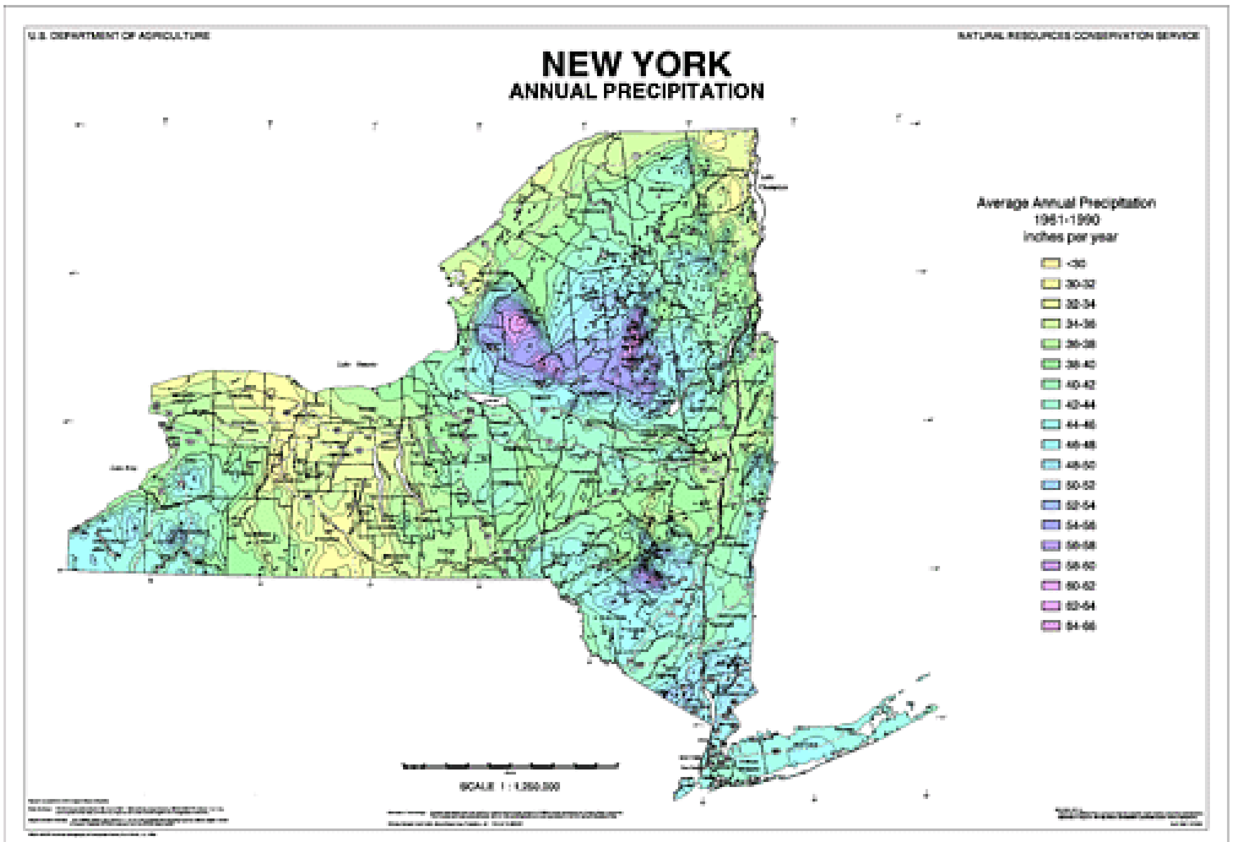
DRAINAGE GUIDE

for

New York State



Map showing the average annual precipitation in New York for a period of 30 years.

USDA

Natural Resources Conservation Service

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PREFACE

The Drainage Guide for New York State has been prepared by the Natural Resources Conservation Service of the U.S. Department of Agriculture and the Biological and Environmental Engineering Department at Cornell University. It is intended for use in the design and installation of drainage for agricultural land use. The standards are recommended to landowners, drainage material manufacturers, contractors, public and private engineers, and vocational agriculture teachers.

The direct benefit of implementing drainage improvements for agricultural land use is the removal of excess water on or within the soil profile, which results in the lowering of the watertable and a drier soil environment. The primary indirect effects are improved workability and aeration of the soil. Improved workability provides for more timely tillage and other cultural operations, without causing detrimental effects on the soil's physical structure and stability (i.e., compaction and erosion). The improved aeration provides several soil biological and chemical enhancements for crop growth including better root respiration, soil mineralization and nitrification, and inhibition of various diseases and pests. Denitrification losses may be reduced. A lower water table also allows crops to root deeper, providing more efficient utilization of soil moisture and nutrients. The economic benefits of appropriately designed drainage improvements have been well documented.

Not all land areas should be drained. The following questions need to be considered before deciding to drain an area:

1. Is drainage a desirable land use practice?
2. Will the soil respond to drainage?
3. Is drainage a sound investment?
4. What will be the environmental effect?
5. Will the drainage effect eligibility for USDA programs?
6. Will the drainage impact a protected wetland?
7. Is there a suitable place to legally dispose the drainage water?

If there is a doubt about the need for drainage, consult personnel who are experienced in agricultural drainage problems.

Specific research data are not available upon which to base all recommendations for drainage of the various soils that require surface and profile drainage. Many of the recommendations in this Guide are based on expanding present research data to similar soils through experience and observation. They are, therefore, subject to revision when additional information or data becomes available.

Designing an effective drainage system is a complex task. Each aspect of a surface or subsurface drainage system depends on several variables. For example, the size of a drain in a subsurface system depends on, among other things, a drainage coefficient, the size of the area to be drained, the grade or slope of the drain, and the internal roughness characteristics of the drain material.

Furthermore, a decision about one aspect of a drainage system may limit the choices available for other aspects. For example, an early decision about the grade necessary to drain the area may determine the choices of drain size. In designing a drainage system, therefore, one must work back and forth between several aspects to meet all the conditions of a particular drainage problem.

This Drainage Guide is an introduction to the many variables in both surface and subsurface drainage systems. It provides detailed descriptions of the components of each system, using figures and tables to familiarize the reader with the concepts involved, and it gives fairly thorough explanations about the relationships among the various components of each system.

This Drainage Guide addresses much of the basic information needed to design a simple drainage system. However, many charts, tables, and other informational materials essential to making assumptions and final decisions have been collected and published elsewhere. Where other information is needed for actual design purposes, the reader is referred to the appropriate publications. In general, the landowner, farm operator, or contractor will most likely need the help of a drainage professional to design more complex drainage systems. Nevertheless, the information provided in this guide should help readers to ask pertinent questions, and to better understand the concepts essential to solving a drainage problem.

Some of the references used in preparing this Guide are:

1. ASABE EP260.4 – "Design and Construction of Subsurface Drains in Humid Areas," American Society of Agricultural and Biological Engineers, St. Joseph, Michigan.
2. ANSI/ASABE EP302.4 – "Design and Construction of Surface Drainage Systems on Agricultural Lands in Humid Areas," American National Standard Institute and Society of Agricultural and Biological Engineers, St. Joseph, Michigan.
3. ASABE EP407.1 – "Agricultural Drainage Outlets — Open Channel," American Society of Agricultural and Biological Engineers, St. Joseph, Michigan.
4. "Part 650 Engineering Field Handbook, Chapter 14 – Water Management (Drainage)" USDA – Natural Resources Conservation Service. (http://www.info.usda.gov/CED/)
5. National Engineering Handbook Section 16 – "Drainage of Agricultural Land," USDA – Natural Resources Conservation Service. (http://www.info.usda.gov/CED/ftp/CED/neh-16.htm)
6. "Standards for Drainage of Michigan Soils," USDA – Soil Conservation Service, (1963).
7. "Ohio Drainage Guide," USDA – Soil Conservation Service, (1973).
8. "Illinois Drainage Guide," USDA – Soil Conservation Service, (1984).
9. American Society for Testing Materials, "Standard Specifications for Clay Drain Tile and Perforated Clay Drain Tile", ASTM C4; and "Standard Specification for Corrugated Polyethylene Pipe and Fittings", ASTM F405.
10. National Conservation Practice Standards, Standard 606 – "Subsurface Drain"; Standard 607 - "Surface Drainage, Field Ditch"; Standard 608 – Surface Drainage, Main or Lateral; Standard 554 – Drainage Water Management, USDA – Natural Resources Conservation Service. For New York, these standards are available at: (http://www.nrcs.usda.gov/technical/Standards/nhcp.html).

