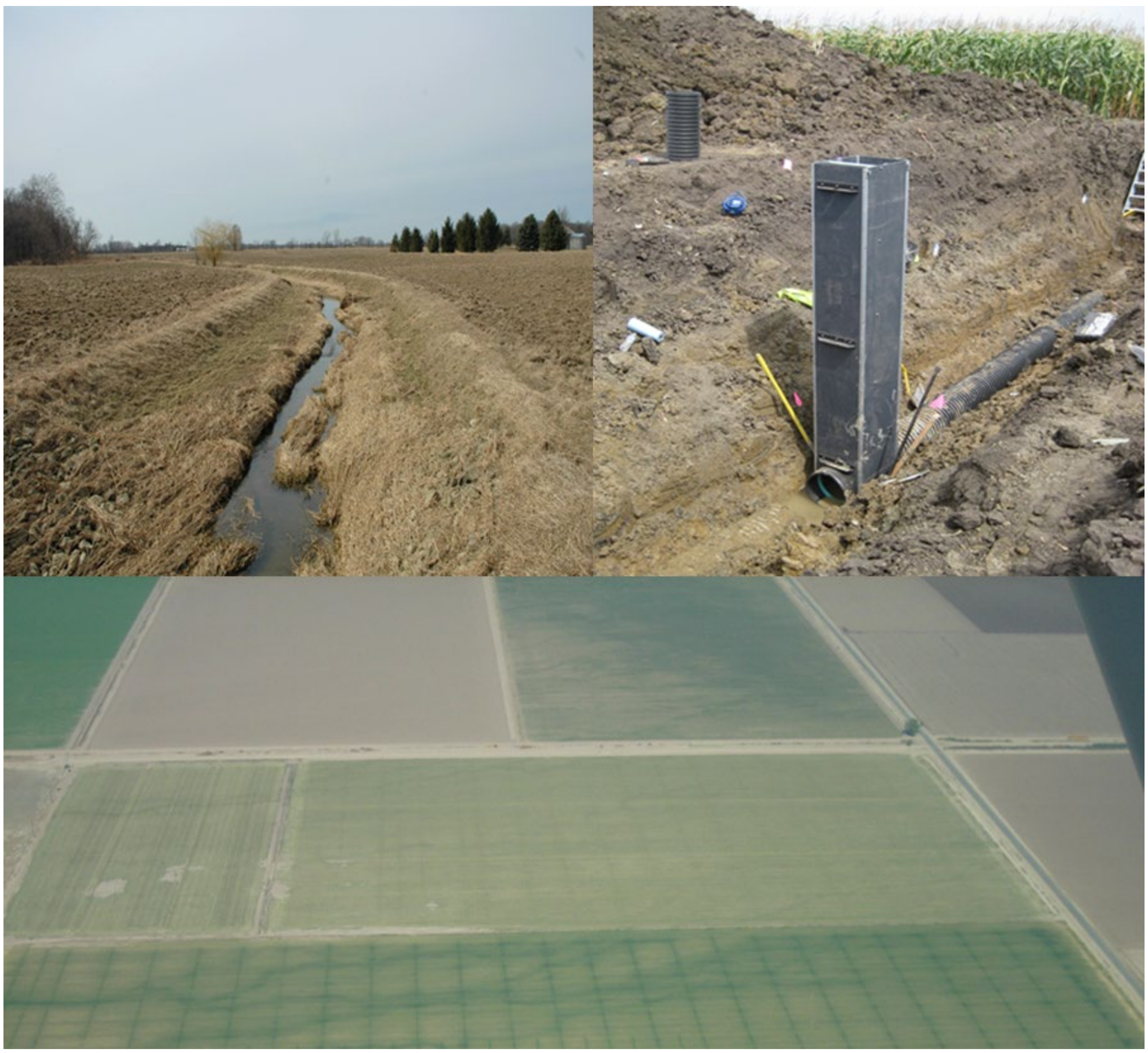
United States Department of Agriculture

Natural Resources Conservation Service

Part 650 Engineering Field Handbook
National Engineering Handbook

Part 2 of 2 Water Management (Drainage)



(210-650-H, 2nd Ed., Feb 2021)

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650.1412 Drain Envelopes

A. Drain envelope is used here as a generic term that includes any type of material placed on or around a subsurface drain for one or more of the following reasons:

(1) To stabilize the soil structure of the surrounding soil material, more specifically a filter envelope.
(2) To improve flow conditions in the immediate vicinity of the drain, more specifically a hydraulic envelope.
(3) To provide a structural bedding for the drain, also referred to as bedding.

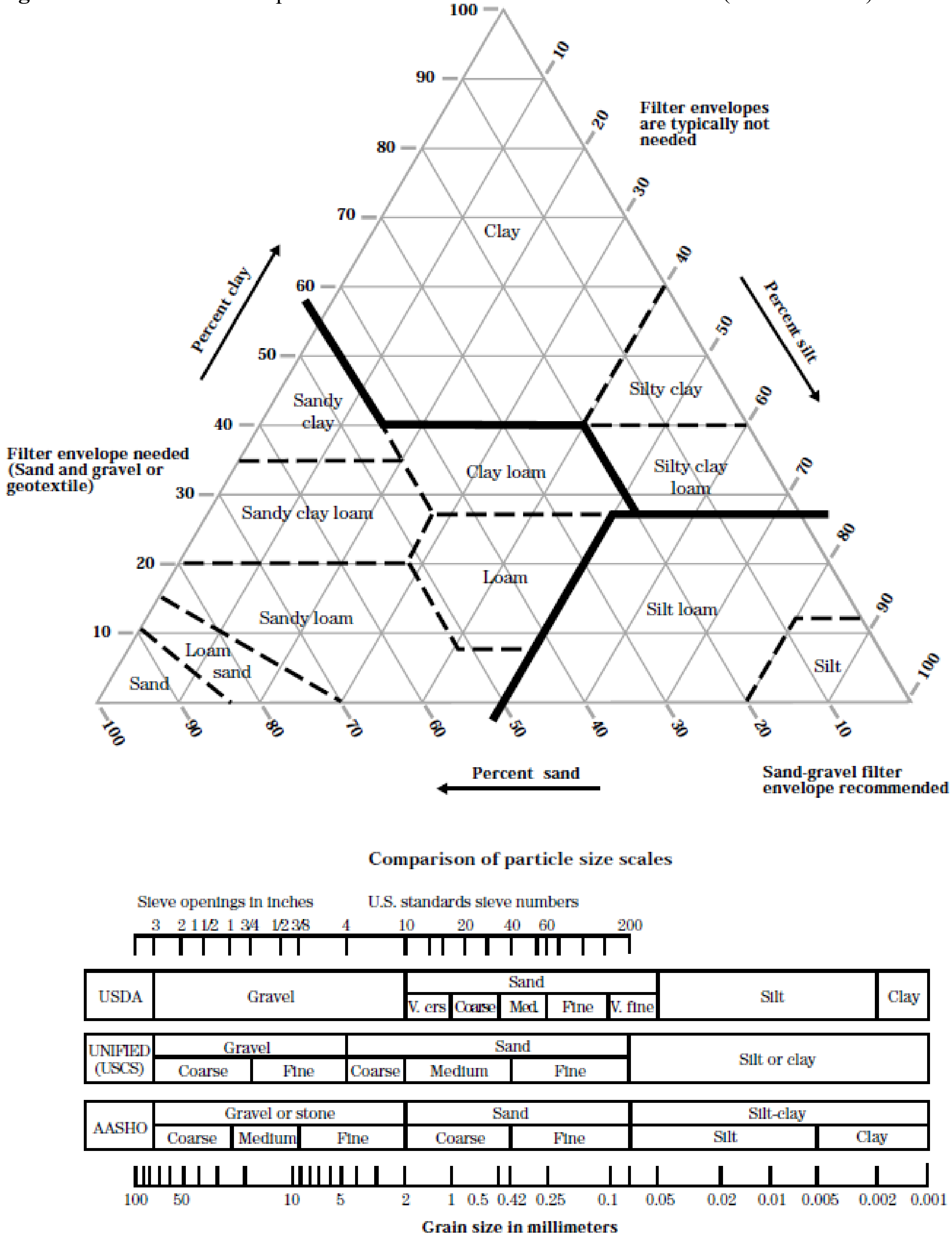
B. Refer to section 650.1422 Definitions of Terms for more complete definitions of envelopes (hydraulic envelope, filter envelope, and bedding).

C. Soils in which drains are prone to mineral clogging are commonly referred to as problem soils because the soil particles tend to migrate into the drain. In practice, all very fine sandy or silty soils with low clay content are probable problem soils. Finer textured soils, even with high clay content if the soil is considered dispersed, may present clogging problems in addition to being difficult to drain. Envelope materials placed around subsurface drains (drain envelopes) have both hydraulic and mechanical functions (Dierickx 1992). The protection and stabilizing of the surrounding soil material should be the planned objective as it is not the filter envelope that fails, but the structure of the surrounding soil (Stuyt 1992b). More complete information on drain envelopes is in the Urban Subsurface Drainage Manual (ASCE 1998).

D. Drain Envelope Materials

(1) Drain envelope materials used to protect subsurface drains include almost all permeable porous materials that are economically available in large quantities. Based on the composition of the substances used, they can be divided into three general categories: mineral, organic, and geotextile envelope materials. Mineral envelopes consist of coarse sand, fine gravel, and glass fiber membranes that are applied while installing the drainpipe. Organic envelopes include prewrapped loose plant materials, fibers, chips, or granules. Synthetic materials are geotextile fabrics specifically manufactured for use in drainage and soil stabilization. Drain envelope materials are most effective when placed completely around the pipe. General drain envelope recommendations are summarized in figure 14-48.
(2) The practice of blinding or covering subsurface drains with a layer of topsoil before backfilling the trench actually provides many humid area drains with permeable envelope material. Humid area surface soils tend to have a well-developed, stable, and permeable structure that functions well as a drain envelope. In stratified soils, drains are blinded by shaving the coarsest textured materials in the soil profile down over the pipe.

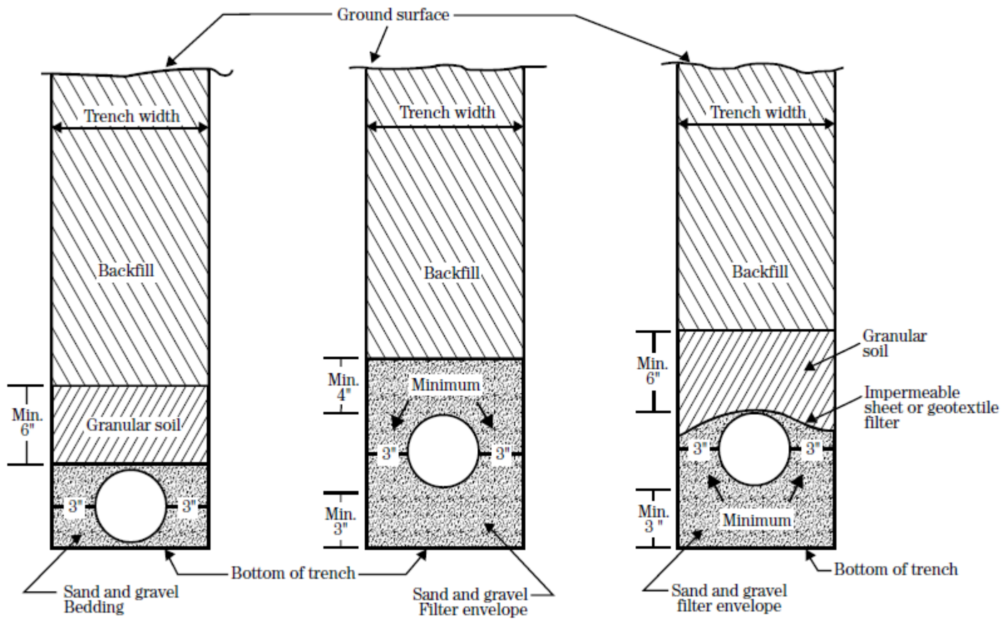
Figure 14-48: Filter Envelope Recommendation Relative to Soil Texture (source USDA)



(3) Sand-gravel

Traditionally, the most common and widely used drain envelope that also satisfies the definition of filter envelope material is graded coarse sand and fine gravel. The envelope material may be pit run coarse sand and fine gravel containing a minimum of fines. Properly designed or selected sand-gravel drain envelopes can fulfill all the mechanical, soil stabilizing, and hydraulic functions of a filter envelope. Figure 14-49 shows typical bedding or sand-gravel envelope installations. One example uses an impermeable sheet or geotextile filter. This is used to reduce costs where sand and gravel envelope materials are expensive.

Figure 14-49: Typical Bedding or Envelope Installations



(4) Organic Material

The service life and suitability of organic materials as drain envelopes for subsurface drains cannot be predicted with certainty. Organic matter placed as a drain envelope may also affect chemical reactions in the soil that result in biochemical clogging problems. Where ochre clogging of drains is expected, organic matter should be used with caution.

(5) Synthetic Fiber Materials

In the United States during the 1970's, several dozen installations of thin filter envelopes of fiberglass and spun bonded nylon were monitored with the assistance of the NRCS (SCS at that time). The drain systems typically used 4-inch (100 mm) corrugated polyethylene tubing (CPE). The fiberglass membrane used in these installations did not successfully span the corrugations of the tubing while the spun bonded nylon did. As a result, the fabricator of fiberglass adopted the use of spun bonded nylon. Figure 14-48 was issued to the field offices at that time to provide guidance on the application of the two major types of filter envelopes, which were sand and gravel or thin spun bonded nylon. The figure has been updated to reflect recommendations for geotextiles rather than just nylon.

(6) Prewrapped Loose Materials

Prewrapped loose materials (PLM) used for drain envelopes have a permeable structure consisting of loose, randomly oriented yarns, fibers, filaments, grains, granules, or beads surrounding a corrugated plastic drainpipe. These materials are assembled with the pipe at the time of manufacture as a permeable hydraulic envelope of uniform thickness held in place by twines or netting. The voluminous materials involved are either organic or geotextile.

(7) Prewrapped Geotextiles

(i) A geotextile is a permeable, polymeric material that may be woven, nonwoven, or knitted. Materials known as geotextiles are widely used as pre-wrapped synthetic drain envelopes. Geotextiles are made of polyester, polypropylene, polyamide, polystyrene, and nylon.

(ii) Geotextiles differ widely in fiber size or weight, smoothness, and weave density. No single geotextile is suitable as a drain envelope for all problem soils. The materials vary in weight, opening size, fiber diameter, thickness, and uniformity. The geotextiles are commonly wrapped on the corrugated plastic drainpipe in the production plant. The finished product must be sufficiently strong to withstand normal handling that is part of the construction and installation process.

E. Principles of drain envelope design.

(1) Exit gradients in soil near drains

As water approaches a subsurface drain, the flow velocity increases as a result of flow convergence. The increased velocity is related to an increase in hydraulic gradient. The hydraulic gradient close to the drain may exceed unity resulting in soil instability. Using a gravel drain envelope increases the apparent diameter of the drain and, therefore, substantially decreases the exit gradient at the soil and drain envelope interface. A major reason for using a filter envelope is to reduce the hydraulic gradient at the soil and envelope interface, which acts to stabilize the soil in the proximity of the drain system.

(2) Hydraulic Failure Gradient

(i) The hydraulic failure gradient is the change in hydraulic head per unit distance that results in soil instability, generally a gradient exceeding unity. As long as the flow rate (and the associated hydraulic gradient) in a soil is low, no soil particle movement occurs. If the velocity of waterflow through the soil toward drains is kept below the hydraulic failure gradient, no failure of the drain and drain envelope system should occur.

(ii) To reduce the hydraulic gradients in the soil near the drain:

- Increase the effective diameter of the drain by using a hydraulic envelope (i.e., gravel).
- Increase the perforation area of the drain.
- Reduce the drain depth and spacing to decrease the possible magnitude of the gradient.
- Use a geotextile having innerflow characteristics to make the full surface of the corrugated drainpipe permeable. If the geotextile does not have innerflow characteristics, perforations in every corrugation should be required (Willardson and Walker 1979, Salem and Willardson 1992).

(3) If a soil has a high hydraulic failure gradient, a drain envelope may not be necessary. Many humid area soils do not require use of a drain envelope. If the drain tubes have an opening or perforation area from 1 to 2.5 square inches per foot, the drain functions well without sedimentation problems in structurally stable soils. In some areas, criteria based on the soil clay content and type is used to determine whether a filter envelope is required. Such criteria are based on local experience and field observations.

F. Design of drain envelopes.

(1) Sand-gravel filter envelope design—

(ii) The general procedure for designing a sand-gravel filter envelope for a given soil is:

- Make a mechanical analyses of both the soil and the proposed filter envelope material.
- Compare the two particle size distribution curves.
- Use criteria to determine whether the filter envelope material is satisfactory.

(ii) The criteria include:

- The D_{15} (defined below) size of the filter material should be at least 4 times the diameter of the d_{15} of the base material. (This would make the filter material roughly more than 10 times more permeable as the base material.)
- The D15 of filter material should not be more than 4 times larger than the d_{85} of the base material. (This prevents the fine particles of the base material from washing through the filter material.)

(iii) The following gradation limits are recommended:

- Upper limit of D100 is 38 mm (1.5 inches).
- Upper limit of D15 is the larger of 7 times d85 or 0.6 mm.
- Lower limit of D15 is the larger of 4 times d15 or 0.2 mm.
- Lower limit of D_5 is 0.075 mm (number 200 sieve).

(iv) D_{100} represents the particle size in the filter material for which 100 percent, by weight, of the soil particles are finer (similarly for D_{15} and D_5). The d85 and d15 represent the particle size in the surrounding base material for which 85 percent and 15 percent, by weight, of the soil particles are finer. In the case of drainage, the base material is the soil.

(v) Procedures for determining filter gradation design limits are found in 210-NEH-633-26, "Gradation Design of Sand and Gravel Filters".

(vi) Research on filter envelopes show that:

- If a filter envelope does not fail with the initial flow of water, it is probably permanently safe.
- The size ratios are critical.
- Materials with a D15/d85 ratio greater than nine always fail.
- Well graded materials are more successful than uniform sized materials.
- A well-graded gravelly sand is an excellent filter or filter envelope for very uniform silt or fine uniform sand.
- It is not necessary for the grading curve of the filter envelope to be roughly the same shape as the grading curve of the soil.

(2) Sand-Gravel Hydraulic Envelope Design—
  (i) The criteria for a sand-gravel hydraulic envelope is less restrictive than for a sand-gravel filter envelope as follows:
    - Upper limit of D100 is 38 mm (1.5 inches).
    - Upper limit of D30 is 0.25 mm (number 60 sieve).
    - Lower limit of D_5 is 0.075 mm (number 200 sieve).
  (ii) Pit run coarse sand and fine gravel containing a minimum of fines often meet this criteria.
  (iii) Sand gradations used for concrete as specified by ASTM C-33 (fine aggregate) or AASHTO M 6-65 will satisfy these hydraulic envelope criteria and will meet the filter envelope requirements for most soils.

(3) Geotextile Filter Envelope Design
  (i) In filter envelope applications, the geotextile must physically survive installation, allow adequate flow of water, and basically retain the soil on its hydraulically upstream side. Both adequate flow capacity (requiring an open geotextile structure) and soil retention (requiring a tight geotextile structure) are required simultaneously. Therefore, critical geotextile parameters for filter envelope applications are permittivity, survivability, and soil retention.
  (ii) **Permittivity**—Unrestricted flow of water through the geotextile is essential. Therefore, the flow capacity (permittivity) of the geotextile should be much greater than the flow capacity of the soil, typically 10 times greater or more. Permittivity values in excess of 1 unit per second ($ft^3/ft \times ft^2 \times sec$) are typically required and are determined according to ASTM D 4491 (1992). Permittivity, not permeability, should be specified because permeability measures the rate at which water will pass through the geotextile under a given head without regard to geotextile thickness.
  (iii) **Survivability—**The geotextile must survive installation without being damaged. AASHTO Designation M288-90 (1990) includes recommendations on minimum physical strength properties for geotextile survivability.
  (iv) **Soil Retention**
    - The geotextile must prevent excessive loss of fines (soil piping) from the upstream side. This is accomplished by checking the coarser soil particles, which in turn retain the finer soil particles. Numerous approaches can accomplish soil retention, all of which use the soil particle grading characteristics and compare them to the apparent opening size (AOS) of the geotextile. AOS is the approximate largest particle that will effectively pass through a geotextile and is determined by glass ball dry sieving (ASTM D 4751). Both AOS and O_{95}, effective opening size of the envelope pore, represent the apparent opening size in millimeters (mm) or sieve size.
    - The simplest method uses the percentage of fines (soil passing the No. 200 sieve). AASHTO Designation M 288-90 recommends the following retention criteria:
    - (i) Soil ≤ 50% passing the No. 200 sieve AOS of the geotextile No. 30 sieve (O95 < 0.59 mm)
    - (ii) Soil > 50% passing the No. 200 sieve AOS of the geotextile No. 50 sieve (O_{95} < 0.297 mm)

  These criteria should meet most drainage requirements.

(v) For more critical applications, figure 14-50 recommends O_{95} values based on relative density (D^R), coefficient of uniformity (CU), and average particle size (d50). The terms are defined as:

- d_{50} = soil particle size corresponding to 50% finer
- CU = coefficient of uniformity = d60/d10
- d60 = soil particle size corresponding to 60% finer
- d10 = soil particle size corresponding to 10% finer
- AOS = O95 apparent opening size of geotextile expressed in millimeters or sieve size

Figure 14-50: Relationships Used to Obtain Fabric Opening Size to Protect Against Excessive Loss of Fines During Filtration (source: Giuard 1982)

Relative density of base material	1 < CU < 3	CU > 3
Loose (DR < 50%)	$O_{95} < (CU)(d_{50})$	$O_{95} < (9d_{50})/CU$
Intermediate (50% < DR > 80%)	$O_{95} < 1.5(CU)(d_{50})$	$O_{95} < (13.5d_{50})/CU$
Dense (DR > 80%)	$O_{95} < 2(CU)(d_{50})$	$O_{95} < (18d_{50})/CU$

(vi) Because the three approaches are restrictive in different degrees, choose one of the three approaches in figure 14-50 (Koener 1986) based on the critical nature of the application.

(vii) Clogging—Once the geotextile is designed, the next question is “Will it clog?” Obviously, some soil particles will embed themselves within the geotextile structure; therefore, the question really is if the geotextile will completely clog such that the liquid flow through it will be shut off before the soil matrix stabilizes. Laboratory tests, such as the Gradient Ratio Test given in ASTM D 5101, are available to answer this question.

(viii) Another approach is to simply avoid situations known to lead to severe clogging problems. Three conditions are necessary for a high likelihood of complete geotextile clogging (Koerner 1986):

- cohesionless sands and silts
- gap graded particle size distribution
- high hydraulic gradients

(ix) If these three conditions are present, use of geotextiles should be avoided. A gravel or sand gravel filter envelope can be used.

(4) Prewrapped Loose Material Filter Envelope Design

(i) Subsurface drain filter envelopes using prewrapped loose materials may be characterized by pore size distribution, filter thickness, and hydraulic conductivity. Filter thickness and pore size distribution are determined for a natural, compressed condition, but for prewrapped loose materials, the hydraulic conductivity is generally so high that it has no bearing on selection of a filter envelope.

(ii) Retention criterion defines the capability of a filter envelope to retain soil particles and is expressed as a ratio of a characteristic pore opening size of the filter envelope to a particle size of the soil granular material in contact with the envelope. The characteristic pore opening size of the envelope material is the O_{90} value.

(iii) Depending on the pore size index O90, prewrapped loose materials are classed into three groups, with recommendations as shown in figure 14-51:

Figure 14-51: Recommendation of Group Classes for Prewrapped Loose Materials

Label	Class	Pore size index range
PLM-XF: XF	extra fine	0.1 mm < O_{90}
PLM-F: F	fine	0.3 mm < O_{90} < 0.6 mm
PLM-S: S	standard	0.6 mm < O_{90} < 1.1 mm

(iv) Coil ends are labeled with tape imprinted with identification PLM-XF, PLM-F, or PLM-S.

(v) Minimum thickness is required to guarantee a homogeneous filter envelope. In addition to these O_{90} ranges, the following minimum filter envelope thicknesses are required regardless of the O_{90} range involved.

Figure 14-52: Minimum Filter Envelope Thicknesses

Material	Minimum filter envelope thickness
synthetic, fibrous	3 mm (e.g., poly-propylene fibers)
synthetic, granular	8 mm (e.g., polystyrene beads)
organic, fibrous	4 mm (e.g., coconut fibers)
organic granular	not yet fixed (e.g., wood chips, sawdust)

(5) Combination Gravel and Geotextile Filter Envelope Design

(i) Properly graded gravel or sand gravel material needed for a satisfactory filter envelope may not be readily available, or the cost of handling, including transportation, may be prohibitive. Also, the soil material in the proximity of the subsurface drain may be either difficult or impossible to stabilize with economically available geotextile materials alone. The opportunity to use gravel and geotextile material together for a practical and economic filter envelope should be considered. On many sites the most feasible filter envelope can be designed and constructed from a readily available pit run sand or gravel that would not be satisfactory alone but can be used along with an economical geotextile to satisfy the filter envelope design requirements.

(ii) A common application incorporates a thin geotextile material adjacent to the pipe with the pit run sand or gap graded gravel surrounding the geotextile. The combination system should be designed using the appropriate criteria given above for each of the filter envelope materials acting independently, resulting in two filter envelopes working in unison. The geotextile is designed to retain the sand or gravel envelope material. The thickness of the sand or gravel envelope should be designed to increase the effective radius of the combination drain envelope to the point that the resulting hydraulic gradient in the soil adjacent to the envelope is reduced satisfactorily.

(iii) The configuration may be reversed with the geotextile outside the gravel envelope and adjacent to the soil being protected. For this combination the gravel should be coarse enough that migration to or into the pipe is not a concern. The key factor is to increase the area of the geotextile in contact with the soil to satisfactorily reduce the flow velocity associated with the exit gradient. This configuration uses more geotextile per linear length of drain than the combination having the geotextile adjacent to the pipe, but in confined areas it may be the most cost effective.

650.1413 Materials

A. Common subsurface drainpipe materials include plastic, concrete, metal, and clay. Standards are continually updated by standards organizations, such as ASTM and AASHTO, so pipe materials meeting recognized standards adopted by these types of organizations should always be used. Current standards that can be considered follow.

B. Concrete Pipe

(1) Reinforced and nonreinforced concrete pipes are used for gravity flow systems. Concrete fittings and appurtenances, such as wyes, tees, and manhole sections, are generally available. A number of jointing methods are available depending on the tightness required. Concrete pipe is specified by diameter, type of joint, and D-load strength or reinforcement requirements.

(2) The product should be manufactured in accordance with one or more of the following standard specifications:

(i) ASTM C14/AASHTO M86 (ASTM C14M/AASHTO M86M)—Concrete Sewer, Storm Drain and Culvert Pipe. These specifications cover nonreinforced concrete pipe from 4- through 36-inch (100 through 900 mm) diameters in Class 1, 2, and 3 strengths.

(ii) ASTM C76/AASHTO M170 (ASTM C76M/ AASHTO M170M)—Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe. These specifications cover reinforced concrete pipe in five standard strengths: Class I in 60- through 144-inch diameters, and Class II, III, IV, and V in 12- through 144-inch (300 through 3,600 mm) diameters.

(iii) ASTM C118 (ASTM C118M)—Concrete Pipe for Irrigation or Drainage. These specifications cover concrete pipe to be used for the conveyance of water under low hydrostatic heads, generally not exceeding 25 feet (75 kPa), and for drainage in sizes from 4- through 24-inch (100 through 600 mm) diameters in standard and heavy-duty strengths.

(iv) ASTM C361 (ASTM C361M)—Reinforced Concrete Low-Head Pressure Pipe. These specifications cover reinforced concrete pipe with low internal hydrostatic heads generally not exceeding 125 feet (375 kPa) in sizes from 12- through 108-inch (100 through 2700 mm) diameters.

(v) ASTM C412/AASHTO M178 (ASTM C412M/ AASHTO M178M)—Concrete Drain Tile. These specifications cover nonreinforced concrete drain tile with internal diameters from 4 through 24inches (100 through 600 mm) for standard quality and 4 through 36 inches (100 through 900 mm) for extra-quality, heavy-duty extra-quality, and special quality concrete drain tile.

