preventive structure, such as rock chute or side inlet pipe, located away from the drain outlet at least 20 m (60 ft).

5.11.2 Swinging gates, rods, screens, or similar protection shall be used on all outlets to prevent small animals from entering the subsurface drain system. Special animal exclusion devices are required for pipe drains that have surface inlets since debris may enter through the inlets and collect on the gratings. Where new pipe drain lines are connected to existing pipe drains that may be subject to animal travel, an animal guard shall be installed to protect the new pipe drain.

5.11.3 Automatic tide gates, flood gates, or other back-water prevention devices shall be required on outlets for pipe drains through diked or levied areas to prevent water from entering through the drainage outlets.

5.12 Junction boxes are used to join three or more pipe drain lines or two lines at different elevations. Junction boxes are best located in permanent fence rows or other areas that are not farmed. The junction box cover shall be at or above ground level to provide easy access for inspection. When a junction box must be located in a farmed area, it shall be designed to have the top at least 0.5 m (1.5 ft) below the ground surface with the location permanently referenced.

5.13 Surface inlets to pipe drains protect grass waterways from damage by prolonged surface water base flow and as an outlet for terraces and sediment and water-control basins as described by ASAE S268. When site conditions prohibit installation of surface drains, surface inlets are used to remove surface runoff. When used, surface inlets shall be offset

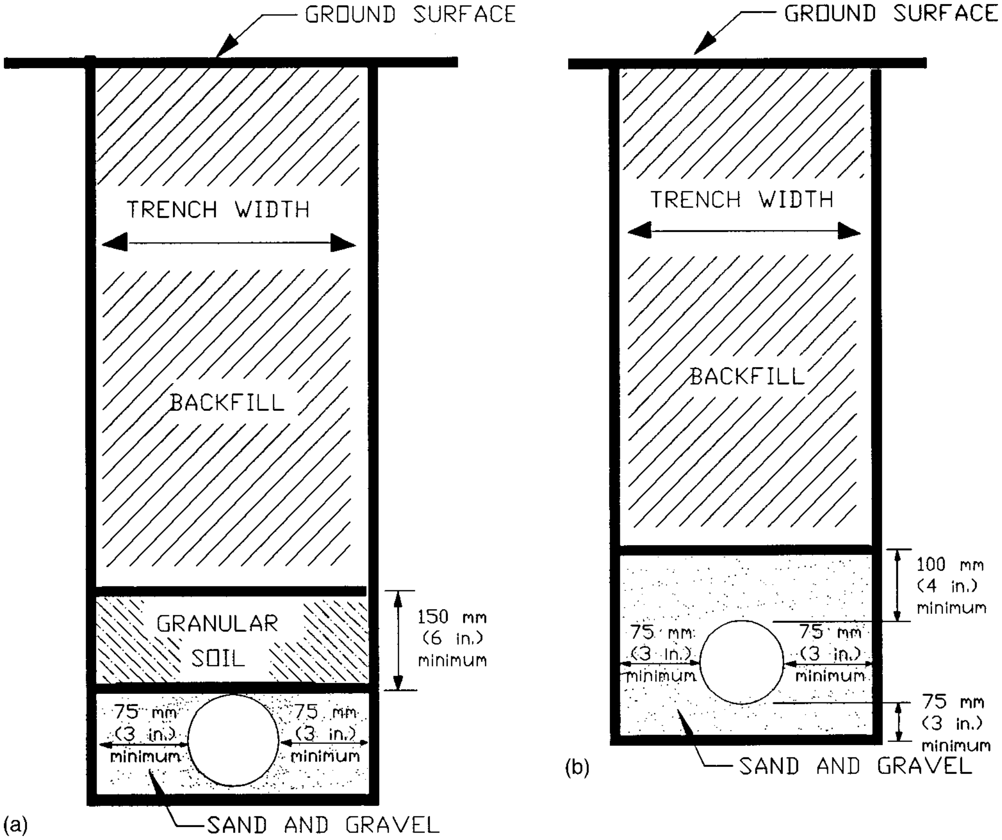


Figure 7 – (a) Corrugated plastic tubing encased in a sand and gravel envelope designed to reduce soil loading on the pipe. (b) Corrugated plastic tubing encased in a sand and gravel envelope designed as a filter to prevent soil particles from entering the pipe and/or as an envelope to increase water flow from the soil into the pipe

at least 2.5 m (8 ft) to one side of the pipe drain line and designed such that the pipe drain will not be damaged if the inlet is impacted by farm equipment. Surface inlets shall be provided with gratings or otherwise designed to prevent debris and animals from entering the subsurface drain system.

5.14 Clogging

5.14.1 Iron ochre. Subsurface drainage systems in soils containing available soluble iron (Fe+3) and organic matter may be adversely affected by bacteria forming iron ochre in the pipe drain openings and inside the pipe. Available soluble iron concentrations in excess of 3 ppm in soil water samples from the soil to be drained are considered severe, and iron ochre will likely be a problem. Iron ochre precipitates as a filamentous and gelatinous deposit that may clog pipe drain openings and the surrounding envelope/filter and sometimes completely fill the pipe drain line. For sandy soils it is important to specify blinding materials that will contain little or no organic matter. If iron ochre conditions are anticipated: (1) consideration shall be given to specifying that blinding materials, free of organic material, be imported, and that spodic (soil profile high in organic matter) materials and top soil be prevented from entering the drain trench near the pipe or blinding; and (2) access maintenance ports shall be specified for periodic cleaning by water jetting equipment. Access ports shall be brought to the surface as shown in figure 10 or be constructed in such a manner as to be easily identified and accessed when needed.