CRITERIA FOR SOIL MOISTURE MANAGEMENT GROUPS

The following soils in New York State are listed and grouped according to the soil characteristics that are most relevant to the design of manmade drainage systems. The two primary group characteristics are the degree of wetness before any drainage practices have been applied (referred to as natural drainage or depth to seasonal watertable), and the general soil texture which largely influences the rate at which water will move through the soil (referred to as soil permeability or hydraulic conductivity and measured in inches per hour). Other important subgroup characteristics in the following list are soil depth, contrasting soil layers and topographic position. Some soils are shallow to bedrock while others occur on bottomlands and have stream flooding problems. Some are located in saucer-like depressions where they have no natural surface outlet. Other factors, such as land use, affect drainage design but are not fundamental to natural soil drainage processes. It should be noted that this list of soil moisture management groups is not the same as a soil's Hydrologic Group (i.e., A, B, C, and D) classification commonly used for making runoff calculations. The latter refers more to how much rainfall may infiltrate into the soil in the absence of a seasonal high water table, and thus does not directly address a soil's internal drainage characteristics or restrictions.

Soil survey information can be found in printed soil surveys or on the web at: http://websoilsurvey.nrcs.usda.gov/app/. Some older printed soil surveys may contain soils series names which are no longer in current use, or there may be new series which may not yet be added to the drainage guide, therefore, some soil series may not be included in this listing. If the soil series of interest is not listed here, it is necessary to use a soil legend that cross references and shows the current concept of the soil map unit. These legends can be found via the Soil Reports link in Section 2A of the Field Office Technical Guide at: http://www.nrcs.usda.gov/technical/efotg/.

To find the information and general drainage recommendations provided by each soil moisture management group, find the soils series name in the alphabetical index list and determine the group identification symbol. Find the group identifier in the descriptive tables which follow and note the drainage recommendation.

GROUP 1 – Well drained to excessively drained.
GROUP 2 – Moderately well drained.
GROUP 3 – Somewhat poorly drained, poorly drained and very poorly drained.

SUBGROUP A – Sandy soils
SUBGROUP B – Loamy soils
SUBGROUP C – Clayey soils

Subdivision of subgroups:

b	- less than 20" over bedrock	l	- over loamy
b_2	- 20" to 40" over bedrock	s	- over sand or gravel
p	- slow or very slow permeability	h	- over organic
r	- rapid or very rapid permeability	h_1	- organic soils 51" deep or greater
c	- over clayey	h_2	- organic soils 16" to 50" deep

The letter designations (A, B, C, D, E, F, or G) below are also assigned to some soil series in each Soil Management Group. These letter designations provide some additional information to consider when designing or installing drainage in these soils. The designations are based primarily on the SSURGO data for soil survey areas in New York (http://soildatamart.nrcs.usda.gov/).

(A) These soils may be highly corrosive to concrete materials.

[Soils are designated (A) if they are rated "high" for concrete corrosion potential in the SSURGO soil data or if the soil reaction range includes very strongly acid or extremely acid.]

(B) These soils can be subject to frequent flooding. Subsurface drainage is not recommended unless the area is protected from the hazard.

[Soils are assigned the (B) designation if the SSURGO data indicates a flooding frequency of "frequent". Note that a particular soil component may be subject to frequent flooding in some survey areas but not in others.]

(C) These soils may contain 40% or more silt sized fraction in the soil, and thus geosynthetic filter fabrics need to be carefully specified.

[The (C) designation is based on the soil particle size distribution.]

(D) Open trenches are unstable in these soils and may cave in when soils are wet.

[The (D) designation is assigned to soils that lack cohesion. These are sands, gravels, or mixed silts and sands, in water-sorted deposits. Typically the gradation of the soil is such that less than 12 percent passes the No. 200 sieve; some SM soils with more than 12 percent passing the No.200 sieve are also included. The Plasticity Index typically is null or zero. Note that the layers that lack cohesion may be only part of the soil profile. Soils without the (D) designation may in some places contain significant lenses of sand, gravel, or silt. Careful on-site examination of the soil is recommended.]

(E) Some phases of these soils contain stones that may interfere with excavating and installing subsurface drains.

[The (E) designation is based on the content of rock fragments greater than 10 inches in diameter.]

(F) These soils are predominantly hydric. Planners should review wetland designations so that producers avoid becoming ineligible for USDA programs.

[The (F) designation is based on the hydric rating for the soil component.]

(G) These soils have significant potential for presence of hydric soils. In some areas hydric soils represent the dominant condition. Planners should review wetland designations so that producers avoid becoming ineligible for USDA programs.

[Soils with a hydric rating of "no" and a drainage class of "somewhat poorly drained" are considered to have potential for significant inclusions of hydric soils.]

ALPHABETICAL INDEX OF NEW YORK STATE SOILS AND SOIL MOISTURE MANAGEMENT GROUPS

Soil	Group
Abram	1Bb
Adams	1Ar
Adirondack	3Bp
Adjidaumo	3Cp
Adrian	$3h_2s$
Agawam	1Bsr
Albrights	2Bp
Alden	3B
Allagash	1Bsr
Allard	1Bsr
Allis	$3Cb_2p$
Almond	3Bp
Altmar	2Ar
Alton	1Bsr
Amboy	1Bsr
Amenia	2Bp
Ampersand	3Bp
Angola	$3Bb_2p$
Appleton	3Bp
Arkport	1Bsr
Arnot	1Bb
Ashville	3Bp
Atherton	3B
Atkins	3B
Atsion	3Ar
Au Gres	3Ar
Aurelie	3Bp
Aurora	$2Bb_2p$
Barbour	1Bsr
Barcelona	3B
Barre	3Clp
Barren	3Ar
Bash	3B
Basher	2B
Bath	1Bp
Becket	1Bp
Belgrade	2B
Benson	1Bb
Bergen	3Bp
Berkshire	1B
Bernardston	1Bp
Berryland	3Ar
Beseman	$3h_2l$
Bice	1B
Biddeford	3Cp
Bigapple	1Ar
Birdsall	3B
Blasdell	1Bsr
Bombay	2B
Bonaparte	1Ar
Boots	$3h_l$
Braceville	2Bsr
Branford	1Bsr
Brayton	3Bp
Breeze	1Ar
Bridgehampton	1B
Brinkerton	3Bp
Broadalbin	1Bp
Brockport	$3Cb_2p$
Buchanan	2Bp
Buckland	2Bp
Bucksport	$3h_l$
Bulkhead	$1h_2p$
Burdett	3Bp
Burnt Vly	$3h_2s$
Busti	3B
Buxton	2Cp
Cadosia	1B
Cambridge	2Bp
Camillus	$1Bb_2$
Camroden	3Bp
Canaan	1Bb
Canadice	3Cp
Canandaigua	3Bp
Canarsie	1Bp
Canaseraga	2Bp
Caneadea	3Cp
Canfield	2Bp
Canton	1Bsr
Carbondale	$3h_l$
Cardigan	$1Bb_2$
Carlisle	$3h_l$
Carrollton	$2Bb_2$
Carver	1Ar
Castile	2Bsr
Catden	$3h_l$
Cathro	$3h_2l$
Cavode	3Cp
Cayuga	2Clp
Cazenovia	2Bp
Centralpark	1Bp
Ceres	1B
Chadakoin	1B
Chagrin	1B
Champlain	1Ar
Charles	3B
Charlton	1B
Chatfield	$1Bb_2$
Chaumont	$3Cb_2p$
Chautauqua	2B
Chazy	$3Bb_2$
Cheektowaga	3Ac
Chenango	1Bsr
Cheshire	1B
Chippeny	$3h_2b_2$
Chippewa	3Bp
Churchville	3Clp
Churubusco	$3h_2b_2$
Claverack	2Acp
Cohactah	3B
Collamer	2B
Colonie	1Ar
Colosse	1Bsr
Colton	1Ar
Conesus	2Bp
Conic	$1Bb_2p$
Constable	1A
Cook	3Al
Copake	1Bsr
Cornish	3B
Cosad	3Ac
Couchsachraga	1Ab
Covert	2Ar
Covertfalls	2Al
Coveytown	3Al
Covington	3Cp
Crary	2Bp
Croghan	2Ar
Dalton	3Bp
Danley	2Bp
Dannemora	3Bp
Darien	3Bp
Dawson	$3h_2s$
Deerfield	2Ar
Deford	3Ar
Deinache	3A
Depeyster	2B
Deposit	2Bsr
Derb	3Bp
Dorval	$3h_2cp$
Dover	1B
Duane	2Ar
Dunkirk	1B
Dutchess	1B
Edwards	$3h_2p$
Eelweir	2B
Eldred	2Bp
Elka	1B
Elko	2Bp
Ellery	3Bp
Elmridge	2Bcp
Elmwood	2Bcp
Elnora	2Ar
Empeyville	2Bp
Enfield	1Bsr
Ensley	3B
Erie	3Bp
Ernest	2Bp
Essex	1A
Factoryville	1Ar
Fahey	2Ar
Farmington	1Bb
Fernlake	1A
Fishkill	3B
Flackville	2Acp
Flatiron	1B
Flatland	3B
Fonda	3Cp
Foresthills	1B
Fortress	2Ar
Franklinville	1B
Fredon	3Bs
Freetown	$3h_l$
Fremont	3Bp
Frewsburg	$3Bb_2$
Fryeburg	1B
Galen	2Bsr
Galoo	1Bb
Galway	$1Bb_2$
Gardenisle	$1Bb_2$
Genesee	1B
Georgia	2Bp
Getzville	3Bs
Gilpin	$1Bb_2$
Glebe	$1Bb_2$
Gloucester	1Ar
Glover	1Bb
Gougeville	3A
Gouverneur	1Bb
Granby	3Ar
Gravesend	1Ar
Greatkills	1B
Greenbelt	1B
Greene	$3Bb_2p$
Greenwood	$3h_l$
Grenville	1Bp
Gretor	$3Bb_2$
Groton	1Ar
Groton variant	$1Ab_2r$
Guff	$3Cb_2p$
Guffin	$3Cb_2p$
Gulf	3B
Haights	2B
Hailesboro	3B
Haledon	3Bp
Halcott	1Bb
Halsey	3Bs
Hamlin	1B
Hamplain	1B
Hannawa	3Bb
Hartland	1B
Hartleton	1B
Hassock	1B
Haven	1Bsr
Hawksnest	1Bb
Hempstead	1Bsr
Henniker	1Bp
Henrietta	3B
Herkimer	2B
Hermon	1Ar
Heuvelton	2Cp
Hilton	2Bp
Hinckley	1Ar
Hinesburg	1Al
Hogansburg	2Bp
Hogback	1Bb
Holderton	3B
Hollis	1Bb
Holly	3B
Holyoke	1Bb
Homer	3Bs
Honeoye	1Bp
Hoosic	1Bsr
Hornell	$3Cb_2p$
Hornellsville	$3Cb_2p$
Houghtonville	1B
Howard	1Bsr
Hudson	2Cp
Ilion	3Bp
Insula	1Bb
Inwood	1B
Ipswich	$3h_l$
Ira	2Bp
Irona	1Bb
Ischua	$2Bb_2p$
Ivory	3Cp
Jamaica	3Ar
Jebary	3Ar
Joliet	3Bb
Junius	3Ar
Kalurah	2B
Kanona	3Cp