(vi) ASTM C444/AASHTO M175 (ASTM C444M/ AASHTO M175M)—Perforated Concrete Pipe. These specifications cover perforated concrete pipe intended to be used for underdrainage in 4-inch (100 mm) and larger diameters.

(vii) ASTM C505 (ASTM C505M)—Nonreinforced Concrete Irrigation Pipe with Rubber Gasket Joints. These specifications cover pipe to be used for the conveyance of water with working pressures up to 30 feet (90 kPa) of head.

(viii) ASTM C506/AASHTO M206 (ASTM C506M/ AASHTO M206M)—Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe. These specifications cover reinforced concrete arch pipe in sizes from 15- through 132-inch (375 through 3,300 mm) equivalent circular diameters.

(ix) ASTM C507/AASHTO M207 (ASTM C507M/ AASHTO M207M)—Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe. These specifications cover reinforced elliptical concrete pipe in five standard classes of horizontal elliptical. 18- through 144-inch (450 through 3,600 mm) in equivalent circular diameter, and five standard classes of vertical elliptical, 36- through 144-inch (900 through 3,600 mm) in equivalent circular diameter.

(x) ASTM C654/AASHTO M176 (ASTM C654M/ AASHTO M176M—Porous Concrete Pipe. These specifications cover porous nonreinforced concrete pipe in sizes from 4- through 24-inch (100 through 600 mm) diameters and in two strength classes.

(xi) ASTM C655/AASHTO M242 (ASTM C655M/ AASHTO M242M)—Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe. These specifications cover acceptance of pipe design and production based on the D-load concept and statistical sampling techniques.

(xii) ASTM C789/AASHTO M259 (ASTM C789M/ AASHTO M259M)—Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers. These specifications cover precast reinforced concrete box sections from 3-foot (900 mm) span by 2-foot (600 mm) rise to 12-foot (3,600 mm) span by 12-foot (3,600 mm) rise.

(xiii) ASTM C850/AASHTO M273 (ASTM C850M/ AASHTO M273M)—Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with less than 2 feet (0.6 m) of Cover Subject to Highway Loading. These specifications cover box sections with less than 2 feet (0.6 m) of earth cover in sizes from 3-foot (900 mm) span by 2-foot (600 mm) rise to 12-foot span (3600 mm) by 12-foot (3600 mm) rise.

(xiv) ASTM C985 (ASTM C985M)—Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe. These specifications cover acceptance of nonreinforced concrete pipe design and production based on specified strengths and statistical sampling techniques.

C. Thermoplastic Pipe

(1) Thermoplastic pipe materials include high density polyethylene (HDPE), poly (vinyl) chloride (PVC), and acrylonitrile-butadiene-styrene (ABS). Thermoplastic pipes are produced in a variety of shapes and dimensions.

(2) High Density Polyethylene (HDPE) Pipe

(i) HDPE pipe is available for gravity and low-pressure flow systems. The application will dictate the quality of the joining system used. Fittings are widely available and can be adapted to many other products. HDPE pipe should be manufactured according to one or more of the following standard specifications:

(ii) AASHTO M252—Corrugated Polyethylene Drainage Tubing. This specification covers corrugated polyethylene tubing from 3- through 10-inch diameter (75 through 250 mm), couplings, and fittings for use in surface and subsurface drainage applications. Provisions are included for corrugated and smooth interior pipe.

(iii) AASHTO M294—Corrugated Polyethylene Pipe, 12- to 48-inch Diameter. This specification covers the requirements of corrugated polyethylene pipe, couplings, and fittings for use in storm sewers and subsurface drainage systems. Provisions are included for both corrugated and smooth interior pipe.

(iv) AASHTO MP7-95—Corrugated Polyethylene Pipe 54 and 60-inch Diameter. This specification covers the requirements of corrugated polyethylene pipe, couplings, and fittings for use in storm sewers and subsurface drainage systems. Provisions are included for smooth interior pipe.

(v) ASTM F405—Corrugated Polyethylene Pipe and Fittings. This specification covers pipe with 3- through 6-inch (75 through 150 mm) diameter. This product is commonly used for subsurface and surface drainage installations.

(vi) ASTM F667—Large Diameter Corrugated Polyethylene Pipe and Fittings. This specification covers pipes from 8- through 24-inch (200 through 600 mm) diameters commonly used for surface and subsurface drainage.

(vii) ASTM F810—Smoothwall Polyethylene (PE) Pipe for Use in Drainage and Waste Disposal Absorption Fields. This specification covers smoothwall HDPE pipe, including co-extruded, perforated and nonperforated, from 3- through 6-inch (75 through 150 mm) diameter.

(viii) ASTM F892—Polyethylene (PE) Corrugated Pipe with a Smooth Interior and Fittings. This specification covers corrugated PE pipe 4 inches (100 mm) in diameter.

(ix) ASTM F894—Polyethylene (PE) Large Diameter Profile Wall Sewer and Drainpipe. The specification covers profile wall PE pipe from 18- to 120-inch (450 to 3,000 mm) diameter for low pressure and gravity flow applications.

(3) Polyvinyl Chloride (PVC) Pipe

(i) PVC pipe is used for gravity and low pressure flow systems. PVC composite pipe is a combination of a PVC pipe with a series of truss annuli. It is filled with lightweight portland cement concrete or other such material. PVC fittings are widely available. PVC pipe should be manufactured in accordance with one or more of the following standard specifications:

(ii) AASHTO M304—Poly (Vinyl Chloride) (PVC) Ribbed Drainpipe and Fittings Based on Controlled Inside Diameter. This specification covers 18- to 48-inch diameter ribbed PVC pipe.

(iii) ASTM D2680/AASHTO M264—Acrylonitrile-Butadiene-Styrene (ABS) and Poly (Vinyl Chloride) (PVC) Composite Sewer Piping. These specifications cover ABS or PVC composite pipe, fittings, and a joining system for storm drain systems in 6- through 15-inch (150 through 375 mm) diameter.

(iv) ASTM D2729—Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings. This specification covers PVC pipe and fittings for sewer and drainpipe from 2-inch (50 mm) to 6-inch (150 mm) diameters.

(v) ASTM D3034—Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings. This specification covers PVC pipe and fittings from 4- through 15-inch (100 to 375 mm) diameters.
(vi) ASTM F679—Poly (Vinyl Chloride) (PVC) Large Diameter Plastic Gravity Sewer Pipe and Fittings. This specification covers PVC gravity sewer pipe and fittings from 18- through 36-inch (450 through 900 mm) diameters with integral bell elastomeric seal joints and smooth inner walls.
(vii) ASTM F758—Smooth-Wall Poly (Vinyl Chloride) (PVC) Plastic Underdrain Systems for Highways, Airports, and Similar Drainage. This specification covers PVC pipe and fittings for underdrains from 4- through 8-inch (100 through 200 mm) diameters with perforated or nonperforated walls for use in subsurface drainage systems.
(viii) ASTM F789—Type PS-46 Poly (Vinyl Chloride) (PVC) Plastic Gravity Flow Sewer Pipe and Fittings. This specification covers requirements for PVC gravity sewer pipe and fittings from 4- through 18-inch (100 through 450 mm) diameters.
(ix) ASTM F794—Poly (Vinyl Chloride) (PVC) Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter. This specification covers PVC pipe and fittings from 4 through 48 inches (200 through 1200 mm) with integral bell and elastomeric seal joints.
(x) ASTM F949—Poly (Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings. This specification gives requirements for PVC pipe and fittings from 4- through 36-inch (100 through 900 mm) diameters with corrugated outer wall and smooth inner wall.

(4) Acrylonitrile-butadiene-styrene (ABS) pipe and ABS composite pipe
(i) ABS and ABS composite pipe should be manufactured in accordance with one of the following standard specifications:
(ii) ASTM D2680/AASHTO M264—Acrylonitrile-Butadiene-Styrene (ABS) and Poly (Vinyl Chloride) (PVC) Composite Sewer Piping. These specifications cover ABS or PVC composite pipe, fittings, and a joining system for 4- to 15-inch (100 to 375 mm) diameter.
(iii) ASTM D2751—Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings. This specification covers ABS pipe and fittings from 3- through 12-inch (75 through 300 mm) diameter.

(5) Metal Pipe
(i) Corrugated metal pipe is fabricated from corrugated steel or aluminum sheets or coils. Corrugated metal pipe is specified by size, shape, wall profile, gauge or wall thickness, and coating or lining. Appurtenances including tees, wyes, elbows, and manholes are available. Corrugated metal pipe should be manufactured in accordance with one or more of the following standard specifications:
(ii) AASHTO M190—Bituminous Coated Corrugated Metal Culvert Pipe. This specification covers characteristics of bituminous coated corrugated metal and pipe arches meeting AASHTO M36.
(iii) ASTM A760/AASHTO M36—Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains. These specifications cover metallic-coated corrugated steel pipe from 4- through 144-inch (100 to 3600 mm) diameter.
(iv) ASTM A762/AASHTO M245—Corrugated Steel Pipe, Polymer Precoated for Sewers and Drains. These specifications cover polymer precoated corrugated steel pipe from 4- through 144-inch (100 through 3600 mm) diameter.

(v) ASTM B745/AASHTO M196—Corrugated Aluminum Pipe for Sewers and Drains. These specifications cover corrugated aluminum pipe from 4- through 144-inch (100 through 3600 mm) diameter.

(6) Vitrified Clay Pipe (VCP)

(i) VCP is manufactured from clays and shales and vitrified at high temperatures. VCP is available in several strength classifications, and is specified by nominal pipe diameter, strength and type of joint. The product should be manufactured in accordance with one or more of the following standard specifications:

(ii) ASTM C4/AASHTO M179—Clay Drain Tile. These specifications cover drain tile from 4- through 30-inch (100 through 750 mm) diameter in standard, extra quality, and heavy-duty strengths.

(iii) ASTM C498—Clay Drain Tile, Perforated. This specification covers perforated drain tile from 4- through 18-inch (100 through 450 mm) diameters in standard, extra quality, heavy duty, and extra strength.

(iv) ASTM C700/M65—Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated. These specifications cover perforated and nonperforated pipe from 3- through 42-inch (75 through 1,050 mm) diameters in extra strength and standard strength.

(7) Other Materials and Products

Geocomposites, geomembranes, geotextiles, aggregates, wick drains, and pump and lift stations may not be covered by conservation practice standards. The requirements for such materials and products must be specified in construction contract documents by an engineer. Contact individual manufacturers for more detail on specific products.

650.1414 Appurtenances

A. Surface Inlets

Surface inlets should be used in low areas where surface drainage otherwise cannot be provided. They must be properly constructed to prevent washouts and silting of the line. Surface inlets should be avoided wherever possible. If silt is a hazard, place a silt trap (fig. 14-53) at a convenient location immediately downstream from the inlet or use a blind inlet (fig. 14-54). Blind inlets allow entry of surface water from small ponded areas into the drain without an open riser. The sand-gravel material for the porous medium must be appropriately designed to keep out sediment and prevent piping of base soil material yet provide free water movement into the drain.

Figure 14-53: Junction Box and Silt Trap

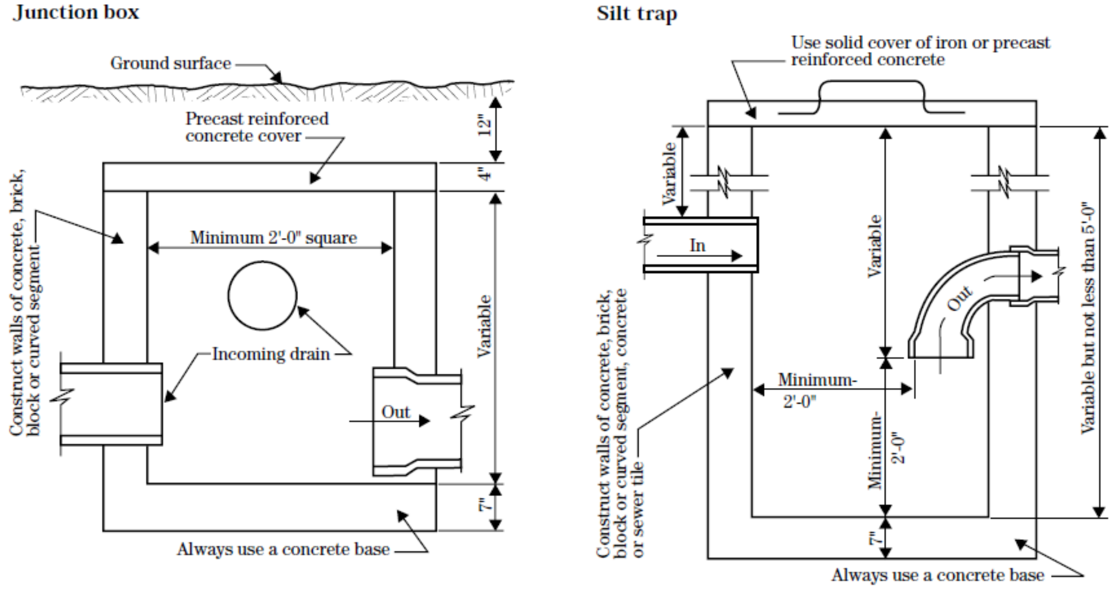
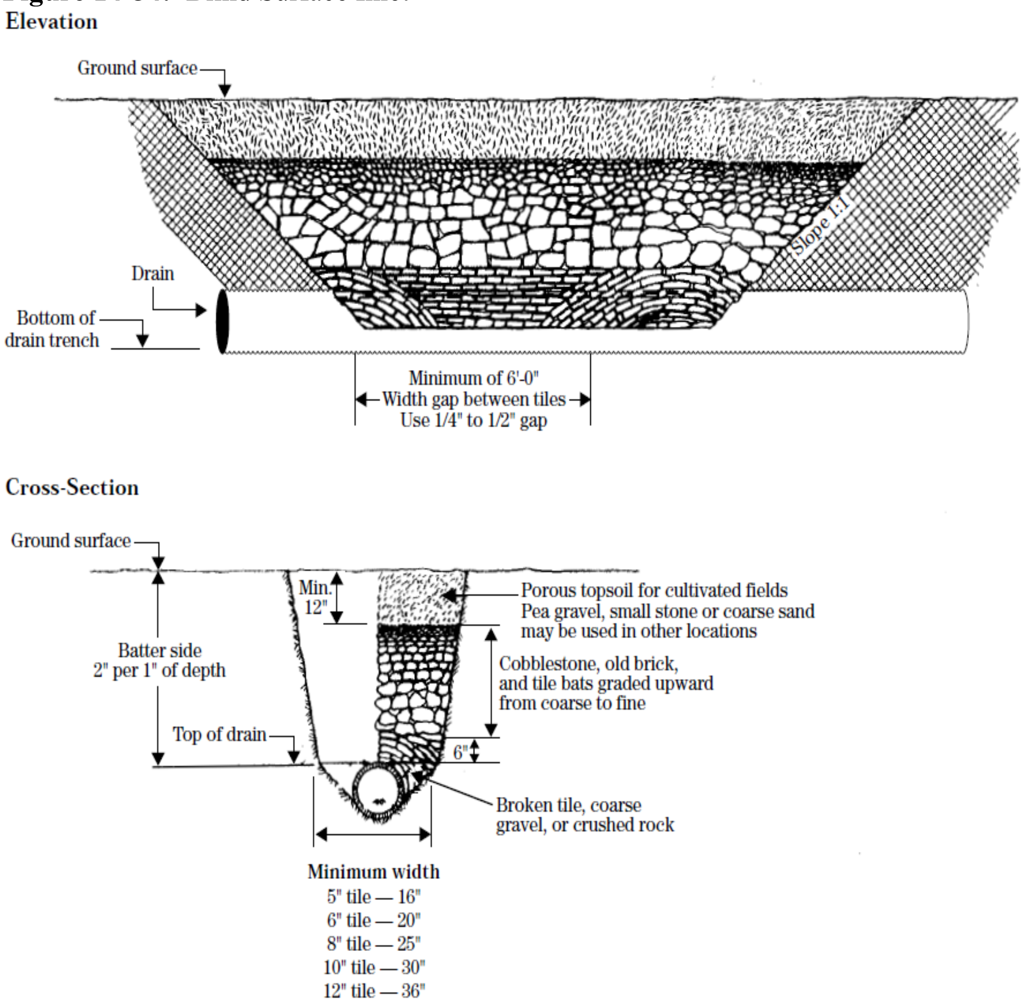


Figure 14-54: Blind Surface Inlet



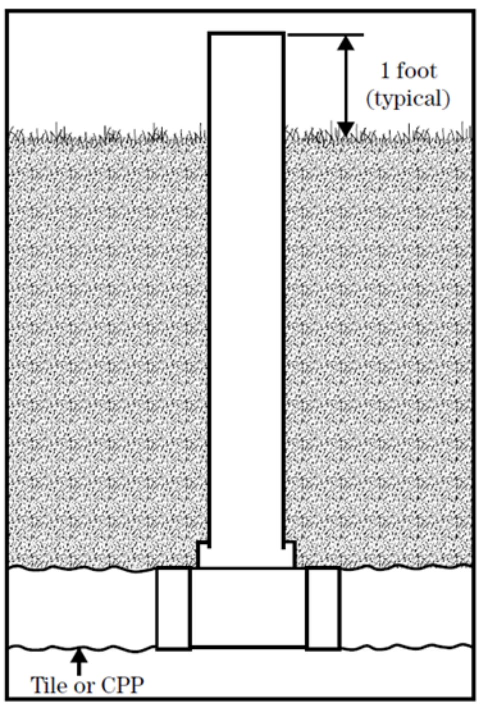
B. Junction Boxes

Junction boxes should be used where two or more main or submain drains join or where several laterals join at different elevations. If the junction is in a cultivated field, the box should be constructed so that the top is at least 18 inches below the surface of the ground. It can be capped and covered, and its position referenced for future relocation (fig. 14-53).

C. Vents and Relief Wells

Vents, or breathers, are used to alleviate vacuum or negative pressure in the line. Breathers should be used where the line changes abruptly from a flat section to a steep section. Permanent fence crossings are good locations for installation. Relief wells relieve pressure in the line. They should be installed where steep sections change to flat sections unless the flatter section has about 25 percent greater capacity than the steeper section. They should be used on lines that have surface inlets, particularly when such inlets are large (fig. 14-55).

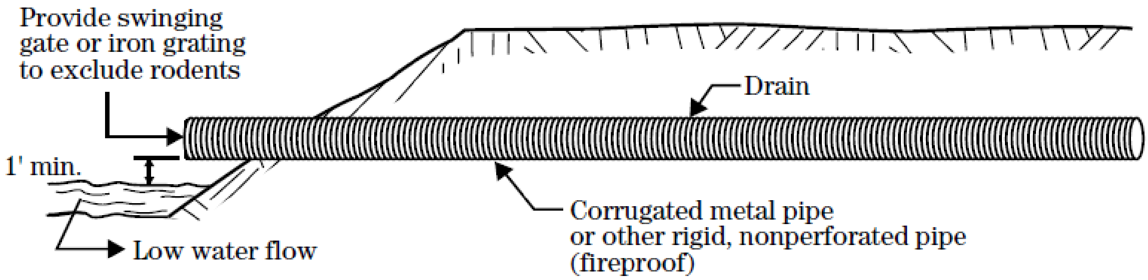
Figure 14-55: Vents or Relief Wells



D. Outlet Protection

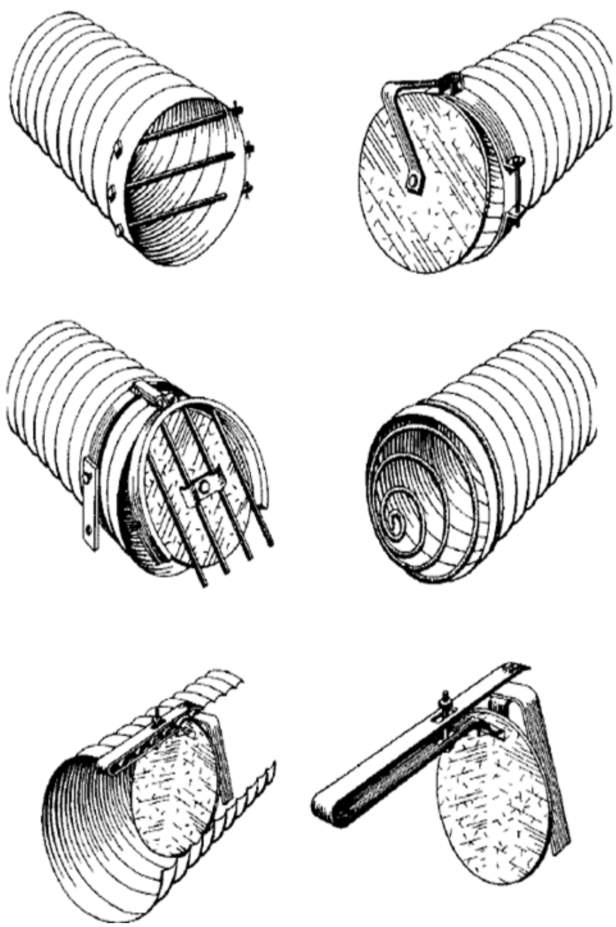
(1) Where drains outlet into an open ditch, the end of the drainage line should be protected. If surface water enters the outlet at the same location as the drain, some type of structure, such as a headwall or earth berm, is needed over the outlet. Where there is no surface water, the most practical and economical outlet is a section of rigid pipe. The pipe should conform to the requirements shown in figure 14-56.

Figure 14-56: Pipe Outlet



(2) Where burning to control weeds may occur, the pipe should be fireproof. A swing gate or some type of grating or coarse screen should be used on all outlets to exclude rodents and other small animals (fig. 14-57). The screen mesh should not be less than 1 inch. Swing gates, rather than fixed screens or grates, should be used where surface water enters a system directly.

Figure 14-57: Outlet Pipe Protection



650.1415 Drain Installation

A. Inspection of Materials

All materials of a subsurface drainage system should be inspected before the system is installed. Materials should be satisfactory for the intended use and should meet standards and specifications. Any defective or damaged clay or concrete drain tile should be rejected, and defective or damaged sections of plastic tubing should be removed. The perforations in the plastic tubing must be the proper size. Check pipe for the specification to which it is manufactured (ASTM, AASHTO) as well as NRCS Practice Standard.

B. Storage of Materials

Drainage materials should be protected from damage during handling and storage. More precautions should be taken to protect plastic tubing. End caps can be used if rodents are a problem. Tubing that has filter wrap should be covered. Because tubing can be harmed by excessive exposure to ultraviolet rays, it must be protected from long exposures to sunlight. Coils of tubing should be stacked no more than four high, and reels should not be stacked.

C. Staking

Presently, field staking is at a minimum because most installations are done with laser controlled equipment (fig. 14-58).

Figure 14-58: Laser Grade Control

D. Utilities

(1) Special caution must be taken when trench or trenchless work is performed because of the danger if utilities are too near. Many jurisdictions have systems in place that require notification and location of utility lines before any excavations. Most require advance notification when excavation is to take place and have special telephone numbers for notification. Some states and metropolitan areas use a single telephone contact to alert local utility companies of pending construction activities (ASCE 1993).

(2) Utilities should be located when preparing plans, and procedures are needed to assure contractors have noted the utilities and have taken the necessary precautions. The location of all underground utilities and structures should be indicated on construction plans or drawings. Safety is the primary concern, but interruption of services can create tremendous economic problems. Whether underground utilities are shown on the plans or not, the contractor is required by OSHA and possibly local or state law to contact local utility companies to ascertain if there is a potential for involvement.

E. Crossing Waterways and Roads

Special precautions should be taken where drains are placed under waterways or roads. Figure 14-59 provides some guidance for these crossings, but, if exceptionally heavy trucks and equipment are expected, an engineer should be consulted.

Figure 14-59: Drain Crossings and Outlets

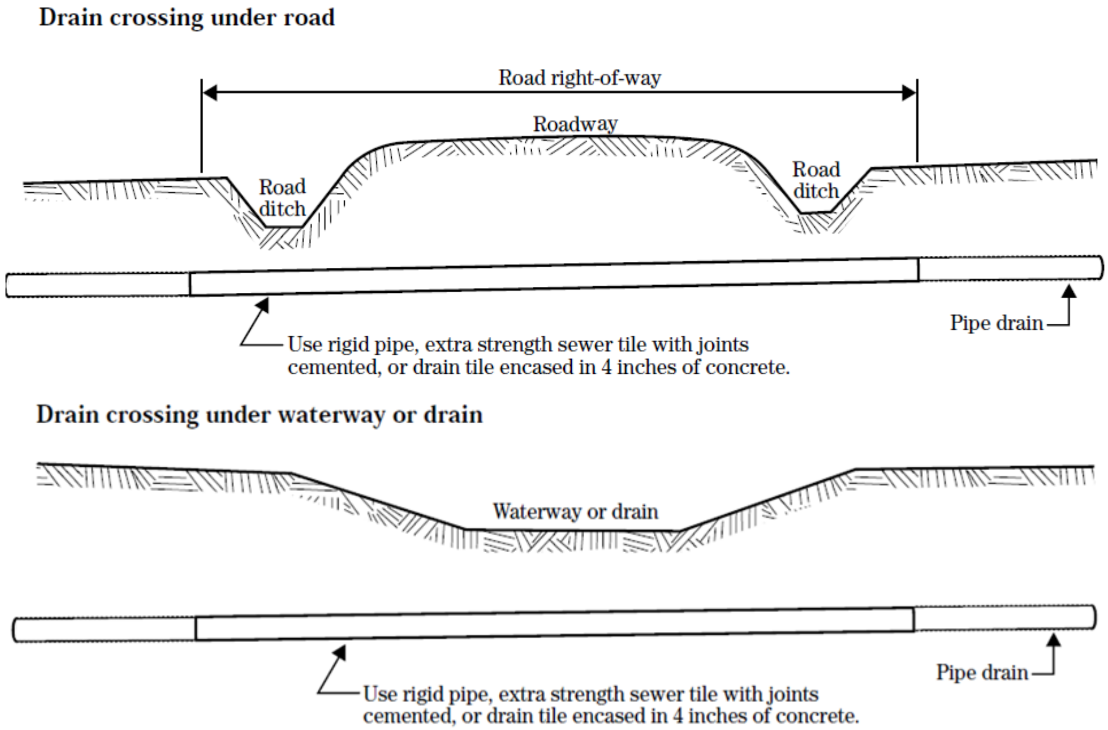
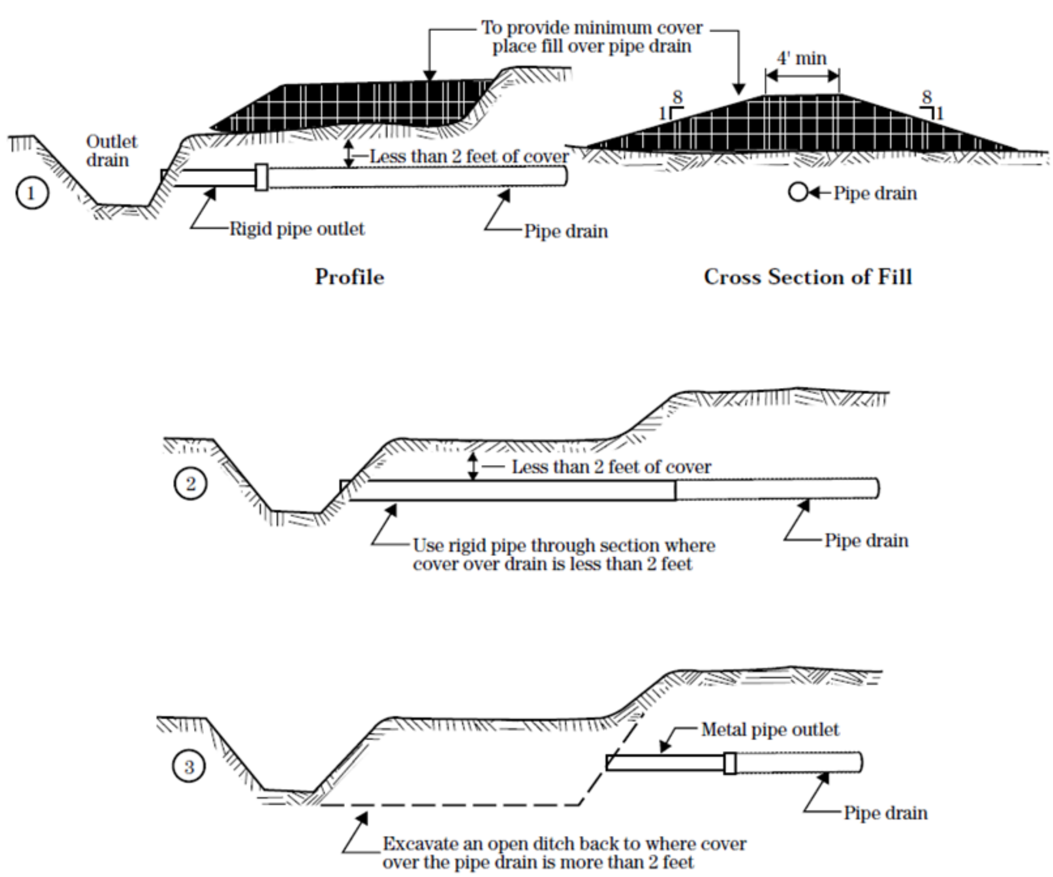


Figure 14-59: Drain Crossings and Outlets - continued

Methods for handling shallow depths at drain outlet



F. Shaping the Trench Bottom

(1) The bottom of the drain trench should be shaped so that a fourth or more of the drain's circumference is on solid ground. Trenching machines shape the trench properly as a part of the trenching operation. Backhoe buckets can also be modified to provide a proper shape. Where drains are laid through unstable pockets of soil, one of the following materials should be placed in the bottom of the trench to support the drain:

(i) stable soil

(ii) crushed rock

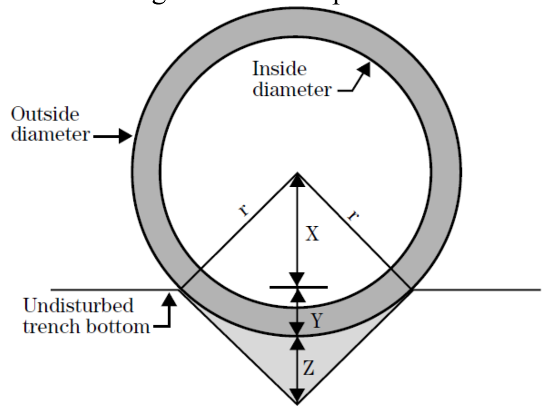
(iii) sand/gravel bedding

(2) For corrugated plastic pipe, a specially shaped groove must be made in the trench bottom if the design does not call for a gravel envelope. The groove shape can be a semicircle, trapezoid, or a 90-degree V. A 90-degree V-groove of sufficient depth is recommended for 3- to 6-inch pipe; however, if the pipe is installed on a steep grade, the bottom of the trench should be shaped to fit the pipe closely (fig. 14-60).