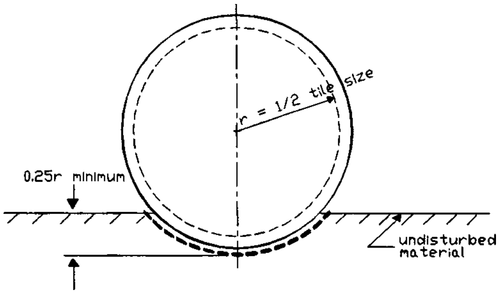


Figure 8 – Circular bedding dimensions for formed trench bottom for clay and concrete drain tile

5.14.2 Roots. Pipe drains may be rendered ineffective due to root penetration from trees and deep-rooting crops. Pipe drain system mains, and laterals when possible, shall be located 30 m (100 ft) from water-loving trees such as willow, elm, cottonwood, and maple and 15 m (50 ft) from other tree species. If trees near pipe drains cannot be eliminated, a non-perforated or closed pipe drain line shall be specified.

5.15 Safety. All potential construction hazards, such as roads, crossings, above- and below-ground utilities, and pipelines, shall be clearly located and identified on the construction drawings. In addition, the design shall consider the need to locate and identify potential hazards to the public during and after construction. These include, but are not limited to, open excavations during construction and surface inlets and drain outlets following construction. The design shall require these potential hazards to be clearly marked with appropriate warnings so as to prevent injury to the public and/or users of the drained area. The design shall avoid crossing utilities wherever possible and shall consider excavation and trench stability in setting design depths and grades.

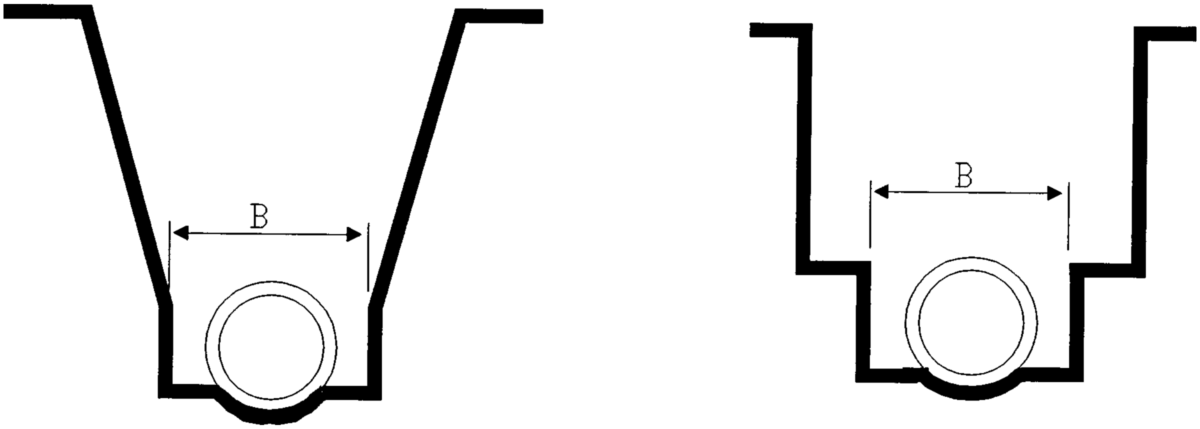
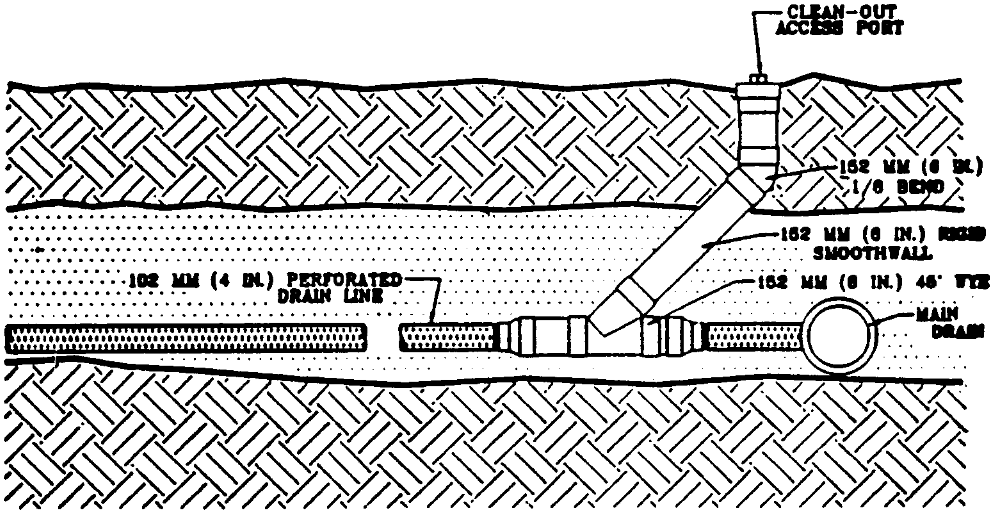


Figure 9 – Cross section alternatives to reduce soil loading on pipe drains for deep and wide trenches; dimension *B* is the trench width measured at the top of the pipe.



NOTE: CLEAN-OUT TRANSITION TO 152 MM (6 IN.) NON-PERFORATED PIPE

Figure 10 – Typical access maintenance port for cleaning iron ochre from 100 mm (4 in.) diameter pipe drains

6 Design documentation

Comprehensive construction drawings and construction specifications shall be prepared in sufficient detail that installation will function as designed. In addition, the construction drawings and specifications shall include the information needed to ensure that the work will be performed in a manner such that erosion and air and water pollution are minimized, that the work will be done in a safe manner, and that the completed job will present a high-quality finish.

Annex A
(informative)
Bibliography

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