Soil	Group
Kars	1Bsr
Kearsarge	1Bb
Kendaia	3Bp
Kings Falls	1Bb
Kingsbury	3Cp
Kinzua	1Bp
Knapp Creek	1B
Knickbocker	1Ar
Knob Lock	1bh$_2$
Lackawanna	1Bp
Lagross	1B
Laguardia	1B
Lairdsville	2Cb$_2$p
Lakemont	3Cp
Lamson	3B
Lanesboro	1Bp
Langford	2Bp
Lansing	1Bp
Leicester	3B
Lewbath	1Bp
Lewbeach	1Bp
Lima	2Bp
Limerick	3B
Linlithgo	3Brs
Livingston	3Cp
Lobdell	2B
Lockport	3Cb$_2$p
Londonderry	1Bb
Lordstown	1Bb$_2$
Lovewell	2B
Lowville	1Bp
Loxley	3h$_l$
Lyman	1Bb
Lyme	3B
Lyonmounten	3B
Lyons	3Bp
Macomber	1Bb$_2$
Madalin	3Cp
Madrid	1B
Malone	3Bp
Manahawkin	3h$_2$s
Mandy	1Bb$_2$
Manheim	3Bp
Manlius	1Bb$_2$
Maplecrest	1B
Marcy	3Bp
Mardin	2Bp
Marilla	2Bp
Markey	3h$_2$s
Marlow	1Bp
Martisco	3h$_2$p
Massena	3Bp
Matoon	3Cb$_2$p
Matunuck	3Ar
Medomak	3B
Melrose	1Bcp
Menlo	3Bp
Merrimac	1Ar
Metacomet	2Bp
Middlebrook	2Bb$_2$p
Middlebury	2B
Millsite	1Bb$_2$
Mineola	2Ar
Mino	3B
Minoa	3B
Mohawk	1Bp

Soil	Group
Monadnock	1Bs
Monarda	3Bp
Mongoup	1Bb$_2$
Montauk	1Bp
Mooers	2Ar
Morris	3Bp
Mosherville	3Bp
Mundalite	1Bp
Munuscong	3Bcp
Muskego	3h$_2$p
Muskellunge	3Cp
Napoleon	3h$_l$
Napoli	3Bp
Nassau	1Bb
Natchaug	3h$_2$l
Naumburg	3Ar
Neckrock	1Bb$_2$
Nehasne	1Bb$_2$
Nellis	1B
Neversink	3B
Newstead	3Bb$_2$
Niagara	3B
Nicholville	2B
Ninigret	2Bsr
Norchip	3Bp
Northway	3Al
Norwich	3Bp
Nuhi	3Bb$_2$p
Nunda	2Bp
Oakville	1Ar
Oatka	3Cp
Occum	1Bsr
Occur	2Al
Odessa	3Cp
Ogdensburg	3Bb$_2$
Oldmill	1Ar
Olean	2Bsr
Olentangy	3Bp
Ondawa	1B
Onjebonge	3B
Onoville	2Bp
Ontario	1Bp
Onteora	3Bp
Ontusia	3Bp
Oquaga	1Bb$_2$
Oramel	2Bcp
Orpark	3Bb$_2$p
Ossipee	3h$_l$l
Otego	2B
Otisville	1Ar
Ovid	3Bp
Palatine	1Bb$_2$
Palms	3h$_2$
Palmyra	1Bsr
Panton	3Cp
Papakating	3B
Patchin	3Bb$_2$p
Pavilion	3B
Pawcatuck	3h$_2$s
Pawling	2Bsr
Paxton	1Bp
Peasleeville	3B
Peru	2Bp
Phelps	2Bsr
Philo	2B
Pillsbury	3Bp

Soil	Group
Pinckney	1Bp
Pinnebog	3h$_l$
Pipestone	3Ar
Pittsfield	1B
Pittstown	2Bp
Plainfield	1Ar
Pleasant Lake	3h$_l$
Plymouth	1Ar
Podunk	2Bsr
Pompton	3Bs
Pondicherry	3h$_2$s
Pootatuck	2Bsr
Pope	1B
Portville	3Bp
Potsdam	1Bp
Punsit	3Bp
Pyrities	1B
Quetico	1Bb
Raquette	1Bsr
Rawsonville	1Bb$_2$
Rayne	1B
Raynham	3B
Raypol	3Brs
Red Hook	3B
Redwater	3B
Remsen	3Cp
Rhinebeck	3Cp
Ricker	1bh$_2$
Ridgebury	3Bp
Rifle	3h$_l$
Riga	2Cb$_2$p
Rikers	1Ar
Rippowam	3Bs
Riverhead	1Bsr
Rockrift	1B
Romulus	3Bp
Roundabout	3B
Rumney	3B
Runeberg	3Bp
Ruse	3Bb
Rushford	2Bp
Sabattis	3B
Salamanca	2Bp
Salmon	1B
Sandyhook	3Ar
Santanoni	1Ab$_2$r
Saco	3B
Saugatuck	3Ar
Scantic	3Cp
Scarboro	3Ar
Schoharie	2Cp
Schroon	2B
Schuyler	2Bp
Scio	2B
Scio variant	2Bsr
Sciota	3Ar
Scituate	2Bsp
Scriba	3Bp
Searsport	3Ar
Shaker	3Bcp
Shea	1Bp
Sheddenbrook	2Ab$_2$r
Shongo	3Bp
Sisk	1Bp
Skerry	2Bp
Skylight	1Ab