Figure 14-60: Dimensions for a 90 Degree V Groove for Corrugated Plastic Pipe

Diameter (D)	r (D/2)	X (0.707r)	Y (o.293r)	Z (0.414r)
3	1.5	1.060	0.439	0.621
4	2.0	1.414	0.586	0.828
5	2.5	1.768	0.732	1.036
6	3.0	2.121	0.879	1.242
8	4.0	2.828	1.171	1.657

[a]Values are based on typical outside diameter, which is assumed to be 20 percent greater than inside diameter.



G. Laying Corrugated Plastic Pipe (CPP)

Trenching machines or drainage plows are used to install most CPP. Any stretch that occurs during installation decreases the pipe strength somewhat and may pull perforations open wider than is desirable. The amount of stretch that occurs during installation depends on the temperature of the CPP at the time it is installed, the amount and duration of drag that occurs when the CPP is fed through the installation equipment, and the stretch resistance of the pipe. The use of a power feeder is recommended for all sizes of CPP. Stretch, which is expressed as a percentage of length, should not exceed 5 percent.

H. Drain Envelope Installation.

(1) Drain Filter Envelopes

(i) The best quality filter envelope material cannot compensate for improper installation, especially in fine, weakly structured soils that are saturated. Reliable drain envelope material will only be successful if installed under favorable physical soil conditions. General excess wetness of a soil may adversely affect structural stability, hence the soil manipulation caused by the trenching operation while installing drains may destroy the soil structure. This leads to soil slaking, enhanced risk of mineral clogging of filter envelopes and pipes, and a low hydraulic conductivity of the soil itself. Gravel filter envelopes tend to be less susceptible to poor installation conditions, but they can also fail because of adverse conditions at the time of installation. Geotextile filter envelopes are normally prewrapped and have sufficient mechanical strength to withstand the mechanical stresses of installation. Because of this, attention should be primarily on preserving the hydraulic function.

(ii) The ideal condition for installation of subsurface drains is to place the drains in an unsaturated soil. If the soil has a high-water table that cannot be lowered before installation, every effort should be made to preserve the existing soil structure and to protect the drain from trench wall failure. Adjusting the forward speed of the installation machine may help to limit the destruction of soil structure. If the condition of the excavated material is observed, it can be a guide to the proper machine speed. The machine should move fast enough to preserve the structure of the soil and not turn the excavated soil into a slurry. Simultaneous and instantaneous backfilling can prevent trench wall failure.

(iii) Drain plows have been developed that install drains with synthetic and gravel drain envelopes. Plowed in (trenchless) drains avoid many of the problems of trenched or backhoe excavated drain installation. Unfortunately, they present their own unique set of problems. They are limited to shallow depths and small pipe sizes and may produce compaction around the drain under certain soil texture and moisture conditions. Moreover, rocky soils can be a problem for this equipment.

(2) Sand-Gravel Drain Envelopes

(i) Most of the water entering a subsurface drain moves through openings in the sides and bottom of the drain, below the hydraulic gradeline inside the drain. The hydraulic gradients that develop at the drain openings are often high enough to cause an unstable condition at the opening, and consequently piping of the soil material may occur. The noncohesiveness of many soils makes them particularly susceptible to movement when saturated. For these reasons, an adequate amount of filter envelope material is needed around the drainpipe.

(ii) Where drains are laid by hand, a layer of drain envelope material is placed in the bottom of the trench and is leveled to the design grade before the drain is laid. The drainpipe is then put into place and covered with envelope material to the required depth. The trench is then backfilled with soil. Some trenching machines are fitted with two hoppers for placing drain envelope material under and over a drain on a continuous basis. One hopper near the digging device covers the trench bottom with the required thickness of drain envelope material. The pipe is placed and the second hopper at the rear of the trenching machine covers the pipe with drain envelope material.

(iii) In a common variation of the two-hopper design, the pipe is guided through an enclosed single gravel hopper chute and emerges at the rear of the shield along with the gravel. In either case, the shield design is critical. If gravel segregation occurs within the shield, an improper gradation results and often leads to drain failure. Also, the design must be such that the pipe is not subject to tension caused by friction between the gravel and the shield walls. Such tension results in stretching the pipe beyond acceptable limits.

(iv) Drainage contractors have recently developed procedures for placing drain envelope material completely around a drainpipe in one operation using a single hopper. Single hopper placement is used for both rigid and flexible pipes. The pipe within the machine is suspended above the bottom of the trench so the granular envelope material can flow around the pipe. This single stage placement has resulted in material economies since it is possible to make an approximately concentric drain envelope by preshaping the trench bottom. Drain plows that install flexible corrugated plastic drainpipes with drain envelopes have uniformly concentric envelope placement.

(v) In unstable soil the drainpipe and drain envelope are sometimes displaced by soil movement before and during backfilling. The sides of the open trench may fall or slough causing lateral misalignment of the pipes. If the soil around or in the bottom of the trench is saturated and unstable, it may move upward as a fluid displacing the envelope material and pushing the pipe out of line. Simultaneous backfilling is particularly desirable in unstable soil conditions. Movement of saturated unstable soil may also cause puddling of the backfill material and plugging of the filter envelope, or any drain envelope material, during construction. A slurry in the bottom of a trench generally causes immediate and complete failure of synthetic drain envelope material.

(vi) Protection of the drain envelope and drain system immediately following installation is important. No heavy loads, mechanical or hydraulic, should be imposed until the soil in the trench is consolidated. The loose backfill material will settle naturally with time. Passage of a lightweight vehicle wheel in the trench speeds up the process, but care must be taken to avoid crushing the drainpipe.

(vii) Application of irrigation water to unconsolidated material in the trenches to settle the backfill is a practice that should be done carefully. Muddy water moving through the porous backfill material directly into the filter envelope under high hydraulic heads can cause plugging of the filter envelope material at the drain openings. Such plugging reduces the effectiveness of the drain envelope. It may also result in sedimentation in the drain or even complete plugging of the filter envelope.

(3) Envelope Thickness

(i) One of the benefits of drain envelope placement is the increase in permeability along the pipe that enables water to flow more freely to the open joints or perforations. The effect is similar to converting the pipe from one with limited openings to one that is completely permeable. This increased permeability can probably be obtained with an envelope 0.5 inches thick. Theoretically, corrugated pipes should be perforated in every corrugation to reduce secondary convergence at the openings.

(ii) Increasing the diameter of the drain envelope effectively reduces the waterflow velocity and exit gradient at the soil and envelope interface (Willardson and Walker 1979), thereby decreasing the probability of soil particle movement. If the permeable hydraulic envelope material is considered to be an extension of the pipe diameter, then the thicker the envelope the better. Some practical limitations to increasing drain envelope thickness include:

- The perimeter of the envelope through which flow occurs increases as the first power of the diameter of the envelope, while the amount of envelope material required increases as the square of the diameter.
- Doubling the diameter of the envelope and consequently decreasing the inflow velocity at the soil and envelope interface by half would require four times the volume of envelope material.

(iii) Corrugated plastic drainpipes with close perforation spacing reduce the requirement for a hydraulic envelope material to transport water to widely spaced openings that were common where 1- to 3-foot lengths of rigid pipe were used for drainage. The practical problems of placement probably dictates a design minimum sand-gravel drain envelope thickness of approximately 3 inches. The principal reason for a thicker envelope in a problem soil would be to reduce the exit gradient to a value below the hydraulic failure gradient of the soil and to nullify the effects of construction inconsistencies. Figure 14-59 illustrates sand-gravel envelope placement recommendations.

I. Alignment and Joints.

(1) Plastic Pipe

Manufactured couplers should be used at all joints and fittings of corrugated plastic pipe, at all changes in direction where the centerline radius is less than three times the pipe diameter, at changes in diameter, and at the end of the line. All connections must be compatible with the pipe. Where certain fittings are not available, hand-cut connections are acceptable if they are reinforced with a cement mortar or other material that makes a strong, tight joint. The connection should not create a means of obstructing flow, catching debris inside the conduit, or allowing soil to enter the line.

(2) Tile

(i) Alignment in main and lateral drains should generally be straight, and junction boxes should be used to affect changes in direction. Y and T joints can be used. Manufactured connections are preferred, but chipped or fitted connections that are sealed may be installed if manufactured connections are not available.

(ii) Laterals should be connected to mains so that their centerlines meet. Any curves in mains and laterals should have a radius of more than 50 feet. If gaps in excess of 1/4 inch in clay soils or 1/8 inch in sandy soils occur in the outer side of a curved line, they should be covered with an impermeable material.

(iii) Joints between tile laid in straight or nearly straight lines should be about 1/8-inch-wide unless the soil is sandy. Tile laid in sandy soil should be butted together. If gaps exceed 1/4 inch in clay soils or 1/8 inch in sand, they should be covered with broken tile batts or wrapped with impermeable material. In certain soils where experience shows that tile lines fill with sediment within a few years, joints should be protected by wrapping or covering.

J. Safety and Protection During Construction

(1) At the end of each day's work, the end of the drain being placed should be completely closed to prevent small animals or, in the event of rain, silt and debris from entering the line. A wooden or metal plate or some other device can be used. Upon completion of the line, the upper end of the drain should be closed tightly using a plate, end cap, or some other permanent material.

(2) Contractors are responsible for construction site safety. Federal regulations covering safety for all types of construction are published in the Safety and Health Regulations for Construction under the Department of Labor, Occupational Safety and Health Administration (OSHA). Many states, municipalities, and other local agencies have established codes and safety practices regarding construction. These regulations apply to subsurface drainage installation as well as all types of construction, including alteration and repair work. Personnel and contractors associated with drainage installation should be thoroughly familiar with the safety requirements and follow the required practices, procedures, and standards.

K. Blinding and Backfill

(1) As soon as the drains are placed, they should be blinded by covering them with soil to a depth of 6 to 12 inches. They should not be left exposed overnight because damage can occur from rain and trench caving. Loose topsoil, either taken from the sides of the trench or excavated during trenching operations, provides good blinding material.

(2) Backfilling of the trench should be done as soon after blinding as possible to prevent damage from surface water. This generally is done by mechanical means. Some trenchers have backfilling attachments that place the excavated material in the trench as the drain is laid.

L. Protection for Biological and Mineral Clogging

(1) The following installation procedures may minimize ochre problems for shallow drains in humid areas.
(2) In ochreous areas, drains should not be installed below the water table. If possible, drains should be installed during the dry season when the water table is low because the iron in the soil will be in the insoluble form and stabilization of the drain and surrounding soil will help to minimize the possibility of ochre becoming a serious problem.
(3) Drains should open into ditches, rather than through collector systems. If a small area in a field is ochreous, the trouble could be confined to a single drain. Cleaning is also easier for single drains.
(4) Clogging is more severe shortly after drain installation. The best cleaning method is to jet the drains during the first year after installation rather than wait until the drains are clogged. One method of cleaning has vents at the upper end of the lines that are used as ports to pour large quantities of water into the drains for flushing action. This method will not clean the valleys of the corrugations.
(5) Shallow drains and closely spaced drains that flow infrequently are not as troublesome, even though the site may be rated serious for ochre potential.
(6) Drains in marl soils generally have fewer problems, unless the drains are installed deep in the soil profile.
(7) Avoid blinding the drain with topsoil or organic materials.

M. Checking

The most practical way to check the drain installation is after the drain has been laid and before the trench is backfilled; however, checking can be done using a probe after backfilling.

N. As-built Plans

As-built or record drawings are recommended for future reference. They can be done by GPS mapping process, aerial photography, or traditional survey methods.

650.1416 Maintenance

A. Maintenance of subsurface drains is needed throughout the drain’s expected useful life. Outlets should be inspected regularly. If they are not fire-resistant or fire-proof, they need to be protected from weed burning operations. Corrugated plastic tubing is not suitable for the outlet section. Maintenance problems are reduced if the outlet is a short section of solid pipe. The gates or screens of outlets must be checked to assure that entry of rodents and other small animals is restricted and that they are free of sediment build-up, weeds, debris, and seasonal ice blockage.

B. General observation of the entire subsurface drainage system will reveal areas of possible failure. Sinkholes or cave-ins over the drains indicate that soil piping problems have occurred. The problem may be a broken or collapsed drainage conduit or an opening in the filter or envelope material that allows soil material to enter the drain. Following the spring drying period, puddles or wet areas can indicate a plugged line or filter fabric or areas where additional drains are needed.

C. Jet Cleaning

(1) High pressure jet cleaning has been successfully used for removal of ochre, silt, and roots from subsurface drains (fig. 14-61). This practice has been used extensively in Northern Europe and in the U.S.
(2) Timely maintenance of subsurface drainage systems in areas of ochre development is critical. Subsurface drains should not be installed in sites having permanent ochre potential unless some provision is made for frequent jet cleaning.
(3) Temporary ochre as a clogging factor may diminish or disappear over a period of 3 to 8 years if drains are maintained in a free-flowing condition. It generally occurs rapidly and often can be detected at drain outlets within the first few months after drain installation. If drains can be maintained in working order, ferrous iron reaching them may diminish over a period of time.
(4) Permanent ochre is the most serious problem because it continues to be a clogging agent for the life of the drainage system, regardless of treatment. The use of high and low pressure water jetting has been successful in cleaning many drains clogged with ochre. Nozzle pressure should not exceed 400 psi in sandy soils; otherwise sand around the drains may become unstable and flow into the drain. Jetting nozzles designed for agricultural drains should be used rather than those designed for cleaning municipal sewer lines. Jet cleaning should not be delayed until the ochre has aged and become crystalline.

Figure 14-61: High Pressure Jet Cleaning

D. Acid Solutions

A second method for cleaning drains involves an acid solution to dissolve the iron. This method cannot be used with synthetic envelopes, and the outflow after treatment may need to be neutralized to prevent pollution downstream. Some acids, especially sulfuric, may damage concrete lines.

650.1417 Interception Drainage Design

A. Interception drainage is used to intercept surface and subsurface water. The investigation, planning, and construction of surface interception drains follow the requirements and procedures given for surface drainage. Interception of subsurface water is discussed in NEH, Section 16.

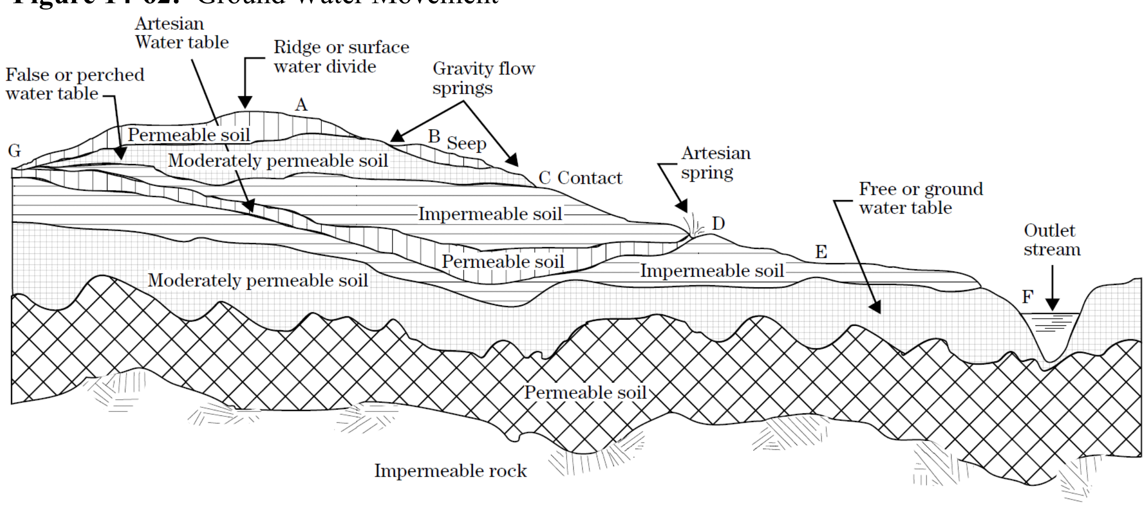
B. Ground Water Movement

(1) Ground water elevation and movement are needed for proper establishment of interceptor drains. Some of the more common conditions indicating the need for interception drainage are illustrated in figure 14-62, which is a sketch of a valley cross section extending beyond the ridge into the adjoining valley.

(2) Most ground water for which drainage is required comes from recent rainfall that accumulates on the soil or within the upper part of the soil profile. After replenishing the soil to water-holding capacity, the excess water moves downward through the soil to the water table or builds up above restricting layers. Here it accumulates and moves laterally, often parallel with the land slope, toward an outlet. Its movement may reach the surface and return to the subsurface a number of times in its course to an outlet.

(3) In a valley, barriers within 8 to 20 inches of the soil surface often cause a perched water table above the true water table. A true water table seldom is encountered until well down the valley side slopes or on the valley floor. For example, in figure 14-62, rainfall penetrating a permeable surface soil below the ridge at A may accumulate water over a less permeable subsoil during wet periods. Resistance to movement into the subsoil diverts most of the water over the less permeable layer to appear at the surface at location B as a wet weather seep. During the summer, such seep spots may completely dry out. Also, where soil is shallow over less permeable layers, a false water table close to the surface may accumulate sufficient water to pond at the surface in wet seasons and later completely disappear.

Figure 14-62: Ground Water Movement



(4) The same water movement also can develop seeps at point C. However, a larger collecting area and more complete interception by the impervious layer may accumulate sufficient water to produce a flowing spring, particularly if it is in a depression where the water converges and is confined in a small area. On the other hand, a rock ledge or compact layer may lie as a shelf with visible flow only at the depressions, even though this may be a small part of the total water coming to the surface along the same approximate contour.

(5) Proceeding down into the valley trough, flow from adjoining watersheds can complicate the problem. Springs developed from these sources frequently have year-round discharge. When the flow is confined between impermeable layers, such as at D, it may build up a head of water a considerable distance above the point of issue. This can create an artesian supply that can discharge under pressure over an extended area. If the flow is not free but is covered by a mantle of moderately permeable to fine textured soil, artesian springs may saturate an extensive area at great depths by pressure and capillary action. Because of this, the location and treatment of these springs are difficult. Abrupt changes in grade of fine textured soils, shown in E, may slow water movement on the flatter slope enough to cause water accumulation and wetness at the surface.

(6) On some sites, open observation wells or piezometers are necessary to locate the source and direction in which subsurface flow takes place.

C. Location of Interceptor

(1) In the planning and establishment of interceptor drains for both surface and subsurface water, the location of the outlet is of utmost importance. Insofar as possible, cross drains should be laid out to use the best natural outlet available. Because the interceptor may intercept other drainageways and add their discharge to the selected outlet, it is necessary to check the adequacy of the outlet to be used. Often, discharge can be spread over a well sodded pasture, stony field, or into gently sloping woods.

(2) If a satisfactory natural outlet is unavailable, special channels can be constructed. Vegetative outlets on slopes are preferred over masonry or similar channels because of their economy. They should be established well ahead of the interceptors so that the turf can safely handle the concentrated flow. If vegetative outlets must handle continuous flow, as supplied by springs, the center of the channel should be troughed to confine low flows.

(3) If surface wetness is undesirable, subsurface drainage can be provided by a conduit placed along one side of the channel, well into the bank and away from possible surface wash. Subsurface drains should be vented at breaks in grade to reduce suction at the head of the slope and pressure at the base. In flats at the base of slopes, main or lateral ditches of trapezoidal or parabolic section can be used.

(4) In planning and establishing an interceptor diversion, a few well-placed lines at obvious seep planes and distinct changes in slope may be enough. In such cases, a detailed map may not be needed, and the line can be staked directly on the site. If subsurface interception must also be considered, the approximate location should be determined first from observations of surface conditions and preliminary borings.

(5) After the line is staked, additional borings should be taken along and across the staked line and the alignment shifted until good interception is obtained. In irregular bowl-shaped areas, some changes in grade or shifting of the diversion lines upslope or downslope may be needed to obtain reasonably uniform farming strips, headlands, and access points for farming equipment.

(6) If a uniform grade from one side to the other causes considerable divergence or location of the drain away from the approximate line of seepage and desirable pattern of farming strips, several parallel drains may be needed. If this is done, the least needed length of drain generally results from placing the shorter line at the higher elevation near the outlet. As an alternate, if an outlet is also available on the opposite side of the seep area, an alternate method is to break the grade along a single line so that the fall is in both directions. The most advantageous point of breaking grade may require several trials until grade and alignment provide the desired location, interception, and outlet points. Such sites often have so many irregularities and outlet location problems that a complete contour map may be needed as an aid to planning.

(7) Interception drainage may be accomplished by open drains or subsurface pipe drains (fig. 14-63). A channel used for controlling surface water (fig. 14-64), commonly called a diversion, may be shallower than one required to intercept subsurface water movement. The open drain must have sufficient depth to intercept subsurface water movement. The drains are frequently V-shaped, with the bottom and top rounded by construction and cultivation so they nearly conform to parabolic sections.

(8) Side slopes preferably should be 6:1 or flatter for ease of construction and farming. However, 4:1 or steeper side slopes may be necessary on land that has slopes of more than 12 percent.

(9) Where a series of interceptor ditches is necessary to reduce the length of slope and contributing drainage area, spacing ordinarily should not exceed 200 feet for slowly permeable soils. More often, break in slope, location of spring or seep lines, and the necessary location of the top interceptor result in spacing of less than 200 feet. In more permeable soils, erosion control requirements may govern spacing.

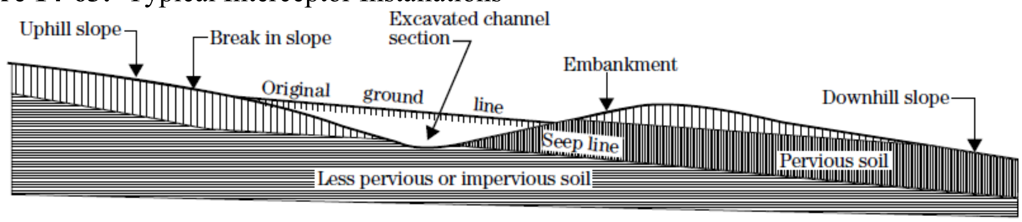
(10) If an interceptor open drain carries spring flow and elimination of continuous wetness in the open drain is desirable, a shallow diversion that has an auxiliary subsurface pipe drain can be used. The subsurface drain can be placed on either side of the surface drain; however, in most shallow soils, a location slightly downhill from the drain provides deeper interception and added cover from the embankment (fig. 14-64).

(11) The subsurface drain need not follow the course of the surface open drain throughout its length if topography warrants deviation.

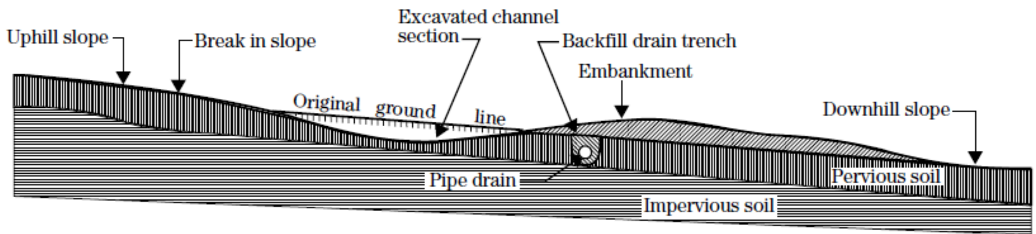
(12) An open drain that has a standard trapezoidal or parabolic cross section (fig. 14-63C) can be used to intercept surface water at the base of a slope surrounding a depression or at the outer edge of a flood plain (fig. 14-65). The depth of the open drain must be ample to provide:

- necessary subsurface interception,
- allowance for shrinkage where peat and muck are involved, and
- lateral movement of water if the drain is also used as an outlet for internal drainage of the protected area.

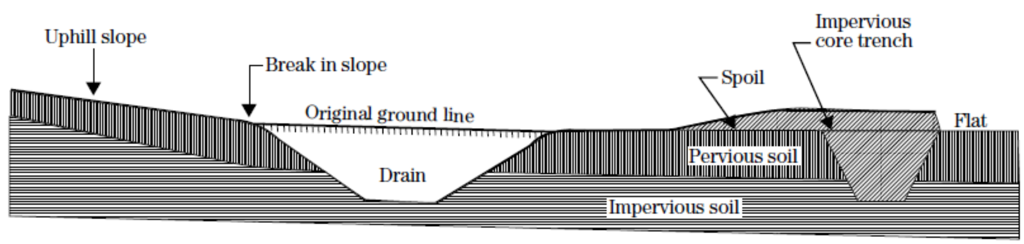
Figure 14-63: Typical Interceptor Installations



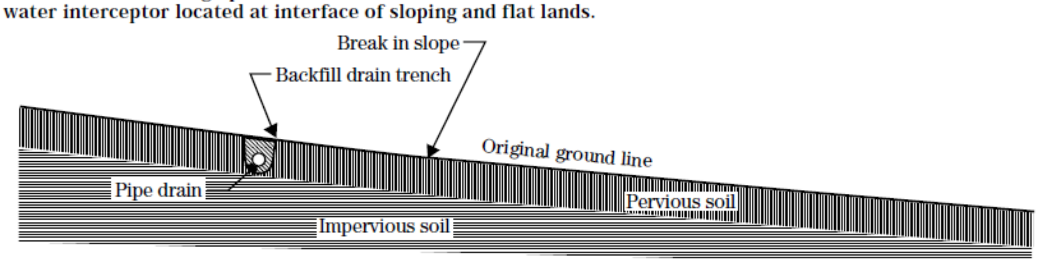
A. - Cross section showing open drain as surface water diversion and interceptor of surface and subsurface water from sloping lands.



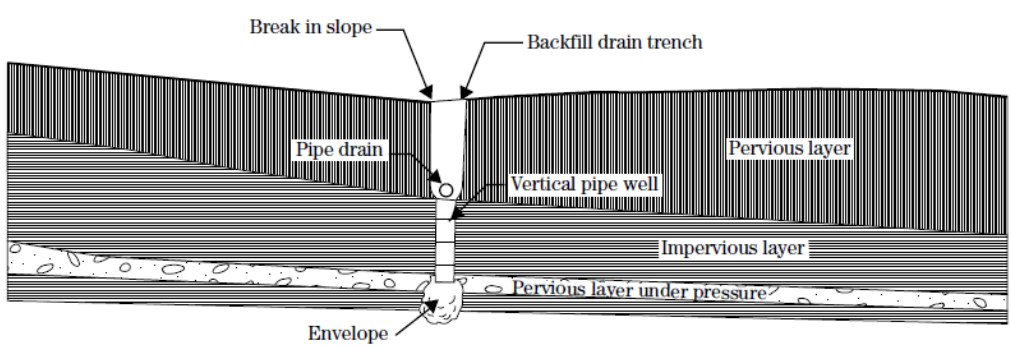
B. - Cross section showing open drain as surface water diversion with pipe drain as subsurface interceptor.



C. - Cross section showing open drain as surface water diversion and subsurface water interceptor located at interface of sloping and flat lands.



D. - Cross section showing drain as subsurface interceptor.



E. - Cross section showing relief well and interceptor drain.

Figure 14-64: Diversion System on Moderate to Steep Slopes

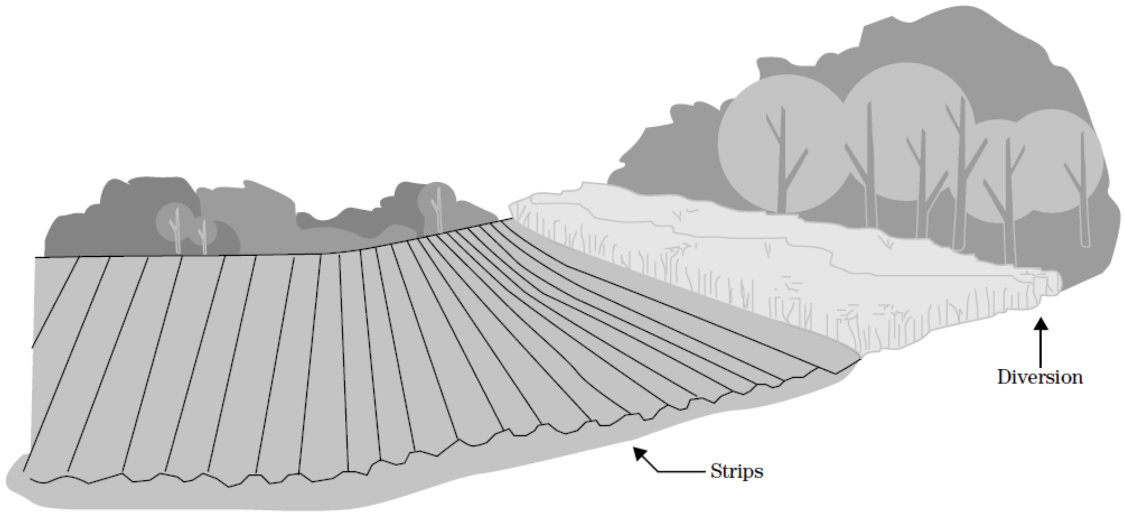
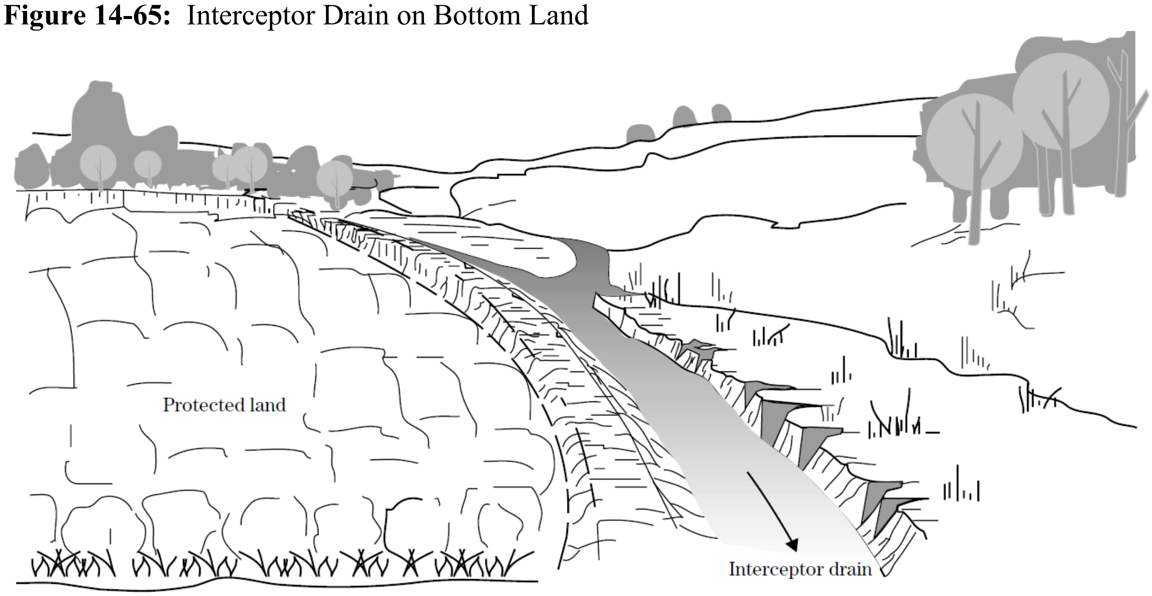


Figure 14-65: Interceptor Drain on Bottom Land



(13) Spoil always should be placed on the downslope bank to permit free movement of upland water into the drain. It can also be used in diking to gain added channel capacity for overflow protection. If diking is not needed, spoil should be spread to blend into the surrounding landscape and to facilitate maintenance.

(14) If drainage areas are small, subsurface drainage often can be used alone for interception of seeps and springs (fig. 14-63D). The drainage lines are generally close to breaks in grades so that the drain has adequate cover and proper depth for intercepting the seepage. Added cover can be obtained on many sites by moving the lines slightly uphill above the break in slope where the impervious layer generally is at a greater depth. The bottom of the drain should be just within the impervious layer. If minimum cover is not available at this depth, the drain should be placed as far into the impervious layer as necessary to attain the needed cover. This may reduce the amount of flow into the pipe and its potential capacity but deepening and widening the trench and installing 4 to 6 inches of envelope material around the pipe improve flow into the drain. In fine textured soils, permeable material should be used as backfill over the line to within plowed depth.

(15) Isolated seeps at elevations above the drain can be tapped with stub relief drains to avoid additional long lines across the slope.

(16) If pervious layers are considerably below normal drain depth or deep artesian flow is present, water under pressure may saturate an area well downslope. Vertical relief wells or pits can be installed at intervals along the cross drain down to an impervious layer or springhead, and the excess flow can rise through these vertical pipes and discharge into the cross drain (fig. 14-63E). Open pits can be filled with bank run gravel or coarse sand, serving much as a French drain to permit water from deep-seated springs to rise into the cross drain. Construct by installing pipe and filling it with filter material; after which the pipe is withdrawn, leaving a vertical or chimney drain.

D. Use of surface or subsurface drains

(1) Open drains can be used to lower or control the water table where subsurface drains are not feasible. They are used in shallow, hardpan soils where the depth of the soil does not permit satisfactory installation of subsurface drains. They are also used in deep soils in cultivated fields, either as temporary measures or permanent installations. Where the entrance of surface water can cause bank erosion, adequate devices, such as pipe inlets, should be considered.

(2) Open drains may be used as temporary installations to intercept and monitor subsurface flow. Often an open drain is retained as a permanent installation if the flow is so great that a pipe drain installation would be too costly.

(3) Drains must be deep enough to tap and provide an outlet for ground water that is in shallow, permeable strata or in water bearing sand. The spacing of drains varies with soil permeability and drainage requirements. The capacity of the open drains generally is greater than required because of the required depth and the construction equipment used. Refer to 210-NEH-624 and NEH, Section 16 for additional information and to State technical guides for recommendations.

(4) The spacing between field ditches can be calculated by the same drainage formulas used for subsurface drains after converting the wetted perimeter u to the radius of drainpipe r, thus:

$$u = 3.14r$$

(5) Advantages of using open drains:
- Nearly always have a smaller initial cost than subsurface drains.
- Are more easily inspected.
- Are applicable in many soils where subsurface drains are not recommended.
- Can be used on a very flat gradient where the permissible depth of the outlet is not adequate to permit the installation of subsurface drains at the minimum required grade.
- Can be used in lieu of subsurface drains to avoid problems with iron ochre.
- Are generally more accessible by equipment for cleaning and maintenance purposes.

(6) The disadvantages:
- Reduce the area of land available for farming, especially to unstable soils that require flat side slopes.
- Are more difficult and costly to maintain than subsurface drains.
- Limit access and interrupt farming patterns.
- Pose both social and environmental impacts.

E. Size of drains.

(1) Humid areas

Figure 14-66 can be used to determine the required capacity of single random interception drains in some humid areas. If one line is insufficient, additional lines may be used.

Figure 14-66: Interception Drain Inflow Rates

Soil texture	Inflow rate per 1,000 feet of line (ft^3/s)*
Coarse sand and gravel	0.15 to 1.00
Sandy loam	0.07 to 0.25
Silt loam	0.04 to 0.10
Clay and clay loam	0.02 to 0.20

* Discharge of flowing springs or direct entry of surface flow through a surface inlet must be added. Such flow should be measured or estimated. Required inflow rates for interceptor drains on sloping land should be increased by 10 percent for 2 to 5 percent slopes, by 20 percent for 5 to 12 percent slopes, and by 30 percent for slopes over 12 percent.

(2) Irrigated Areas in the West

Darcy's Law, which relates to the flow of water in saturated soils, has been used to approximate the discharge of irrigation water. Measuring discharge of an open pilot interceptor has been employed. Local experience with interception drainage is generally relied upon. Additional information is in 210-NEH-624; NEH, Section 16; and in State drainage guides. The procedure for obtaining the drain size after the discharge has been determined is described in section 650.1411(I).

F. Grades and Velocities

(1) Both minimum and maximum grades should be considered in design and installation of subsurface drains.

(2) Minimum Grades

If silt or fine sand is a problem, minimum grades should produce a velocity of at least 1.4 feet per second, if possible, to keep the material suspended in the effluent. Grades as low as 0.1 foot per 100 feet are permissible where silt is not a problem or where a filter is used.

(3) Maximum Grades

(i) Because grades frequently must vary with topographic conditions, it is not always possible to hold to specific maximums. Where practical, main drains should not be placed on grades of more than 2 percent. Special precautions must be taken where locations and conditions require the use of steep grades. Some added precautions that should be considered include:

- Use nonperforated pipe for steep sections.
- If perforated drainage pipe is used, a filter fabric or sand-gravel envelope should be used to prevent soil from entering the drain.
- Use bell-and-spigot or tongue-and-groove concrete pipe with sealed joints and sand-gravel envelope material for unsealed joints.
- Use tile that is uniform in size and shape and has smooth ends or joints.
- Lay the tile in a firm foundation with tight-fitting joints bound with the best material available.

(ii) A breather pipe near the beginning of a steep section and a relief well at the point where a steep section changes to a flat section should be considered. This will be determined by the velocities in the drain, the soil in which the drain is laid, and the capacity of the drain below the steep section with respect to that in the steep section.

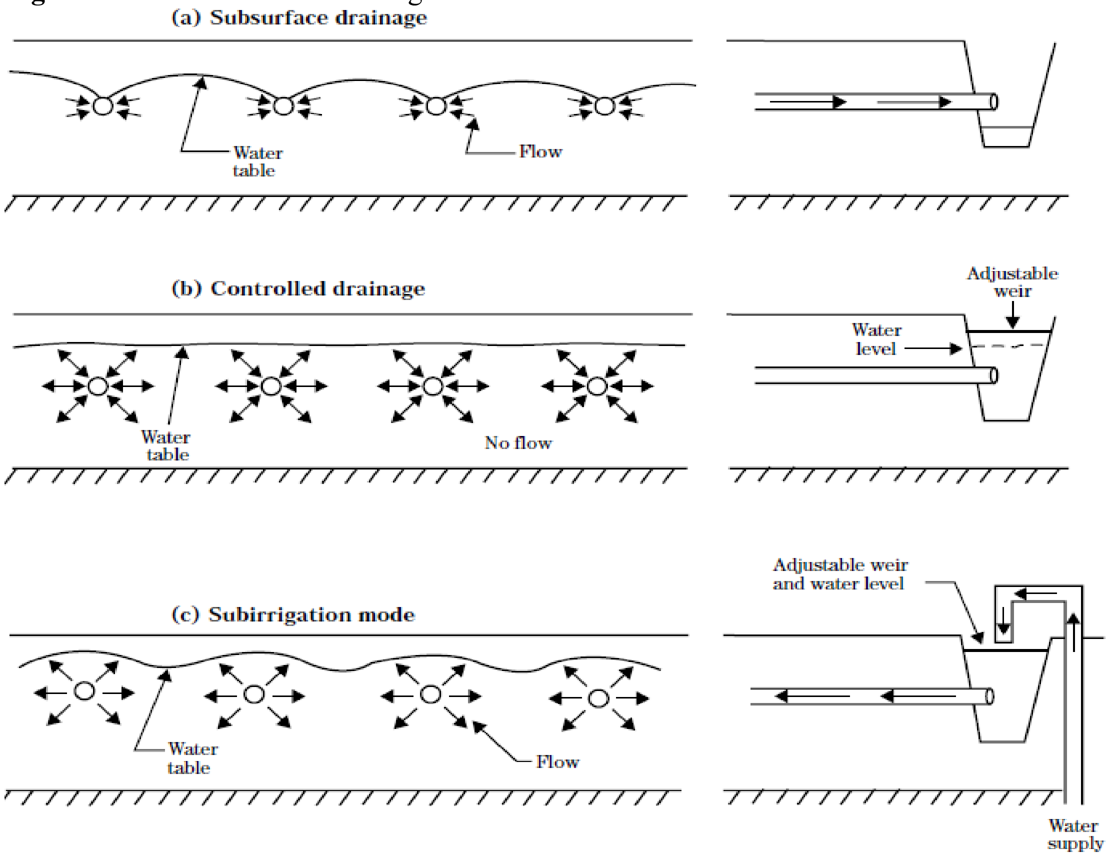
650.1418 Water Table Management

A. This section describes water table management, which includes controlled drainage and subirrigation. See 210-NEH-624-10, for additional details. Controlled drainage and subirrigation have many benefits. Controlled drainage, as the name implies, is a modification of a drainage system that restricts or allows for management of outflow. Subirrigation is typically an additional refinement of controlled drainage in which a water source is added to maintain a water table at the desired stage to provide capillary water for plant use. Refer to figure 14-67.

B. Water table management systems not only improve crop production and reduce erosion, but also protect water quality.

C. Most water table management systems include water control structures that raise or lower the water table, as needed. Lowering the water table in a soil increases the infiltration of water by providing more room in the soil profile for water storage. The result is less surface runoff, less erosion, and less sedimentation of surface water.

Figure 14-67: Water Table Management Alternatives



D. Nitrates (mostly from nitrogen fertilizer) commonly move in solution with water and have been measured in subsurface drain flows. Some studies suggest that ground water can be denitrified and the nitrogen returned to the atmosphere as a gas if the water table is maintained close to the soil surface. This is especially true during the nongrowing, dormant periods. The use of water table management practices to reduce the loss of nitrates to public water is being studied for various soil, cropping, and climatic conditions. Management of the systems to accomplish denitrification is critical.

E. Interest in water table management systems has increased in the Atlantic Coastal Plain and other humid areas. The NRCS has helped landowners install water control structures in open drains in for water quality protection and water conservation. The drainage water management facilities are closely monitored to avoid conflict with the objectives of protection and enhancement of wetlands and to guide management of the systems to achieve the intended purpose.

650.1419 Controlled Drainage

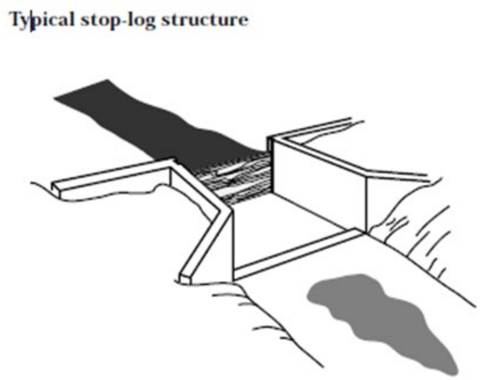
A. Controlled drainage is beneficial for water quality protection and water conservation. This form of water table management does not include adding an outside water source. Controlled drainage has been used historically in organic and muck soils but is also applicable in mineral soils. Some drainage systems may remove water needed for crop production later in the season. Structures that retard drainage water losses can partly overcome this problem. The conserved water is used as needed during the growing season.

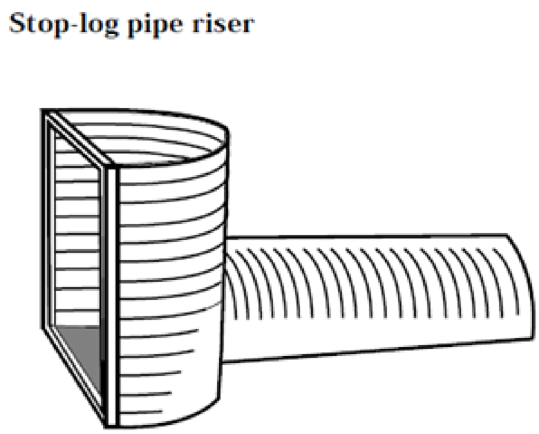
B. Growing rice in flooded basins requires water levels above ground surface to be kept within certain limits in accordance with the water requirements of the different growth stages. If rice is rotated with other crops in an area that has a subsurface drainage system, the drain outlets should have a water level control structure that can prevent or allow the outflow of drainage water as needed.

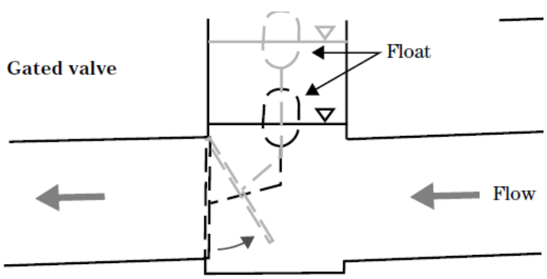
C. Structures for water control normally use spillways fitted with stoplogs or gates to control the water level. Control structures in conjunction with wells may be placed in the subsurface drain system. They generally are a type of manhole fitted with stoplogs or adjustable metal slides that control the flow of water in the subsurface drain system (fig. 14-68). 210-NEH-650-6 gives more information on using structures for water control.

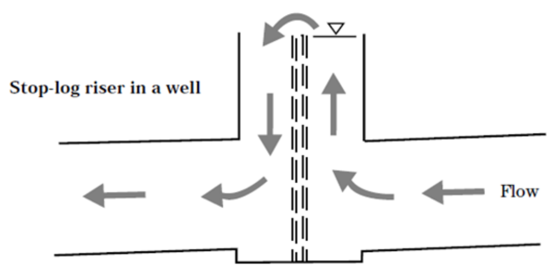
D. Management of controlled drainage systems is beneficial in protection of surface and ground water quality. Local technical guides give detailed information on retention of nutrients and agricultural chemicals.

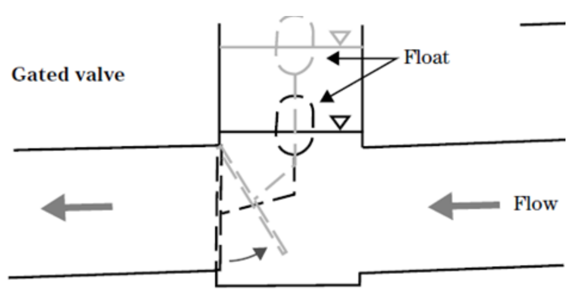
Figure 14-68: Water Control Structures











650.1420 Subirrigation

A. Water table management (WTM) is the control of ground water level by regulating the flow of water in the drainage and subirrigation modes. It is accomplished using structures that control the rate of flow or maintain a desired water surface elevation in natural or artificial channels. A source of water along with a pumping plant may be needed to satisfy the subirrigation objective. Figure 14-67 shows the effect of using these water management alternatives with a subsurface drainage system.

B. General Requirements

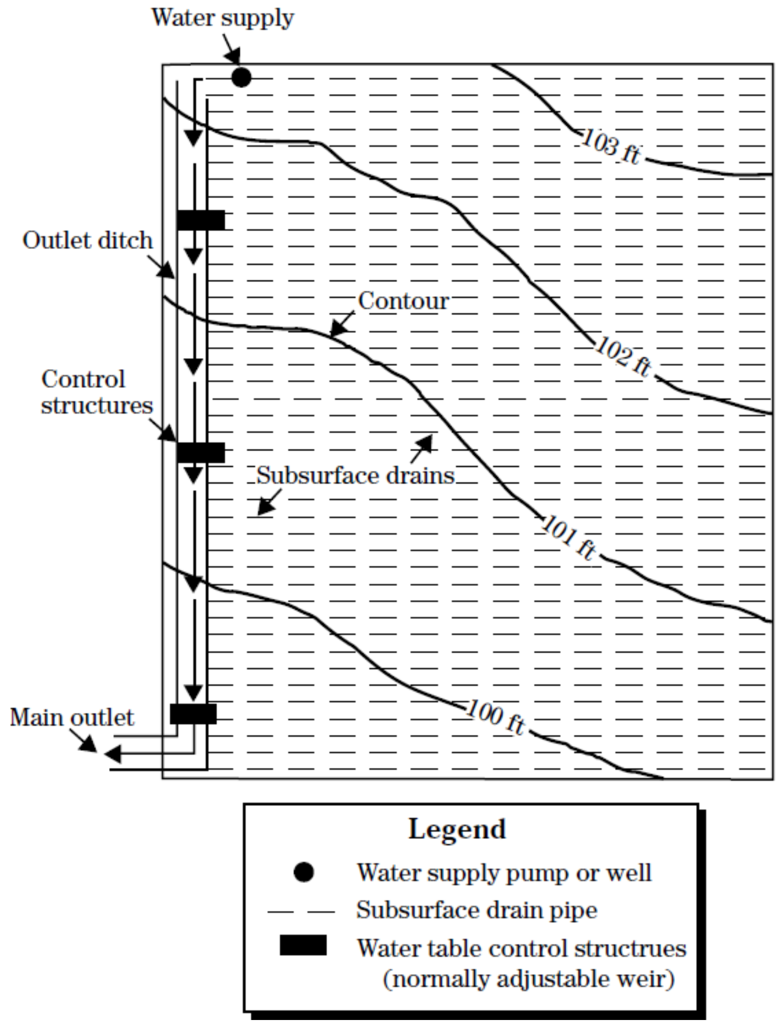
(1) For water table management to be successful, the following conditions generally must be met.
- (i) The site has a relatively flat surface and the slope is no greater than 1 percent.
- (ii) The soils at the site have a moderate-to-high hydraulic conductivity.
- (iii) The soil has a natural high-water table or a shallow, impermeable layer. Deep seepage losses should not be a problem where these conditions exist.
- (iv) The site has a satisfactory drainage outlet. This can be a pumped or natural gravity outlet.
- (v) An adequate water supply is available.
- (vi) Saline or sodic soil conditions can be maintained at an acceptable level for efficient production of crops.
- (vii) Unacceptable degradation of offsite water will not result from operation of the system.
- (viii) Benefits of the proposed water table control will justify installation of the system.

C. Planning a Water Table Management System

(1) The entire area impacted by the management of the WTM system must be evaluated. The control of the water table by an adjustable weir or gates may impact adjoining fields. Figure 14-68 shows typical water table management structures. A topographic survey of the field or fields is needed to plan the system, including avoiding an adverse impact on adjacent fields and drainage systems. Figure 14-69 depicts basic layout features of a WTM system.

(2) The type of system that can be used must be determined. It should be consistent with the landowner's needs and management requirements. Planning considerations include:
- (i) Type and layout of the surface and subsurface drainage system.
- (ii) Need for land smoothing or precision leveling.
- (iii) Alignment of system to best fit topography, spacing, and location of structures. Structures should be located to maintain the water table within an acceptable level below the root zone so that good drainage is provide when needed and water is furnished by capillary movement from the water table throughout the growing season.

Figure 14-69: Field Layout of WTM System



(3) The most critical factor is the feasibility of maintaining a water table, which is often dependent on the presence of a barrier. This is discussed later as well as hydraulic conductivity and determining spacing of subsurface drain laterals to provide for both drainage and subirrigation.

(4) Water Table Location

(i) The location of the natural seasonal high-water table in the soil profile is critical. A seasonal high-water table indicates that the soil can maintain the water table required for subirrigation during dry periods. If the seasonal high-water table is more than 30 inches below the surface (with natural drainage), the soil is considered to be well drained, and a water table may be difficult to develop and maintain close enough to the root zone to supply the plant's water needs because of excessive seepage.

(ii) In most areas where water table control systems will be used, the natural seasonal water table has been altered by artificial drainage, and the depth of the drainage channels control the depth to the modified seasonal water table. Excessive lateral seepage can be a problem if the proposed system is surrounded by drainage channels that cannot be controlled or by fields that have excessively deep seasonal water tables. The depth to the seasonal water table during periods of a crop's peak demand for water must be evaluated and potential seepage losses estimated.

(5) Barrier

If water table management is successful, a barrier on which to build the artificial high-water table during the growing season must occur at a reasonable depth. An impermeable layer or a permanent water table must be reasonably assured.

(6) Hydraulic Conductivity

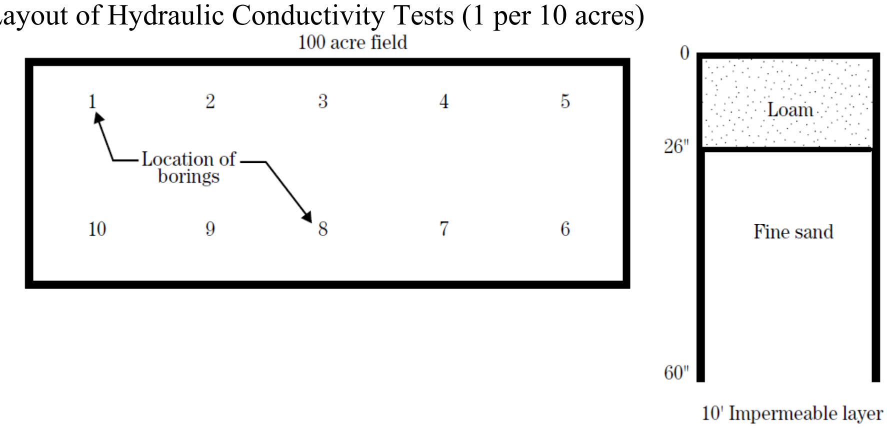
(i) Hydraulic conductivity is the most important soil property affecting the design of a water table management system. The final design must be based on actual field measured conductivity. A soil hydraulic conductivity of 0.75 inches per hour should be used as a benchmark for planning. If the flow rate is less than 0.75 inches per hour, the cost of installing the system may be the limiting factor. However, all costs should be evaluated before rejecting the site. If other system costs, especially that of water supply, are low, soils that have a hydraulic conductivity of less than 0.75 inches per hour may still be economical.

(ii) Appendix 14-C provides detailed information on the auger-hole method of determining hydraulic conductivity. A single value will be determined to use in all calculations, and this value must be representative of the entire field. At least one hydraulic conductivity test per 10 acres is recommended. As the complexity of the soil increases, more tests are needed to assure that a representative value is obtained. Figure 14-70 shows an example field that requires only one test per 10 acres. The site characteristics are:

- One soil with uniform horizons over entire field. Loam is 26 inches thick. Fine sand continuous to 10 feet.
- Conductivity values vary slightly between test hole but are uniform enough that only 1 per 10 acres is needed.