Soil	Group
Sloan	3B
Sodus	1Bp
Stafford	3Ar
Stockbridge	1B
Stockholm	3Ac
Stowe	2Bp
Success	1A
Sudbury	2Ar
Summerville	1Bb
Sun	3Bp
Sunapee	2B
Suncook	1Ar
Suny	3Bp
Sutton	2B
Swanton	3Bcp
Swartswood	1Bp
Swormville	3Bs
Taconic	1Bb
Tahawus	3A
Teel	2B
Tioga	1B
Todthill	1Bb$_2$
Tonawanda	3B
Topknot	3Bb
Tor	3Bb
Torull	3Bb
Towerville	2Bb$_2$
Trestle	1Bsr
Trout River	1Ar
Tughill	3Bp
Tuller	3Bb
Tunbridge	1Bb$_2$
Tunkhannock	1Bsr
Unadilla	1B
Uwihreh	3Cb$_2$p
Valois	1B
Varick	3Bb$_2$p
Varysburg	2Bcp
Venango	3Bp
Vergennes	2Cp
Verrazano	1Bs
Vly	1Bb$_2$
Volusia	3Bp
Waddington	1Bsr
Wakefiled	2Bp
Wakeland	3B
Wakeville	3B
Wallace	1Ar
Wallington	3Bp
Wallkill	3Bh
Walpole	3Ar
Wampsville	1Bsr
Wappinger	1Bsr
Wareham	3Ar
Warners	3B
Wassaic	1Bb$_2$
Watchaug	2B
Waumbek	2Ar
Wawayanda	3h$_2$
Wayland	3B
Weaver	2B
Wegatchie	3B
Wellsboro	2Bp
Wenonah	1B
Westbury	3Bp
Westland	3Bs

Soil	Group
Wethersfiled	1Bp
Whallonsburg	$3h_2cp$
Wharton	2Bp
Whately	3Bcp
Whitman	3Bp
Willdin	2Br
Willette	$3h_2cp$

Soil	Group
Williamson	2Bp
Willowemoc	2Bp
Wilmington	3Bp
Wilpoint	$2Cb_2p$
Windsor	1Ar
Winhole	2B
Wiscoy	3Bp

Soil	Group
Wonsqueak	$3h_2l$
Woodbridge	2Bp
Woodstock	1Bb
Woostern	1B
Worden	3Bp
Worth	1Bp
Wotalf	1Bb

Soil	Group
Wurtsboro	2Bp
Wyalusing	3Brs
Yaleville	$1Bb_2$
Yorkshire	2Bp
Yunenyeti	$2Bb_2p$

TYPICAL SOIL DESCRIPTION and SUBSURFACE DRAINAGE REQUIREMENTS

1A Well drained, sandy soils that have moderately slow permeability in the subsoil or substratum.

Constable(A)(D)	Essex(A)(E)	Fernlake(A)(D)	Success(A)(E)(D)

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Ab Well drained, sandy soils with less than 20" to bedrock.

Couchsachraga(A)(E)	Skylight(A)(E)

Subsurface drainage: not recommended

$1Ab_2r$ Somewhat excessively drained or excessively drained, sandy soils with 20" to 40" over bedrock and rapid or very rapid permeability in the subsoil and substratum.

Groton variant(D)	Santanoni(A)(E)

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Al Well drained, sandy soils over loamy substratum.

Hinesburg(D)

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Ar Well drained to excessively drained, sandy soils that have rapid or very rapid permeability in the substratum.

Adams(A)(D)	Colton(A)(D)(E)	Knickerbocker(D)	Rikers(A)(D)
Bigapple(A)(D)	Factoryville(D)	Merrimac(D)	Suncook (A)(D)
Bonaparte(D)	Gloucester(A)(E)	Oakville(D)	Trout River(A)(D)(E)
Breeze(D)	Gravesend(D)	Oldmill(D)	Wallace(A)(D)
Carver(A)(D)	Groton(D)	Otisville(A)(D)	Windsor(A)(D)
Champlain(D)	Hermon(A)(D)(E)	Plainfield(A)(D)	
Colonie(D)	Hinckley(A)(D)	Plymouth(A)(D)	

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1B Well drained, loamy soils that have moderate permeability in the substratum.

Berkshire (A)(E)	Elka(A)(E)	Hassock	Rayne(A)(C)(E)
Bice(A)(E)	Flatiron(A)(E)	Houghtonville(A)(E)	Rockrift(A)(E)
Bridgehampton(C)	Foresthills(A)(C)	Inwood	Salmon(C)
Cadosia(A)(E)	Franklinville(A)(C)	Knapp Creek(A)	Stockbridge(E)
Ceres(A)(E)	Fryeburg(C)	Lagross (C)	Tioga(B)(C)(D)
Chadakoin(A)(C)	Genesee (C)	Laguardia	Unadilla(C)
Chagrin(C)	Greatkills	Madrid(E)	Valois(A)(C)(E)
Charlton(A)(E)	Greenbelt(A)(C)	Maplecrest(A)(E)	Wenonah(A)(C)(D)
Cheshire(A)(C)(E)	Hamlin(C)	Nellis(C)(E)	Woostern(A)(E)
Dover(E)	Hamplain(C)	Pittsfield(E)	
Dunkirk(C)	Hartland(C)	Pope(A)(D)	
Dutchess(C)	Hartleton(A)(E)	Pyrities(E)	

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Bb Well drained and somewhat excessively drained loamy soils, shallow or very shallow to bedrock, that have moderate permeability in the subsoil.

Abram(A)(E)	Gouverneur	Irona(E)	Summerville(C)(E)
Arnot(A)(E)	Halcott(A)(E)	Kearsarge(A)(C)	Taconic(A)(E)
Benson(E)	Hawksnest(A)(E)	Kings Falls(C)	Woodstock(A)(E)
Canaan(E)	Hogback(A)(E)	Londonderry(A)(E)	Wotalf(A)
Farmington(C)(E)	Hollis(A)(E)	Lyman(A)(E)	
Galoo(E)	Holyoke(A)(C)(E)	Nassau(A)	
Glover(E)	Insula(E)	Quetico(E)	

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

$1Bb_2$ Well drained, loamy soils moderately deep to bedrock that have moderate permeability in the subsoil.

Camillus(C)	Glebe(A)(E)	Mongaup(A)(C)(E)	Todthill
Cardigan(A)(C)(E)	Lordstown(A)(C)(E)	Neckrock(C)	Tunbridge(A)(E)
Chatfield(E)	Macomber(A)(C)(E)	Nehasne(E)	Vly(A)(E)
Galway(C)(E)	Mandy(A)(E)	Oquaga(A)(E)	Wassaic(C)(E)
Gardenisle	Manlius(C)	Palatine(C)	Yaleville(A)(E)
Gilpin(A)(C)(E)	Millsite(A)(E)	Rawsonville(A)(E)	

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Bb$_2$p Well drained, loamy soils moderately deep to bedrock that have slow permeability in the subsoil.

Conic(E)

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Bcp Well drained loamy soils over clay that have slow or very slow permeability in the lower part of the subsoil or in the substratum.

Melrose

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1bh$_2$ Well drained organic soils that are shallow to bedrock.

Knob Lock(A)	Ricker(A)

Subsurface drainage is seldom needed and may not be practical.

Soils must be field checked to determine if subsurface drains can be installed above bedrock. They should not be installed where bedrock is less than 30 inches from the surface.

1Bp Well drained, loamy soils with that have slow or very slow permeability in the lower part of the subsoil or in the substratum.

Bath(A)(C)(E)	Honeoye(C)(E)	Marlow(A)(E)	Shea
Becket(A)(E)	Kinzua(A)(C)(E)	Mohawk(C)(E)	Sisk(A)(E)
Bernardston(C)(E)	Lackawanna(A)(C)(E)	Montauk(A)(E)	Sodus(A)(E)
Broadalbin(C)(E)	Lanesboro(A)(C)(E)	Mundalite(A)(E)	Swartswood(A)(E)
Canarsie(C)(E)	Lansing(C)(E)	Ontario(C)(E)	Wethersfield(C)
Centralpark(A)	Lewbath(A)(C)(E)	Paxton(A)(E)	Worth(A)(E)
Grenville(E)	Lewbeach(A)(C)(E)	Pinckney(C)(E)	
Henniker(E)	Lowville(C)	Potsdam(A)(C)(E)	

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Bs Well drained and somewhat excessively drained loamy soils over sand and gravel.

Monadnock(A)(E)	Verrazano(A)(C)

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

1Bsr Well drained and somewhat excessively drained loamy soils over sand and gravel that have rapid or very rapid permeability in the substratum.

Agawam(A)(D)	Branford(D)	Hoosic(A)(D)	Trestle(D)
Allagash(A)(C)(D)	Canton(A)(D)	Howard(D)	Tunkhannock(A)(D)
Allard(C)(D)	Chenango(D)	Kars(D)(E)	Waddington(D)
Alton(D)	Colosse(A)(D)	Occum(B)(C)(D)	Wampsville(D)
Amboy(C)(D)	Copake(C)(D)	Ondawa(B)(D)	Wappinger(B)(D)
Arkport(C)(D)	Enfield(C)(D)	Palmyra(D)	
Barbour(B)(D)	Haven(A)(C)(D)	Raquette(D)	
Blasdell(C)(D)	Hempstead(C)(D)	Riverhead(A)(D)	

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

$1h_2p$ Well drained organic soils that are 10" to 20" deep over a layer of impermeable buried pavement, which overlies mineral soil.

Bulkhead(A)

Subsurface drainage: not recommended.

2Al Moderately well drained, sandy soils with loam in the substratum.

Covertfalls(D)(E) Occur(D)(E)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

$2Ab_2r$ Moderately well drained, sandy soils that have 20' to 40' over bedrock that have rapid to very rapid permeability in the substratum.

Sheddenbrook(A)(D)

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

Soils must be field checked to determine if subsurface drains can be installed above bedrock. They should not be installed when bedrock is less than 30 inches from the surface.

2Acp Moderately well drained sandy over clayey soils that have slow or very slow permeability in the substratum.

Claverack(D)	Flackville(D)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

2Ar Moderately well drained, sandy soils that have rapid or very rapid permeability in the substratum.

Altmar(D)	Deerfield(A)(D)	Fahey(A)(D)(E)	Mooers(D)
Covert(D)	Duane(A)(D)	Fortress(A)(D)	Sudbury(A)(D)
Croghan(A)(D)	Elnora(D)	Mineola (D)	Waumbek(A)(D)(E)

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

2B Moderately well drained, loamy soils that have moderate permeability in the substratum.

Basher(B)(C)(D)	Haights(C)	Otego(C)	Watchaug(A)
Belgrade(C)	Herkimer(C)	Philo(A)(C)(D)	Weaver(B)(C)
Bombay(E)	Kalurah(E)	Schroon(A)(E)	Winhole
Chautauqua(C)	Lobdell(C)	Scio(C)	
Collamer(C)	Lovewell(C)(D)	Sunapee(A)(E)	
Depeyster(C)	Middlebury(B)(C)(D)(G)	Sutton(A)(E)	
Eelweir(C)(D)	Nicholville(C)	Teel(B)(C)(G)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

$2Bb_2$ Moderately well drained, loamy soils, moderately deep to bedrock.

Carrollton(A)(C)(E)	Towerville(A)(C)(E)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

Soils must be field checked to determine if subsurface drains can be installed above bedrock. They should not be installed when bedrock is less than 30 inches from the surface.

$2Bb_2p$ Moderately well drained, loamy soils, moderately deep to bedrock, that have slow permeability in the subsoil.

Aurora(C)	Ischua(A)(C)	Middlebrook(C)(E)	Yunenyeti(C)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

Soils must be field checked to determine if subsurface drains can be installed above bedrock. They should not be installed when bedrock is less than 30 inches from the surface.

2Bcp Moderately well drained, loamy soils over clay that have slow or very slow permeability in the substratum.

Elmridge(C)(D)	Elmwood(C)(D)	Oramel(C)(D)	Varysburg(C)(D)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

2Bp Moderately well drained, loamy soils that have slow or very slow permeability in the subsoil or substratum.

Albrights(A)(C)(E)	Eldred(A)(C)	Marilla(C)	Wellsboro(A)(C)(E)
Amenia(C)(E)	Elko(A)(C)	Metacomet(E)	Wharton(A)(C)(E)
Buchanan(A)(C)(E)	Empeyville(A)(E)	Nunda(C)	Willdin(A)(C)(E)
Buckland(C)(E)	Ernest(A)(C)(E)	Onoville(A)(C)(E)	Williamson(C)
Cambridge(C)	Georgia(C)(E)	Peru(A)(E)	Willowemoc(A)(C)(E)
Canaseraga(C)	Hilton(C)(E)	Pittstown(C)(E)	Woodbridge(A)(E)
Canfield(C)(E)	Hogansburg(E)	Rushford(C)	Wurtsboro(A)(E)
Cazenovia(C)	Ira(A)(E)	Salamanca(A)(C)	Yorkshire(C)
Conesus(C)(E)	Langford(C)(E)	Schuyler(A)(C)	
Crary(A)(C)(E)	Lima(C)(E)	Skerry(A)(E)	
Danley(C)	Mardin(A)(C)(E)	Stowe(A)(E)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

2Bsp Moderately well drained, loamy over sandy soils that have slow permeability in the substratum.

Scituate(A)(E)

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

2Bsr Moderately well drained, loamy soils over sand and gravel that have rapid permeability in the substratum.

Braceville (C)(D)	Ninigret(A)(D)	Podunk(B)(D)
Castile(D)	Olean(C)(D)	Pootatuck(B)(C)(D)
Deposit(D)	Pawling(B)(C)(D)	Scio variant(C)(D)
Galen(C)(D)	Phelps(C)(D)	

Subsurface drainage: 3 to 4 feet deep.

These soils seldom need subsurface drainage. For small wet areas and seeps, use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

$2Cb_2p$ Moderately well drained, clayey soils moderately deep to bedrock that have slow or very slow permeability in the subsoil.

Lairdsville(C)	Riga(C)	Wilpoint(C)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 70 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

2Clp Moderately well drained, clayey soils over loamy till that have slow or very slow permeability in the subsoil or substratum.

Cayuga(C)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 70 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

2Cp Moderately well drained, clayey soils that have slow or very slow permeability in the subsoil or substratum.

Buxton(C)	Hudson(C)	Vergennes(C)
Heuvelton(C)	Schoharie(C)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3A Somewhat poorly drained, poorly drained, and very poorly drained sandy soils.

Deinache(C)(D)(F)	Gougeville(C)(D)(F)	Tahawus(A)(D)(E)(F)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 60 to 100 feet apart.
Special crops: 50 to 70 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Ac Somewhat poorly drained, poorly drained, and very poorly drained sandy soils over clay that have slow or very slow permeability in the substratum.

Cheektowaga(C)(D)(F)	Cosad(C)(D)(G)	Stockholm(A)(C)(D)(F)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 70 feet apart.
Special crops: 30 to 50 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Al Somewhat poorly drained, poorly drained, and very poorly drained sandy over loamy soils that have moderately slow permeability in the substratum.

Cook(D)(E)(F)	Coveytown(D)(E)(G)	Northway(D)(E)(G)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 70 feet apart.
Special crops: 30 to 50 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Ar Somewhat poorly drained, poorly drained, and very poorly drained sandy soils that have rapid or very rapid permeability in the substratum.

Atsion(A)(D)(F)	Granby(D)(F)	Naumburg(A)(D)(G)	Sciota(D)(G)
Au Gres(A)(D)(G)	Jamaica(A)(D)(F)	Pipestone(D)(G)	Searsport(A)(D)(F)
Barren(A)(D)(G)	Jebavy(A)(D)(F)	Sandyhook(D)(F)	Stafford(A)(D)(G)
Berryland(A)(D)(F)	Junius(D)(G)	Saugatuck(A)(D)(G)	Walpole(A)(D)(G)
Deford(D)(G)	Matunuck(A)(D)(F)	Scarboro(A)(D)(F)	Wareham(A)(D)(F)

Subsurface drainage: 3 to 4½ feet deep.
Field crops: 80 to 120 feet apart.
Special crops: 50 to 90 feet apart.

When wider spacings are used, increase depth of subsurface line.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3B Somewhat poorly drained, poorly drained, and very poorly drained loamy soils that have moderate permeability in the substratum.