Figure 14-70: Field Layout of Hydraulic Conductivity Tests (1 per 10 acres)

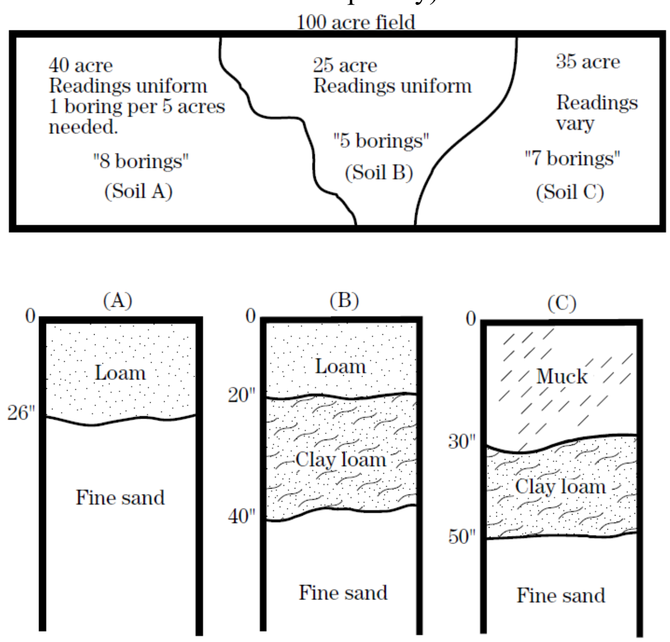
Hole #	Permeability
1	1.0 in/hr
2	1.5 "
3	1.2 "
4	0.9 "
5	1.7 "
6	1.6 "
7	1.3 "
8	1.5 "
9	0.8 "
10	0.7 "



(iii) Figure 14-71 shows an example of a more complex field that requires many tests. Site characteristics are:

- Three soil types.
- Considerable variations in soil characteristics. Many variations in texture and thickness of horizons within each soil type.
- Readings vary considerably over a wide range in soil C and are uniform in soils A and B.

Figure 14-71: Field Layout of Hydraulic Conductivity Test (Variable Concentration Based on Complexity)



(iv) Determining the amount of variability that can be tolerated before additional readings are needed can be left to the discretion of the designer or determined by a statistical analysis. Regardless of the method used, the designer must obtain a representative value of the hydraulic conductivity of the field. If initial tests are performed and readings are uniform, no further tests are necessary.

(7) Determining which hydraulic conductivity rate to use for design

(i) Only one rate can be chosen to represent each area that is to be designed as a single unit. This is often difficult because of variations in measurements. Computing the arithmetic average will not be adequate for design purposes because the resultant tubing or ditch spacing will be too close if actual hydraulic conductivity is greater than average and too far apart when actual conductivity is less than the average. To keep things simple, the following method is recommended.

- Group all the conductivity values according to the rate of flow using the following example. The range of these groupings can be varied based on the magnitude, variability, and arrangement of the conductivity values as shown in figure 14-72.

Figure 14-72: Range of Conductivity Groups

Group	Range of conductivity
Very slow	Less than 0.05 inch/hour
Slow	0.05 - 0.5 inch/hour
Moderate	0.5 - 2.0 inch/hour
Rapid	2.0 inch/hour or more

- Subdivide the field according to the group of conductivity values. Each area can then be designed as a separate unit based on the selected hydraulic conductivity rate for that unit.
- If the field has several hydraulic conductivity group values so intertwined that they cannot be subdivided into separate areas and designed as individual units, the lowest conductivity that represents most of the area should be used to determine the design value.

(ii) The simplest and most reliable method of determining the hydraulic conductivity of a soil is the "auger-hole method" (see appendix 14D). The disadvantage of this method is that the tests must be made when a high-water table is available.

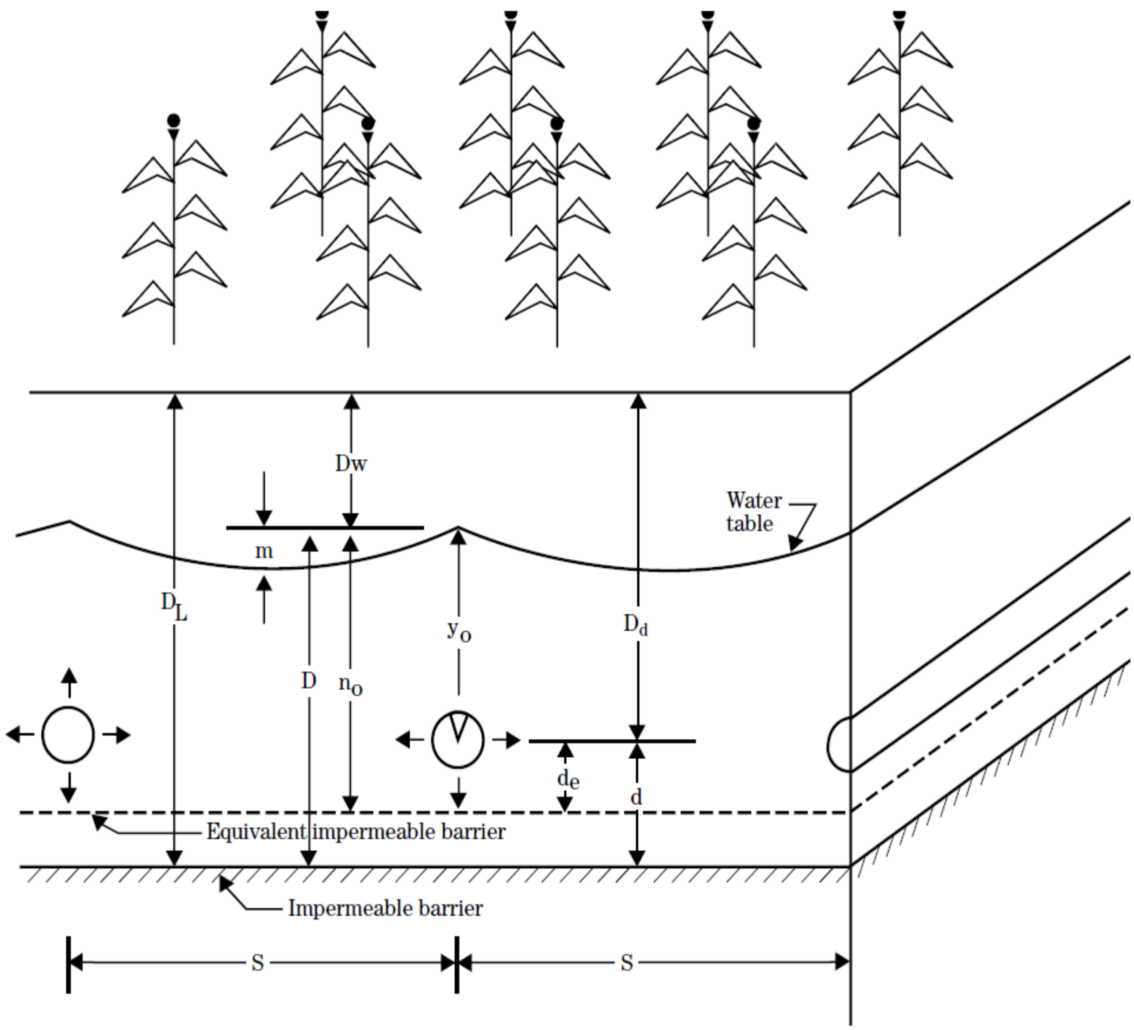
(iii) The hydraulic conductivity of the soil profile should be measured from the surface of the soil to the impermeable layer (if less than 6 feet from the surface of the soil). The 6-foot limitation is based on field experience using normal equipment. Beyond this depth it becomes difficult, if not impossible, to determine the hydraulic conductivity of the soil using field techniques. If the impermeable layer is at a depth of more than 6 feet, the designer can extend the auger in the same hole or perform the auger-hole tests in the bottom of an existing ditch. A procedure for estimating hydraulic conductivity and using Soil Interpretation Form 5, is presented in Section 650.1410(B), Soils.

(8) Lateral Spacing

(i) If water is being added to the system, the water level over the drains must be maintained higher to create enough head to cause water to flow laterally outward from the drain. Figure 14-73 depicts the water table in the soil during subirrigation while water is being supplied to the laterals and at the same time is being withdrawn from the soil by evapotranspiration. It also details the notation to use in the design process and the terminology used to relate the position of the water table in relation to the ground surface, the laterals, and the barrier.

(ii) The spacing of subsurface drain laterals is less (placed closer together) for either controlled drainage or subirrigation than for drainage alone. This is basically because the restricted drainage effect of holding the water table above the drains causes the drains to be less efficient. Further the subirrigation mode of moving water horizontally to the midpoint between laterals requires less space than for drainage alone. For the numerous systems designed and installed, the average lateral spacing is about 70 percent of the recommended drainage spacing from local drainage guides. Because of the many variables, it is recommended that the DRAINMOD computer program be used for the spacing of laterals. For additional details refer to 210-NEH-624-10, "Water Table Control".

Figure 14-73: Subirrigation Lateral Spacing and Water Table Position



D. Operation of water table management system

(1) Operation of a water table management system can be automated. However, until experience has proven the timing and selected stages for the structure settings that give the desired results, frequent observations, manual structure setting, and pump operation should be used. To conserve water and minimize the amount of pumping necessary, the controlled drainage mode should be used to the greatest extent feasible.

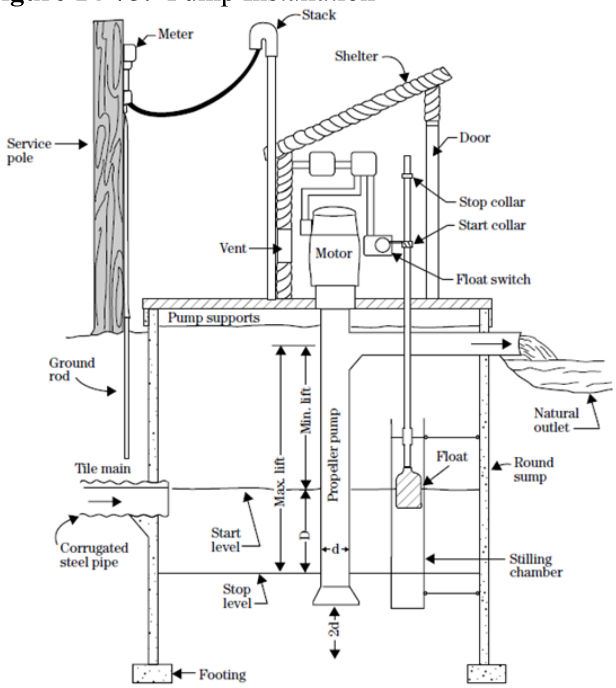
(2) Monitoring wells in the field can provide for direct reading of water table levels that are correlated to stage settings of the control structures. As experience is gained, fewer well readings are needed to provide the information to operate the system. The water table should be maintained close enough to the root zone so that capillary upward flux as demonstrated on the ditch side slope in figure 14-74 provides all the water needed for evapotranspiration. If the water table is too far below the root zone, sufficient water may need to be provided at the source or moved through the soil profile rapidly enough to reestablish the desired water table level. Adequate drainage is needed at all crop stages.

Figure 14-74: Capillary Upard Flux as Demonstrated on the Ditch Side Slope

650.1421 Drainage Pumping

A. Drainage pumping plants remove excess surface or ground water where it is impossible or economically infeasible to obtain gravity outlets for drainage. They are also used on sites that have adequate outlets except during periods of prolonged high-water (fig. 14-75). A much more detailed description of drainage pumping is in NEH, Section 16.

Figure 14-75: Pump Installation



B. Surface Drainage Pumping Conditions

(1) Pumping for surface drainage may be feasible on the following landforms:
(2) Bottom lands or flatlands protected from flooding by dikes, where gravity drainage is restricted because of periodic high stages in the outlet, or where the outlet has inadequate capacity. Floodgates are installed to permit the maximum gravity drainage possible while preventing the inflow of floodwater. The amount of pumping required can vary from a small percentage of the drainage flow to practically all of it.
(3) Coastal plains that do not afford enough slope to the water surface for gravity drainage. Here, the land to be drained is diked, and pumping is done from a sump. The amount of the drainage water that must be pumped depends on the elevation of the land above tidewater. In some situations, the entire runoff must be pumped.
(4) Areas in which the runoff water is to be used for irrigation. The area may or may not be diked, depending on the outlet situation for gravity drainage. Water control structures are necessary.
(5) Areas in which the soil requires a high degree of water table control, such as in areas of organic soils. Pumping is sometimes required to lower water levels during wet periods and raise water levels during dry periods.

C. Subsurface Drainage Pumping Conditions

Conditions under which pumping for subsurface drainage may be feasible:

(1) Where it is desired to add the drainage water to the irrigation water.
(2) Where the outlet is at an elevation that does not permit gravity flow from drains located at depths required for adequate drainage.
(3) Where the indicated method of drainage is to pump the water from an underlying aquifer, which may or may not be under artesian pressure.

D. Relation of Pumping Plant to Drainage System

(1) The pumping plant should be planned and designed as an integral part of the drainage system. The reconnaissance or preliminary survey determines the condition of the drainage outlet and whether pumping is required. A drainage system in which the pumping plant is designed into the system generally functions much more efficiently than one in which the pumping facilities are added after the system is installed because the outlet is inadequate.

(2) Features that Require Coordination

(i) The pumping plant must be designed to pump the amount of water necessary to give adequate drainage against the total head expected. In determining this, disposing of all the runoff possible by diversion around the area and providing for all possible gravity flow through floodgates should be considered.

(ii) The plant should be located where it best serves the intended purposes. Condition of the foundation, access for servicing, proximity to sources of power, and locations that might be susceptible to vandalism should be considered. Where significant sump storage is available, the pumping plant should be located to take maximum advantage of the storage provided. The location should permit safe discharge into the outlet with a minimum of construction outside the diked area

(iii) If possible, the plant should be easily accessible. Ordinarily, the dike can be widened to accommodate vehicular traffic. An all-weather access road is desirable.

(iv) The requirements for a stable foundation often conflict with the other requirements of location. Borings should be made, and the location selected that has the best foundation conditions consistent with other site requirements. An unstable foundation material can considerably increase the cost of a pumping plant. A more intensive investigation before selecting the plant location often yields big dividends in reduced costs.

(3) Sump Storage

(i) Careful consideration should be given to providing storage for runoff within the diked area. The effective storage is that capacity in sump areas and ditches between the lowest elevation at which drainage is by gravity, or the cutoff elevation for the pumps, and the elevation at which flooding of the land to be protected begins. This is determined largely by the topography of the project area and the type of drainage system. A sump for a subsurface drainage system may be only a circular well 8 feet or less in diameter that has 2 feet of effective storage.

(ii) A sizeable area near the surface drainage system outlet that is lower than the area to be drained can be used for storage without crop loss. Borrow pits of appreciable size for dike construction and drainage ditches that have sufficient storage capacity can also be used.

(iii) All of the storage capacity available should be used to reduce the required pumping capacity, considering the economics of the project. For high-value, highly developed cultivated land, the only storage capacity that may be available is that in open ditches. For watersheds used for low-value crops and that may contain appreciable areas of undeveloped land, a rather large area of low-lying land may be devoted to sump storage. This will result in a less expensive pumping plant. Where the area needs to be developed to more intensive use, the pumping capacity can be increased and some of the area otherwise devoted to sump storage can be developed.

(iv) The ditches supplying runoff to the pumps must be capable of delivering water at the maximum pumping rate. The highest roughness factor considered likely to occur should be used to determine the ditch size for this requirement.

(v) Sumps designed to collect, and store large volumes of water generally collect runoff as well as subsurface drainage discharge. These sumps can be used where a uniform rate of discharge is desirable in the drainage outlet or where the discharge is desirable only during specified times.

(vi) The following formula helps determine sump storage requirements for continuous pumping operations over a specified time period:

$$S = V\left(1 - \frac{I}{P}\right)$$

where: V = Total volume of drain water to be stored over a specified time period
S = Sump storage (gallons)
I = Inflow rate (gallons per minute)
P = Pumping rate (gallons per minute)

(vii) The total time during which the pump will operate continuously is defined by:

$$T = \frac{V}{60P}$$

where: T = Pumping time (hr)

(viii) Example: If a continuous flow of 600 gpm is desired and an inflow of 250 gpm occurs for 12 hours, then the storage volume needed in the sump will be:

$$S = 250 \times 12 \times 60 \times \left(1 - \frac{250}{600}\right) = 104{,}994\ gal$$

To convert this to cubic feet, divide the 104,994 gallons by 7.48. S = 14,037 cubic feet.

The continuous flow of 600 gpm would occur for a time of:

$$t = \frac{250x12x60}{60x600} = 5hrs$$

Thus, sump and pumps can be selected for individual farm needs or desires.

(ix) Concrete sumps are most commonly used for subsurface drainage systems because they are easily equipped with automatic controls and require little space and minimum maintenance.

(x) The sump capacity is based upon the inflow and pumping rate so that the pump cycle is sufficient to allow the pump to operate with an acceptable overall efficiency. A sump should be designed to allow about 10 cycles per hour in the pump system. If it exceeds 15 cycles per hour, pump efficiency and power costs may be undesirable.

(xi) The inflow rate, pumping rate, storage capacity, and cycle time for drainage outlets can be determined using the following formula.

$$\frac{60}{N} = \frac{S}{I} + \frac{S}{P - I}$$

where: P = Pumping rate (gpm)
I = Inflow rate (gpm)
S = Storage volume (gal) between the on and off stage of the sump
N = Number of complete cycles per hour where the length of the complete cycle equals the standing time plus the running time

(xii) The following formula can be used to rearrange and change the storage from S in gallons to S in cubic feet:

$$N = \frac{7.48 \times I \times (P - I)}{P} \times S$$

(xiii) This formula can also be used to compute the frequency of cycling for given values of S and P and for various rates of inflow.

(xiv) The maximum S occurs when I = (1/2)P. For design purposes the amount of storage required in cubic feet is determined by the following equation:

$$S = \frac{2P}{N}$$

where: N = the maximum or permissible number of cycles per hour
S = the storage in cubic feet

(xv) The sump depth between the on and off positions of the pump control and the cross-sectional area of the sump are chosen so that their product is equal to or greater than S. Generally, the S value is used as a minimum sump requirement.

(xvi) If the number of cycles per hour is set at 5, the last formula may be further simplified as

$$S = 0.4P$$

(xvii) The pumping rate P should be equal to or greater than the peak discharge rate from the drain system. For sump depth of more than 15 feet between on and off positions, consideration should be given to a horizontal type sump, which may be more economical.

E. Economic Justification of Pumping Plant

Frequently, a decision must be made as to whether areas protected against flooding by dikes and floodgates should be provided with a pumping plant to remove interior drainage during periods when the floodgates are closed. Such a decision cannot be made without a frequency study of precipitation and flood stage records, a determination of the project area that will be flooded without a pumping plant, and an estimate of the resulting damages. The study required for the justification of a pumping plant should be based on a comparison of its cost against the damages expected without it.

F. Pumping from Subsurface Aquifers

In drainage systems that require pumping from an underlying aquifer, location of the wells and pumps must be based on an extensive subsurface investigation. This investigation must determine the practicability of lowering the water table by pumping the aquifer and also determine the most suitable location for the wells to accomplish the objectives. The drainage water may be discharged either into an irrigation system or through shallow surface ditches to a drainage outlet. In either case, location of the well would be based primarily on requirements for pumping the aquifer instead of conditions for discharge of the effluent.

G. Basic information required for plant design

(1) The amount of data required varies according to specific arrangements. As a general rule, data on the following items are needed:

(2) Location of plant—detailed topography and data on foundation investigations may or may not be provided.

(3) Pump capacity—design removal rate less available storage.

(4) Maximum, minimum, and average static heads—based on stage-frequency analysis of the outlet.
    (i) The maximum static head is the elevation of the maximum stage in the outlet minus the optimum elevation in the suction bay. Efficiency at this head may be lower than that required at the average head.
    (ii) The minimum static head is the difference between the mean monthly minimum stage in the outlet and the optimum stage in the suction bay. Where multiple pumping units are required, at least one unit should have a high efficiency at this head.
    (iii) The average static head is the difference between the average monthly stage in the outlet and the optimum stage in the suction bay, weighted according to the amounts of runoff to be expected for the respective months. The plant should operate at peak efficiency for this stage.
(5) Type, Number, and Size of Pumps—For low heads of up to 15 to 20 feet, the axial flow pump is recommended. For heads of up to 40 to 50 feet, the mixed flow pump is recommended. For large installations, at least two pumps should be recommended with the relative size based on operational requirements. For average conditions, one of the two pumps should have about twice the capacity of the other. A 3-unit plant gives good flexibility of operation. Sizes recommended should be based on holding velocities in the discharge pipe at 8 to 10 feet per second for the design capacity.
(6) Recommended Start and Stop Elevations for Each Unit.
(7) Schematic layout of the proposed plant—should include suggestions for layout and appurtenant facilities. Such items as the installation of discharge pipes over dikes, trash racks, siphon breakers, equipment for automatic control of operation, and access roads should be indicated.

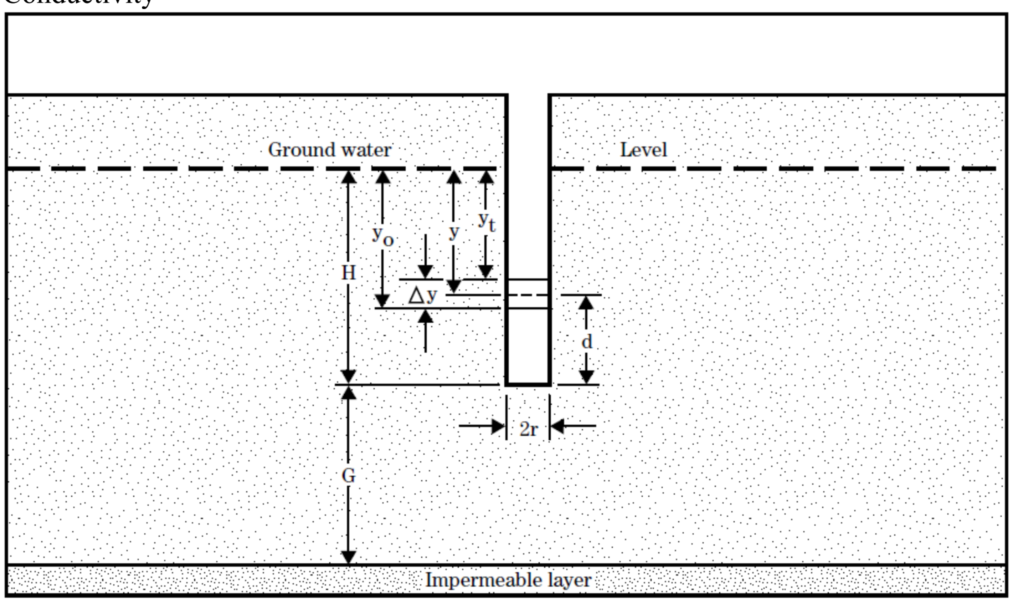
Appendix 14D Auger-hole Procedure for Hydraulic Conductivity

A. Auger-hole Method

(1) The auger-hole method is the simplest and most accurate way to determine soil permeability (fig. 14D-1). The measurements obtained using this method are a combination of vertical and lateral conductivity, however, under most conditions, the measurements represent the lateral value. The most limiting obstacle for using this method is the need for a water table within that part of the soil profile to be evaluated. This limitation requires more intensive planning. Tests must be made when a water table is available during the wet season. Obtaining accurate readings using this method requires a thorough knowledge of the procedure.

(2) The principle of the auger-hole method is simple. A hole is bored to a certain distance below the water table. This should be to a depth about 1 foot below the average depth of drains. The depth of water in the hole should be about 5 to 10 times the diameter of the hole. The water level is lowered by pumping or bailing, and the rate at which the ground water flows back into the hole is measured. The hydraulic conductivity can then be computed by a formula that relates the geometry of the hole to the rate at which the water flows into it.

Figure 14D-1: Symbols for Auger-hole Method of Measuring Hydraulic Conductivity



B. Formulas for determination of hydraulic conductivity by auger-hole method—Determination of the hydraulic conductivity by the auger-hole method is affected by the location of the barrier or impermeable layer.

(1) A barrier or impermeable layer is defined as a less permeable stratum, continuous over a major portion of the area and of such thickness as to provide a positive deterrent to the downward movement of ground water. The hydraulic conductivity of the barrier must be less than 10 percent of that of the overlying material if it is to be considered as a barrier. For the case where the impermeable layer coincides with the bottom of the hole, a formula for determining the hydraulic conductivity (K) has been developed by Van Bavel and Kirkham (1948).

$$K = \left(\frac{2220r}{SH}\right)\left(\frac{\Delta y}{\Delta t}\right)$$

where: S = a function dependent on the geometry of the hole, the static depth of water, and the average depth of water during the test
K = hydraulic conductivity (in/hr)
H = depth of hole below the ground water table (in)
r = radius of auger-hole (in)
y = distance between ground water level and the average level of water in the hole (in) for the time interval t (s)
Δy = rise of water (in) in auger-hole during Δt
t = time interval (s)
G = depth of the impermeable layer below the bottom of the hole (in). Impermeable layer is defined as a layer that has the permeability of no more than a tenth of the permeability of the layers above.
d = average depth of water in auger-hole during test (in)

(2) A sample form for use in recording field observations and making the necessary computations is illustrated in figure 14D-2. This includes a chart for determining the geometric function S for use in the formula for calculation of the hydraulic conductivity.

(3) The more usual situation is where the bottom of the auger-hole is some distance above the barrier. Formulas for computing the hydraulic conductivity in homogeneous soils by the auger-hole method have been developed for both cases (Ernst, 1950). These formulas (2 and 3) are converted to English units of measurement.

(4) For the case where the impermeable layer is at the bottom of the auger-hole, G = 0:

$$K = \frac{15{,}000r2}{(H + 10r)\left(2 - \frac{y}{H}\right)y}\frac{\Delta y}{\Delta t}$$

(5) For the case where the impermeable layer is at a depth ≥ 0.5H below the bottom of the auger-hole:

$$K = \frac{16{,}667r2}{(H + 20r)\left(2 - \frac{y}{H}\right)y}\frac{\Delta y}{\Delta t}$$

(6) The following conditions should be met to obtain acceptable accuracy from use of the auger-hole method:
- $2r > 2\ 1/2$ and $< 5\ 1/2$ inches
- $H > 10$ and < 80 inches
- $y > 0.2\ H$
- $G > H$
- $y < 1/4\ y_o$

(7) Charts have been prepared for solution of equation 3 for auger-holes of r = 1 1/2 and 2 inches. For the case where the impermeable layer is at the bottom of the auger-hole, the hydraulic conductivity may be determined from these charts by multiplying the value obtained by a conversion factor f as indicated on figure 14D-3.

Figure 14D-2a: Auger-hole Method of Measuring Hydraulic Conductivity—sheet 1 of 2

Field Measurement of Hydraulic Conductivity
Auger-Hole Method

For use only where bottom of hole coincides with barrier.