Alden(C)(E)(F)	Flatland(G)	Mino(C)(D)(G)	Rumney(A)(B)(D)(F)
Atherton(C)(D)(F)	Gulf(C)(F)	Minoa(C)(D)(G)	Sabattis(A)(E)(F)
Atkins(A)(B)(C)(F)	Hailesboro(C)(G)	Neversink(A)(E)(F)	Saco(B)(C)(F)
Barcelona(C)(G)	Henrietta(C)(F)	Niagara(C)(G)	Sloan(B)(C)(F)
Bash(B)(C)(G)	Holderton(C)(G)	Onjebonge(C)(D)(F)	Tonowanda(C)(G)
Birdsall(C)(F)	Holly(B)(C)(F)	Papakating(B)(C)(F)	Wakeland(C)(G)
Busti(C)(G)	Lamson(C)(D)(F)	Pavilion(C)(F)	Wakeville(C)(G)
Charles(B)(C)(D)(F)	Leicester(A)(E)(G)	Peasleeville(E)(G)	Warners(B)(C)(F)
Cohoctah(B)(C)(F)	Limerick(B)(C)(F)	Raynham(C)(G)	Wayland(B)(C)(F)
Cornish(B)(C)(D)(G)	Lyme(A)(E)(F)	Red Hook(C)(D)(G)	Wegatchie(C)(F)
Ensley(E)(F)	Lyonmounten(E)(F)	Redwater(B)(C)(G)	
Fishkill(F)	Medomak(B)(C)(D)(F)	Roundabout(C)(G)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 100 feet apart.
Special crops: 30 to 60 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Bb Somewhat poorly drained, poorly drained, and very poorly drained loamy soils, shallow to bedrock, that have moderate permeability in the subsoil.

Hannawa(C)(F)	Ruse(E)(F)	Tor(A)(E)(G)	Tuller(A)(C)(E)(G)
Joliet(C)(F)	Topknot(E)(G)	Torull(A)(C)(E)(G)	

Subsurface drainage: Not recommended.

$3Bb_2$ Same as $3Bb_2p$ below, except with moderate or moderately rapid permeability.

Chazy(E)	Gretor(A)(C)(E)(G)	Ogdensburg(C)(E)(G)
Frewsburg(A)(C)(G)	Newstead(C)(E)(G)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 70 feet apart.

$3Bb_2p$ Somewhat poorly drained and poorly drained loamy soils, moderately deep to bedrock, that have slow and very slow permeability in the subsoil.

Angola(C)(G)	Nuhi(C)(G)	Patchin(A)(C)(F)
Greene(A)(C)(E)(G)	Orpark(A)(C)(G)	Varick(C)(F)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 70 feet apart.
Special crops: 30 to 50 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

Soils must be field checked to determine if subsurface drains can be installed when bedrock is less than 30 inches from the surface.

3Bcp Somewhat poorly drained, poorly drained, and very poorly drained loamy soils over clay, with slow and very slow permeability in the substratum.

Munuscong(C)(D)(F)	Shaker(C)(D)(G)	Swanton(C)(D)(G)	Whately(C)(D)(F)

Subsurface drainage: 2½ to 4 feet deep.
Field crops: 40 to 100 feet apart.
Special crops: 30 to 70 feet apart.

Special backfilling with gravels or organic materials (hay, straw, corncobs, etc.) and/or topsoil may be helpful to the function of subsurface drainage in these soils.

Subsurface drainage of these soils may not be economical in some instances where the underlying clay layer is close to the surface. A careful study of each site is recommended.

3Bh Very poorly drained loamy soils over organic deposits that have moderate permeability in the substratum.

Wallkill(B)(C)(F)

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 100 feet apart.
Special crops: 30 to 60 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Bp Somewhat poorly drained, poorly drained, and very poorly drained loamy soils that have slow and very slow permeability in the subsoil or substratum.

Adirondack(A)(E)(G)	Darien(C)(G)	Morris(A)(C)(E)(G)	Scriba(C)(E)(G)
Almond(A)(C)(G)	Derb(C)(G)	Mosherville(C)(E)(G)	Shongo(A)(C)(E)(G)
Ampersand(A)(E)(G)	Ellery(C)(E)(F)	Napoli(C)(G)	Sun(C)(E)(F)
Appleton(C)(E)(G)	Erie(C)(E)(G)	Norchip(C)(E)(F)	Suny(A)(C)(E)(F)
Ashville(C)(F)	Fremont(A)(C)(G)	Norwich(C)(E)(F)	Tughill(A)(E)(F)
Aurelie(C)(F)	Haledon	Olentangy(A)(C)(F)	Venango(A)(C)(E)(G)
Bergen(C)(F)	Ilion(C)(E)(F)	Onteora(A)C)(E)(G)	Volusia(A)(C)(E)(G)
Brayton(E)(G)	Kendaia(C)(E)(G)	Ontusia(A)(C)(E)(G)	Wallington(A)(C)(D)(G)
Brinkerton(A)(C)(E)(F)	Lyons(C)(E)(F)	Ovid(C)(G)	Westbury(A)(E)(G)
Burdett(C)(G)	Malone(E)(G)	Pillsbury(A)(E)(G)	Whitman(A)(C)(E)(F)
Camroden(C)(E)(G)	Manheim(C)(E)(G)	Portville(A)(C)(E)(G)	Wilmington(A)(E)(F)
Canandaigua(C)(F)	Marcy(C)(F)	Punsit(C)(G)	Wiscoy(C)(G)
Chippewa(C)(E)(F)	Massena(E)(G)	Ridgebury(A)(E)(G)	Worden(A)(E)(G)
Dalton(C)(G)	Menlo(C)(E)(F)	Romulus(C)(F)	
Dannemora(A)(E)(F)	Monarda(A)(C)(E)(F)	Runeberg(C)(E)(F)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 35 to 100 feet apart.
Special crops: 30 to 60 feet apart.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Brs Somewhat poorly drained, poorly drained, or very poorly drained loamy soils over sand or gravel, with rapid or very rapid permeability in the subsoil.

Linlithgo(B)(C)(D)(G)	Raypol(C)(D)(F)	Wyalusing(B)(C)(D)(F)

Subsurface drainage: 3 to 4½ feet deep.
Field crops: 60 to 100 feet apart.
Special crops: 60 to 70 feet apart.

3Bs Somewhat poorly drained, poorly drained, and very poorly drained loamy soils over sand and gravel that have moderate permeability in the subsoil.

Fredon(C)(D)(G)	Homer(A)(C)(D)(G)	Swormville(C)(D)(G)
Getzville(C)(D)(F)	Pompton(A)(C)(D)	Westland(C)(D)(F)
Halsey(C)(D)(F)	Rippowam(A)(B)(C)(D)(F)	

Subsurface drainage: 3 to 4 feet deep.
Field crops: 45 to 75 feet apart.
Special crops: 30 to 50 feet apart.

For small areas use random lines.

When fine sands or silts are encountered, they must be excluded from the drains by covering (360° protection) with suitable geosynthetic or gravel envelope filter material.

3Cb$_2$p Somewhat poorly drained and poorly drained clayey soils, moderately deep to bedrock, that have slow permeability in the subsoil.

Allis(A)(C)(F)	Guff(C)(F)	Hornellsville(A)(C)(G)	Uwihreh(C)(F)
Brockport(C)(G)	Guffin(C)(F)	Lockport(C)(G)	
Chaumont(C)(G)	Hornell(A)(C)(G)	Matoon(C)(G)	

Subsurface drainage: 2½ to 4 feet deep.
Field crops: 35 to 100 feet apart.
Special crops: 25 to 60 feet apart.

3Clp Somewhat poorly drained, poorly drained, or very poorly drained, clayey soils over loamy subsoil that have slow or very slow permeability in the subsoil.

Barre(C)(E)(F)	Churchville(C)(E)(G)

Subsurface drainage: 3 to 4½ feet deep.
Field crops: 30 to 80 feet apart.
Special crops: 25 to 60 feet apart.

3Cp Somewhat poorly drained, poorly drained, or very poorly drained clayey soils that have slow and very slow permeability in the substratum.

Adjidaumo (C)(F)	Covington(C)(F)	Lakemont(C)(F)	Odessa(C)(G)
Biddeford(C)(F)	Fonda(C)(F)	Livingston(C)(F)	Panton(C)(F)
Canadice(C)(F)	Ivory(A)(C)(G)	Madalin(C)(F)	Remsen(C)(G)
Caneadea(C)(G)	Kanona(C)(G)	Muskellunge(C)(G)	Rhinebeck(C)(G)
Cavode(A)(C)(G)	Kingsbury(C)(G)	Oatka(B)(C)(G)	Scantic(C)(F)

Subsurface drainage: 2½ to 4 feet deep.
Field crops: 35 to 70 feet apart.
Special crops: 25 to 50 feet apart.

Special backfilling with gravels or organic materials (hay, straw, corncobs, etc.) and/or topsoil may be helpful to the function of subsurface drainage in these soils.