Soil Conservation District *Dry River* Field Office *Salt Flat*

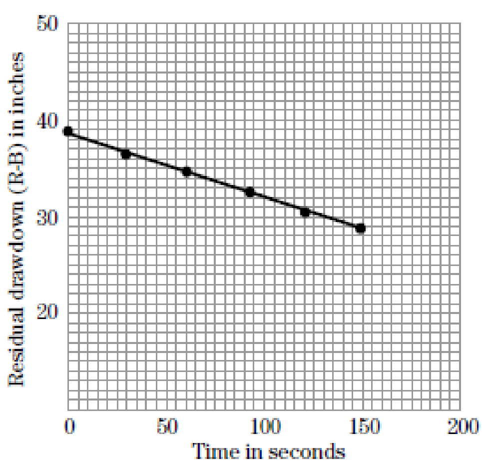
Cooperator *Joe Doe - Farm No. 2* Location *1/2 Mi. E. Big Rock Jct.*

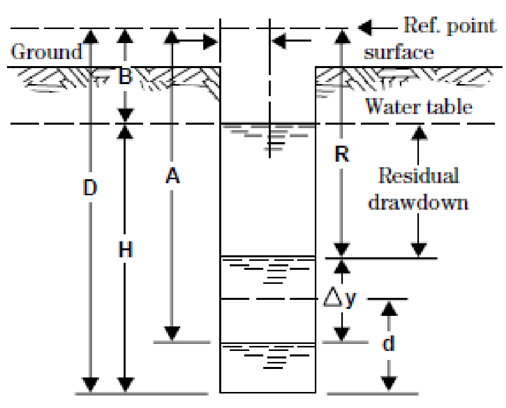
SCD Agreement No. *264* Field No. *4* Farm No. *B-817*

Technician *Tom Jones* Date *1 June 64*

Boring No. *4* Salinity (EC) Soil *—* Water *5.6* Estimated K *1.0 in/hr*

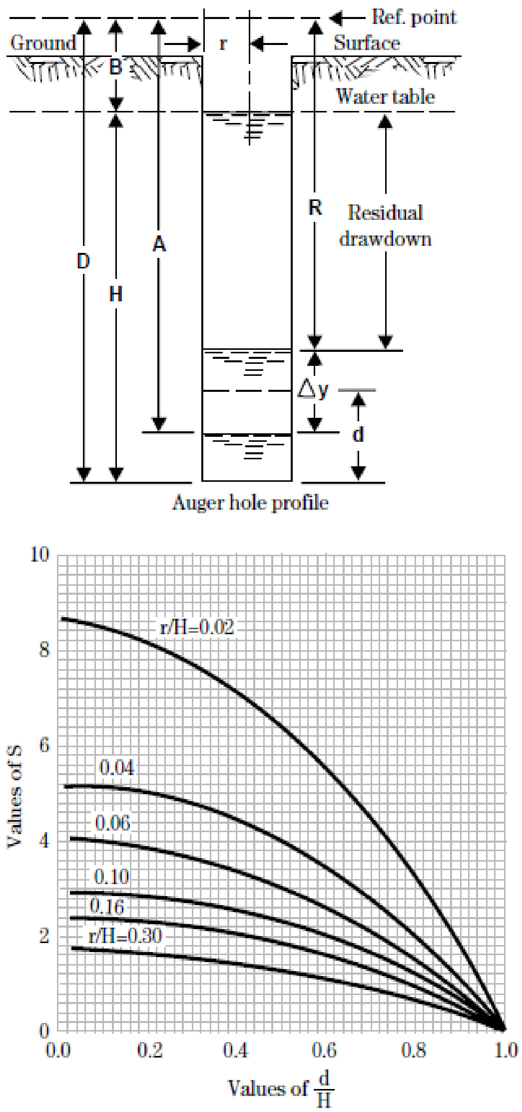
Start 10:03 Elapsed Time	Δt	Distance to water surface from reference point			Δy	Residual drawdown
		Before pumping	After pumping	During pumping		
		B	A	R	A-R	R-B
Seconds	Seconds	Inches	Inches	Inches	Inches	Inches
XX	XX	43	XX	XX	XX	XX
0.0	XX	XX	81.5		0.00	38.5
30				79.0		36.0
60				77.5		34.5
90				76.0		33.0
120				74.0		31.0
150	150			72.0	9.5	29.0





Auger hole profile

Figure 14D- 2a: Auger-hole Method of Measuring Hydraulic Conductivity—sheet 2 of 2



Hole dia. 4"

Hole depth 84" Ground to Ref.=11"

D= 93"

r= 2

H= 50

d= 16.2

Δy= 9.5

Δt= 150 seconds

r/H= 2 / 50 = 0.04

d/H= 16.2 / 50 = 0.32

S= 4.7

$$K = 2220 \times \frac{2}{(4.7)\,(50)} \times \frac{9.5}{150}$$

K= 1.2 in/hr

Figure 14D- 2b: Auger-hole Method of Measuring Hydraulic Conductivity—sheet 1 of 2

Field Measurement of Hydraulic Conductivity Auger-Hole Method

For use only where bottom of hole coincides with barrier.

Soil Conservation District____________________ Field Office________________

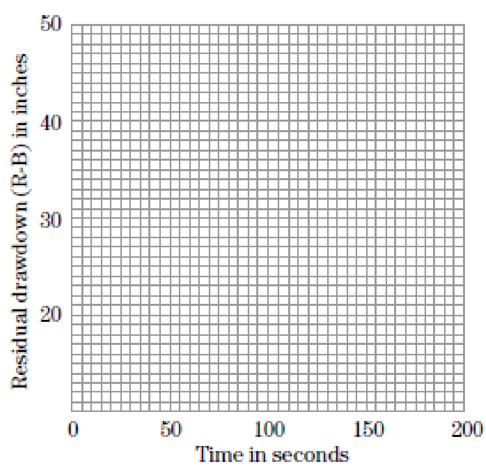
Cooperator__________________________ Location________________

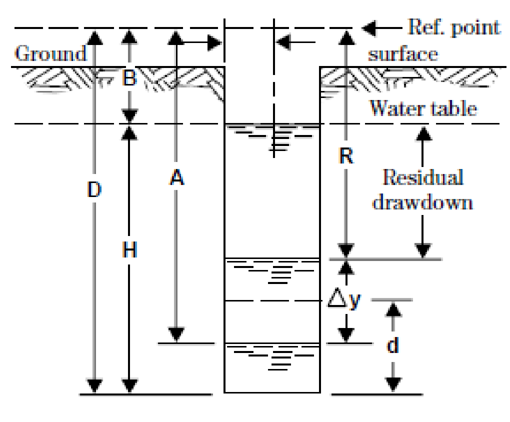
SCD Agreement No.__________Field No._______ Farm No.________________

Technician__________________________ Date________________

Boring No.______ Salinity (EC) Soil ______ Water______ Estimated K__________

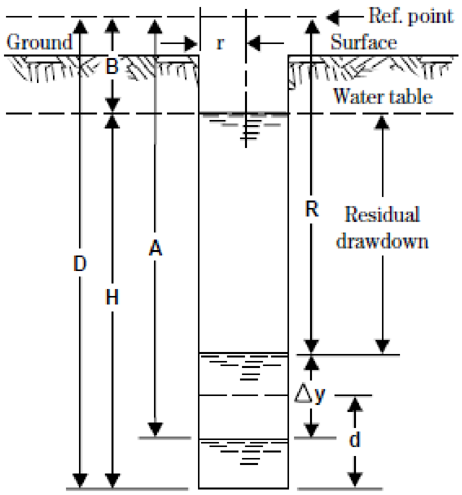
Start 10:03 Elapsed Time	Δt	Distance to water surface from reference point			Δy	Residual drawdown
		Before pumping	After pumping	During pumping		
		B	A	R	A-R	R-B
Seconds	Seconds	Inches	Inches	Inches	Inches	Inches



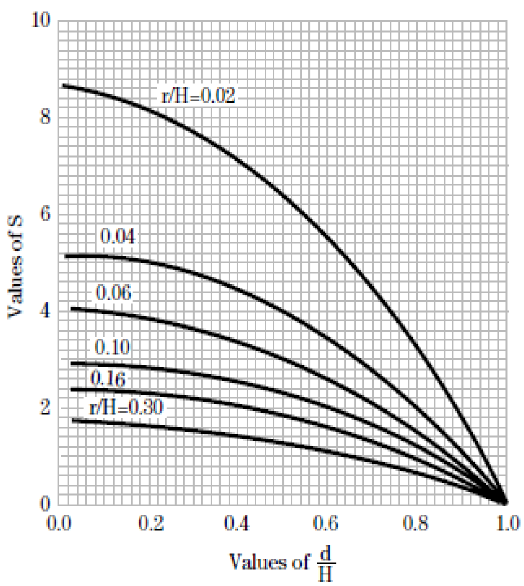


Auger hole profile

Figure 14D- 2b: Auger-hole Method of Measuring Hydraulic Conductivity—sheet 2 of 2



Auger hole profile



Hole dia. 4"

Hole depth 84" Ground to Ref.=11"

D= 93"

r= 2

H= 50

d= 16.2

Δy= 9.5

Δt= 150 seconds

r/H= 2 / 50 = 0.04

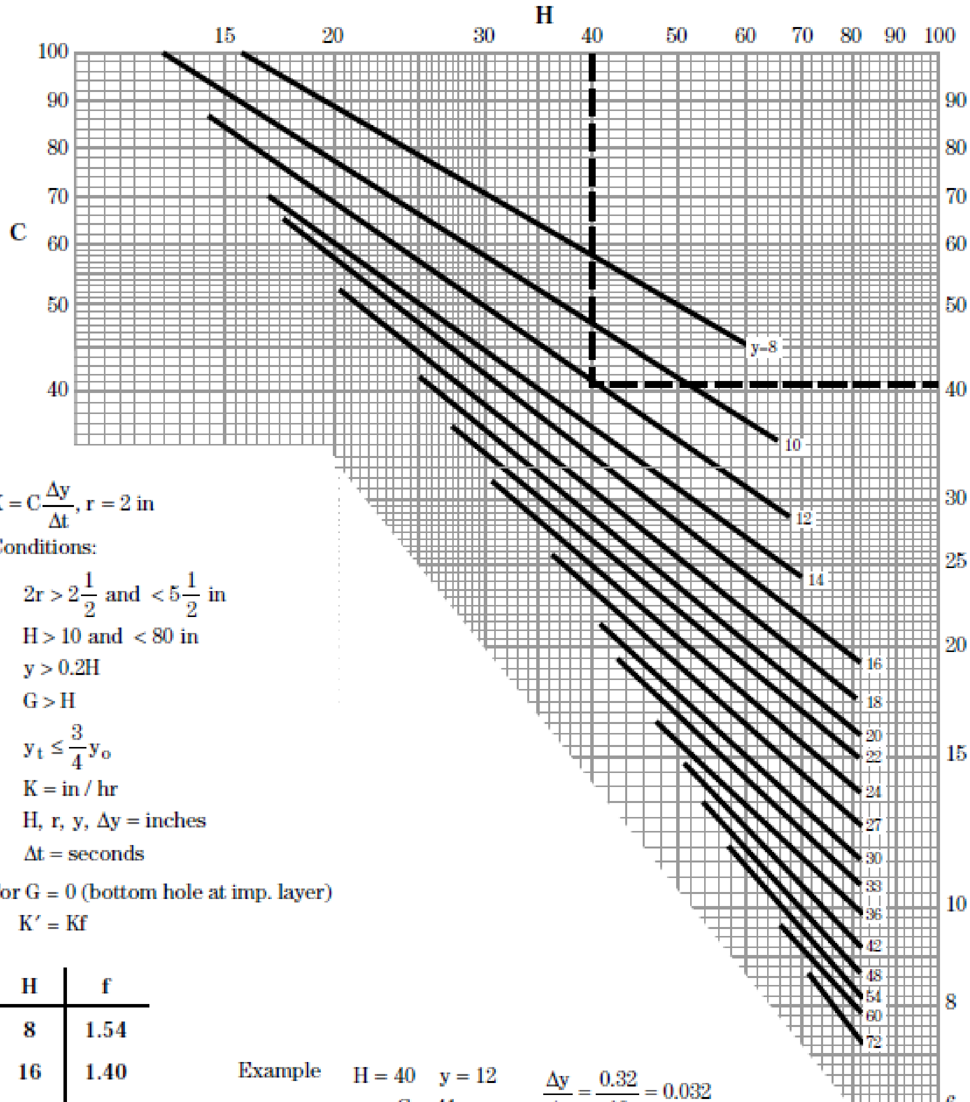
d/H= 16.2 / 50 = 0.32

S= 4.7

$$K=2220 \times \frac{2}{(4.7)\,(50)} \times \frac{9.5}{150}$$

K= 1.2 in/hr

Figure 14D-3: Hydraulic Conductivity—Auger-hole Method Using the Ernst Formula



$K = C\dfrac{\Delta y}{\Delta t}$, r = 2 in

Conditions:

$2r > 2\frac{1}{2}$ and $< 5\frac{1}{2}$ in

$H > 10$ and < 80 in

$y > 0.2H$

$G > H$

$y_t \leq \frac{3}{4} y_o$

K = in / hr

H, r, y, Δy = inches

Δt = seconds

For G = 0 (bottom hole at imp. layer)

$K' = Kf$

H	f
8	**1.54**
16	**1.40**
24	**1.31**
36	**1.22**
48	**1.16**
60	**1.13**
72	**1.10**

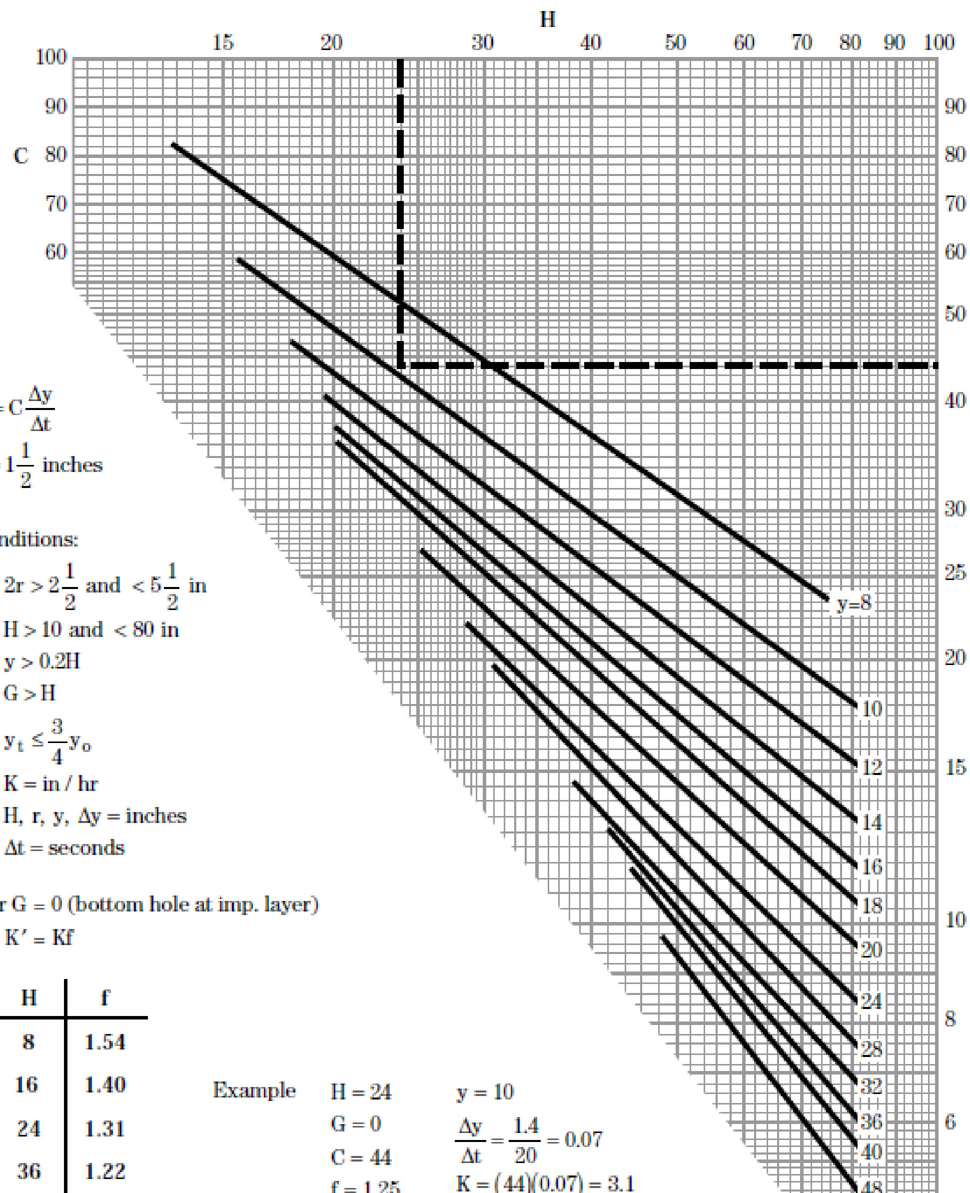
Example H = 40 y = 12 $\dfrac{\Delta y}{\Delta t} = \dfrac{0.32}{10} = 0.032$

C = 41

$K = 41 \times 0.032 = 1.31$ in/hr

REFERENCE From formula L.F. Ernst Groningen, The Netherlands	U.S. DEPARTMENT OF AGRICULTURE	STANDARD DWG. NO.
$K = \dfrac{16{,}667r^2}{(H+20r)\left(2-\frac{y}{H}\right)y}\dfrac{\Delta y}{\Delta t}$	SOIL CONSERVATION SERVICE	ES-734 SHEET 1 OF 2
	ENGINEERING DIVISION-DRAINAGE SECTION	DATE 3-23-71

Figure 14D-3. Hydraulic Conductivity—Auger-hole Method Using the Ernst Formula – continued



$K = C\dfrac{\Delta y}{\Delta t}$

$r = 1\frac{1}{2}$ inches

Conditions:

- $2r > 2\frac{1}{2}$ and $< 5\frac{1}{2}$ in
- $H > 10$ and < 80 in
- $y > 0.2H$
- $G > H$
- $y_t \le \frac{3}{4} y_o$
- K = in / hr
- H, r, y, Δy = inches
- Δt = seconds

For G = 0 (bottom hole at imp. layer)
$K' = Kf$

H	f
8	1.54
16	1.40
24	1.31
36	1.22
48	1.16
60	1.13
72	1.10

Example

$H = 24$ $\quad y = 10$

$G = 0$ $\quad \dfrac{\Delta y}{\Delta t} = \dfrac{1.4}{20} = 0.07$

$C = 44$ $\quad K = (44)(0.07) = 3.1$

$f = 1.25$ $\quad K' = (3.1)(1.25) = 3.9$ in/hr

REFERENCE From formula L.F. Ernst Groningen, The Netherlands

$$K = \frac{16,667r^2}{(H+20r)\left(2-\frac{y}{H}\right)y}\,\frac{\Delta y}{\Delta t}$$

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DRAINAGE SECTION

STANDARD DWG. NO.
ES-734
SHEET 2 OF 2
DATE 3-23-71

B. Equipment for auger-hole method

(1) The following equipment is required to test hydraulic conductivity:
- suitable auger
- pump or bail bucket to remove water from the hole
- watch with a second hand
- device for measuring the depth of water in the hole as it rises during recharge
- well screen may be necessary for use in unstable soils

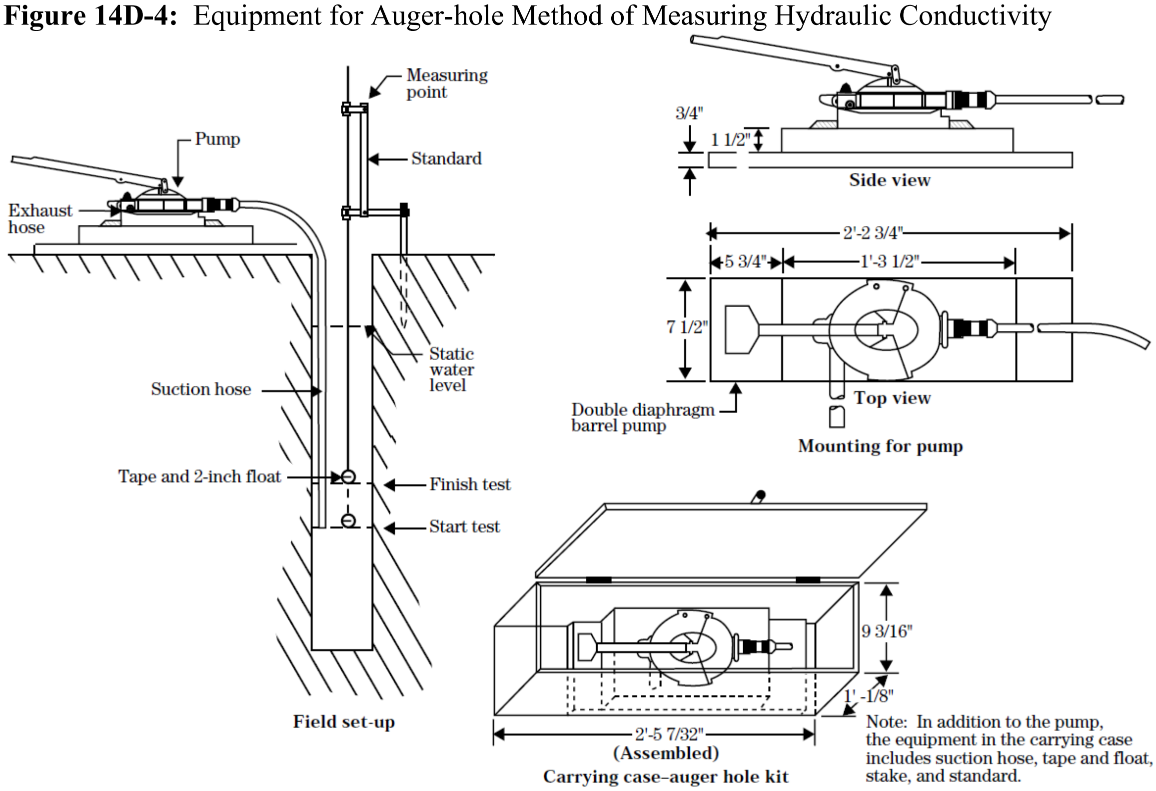
(2) Many operators prefer a well-made, lightweight boat or stirrup pump that is easily disassembled for cleaning. A small, double diaphragm barrel pump has given good service. It can be mounted on a wooden frame for ease of handling and use.

(3) For the depth measuring device, a lightweight bamboo fishing rod marked in feet tenths and hundredths and that has a cork float works well. Other types of floats include a juice can with a standard soldered to one end to hold a light weight measuring rod.

(4) A field kit for making the auger hole measurement of hydraulic conductivity is illustrated in figure 14D-4. In addition to the items indicated in this figure, a watch and a soil auger are needed.

(5) A perforated liner for the auger-hole is used in making the auger-hole measurement in fluid sands. This liner keeps the hole open and maintains the correct size. Several types of liners are used. Adequate slot openings or other perforations must be provided to allow free flow into the pipe.

Figure 14D-4: Equipment for Auger-hole Method of Measuring Hydraulic Conductivity



(6) The openings in the screen should not restrict flow appreciably. The head loss through the screen should be negligible, and the velocity of flow through the openings should be small (0.3 foot per second or less) to prevent movement of fines into the hole. These criteria generally are met if the area of openings is 5 percent or more of the total screen area.
(7) The Bureau of Reclamation uses 4-inch down spouting with 60 1/8- by 1-inch slots per foot of length. This works well in a variety of soils. A screen from the Netherlands is made from a punched brass sheet 2 millimeters thick with holes averaging about 0.5 millimeter in diameter. It is rolled into a tube 8 centimeters in diameter by 1 meter long. This screen works well because the sheet is rolled so that the direction in which the holes are punched is outward and the holes are variable in size. It has been used in many troublesome soils, and no clogging or failure to keep fines out of the hole has been reported.
(8) Good judgment is needed in determining how far to drawdown the water level in the auger-hole for the test. A minimum drawdown is necessary to physically satisfy theoretical criteria (refer to conditions given in fig. 14D-4). Generally, a larger drawdown is made for slowly permeable soils than that for more permeable soils. A small drawdown for holes in sloughing soils may reduce the amount of sloughing. To prevent picking up sand in the pump, pumping should stop when the water level is within a few inches of the bottom of the hole.
(9) Measurement of the rate of recovery of water in the auger-hole should be completed before a fourth of the total amount of drawdown is recovered. Four or five readings should be taken at uniform short time intervals, and a plot of the readings made to determine a uniform rate of recovery to use in the formula. Plotting of time in seconds against the residual drawdown in inches indicates those readings at the beginning and end of the test that should be discarded and the proper values of t and y to use.

Appendix 14E Transient Flow Method

A. The following transient state procedure for determining drain spacing was developed by the U.S. Bureau of Reclamation. With permission from USBR the description and figures are reproduced from their Drainage Manual (USBR, 1993).

B. Transient Flow Method of Drain Spacing

In the 1950’s, the Bureau of Reclamation developed a method for estimating drain spacing based on transient flow conditions that relates the behavior of the water table to time and drain spacing. The validity of this method is demonstrated by the close correlation between actual spacing and drawdown values, and the corresponding predicted values. Reclamation’s method of determining drain spacing accounts for time, water quantity, geology, and soil characteristics pertinent to the irrigation of specific areas. Although this method was developed for use in a relatively flat area, laboratory research and field experience show the method is applicable for areas having slopes up to 10 percent.

C. Background of the Method

(1) In general, water tables rise during the irrigation season in response to deep percolation water from irrigation applications. In arid areas, water levels reach their highest elevation after the last irrigation of the season. In areas of year-round cropping, maximum levels occur at the end of the peak period of irrigation. The water table recedes during the slack or nonirrigation period and starts rising again with the beginning of irrigation the following year. Nearly all shallow water tables exhibit this cyclic phenomenon on an annual basis. Shallow water table rises also occur after each recharge to the ground water from precipitation or irrigation. Lowering of the water table occurs between recharges.

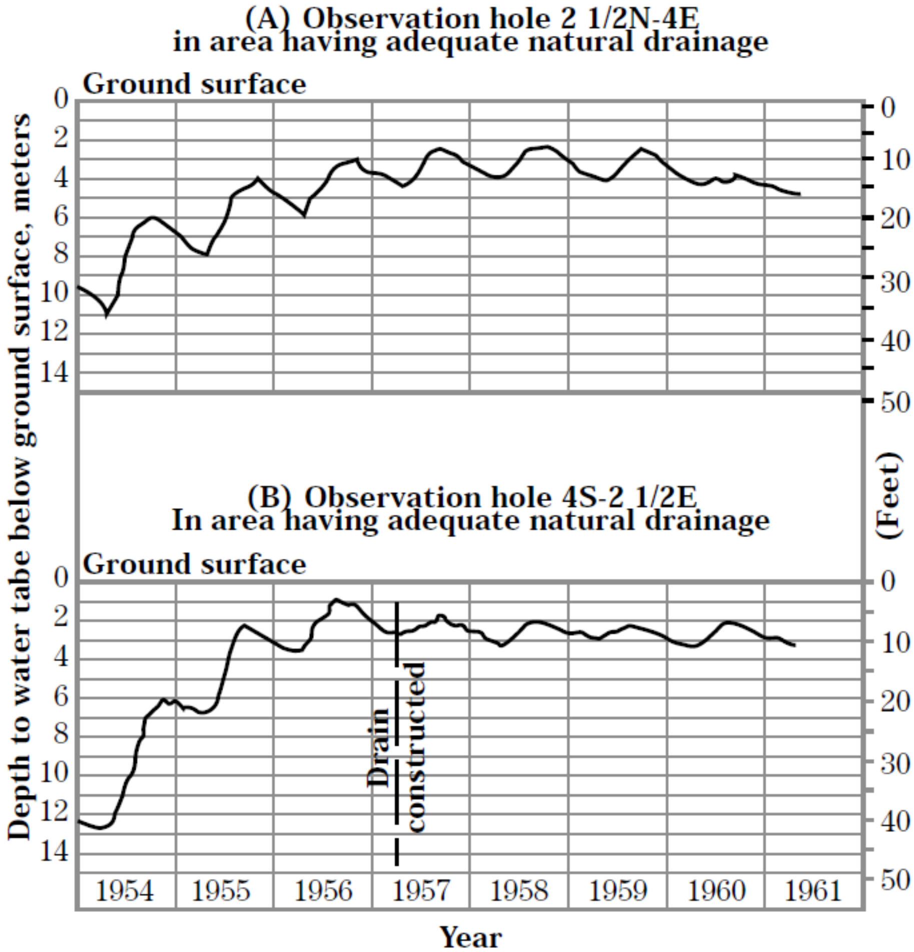
(2) If annual discharge from an area does not equal or exceed annual recharge, the general cyclic water table fluctuation trend will progress upward from year to year. Specifically, the maximum and minimum water levels both reach progressively higher levels each year.

(3) When the annual discharge and recharge are about equal, the range of the cyclic annual water table fluctuation becomes reasonably constant. This condition is referred to as dynamic equilibrium.

(4) Figure 14E-1 shows two ground water hydrographs that indicate how the above conditions developed under irrigation in two specific areas. The hydrograph for (A) on this figure shows the upward cyclic trend and the stabilization of the cyclic fluctuation. Dynamic equilibrium occurred when the maximum water table elevation reached a point sufficiently below ground level to preclude the need for artificial drainage. The hydrograph for (B) shows a similar upward trend of the water table in another area. At this location, the maximum 1956 water table elevation and the continued upward trend indicated the imminence of a damaging water table condition in 1957. Therefore, a drain was constructed early in 1957, and its effect in producing dynamic equilibrium at a safe water table level is evident in the graph.

(5) Reclamation’s method of determining drain spacing takes into account the transient regimen of the ground water recharge and discharge. The method gives spacings that produce dynamic equilibrium below a specified water table depth. The method also provides for consideration of specific soils, irrigation practices, crops, and climatic characteristics of the area under consideration.