Subsurface drainage of these soils may not be economical in some instances. A careful study of each site is recommended.

$3h_1$ Very poorly drained organic soils that are more than 51" deep.

Boots(F)	Catden(F)	Loxley(A)(F)	Rifle(F)
Bucksport(A)(F)	Freetown(A)(F)	Napoleon(A)(F)	
Carbondale(F)	Greenwood(A)(F)	Pinnebog(F)	
Carlisle(F)	Ipswich(A)(F)	Pleasant Lake(A)(F)	

Subsurface drainage: 4 to 5 feet deep.
Field crops: 60 to 100 feet apart.
Special crops: 50 to 100 feet apart.

Deep, open ditches at the suggested spacing are recommended for both surface and subsurface water control. Controlled drainage is recommended. Subsurface drains in newly developed land should be placed at a maximum depth because of initial subsidence. Subsurface drains may fail in some soils in some areas as a result of iron oxidation and/or iron ochre formation.

$3h_2$ Very poorly drained organic soils that are 16" to 50" deep over mineral soils.

Palms(F)

Subsurface drainage: 4 to 5 feet deep.
Field crops: 60 to 100 feet apart.
Special crops: 50 to 100 feet apart.

Controlled drainage is recommended. Subsurface drains in newly developed land should be placed at a maximum depth because of initial subsidence.

For sites where organic material is less than 30 inches, use depth and spacing recommended for underlying material or use deep, open ditches. A careful study of each site is recommended.

$3h_2cp$ Very poorly drained organic soils that are 16" to 50" over clay.

Dorval(F)	Whallonsburg(F)	Willette(F)

Similar to $3h_2$ but subsurface drain spacing may need to be closer.

$3h_2p$ Very poorly drained organic soils that are 8" to 50" over marl or coprogenous earth.

Edwards (F)	Martisco(F)	Muskego (F)	Wawayanda(F)

Similar to $3h_2$

$3h_2s$ Very poorly drained organic soils that are 16" to 50" over sand.

Adrian(D)(F)	Dawson(A)(D)(F)	Markey(D)(F)	Pondicherry(D)(F)
Burnt Vly(A)(D)(F)	Manahawkin(A)(D)(F)	Pawcatuck(A)(D)(F)	

For sites where organic material is less than 30 inches, use depth and spacing recommended for underlying sand material.

$3h_2l$ Very poorly drained organic soils that are 16" to 50" deep over loam

Beseman(A)(F)	Natchaug (F)	Wonsqueak (F)
Cathro(F)	Ossipee(A)(F)	

Subsurface drainage: 4 to 5 feet deep.
Field crops: 60 to 100 feet apart.
Special crops: 50 to 100 feet apart.

Controlled drainage is recommended. Subsurface drains in newly developed land should be placed at a maximum depth because of initial subsidence. use depth and spacing recommended for underlying loam material.

$3h_2b_2$ Very poorly drained organic soils that are 16" to 50" over bedrock.

Chippeny (F)	Churubusco(A)(F)

Controlled drainage is recommended. Subsurface drains in newly developed land should be placed at a maximum depth because of initial subsidence.

For sites where organic material is less than 30 inches, use open ditches. A careful study of each site is recommended

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OUTLETS FOR DRAINAGE SYSTEMS

All drainage systems require outlets of adequate capacity, depth and stability to meet design requirements (Figure 1). If the outlet is inadequate, the effectiveness of the entire drainage system can be greatly reduced or lost. An outlet channel must have the capacity to carry flow not only from the drainage system but also from the entire area served by the system. Where the outlet carries flow from subsurface drains, the outlet should be deep enough that the drains can be discharged into it above normal low-water flow.

Installation of an outlet channel or improvement of an existing channel usually increases peak discharge downstream from the end of the improvement. Take steps to prevent increased stages downstream from creating significant damage. The channel must be stable when flow reaches design capacity. Where the drainage area exceeds 1 square mile, consult Design of Open Channels, Natural Resource Conservation Service Technical Release No. 25, U.S. Department of Agriculture. This publication contains procedures for evaluating channel stability.

Design Considerations

Capacity

Crops can tolerate a limited amount of flooding or ponding but should normally not be flooded or ponded for longer than 24 to 48 hours. To determine what the capacity of the outlet channel must he to remove water quickly enough, either calculate flood routings of the drainage area or refer to drainage curves like those shown in Figure 2. The curves show the rate of discharge that will provide a certain level of drainage in the watershed area. They were developed from many field measurements of drainage flow rates and from observation of drainage systems. The curves are applicable only to drainage areas having average slopes of less than 25 feet per mile and do not allow for peak flows after heavy rains. Excess runoff will be discharged overland, temporarily flooding adjacent areas.

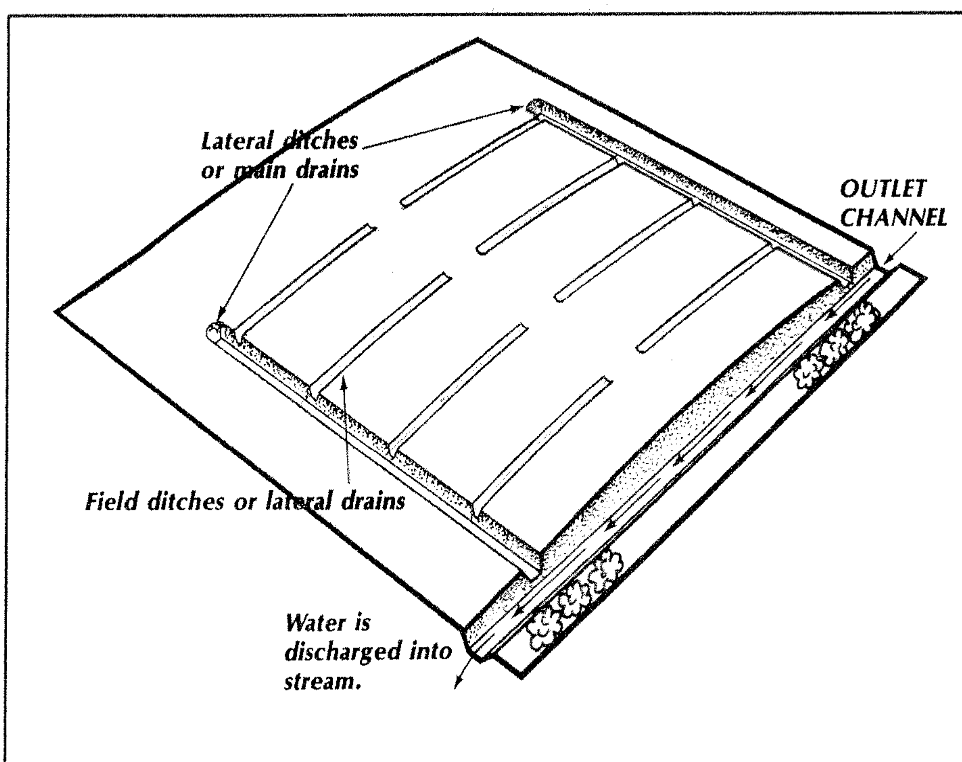


Figure 1. Systematic drainage. An adequate outlet is very important to the effectiveness of a drainage system. Any part or all of the system pictured could be a surface ditch or subsurface drain.

Outlet channels designed according to **curve B** will provide excellent agricultural drainage. Use this curve for drainage of truck crops, nursery crops, and other specialty crops. Designs based on curve B will provide the best drainage that can normally be justified in agricultural areas. Channels that are designed according to **curve C** will provide good agricultural drainage. This curve is the one most often recommended for drainage of cropland. Designs based on **curve D** provide satisfactory agricultural drainage as long as frequent overflow does not cause excessive damage. This curve is generally recommended for pasture or woodland. It may also he adequate for drainage of general cropland, provided that the landowner carries out an excellent maintenance program. Designs based on curve D provide the minimum amount of drainage. Another alternative is to design these channels based on acceptable storm frequency return periods.

Once you know what the capacity of the outlet channel must be, you need to determine the size that will enable it to convey the desired amount of flow without letting the water surface rise above a predetermined elevation. The following sections describe some basic hydraulic concepts that will help you design a channel of the proper size.