Figure 14E-1: Comparison between Computed and Measured Drain Spacings



D. Data required

(1) Figure 14E-2 shows graphically the relationship between the following dimensionless parameters based on the transient flow theory:

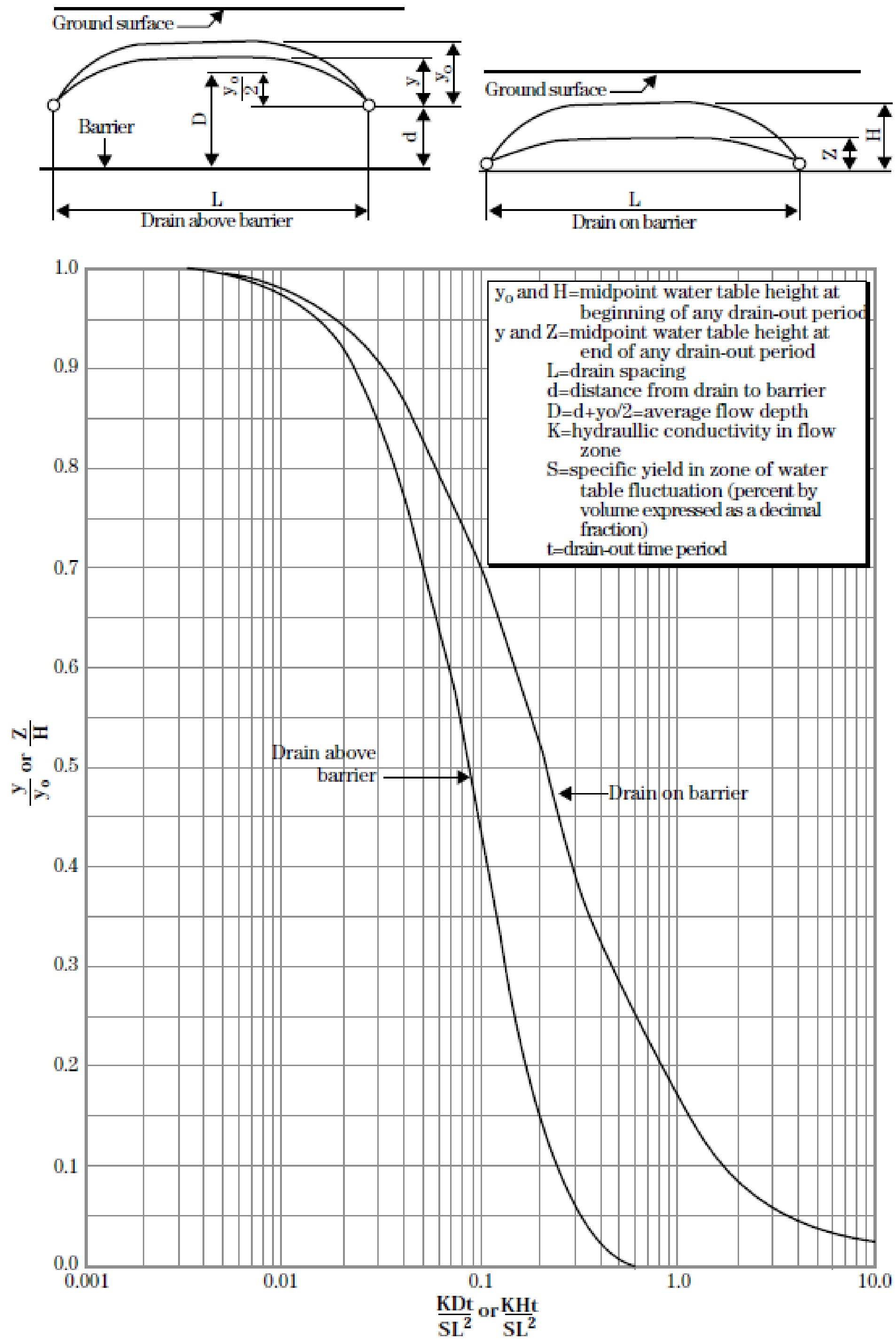
$$\frac{y}{y_o}\ versus \frac{KDt}{SL2} and \frac{Z}{H} versus \frac{KHt}{SL2}$$

(2) This figure shows relationships midpoint between drains for cases where drains are located above or on a barrier. Definitions of the various terms in the parameters are as follows:

(3) y_o and H—The water table height above the drain, midway between the drains and at the beginning of each individual drain-out period, is represented by y_o and H for drains above and on the barrier, respectively. As used in the drain spacing calculations, y_o and H represent the water table height immediately after a water table buildup caused by deep percolation from precipitation or irrigation. Parameter terms y_o and H also represent the height of the water table at the beginning of each new drain-out period during the lowering process which occurs in the nonirrigation season. The maximum values of y_o and H are based on the requirements for an aerated root zone which, in turn, are based on the crops and climatic conditions of each specific area.

(4) y and Z—The water table height above the drain, midway between the drains and at the end of each individual drain out period, is represented by y and Z for drains above and on the barrier, respectively. These terms represent the level to which the midpoint water table elevation falls during a drain-out period.

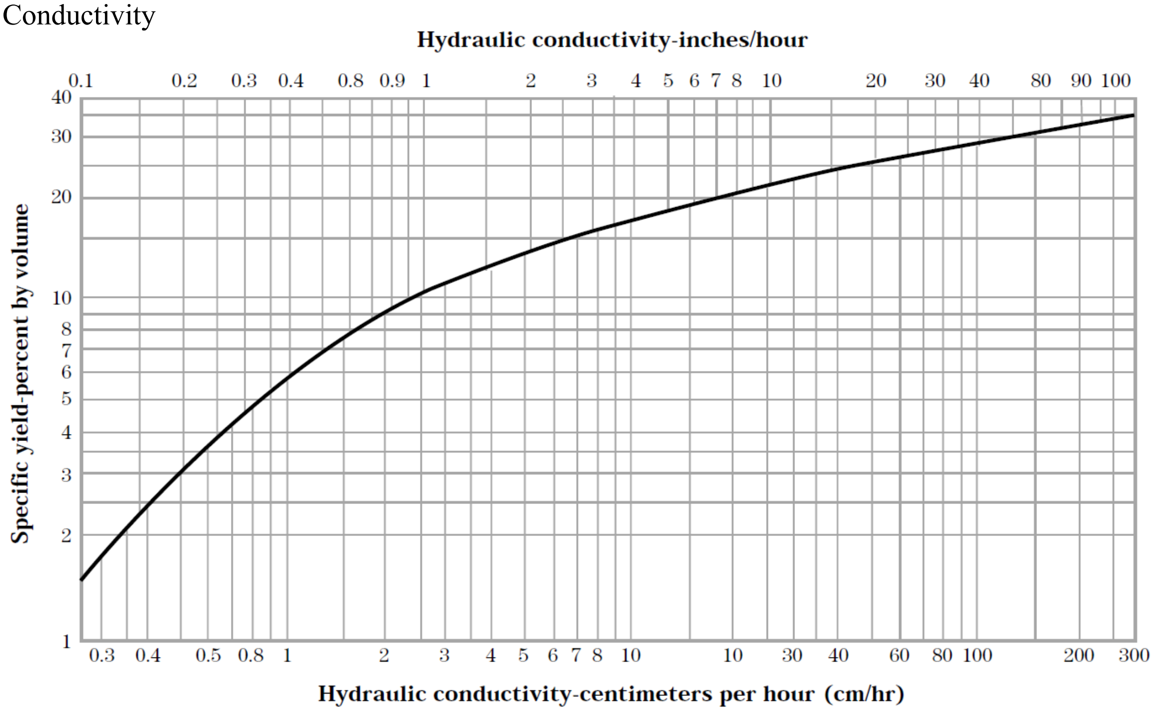
Figure 14E-2: Curves Showing Relationship of Parameters Needed for Drain Spacing Calculations Using the Transient-Flow Theory



(5) Hydraulic conductivity, K—As used in this method, K represents the hydraulic conductivity in the flow zone between drains. Specifically, K is the weighted average hydraulic conductivity of all soils between the maximum allowable water table height and barrier, the barrier being a slowly permeable zone. The mathematical solution of the transient flow theory assumes homogeneous, isotropic soils in this zone. Such assumptions rarely exist; however, the use of a weighted K value has given a good correlation between measured and computed values for drain spacing and water table fluctuations. The K value is obtained by averaging the results from in-place hydraulic conductivity tests at different locations in the area to be drained.

(6) Specific yield, S—The specific yield of a soil is the amount of ground water that will drain out of a saturated soil under the force of gravity. S is approximately the amount of water held by a soil material, on a percent-by-volume basis, between saturation and field capacity. Specific yield, therefore, relates the amount of fluctuation of the water table to the amount of ground water added to or drained from the system. Based on considerable data, a general relationship has been developed between hydraulic conductivity and specific yield. This relationship is shown on figure 14E-3 and values from this figure can be used to estimate specific yield values used in the drain spacing calculations in most cases.

Figure 14E-3: Curve Showing General Relationship between Specific Yield and Hydraulic Conductivity



(7) Because the fluctuation of the water table in a drained area takes place in the soil profile zone between the drains and the maximum allowable water table height, it is reasonable to assume that the average specific yield in this zone will adequately reflect water table fluctuations. The use of figure 14E-3 to estimate the specific yield requires that the weighted average hydraulic conductivity in this zone be determined.

(8) The specific yield value, when used in the parameters of figure 14E-2, accounts for the drain out associated with lowering the water table. To determine the buildup of the water table from each increment of recharge, the depth of each recharge should be divided by the specific yield.

(9) Time, t—This variable represents the drain out time between irrigations or at specified intervals during the nonirrigation season. In an irrigated area, the periods between irrigations have generally been established. The drain spacing calculations should separate the longer nonirrigation season into two or three approximately equal periods for accuracy in results.

(10) Flow depth, D—The flow depth is the average flow depth transmitting water to the drain. As shown on figure 14E-2, D is equal to the distance from the barrier to the drain, plus one-half the distance from the drain to the midpoint water table at the beginning of any drain out period.

$$D = d + \frac{y_o}{2}$$

(11) The theoretical derivation for the case where drains are located above a barrier was based on the assumption that the distance from the drain to the barrier, d, is large compared with the midpoint water table height, y_o. This poses a question regarding cases where the drains are above the barrier, but d is not large compared with y_o. In verifying the applicability of figure 14E-2, studies have indicated when

$$\frac{d}{yo} \leq 0.10$$

(12) the spacing computations should be made as if the drains were located on the barrier, and when

$$\frac{d}{yo} \geq 0.80$$

(13) the computations should be made as if the drains were located above the barrier. A family of curves could be drawn between the two curves shown on figure 14E-2, or a computer program could be used to account for the values between 0.10 and 0.80.

$$\frac{d}{y_o}$$

(14) The need for either of these refinements in the practical application of this method is not necessary.

(15) Drain spacing, L—The drain spacing is the distance between parallel drains. However, this distance is not calculated directly using this method. Values of L must be assumed until a solution by trial and error results in annual water table buildup and decline that will offset each other within acceptable limits. This resulting condition is defined as a state of dynamic equilibrium.

E. Convergence

(1) When ground water flows toward a drain, the flow converges near the drain. This convergency causes a head loss in the ground water system and must be accounted for in the drain spacing computations. Figure 14E-2 does not account for this convergency loss when the drain is above the barrier, and the drain spacing derived using this curve is too large.

(2) A method of accounting for convergence loss, developed by the Dutch engineer Hooghoudt, considers the loss in head required to overcome convergence in the primary spacing calculation. His method accounts for this head loss by using an equivalent depth, d´, to replace the measured depth, d in the calculation of

$$D = d + \frac{y_o}{2}$$

(3) Hooghoudt's correction for convergence can be determined from the following equations:

$$d' = \frac{d}{1 + \frac{d}{L\left(2.55 ln\left(\frac{d}{r - c}\right)\right)}} \; for \; 0 < \frac{d}{L} \leq 0.31$$

$$d' = \frac{L}{2.55\left(ln\left(\frac{L}{r - 1.15}\right)\right)} \; for \; \frac{d}{L} > 0.31$$

where: d = distance from drain to barrier
d´ = Hooghoudt's equivalent distance from drain to barrier
L = drain spacing
r = outside radius of pipe plus gravel envelope
c = $3.55 - 1.6\frac{d}{L} + 2\left(\frac{d}{L}\right)^2$
ln = $\log_e$= natural log

(4) Curves have also been developed for determining d´ and are shown on figures 14E-4 and 14E-5. These curves were developed for an effective drain radius, r, of 0.18 meter (0.6 foot) and should cover most pipe drain conditions. The effective drain radius is defined as the outside radius of the pipe plus the thickness of the gravel envelope. The use of the Hooghoudt method is also a trial and error process of assuming drain spacings. The d´ value for the assumed spacing is obtained from figures 14E-4 or 14E-5 and is used to obtain the corrected average flow depth. This method of correcting for convergence has been found to be most appropriate for use with Reclamation's method of determining drain spacing and discharge rates.

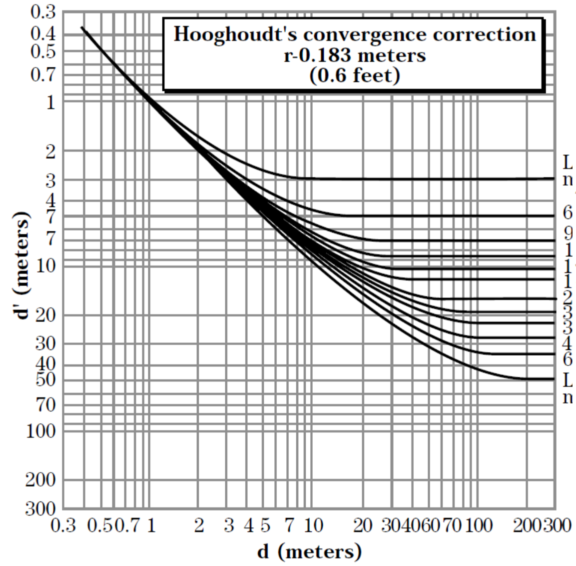
$$D' = d' + \frac{y_o}{2}$$

(5) If the spacing that results from use of the equivalent depth d´ is reduced by more than 5 percent from the spacing that results from use of the initial depth d, another iteration should be done using the initial depth d and the reduced spacing that resulted from the first d´.

(6) The curve of figure14E- 2 for the drain on the barrier is based on a solution with the convergence accounted for in the initial mathematical model. Therefore, no correction for convergence is required when using this curve.

Figure 14E-4: Curves for Determining Hooghoudt's Convergence Correction

a. metric units



b. U.S. customary units

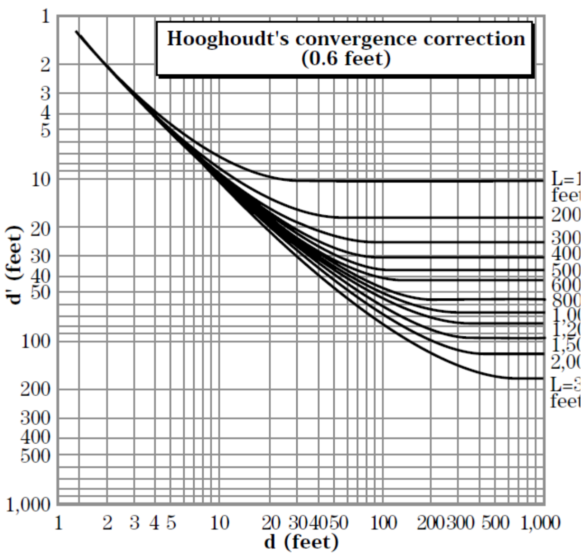
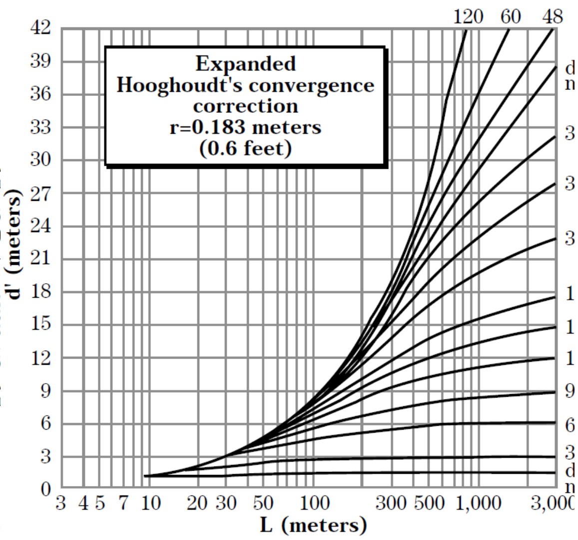
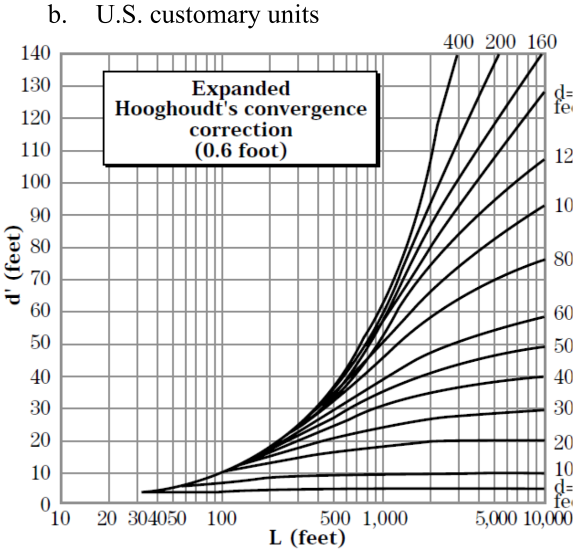


Figure 14E-5: Expanded Curves for Determining Hooghoudt's Convergence Correction

a. metric units



b. U.S. customary units



F. Deep Percolation and Buildup

(1) Deep percolation from any source causes a buildup in the water table. The methods of estimating drain spacing developed by the Bureau of Reclamation require that deep percolation and buildup in the water table from each source of recharge (rainfall, snowmelt, or irrigation application) be known or estimated and accounted for in the drain spacing calculations.

(2) When a drainage problem exists on an operating project and drains are being planned, the buildup in the water table caused by irrigation applications can best be determined by field measurements. The water table depth should be measured at several locations in the area to be drained on the day before and on the day after several irrigation applications. The average buildup shown by these two measurements should be used in the spacing computations. These measurements obviate the need for theoretical estimates on the amount of deep percolation and relate the buildup to the actual irrigation operations of the area to be drained.

(3) In the planning stage of new projects or on operating projects where the measured buildup is not available, the amount of expected deep percolation must be estimated from each irrigation application. The buildup is computed by dividing the amount of deep percolation by the specific yield of the material in the zone where the water table is expected to fluctuate. Table 1 shows deep percolation as a percentage of the irrigation net input of water into the soil to be considered. These percentages are given based on various soil textures and on infiltration rates of the upper root zone soils. These valves should be used only for preliminary planning. More detailed investigations of deep percolation are required for project designs.

(4) The following examples show how to use figure 14E-6 to obtain deep percolation and, in turn, the water table buildup:

Figure 14E-6: Approximate Deep Percolation from Surface Irrigation (Percent of Net Input) 1

By texture

Texture	Percent	Texture	Percent
LS	30	CL	10
SL	26	SiCL	6
L	22	SC	6
SiL	18	C	6
SCL	14		

By infiltration rate

–Inf. rate– mm/h	(in/h)	Deep percolation percent	–Inf. rate– mm/h	(in/h)	Deep percolation percent
1.27	(0.05)	3	25.4	(1.00)	20
2.54	(.10)	5	31.8	(1.25)	22
5.08	(.20)	8	38.1	(1.50)	24
7.62	(.30)	10	50.8	(2.00)	28
10.2	(.40)	12	63.5	(2.50)	31
12.7	(.50)	14	76.2	(3.00)	33
15.2	(.60)	16	102.0	(4.00)	37
20.3	(.80)	18			

[1]. These values should be used only for preliminary planning. More detailed investigations of deep percolation are required for project designs.

(5) Example 1

(i) Assume the irrigation application is known to be 150 millimeters (about 6 inches) per irrigation, soils in the root zone have a loam texture with an infiltration rate of 25 millimeters (1 inch) per hour, and about 10 percent of the 150-millimeter (6-inch) application runs off.

(ii) The net input of water into the soil per irrigation would then be 90 percent of the 150-millimeter (6-inch) application, or 135 millimeters (5.4 inches). From table 1, the deep percolation would be 20 percent for an infiltration rate of 25 millimeters (1 inch) per hour. Therefore, the deep percolation is 135 x 0.20 = 27 millimeters (1.08 inches). If the hydraulic conductivity in the zone between the root zone and the drain depth is 25 millimeters (1 inch) per hour, then the specific yield corresponding to this hydraulic conductivity is 10 percent, as given by figure 14E-3. The buildup of the water table per irrigation is the deep percolation divided by the specific yield, or millimeters (10.8 inches).

$$\frac{27}{0.10} = 270\ mm(10.8\ in)$$

(6) Example 2

(i) Assume the total readily available moisture in the root zone (allowable consumptive use between irrigations) has been determined as 107 millimeters (4.2 inches) and that the infiltration rate of the soil in the area is 25 millimeters (1 inch) per hour with a corresponding deep percolation of 20 percent.

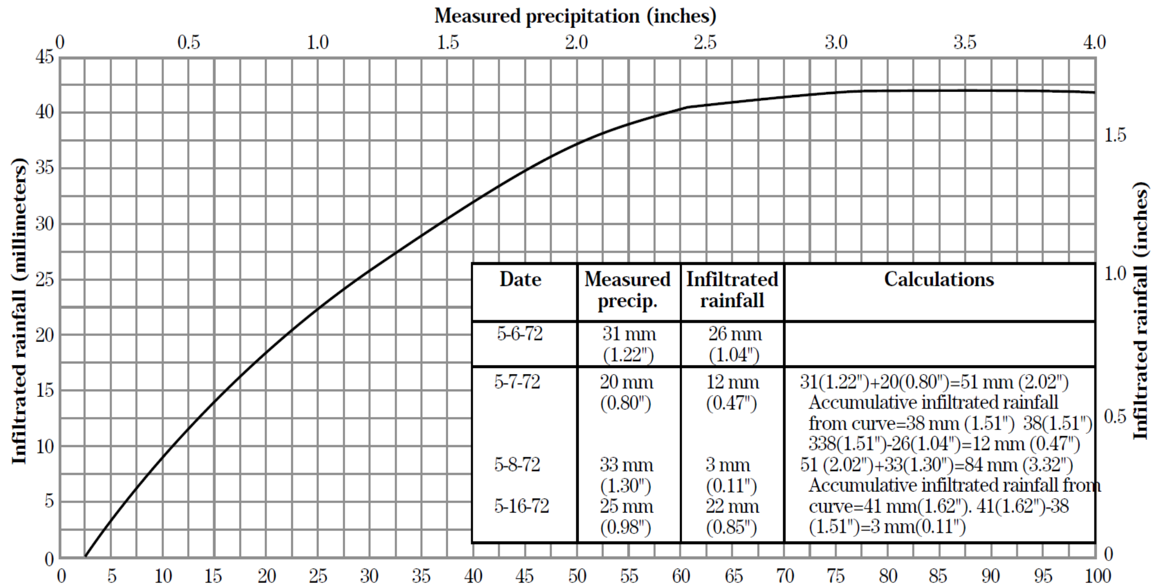
$$\frac{107}{0.80} = 134\ mm(5.25\ in)$$

(ii) The net input of water into the soil per irrigation will be 134 millimeters (5.25 inches), where 0.80 = 1.00 – 0.20. The deep percolation will be 134 – 107 = 27 millimeters (1.05 inches). The buildup in the water table per irrigation would be this deep percolation amount divided by the specific yield in the zone between the drain and the maximum allowable water table.

(iii) Rainfall in arid areas is usually, but not necessarily, so small that the effects of deep percolation from this source during the irrigation season can be neglected. In semi-humid areas, deep percolation from rain may be appreciable and must be accounted for in estimating subsurface drainage requirements. When it is apparent that precipitation is a significant source of soil moisture and deep percolation, the curve of figure 14E-7 can be used to estimate the infiltrated precipitation. This infiltrated precipitation can then be used to determine the resultant irrigation schedule and the amount and timing of deep percolation from rainfall and irrigation. In areas that frequently have 3 or 4 days of rainfall separated by only 1 or 2 rainless days, the transient flow methods yield more accurate values for discharge if the accumulated deep percolation from infiltrated precipitation is assumed to occur on the last day of rain.

(iv) Deep percolation from spring snowmelt occurs in some areas and should be accounted for where possible. In some areas the buildup in the water table from this snowmelt can be measured in observation wells and used directly in the spacing computations. In others the estimate may need to be based entirely on judgment and general knowledge of the area.

Figure 14E-7: Curve for Estimating Infiltrated Rainfall



Date	Measured precip.	Infiltrated rainfall	Calculations
5-6-72	31 mm (1.22")	26 mm (1.04")	
5-7-72	20 mm (0.80")	12 mm (0.47")	31(1.22")+20(0.80")=51 mm (2.02") Accumulative infiltrated rainfall from curve=38 mm (1.51") 38(1.51") 338(1.51")-26(1.04")=12 mm (0.47")
5-8-72	33 mm (1.30")	3 mm (0.11")	51 (2.02")+33(1.30")=84 mm (3.32") Accumulative infiltrated rainfall from curve=41 mm(1.62"). 41(1.62")-38 (1.51")=3 mm(0.11")
5-16-72	25 mm (0.98")	22 mm (0.85")	

G. Using the Data

(1) The method of using the data described in the previous section to obtain dynamic equilibrium is briefly described in this section. A more detailed description is given in examples shown in subsequent sections. A computer program has also been developed by Reclamation personnel to perform drain spacing computations and analyze return flows for salinity studies.

(2) The drain spacing computations have been adapted for use on a personal computer. This program is called the Agricultural Drainage Planning Program (ADPP). The program manual and disks are available through the Superintendent of Documents, U.S. Government Printing Office.

(3) Begin the calculations by assuming a drain spacing, L, and the assumption that the water table reaches its maximum allowable height, y_o, immediately after the last irrigation application of each season. At least two successive positions of the water table are calculated during the nonirrigation season (even in areas of year-round cropping, a slack period occurs sometime during the year). Then the buildup and drainout from each irrigation is calculated for the irrigation season. If the assumed spacing results in dynamic equilibrium conditions, the water table height at the end of the series of calculations for the irrigation season will equal the maximum allowable water table height, y_o. If y_o after the last irrigation is not equal to the maximum allowable y_o, the procedure is repeated with a different L. Normally, only two drain spacing assumptions are necessary to verify the dynamic equilibrium producing spacing. A straight-lined relation between two assumed spacings and their resulting values of y_o after a complete annual cycle will permit determination of the proper spacing if the original assumptions are reasonably close.

(4) Where the annual hydrograph peaks at some time other than the end of the irrigation season, the normal high point should be used as a starting point for calculations. This high point often occurs in the spring where sprinkler irrigation is used in semiarid or subhumid climates.

H. Drain Above the Barrier Layer

(1) The following example is given to illustrate the method of determining the drain spacing for a drain above the barrier. The following conditions are assumed:
- The distance from the barrier to the drain, d, is 6.7 meters (22 feet), and the depth of the drain is 2.4 meters (8 feet).
- The root zone requirement is 1.2 meters (4 feet), which gives a maximum allowable water table height, yo, above the drain of 2.4 – 1.2 = 1.2 meters (8– 4 = 4 feet).
- The weighted average hydraulic conductivity in the zone between the barrier and the maximum allowable water table height is 127 millimeters (5 inches) per hour, or 3.05 meters (10 feet) per day.
- The hydraulic conductivity is uniform with depth. Therefore, the hydraulic conductivity in the zone between the maximum allowable water table height and the drain is also 127 millimeters (5 inches) per hour. From figure 14E-3, the corresponding value of specific yield is 18 percent.
- The deep percolation from each irrigation (also assumed to be the same from a spring snowmelt) is 25.4 millimeters (1 inch), or 0.0254 meter (0.083 foot). The water table buildup from each increment of recharge is the deep percolation divided by the specific yield, or

$$\frac{0.0254}{0.18} = 0.14\ meter (0.46\ ft)$$

- The approximate dates of the snowmelt and the irrigation applications are as follows:

Figure 14E-8: Approximate Snowmelt and Irrigation Application Dates

Irrigation or snowmelt (sm)	Date	Time between irrigations, days
SM	April 22	
First	June 6	45
Second	July 1	25
Third	July 21	20
Fourth	August 4	14
Fifth	August 18	14
Sixth	September 1	14
	TOTAL	132

(2) Therefore, the nonirrigation period is 233 days (365 – 132). As previously mentioned, this period should be divided into two or three approximately equal periods; for this example, use two periods: one of 116 days and one of 117 days.

(3) A drain spacing, L, of 442 meters (1,450 feet) resulted from two prior trial calculations. If the water table reaches the maximum allowable height immediately after the application of the last irrigation of each season, the computations begin at this point in time.

(4) The first step in applying the method is to compute the value for the first time period.

$$\frac{KDt}{SL^2}$$

(5) Using this value, the value of y divided by y_o is then found from figure 14E-2. Knowing the initial y_o, we can then calculate y, the height to which the midpoint water table falls during this period. This process is repeated for each successive period, which results in a water table height for each successive recharge and drainout. The process is shown in figure 14E-9.

(6) Explanation of each column in figure 14E-9.

(i) Column 1—Number of each successive increment of recharge, such as snowmelt (SM), rain, or irrigation.

(ii) Column 2—Length of drainout period (time between successive increments of recharge or between incremental drainout periods).

(iii) Column 3—Instantaneous buildup from each recharge increment (deep percolation divided by specific yield).

(iv) Column 4—Water table height above drains at midpoint between drains immediately after each buildup or at beginning of incremental time periods during the nonirrigation season drainout (col. 8 of preceding period plus col. 3 of current period).

(v) Column 5—Average depth of flow,

$$D = d + \frac{y_0}{2} \left(d \text{ should be limited to } \frac{L}{4} \right)$$

Column 6—A calculated value representing the flow conditions during any particular drainout period:

$$\frac{K}{SL^2} \times col.5 \times col.2$$

Column 7—Value taken from the curve on figure 14E-2.

Column 8—Midpoint water table height above drain at end of each drainout period, col. 4 x col. 7.

(7) Figure 14-9 shows a final y_o = 1.235 meters (4.04 feet), which is approximately equal to the maximum allowable y_o of 1.22 meters (4.00 feet). Therefore, the spacing of 442 meters (1,450 feet) results in dynamic equilibrium. As stated previously, this spacing solution does not account for head loss due to convergence.

(8) Using Hooghoudt's method of correcting for convergence and using figure 14E-4, we find that for d = 6.7 meters (22 feet) and a drain spacing of 442 meters (1,450 feet), the equivalent depth, d´, is 6.1 meters (20 feet). The D´ to be used in the drain spacing computations is:

$$D' = d' + \frac{y_0}{2} = 6.1 + \frac{y_0}{2}$$

(9) The trial and error approach is again used to find the corrected spacing of 427 meters (1,400 feet). Figure 14E-10 shows the results of using D´ with a spacing of 427 meters (1,400 feet).

(10) The calculations in figure 14E-10 result in essentially the same water table heights, y_o, that were obtained in the previous calculations in figure 14E-9 and verify the 427-meter (1,400-foot) spacing as corrected for convergence. Figure 14E-11 illustrates the water table fluctuation produced as a result of the conditions of this example.

Figure 14E-9: Computation of Water Table Fluctuation with Drain on the Barrier Layer

(a) Meters

(1) Irrigation no.	(2) Period, t, days	(3) Buildup per irrigation, meters	(4) y_o meters	(5) D', meters	(6) $\frac{Kdt}{SL2}$	(7) $\frac{y}{yo}$	(8) y, meters
6							
	117		1.22	7.31	0.0742	0.575	0.701
	116		0.701	7.05	.0710	.590	0.414
SM		0.140					
	45		0.554	6.98	.0272	.870	0.482
1		.140					
	25		0.622	7.01	.0152	.958	0.596
2		.140					
	20		0.736	7.07	.0123	.978	0.720
3		.140					
	14		0.860	7.13	.0087	.985	0.847
4		.140					
	14		0.987	7.19	.0087	.985	0.972
5		.140					
	14		1.112	7.26	.0088	.985	1.095
6		.140					
			1.235				

(b) Feet

(1) Irrigation no.	(2) Period, t, days	(3) Buildup per irrigation, feet	(4) y_o feet	(5) D', feet	(6) $\frac{Kdt}{SL2}$	(7) $\frac{y}{yo}$	(8) y, feet
6							
	117		4.00	24.00	0.0742	0.575	2.30
	116		2.30	23.15	.0710	.590	1.35
SM							
	45	0.46	1.82	22.91	0.272	.870	1.58
1							
	25	.46	2.04	23.02	.0152	.958	1.95
2							
	20	.46	2.41	23.20	.0123	.978	2.36
3							
	14	.46	2.81	23.41	.0087	.985	2.77
4							
	14	.46	3.22	23.61	.0087	.985	3.17
5							
	14	.46	3.63	23.82	.0088	.985	3.58
6							
		.46	4.04				

Figure 14E-10: Computation of Water Table Fluctuation with Drain on the Barrier Layer Using D′ as Corrected by Hooghoudt

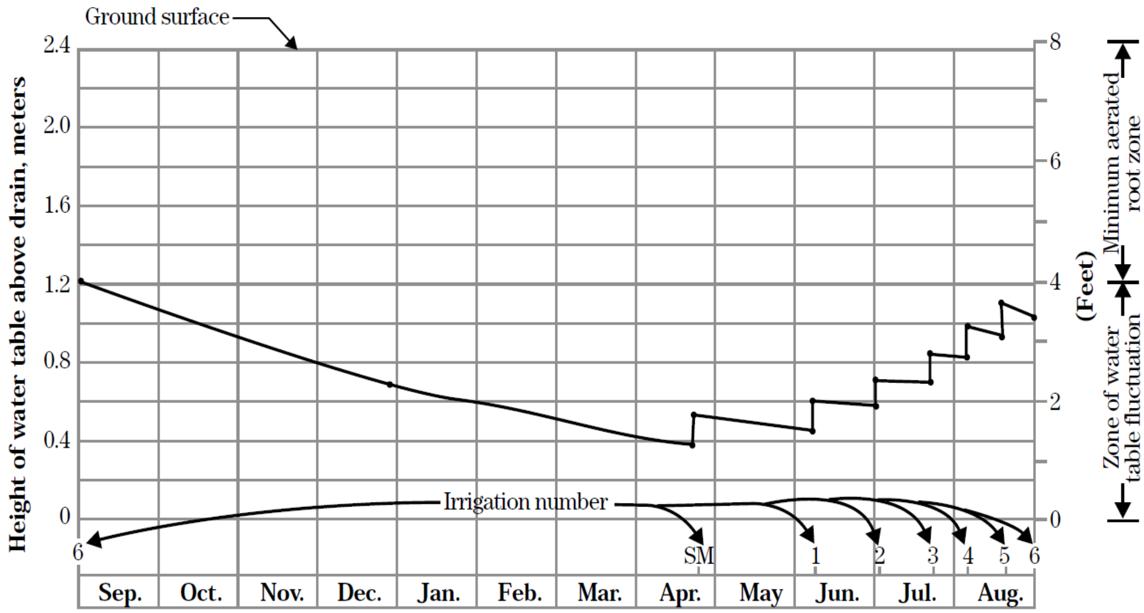
(a) Meters

(1) Irrigation no.	(2) Period, t, days	(3) Buildup per irrigation, meters	(4) y_o meters	(5) D', meters	(6) $\frac{Kdt}{SL2}$	(7) $\frac{y}{yo}$	(8) y, meters
6							
	117		1.22	6.71	0.0730	0.565	0.69
	116		0.689	6.44	.0695	.600	0.41
SM							
	45	0.140	0.554	6.73	.0272	.870	0.48
1							
	25	.140	0.622	6.41	0.149	.955	0.59
2							
	20	.140	0.736	6.46	0.120	.970	0.71
3							
	14	.140	0.856	6.52	.0085	.986	0.84
4							
	14	.140	0.987	6.59	.0086	.986	0.97
5							
	14	.140	1.112	6.65	.0087	.985	1.09
6							
		.140	1.235				

(b) Feet

(1) Irrigation no.	(2) Period, t, days	(3) Buildup per irrigation, feet	(4) y_o feet	(5) D', feet	(6) $\frac{Kdt}{SL2}$	(7) $\frac{y}{yo}$	(8) y, feet
6							
	117		4.00	22.00	0.0730	0.565	2.26
	116		2.30	21.13	.0695	.600	1.36
SM							
	45	0.46	1.82	20.91	.0267	.870	1.58
1							
	25	.46	2.04	21.02	.0149	.955	1.95
2							
	20	.46	2.41	21.21	.0120	.970	2.34
3							
	14	.46	2.80	21.40	.0085	.986	2.76
4							
	14	.46	3.22	21.61	.0086	.986	3.17
5							
	14	.46	3.63	21.82	.0087	.985	3.58
6							
		.46	4.04				

Figure 14E-11: Water Table Fluctuation



I. Drain on the Barrier Layer

(1) Example 3 illustrates the method for determining the drain spacing for a drain on the barrier.

(2) Example 3

(i) All assumptions are the same as those in the previous example above except that d in this example is zero. The assumption of a drain spacing, and subsequent computations of water table heights are also similar to those for a drain above the barrier.

(ii) A drain spacing of 125 meters (410 feet) is assumed, and subsequent computations are shown in figure 14E-12.

(iii) Figure 14E-12 shows a final H = 1.243 meters (4.08 feet), which is essentially equal to the maximum allowable H of 1.22 meters (4.00 feet). Therefore, the spacing of 125 meters (410 feet) results in dynamic equilibrium, and because no correction for convergence is required for this case, the final drain spacing is 125 meters (410 feet).

Figure 14E-12: Computation of Water Table Fluctuation with DRAIN on the Barrier Layer

(a) Meters

Irrigation no.	t, days	Buildup per irrigation, meters	H meters	$\frac{Kdt}{SL2}$	$\frac{Z}{H}$	Z, meters
6						
	117		1.22	0.1546	0.590	0.719
	116		0.719	.0905	.720	0.518
SM						
	45	0.140	0.658	.0321	.900	0.591
1						
	25	.140	0.732	.0199	.945	0.691
2						
	20	.140	0.832	.0180	.950	0.789
3						
	14	.140	0.930	.0141	.975	0.911
4						
	14	.140	1.051	0159	.970	1.015
5						
	14	.140	1.158	.0176	.955	1.103
6						
		.140	1.243			

(b) Feet

Irrigation no.	t, days	Buildup per irrigation, meters	H meters	$\frac{Kdt}{SL2}$	$\frac{Z}{H}$	Z, meters
6						
	117		4.00	0.1546	0.590	2.36
	116		2.36	.0905	.720	1.70
SM						
	45	0.140	2.16	.0321	.900	1.94
1						
	25	.140	2.40	.0199	.945	2.27
2						
	20	.140	2.73	.0180	.950	2.59
3						
	14	.140	3.05	.0141	.975	2.99
4						
	14	.140	3.45	.0159	.970	3.33
5						
	14	.140	3.80	.0176	.955	3.62
6						
		.140	4.08			

Appendix 14F Drainage Around Home Sites

A. A drainage problem may exist around a home if the basement is wet, the yard is flooded periodically, water ponds on a lawn for long period after a rain, or trees, shrubs, and other plants grow poorly. About 20 percent of the land in the United States is affected by excess water. Wetness generally is caused by flooding, springs and seeps, seasonal high-water tables, ponding of surface water, or slow soil permeability.

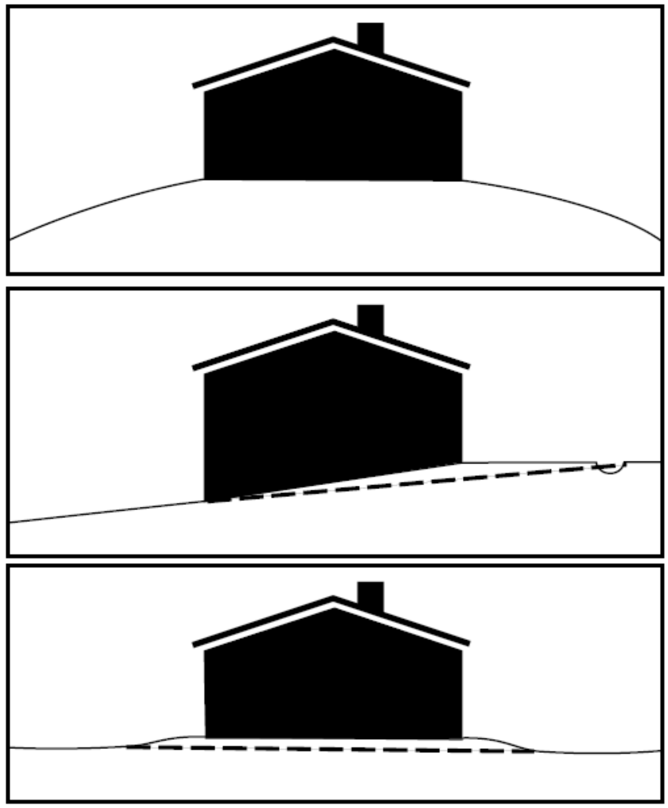
B. Following are some of the more common causes of wet or damp basements:

(1) The land is flat or slopes toward the house, permitting surface water (rain and melting snow) to drain down against the basement walls. Water leaks through cracks or other openings in the walls and causes wet spots on the walls or standing water on the floor.
(2) No gutters and downspouts (or defective ones) to handle roof water from rain and snow. The free-falling water forms puddles or wet soil near or against the basement walls. Water leaks in or enters by capillarity.
(3) The ground water level is close to the underside of the floor slab. Water rises through the slab by capillarity, producing dampness.
(4) The ground water level is higher than the basement floor. Water leaks in or enters by capillarity, causing standing water in the basement and, at times, dampness in the rooms above.
(5) Condensation (sweating) of atmospheric moisture on cool surfaces—walls, floor, cold-water pipes—in the basement.
(6) Leaky plumbing or other sources of moisture increase the humidity of the basement air. Dense shrubbery and other plantings around the basement walls prevent good ventilation.
(7) Existing drainage system around the basement or foundation have not been properly maintained.

C. Selection of Building Site

(1) With proper site selection and planning, many of these causes can be prevented. General information on soil conditions, seasonal high-water tables and so forth may be found in the local soil survey report.
(2) An important consideration in selecting the site for a new house is proper drainage. This includes not only drainage of surface, but also drainage of any subsurface or ground water that may be present or that may accumulate over time and be blocked from its normal course of flow by the new construction.
(3) The highest point on the property is often the best building site and provides the best surface drainage (fig. 14F-1a). An elevated site provides good surface drainage away from the house in all directions.
(4) Second choice might be a hillside (fig. 14F-1b). The advantage of such a location is that drainage water can be routed around the high side of the house for runoff at the ends and low side.
(5) If the site is flat, the ground around the house must be built up or graded to drain surface water away from the basement walls or foundation (fig. 14F-1c).

Figure 14F-1: Selection of Building Sites



(a) An elevated site provides good surface drainage away from the house in all directions.

(b) Drainage can be routed around a side hill located house (note drainage ditch on uphill side).

(c) On a flat site, the ground around the house must be built up to drain water away from the basement walls.

(6) The surface soil and subsoil should be open and porous so that air and water are admitted readily. Desirable soils include sands, loams, and gravels which provide good, deep, natural drainage. Under ideal conditions, the soil is so well drained that during the rainy season the subsurface or ground water level is at least 10 feet below the finished grade. Water at that level is well below the level of the average basement floor.

D. Flooding

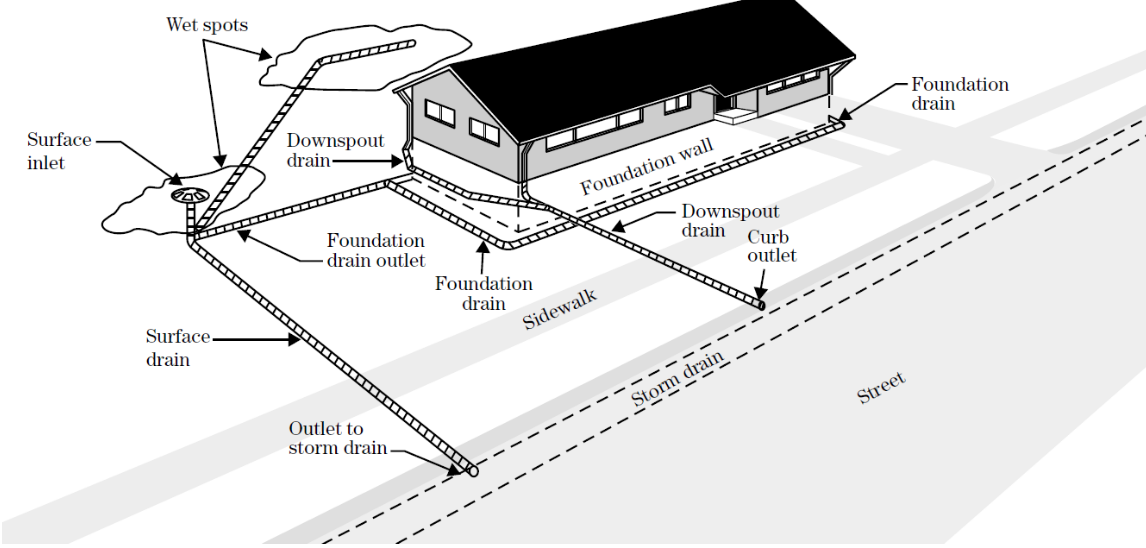
(1) If a home is in the flood plain of a nearby stream or creek, it may be flooded if the stream overflows during periods of heavy rainfall or rapid snowmelt. Usually community-wide measures are needed to ensure adequate protection. Floodproofing a house may reduce damage but is not always effective against severe floods. Floodproofing measures can be include diking, provisions for blocking opening such as windows and doors, regulating drain outlets, and waterproofing walls. Floodproofing measures can be expensive and require careful evaluation to prevent structural damage. When selecting a home site, be sure the site is not highly flood prone. The house foundation should be built above any expected flood level. Local government planning offices should have information designating flood prone areas.

(2) In upland areas, flooding can occur if a house is built in the path of a natural drainageway or in a pothole or site that is lower than the surrounding area. A drainageway or low area may appear safe in dry seasons but carry runoff water in wet seasons. In housing developments where the landscape has been greatly modified, natural drainageways are often blocked or altered. If man-made drainageways or storm sewers are not built to carry the seasonal flow of water, nearby homes may be flooded. Runoff from areas as small as one acre or less can cause flooding. Measures to remedy this kind of hazard usually require the cooperation of several homeowners.

E. Springs and Seeps

(1) On many sites, natural springs and seeps occur because of existing soil, rock, and landscape characteristics. Water may flow throughout the year or only seasonally during periods of heavy rainfall.
(2) Water may flow into or around a house if it is constructed over or near a spring or seep. For protection, it is a good practice to install subsurface drains, at least 4 inches in diameter and surrounded with 6 to 12 inches of gravel or sand and gravel, along the outside of the foundation wall (fig. 14F-2).

Figure 14F-2: Subsurface Drains Can be Installed Around a Home to Remove Excess Water



(3) Springs and seeps also affect lawns and onsite fields. Following local building codes and health department regulations, subsurface drains may be installed to collect the ground water and divert it from such areas.
(4) The most commonly used material is currently perforated corrugated plastic pipe. Local building codes and other drainage regulations should be checked for approved materials, controls of discharge into storm sewers, road ditches, street gutters, and so forth. Existing subsurface drains may be made of clay and concrete tile, perforated plastic, metal, asbestos cement, or bituminous wood fiber. Homeowners can check their site plans for these existing drains.

F. Seasonal High-water Table

(1) A water table can be defined as the upper surface of ground water or the level below which the soil is saturated with water. This level may fluctuate by several feet throughout the year depending on soil, landscape, and weather conditions. In many areas of the United States, especially where annual rainfall is 20 inches or more, the seasonal high-water table is 2 to 5 feet below the surface.
(2) In selecting a new home site, the level of the seasonal high-water table is a very important consideration. On some sites the seasonal high-water table may be at or near the ground surface for long periods. These areas should be avoided. If the water table is 6 feet deep or more, it may be of little concern for houses without basements.
(3) When building a new house, a sump pump with a system of subsurface drains can be used to lower the water table. A good outlet is needed for the discharge flow from the pump. A safer method is to limit excavation and build the house on a reinforced concrete slab above the seasonal high-water table.
(4) If a house is already built, drains can be installed around the outside wall or under the basement floor. Lowering the water table under the basement floor should be done with caution. On some soils, especially slow-draining silts and clays, unequal settlement may crack the walls.
(5) On lawns, where only a small part is affected by a high-water table, a small excavated pond may be a suitable remedy. The nuisance wet area can be developed into an attractive landscaping feature. Before building a pond, state and local safety regulations that apply to pond construction should be checked.

G. Ponding of Surface Water

(1) If surface water ponds on a lawn or driveway, small diversions or ditches can be installed to channel off the water. In developed residential areas, these structures usually are installed near property lines behind or beside houses.
(2) For low flows of surface water, a surface inlet leading to a subsurface drain can be installed. The drain outlet can empty into street gutters or storm sewers if permitted by local building codes and other drainage regulations.
(3) A lawn should be graded so that surface water drains away from the house. A minimum grade of 1 foot in 100 feet (1/8) inch per foot) is generally adequate. When filling in low areas during grading, use the most permeable soil available. The topsoil should be saved and spread over the newly filled and graded areas to help establish vegetation. Sodding prevents the washing away of newly graded area during heavy rains.
(4) When a large area of land slopes toward the house, surface drainage should be intercepted and rerouted some distance from the house. A shallow, half round drainage ditch or depression designed to route the water around the house (fig. 14F-1b) should be installed. The ditch should be sodded or seeded to grass. If the ditch is objectionable, corrugated plastic drainage tubing with one or more catch basins at low spots may be installed.

H. Roof Water

(1) Houses should have gutters and downspouts to take care of roof water from rain and snow. The gutters and downspouts should be kept free of debris. Where leaves and twigs from nearby trees may collect in a gutter, a basket-shaped wire strainer may be installed over the downspout outlet. Gutters and downspouts should be repaired and painted as soon as the need appears.

(2) Downspouts usually have an elbow or shoe on the lower end to discharge the water slightly above the ground and away from the foundation or basement wall. To prevent concentration of water at the point of discharge, a concrete gutter or a splash should be used to carry the water away. The gutter or block should slope one inch per foot, and its edges should be flush with the grade.
(3) Disposal of roof water as shown in figure 14F-3 makes it easy to clear clogged downspouts. Roof water can also be piped underground to a storm water drain, dry well, or surface outlet, 15 feet or more from the house (fig. 14F-4). The bottom of a dry well should be lower than the basement floor and in earth or rock that drains rapidly.
(4) Installing suitable downspouts to control roof water may be adequate to prevent ponding in low areas of a yard. Downspouts can empty into a subsurface drain or into outlet spreaders installed to discharge water in a thin layer over a grassy area.

I. Slow Soil Permeability

(1) If the soil at a home site has a slowly permeable layer, especially a layer of clay, flow of water through the soil may be restricted and water may pond on a lawn. If the layer with slow permeability is near the surface, a small trench can be dug through the layer and filled with sand, gravel, pine bark, sawdust, or other coarse material to improve permeability in a small, low-lying wet spot. For larger wet areas, subsurface drains may be required.
(2) Even on well-drained soil, heavy foot traffic during wet periods compacts soil and reduces permeability. Restricting foot traffic in the wet lawn helps prevent soil compaction.

J. Maintenance

(1) To continue their usefulness, drains require periodic maintenance. Gates and screens of outlets must be checked to assure that entry of rodents and other small animals is restricted and that they are free of sediment buildup, weeds, debris, and seasonal ice blocks. Where drainage outlets extend beyond the property line, check with the local governmental entity such as drainage district or the county to determine maintenance responsibility.
(2) General observation of the existing system will reveal possible need for maintenance. Sinkholes or cave-ins over the drains indicate a broken or collapsed drainage conduit or an opening in the filter or envelop material that allows soil material to enter the drain. Unusual wetness of the basement wall or foundation, surface puddles, or wet areas can indicate a plugged line or filter fabric.

K. Foundation and Basement Construction

(1) Constructions required for foundation and basement walls and floor depends largely upon soil drainage conditions. In well-drained soil, good, water-resistant construction may be adequate. In poorly drained soil or where the basement floor will be below the subsurface water level, watertight construction is required.
(2) Construction plans complying with local building codes and architectural guidelines plans should be followed for construction of foundation and basement walls and floors and associated footing drains. (fig. 14F-5)

Figure 14F-3: Correctly installed gutters and downspouts prevent roof water from forming wet or damp conditions around foundation or basement walls

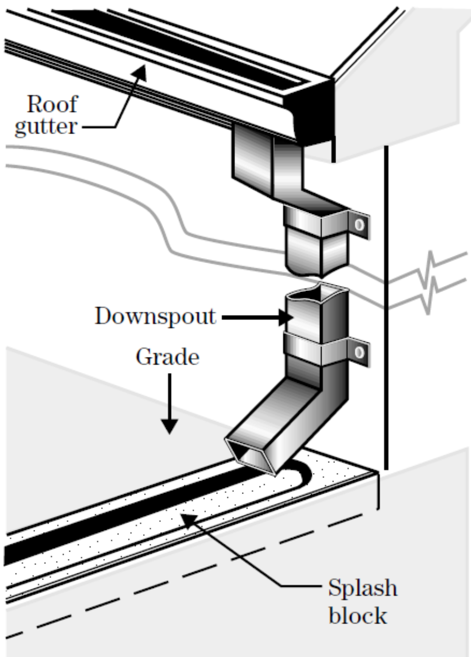


Figure 14F-4: Roof water can be routed away from the foundation or basement walls to a storm water drain or another outlet using non-perforated pipe

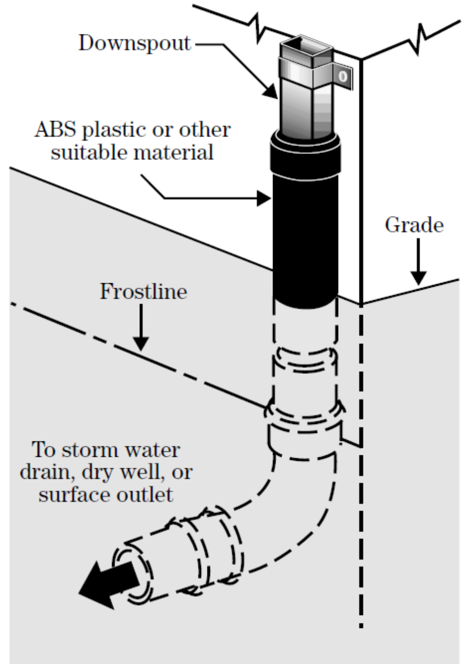
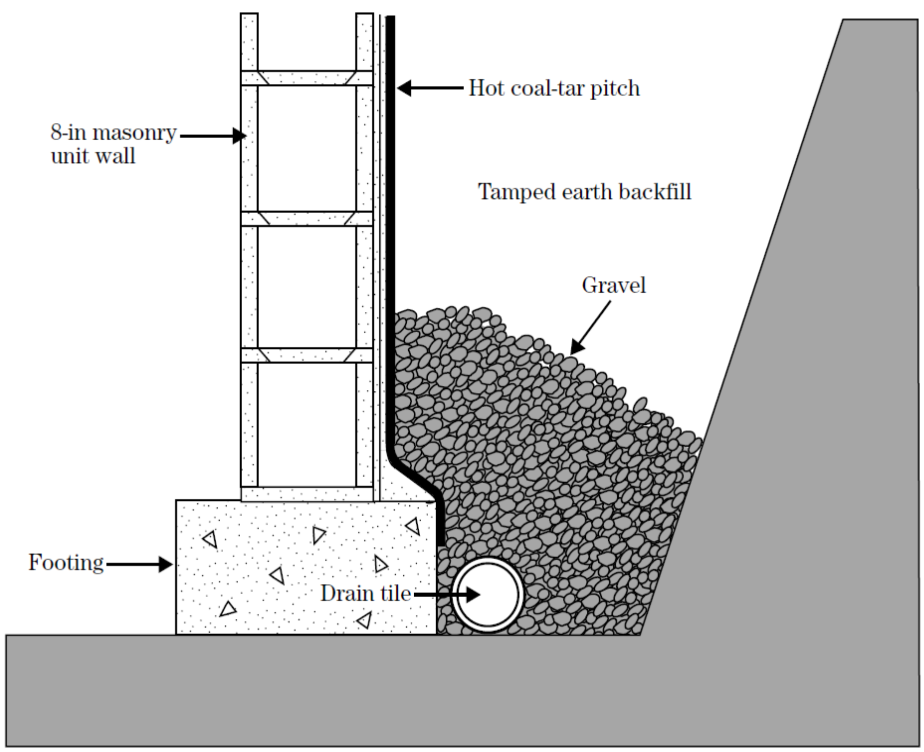


Figure 14F-5: Foundation Drain Application



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