Hydraulic and Erosion Considerations

Ideal open channels would have neither excessive scour nor deposition of sediments; however, in practice, ideal conditions are very difficult to achieve since flows both lower and higher than design flows occur. Design engineers should select velocities that are neither excessively erosive nor so low as to cause large amounts of sediment deposition. Grades should be as uniform as possible; gradual curves should be designed where needed; and control structures should be used to conduct side drainage into the channels. Drop structures and erosion protective measures should he installed in open channels when erosion is anticipated. During construction erosion control practices may be needed to prevent siltation offsite either directly downstream or from spoil sites. Although agricultural practices are exempt from obtaining an erosion and sediment control permit an erosion and sediment control plan must be made and implemented.

Velocities less than 2 feet per second should be avoided, as siltation is likely to occur, resulting in reduced channel capacity. The following table provides a guide to maximum allowable velocities for drainage areas less than one square mile. For drainage areas greater than one square mile, consult Design of Open Channels, Soil Conservation Service Technical Release No. 25, U.S. Dept. of Agriculture.

Velocity

The velocity of water flow must be high enough to prevent siltation in the channel but low enough to avoid erosion. Listed below are the maximum velocities for drainage areas of 640 acres or less. The velocity should be no lower than 1.5 feet per second. A lower velocity will cause siltation, which encourages moss and weed growth and reduces the cross section of the channel.

Soil Texture	Maximum Allowable Velocity* ft./sec.
Sandy or sandy loam, loamy sand	2.5
Silt loam, loam	3.0
Sandy clay loam, sandy clay	3.5
Clay loam, silty clay loam	4.0
Clay or silty clay	5.0
Fine gravel, cobbles, or graded loam to cobbles	5.0
Graded mixture silt to cobbles	5.5
Coarse gravel, shales, or hardpans	6.0

*Use most critical soil layer if stratified.

DRAINAGE CURVES

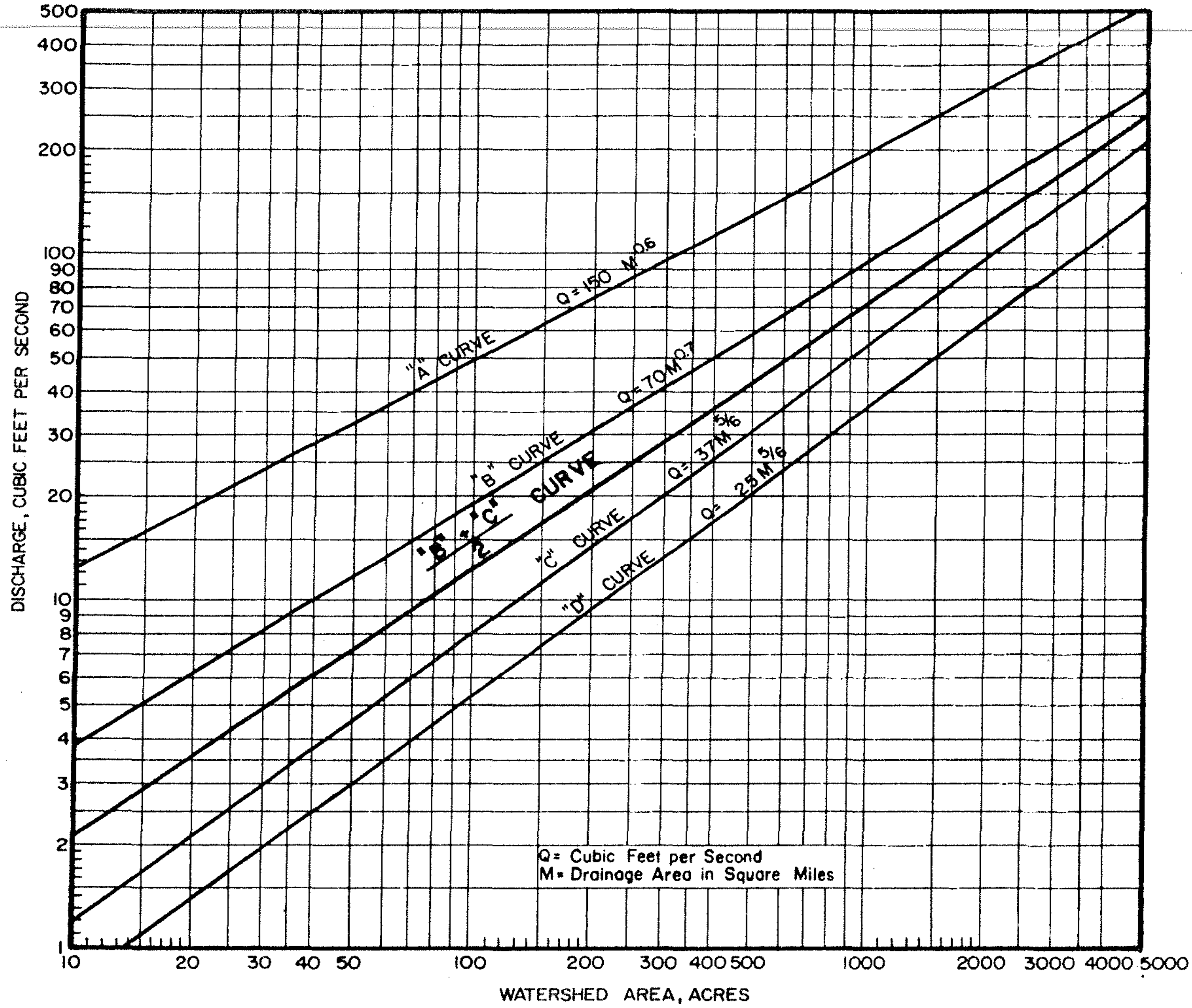


Figure 2. Drainage curves for determining what the capacity of an open ditch must be to provide a certain level of drainage in a specified area. Channels based on curve **B** *provide excellent agricultural drainage; those on curve* **C***, good drainage; and those on curve* **D***, satisfactory drainage. (Adapted from Soil Conservation Service,* **National Engineering Handbook***, Section 16, Chapter 5.)*

Hydraulic Gradient

The hydraulic gradient represents the surface of the water when the outlet channel is operating at its design flow (Fig. 3). The hydraulic gradient for the channel should he determined from control points such as the elevation of low areas served by the channel and the hydraulic gradients of tributary ditches. Draw the hydraulic gradient through or below as many important control points as possible after studying the profile of the natural ground surface, elevations established by surveys, and channel restrictions such as culverts and bridges.

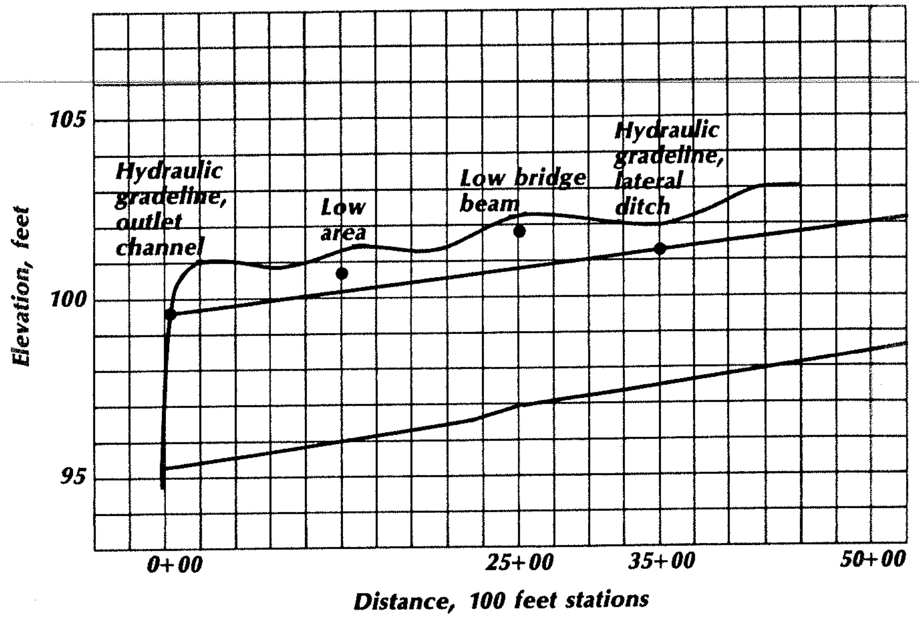


Figure 3. Profile of an outlet channel showing the hydraulic gradeline designed through or below critical control points.

<u>Manning's Equation</u>

The most widely used equation for designing outlet channels was developed by Robert Manning in 1890 and is known as Manning's equation:

$$\mathbf{V} = \frac{1.486}{n} r^{2/3} s^{1/2}$$

where

V = average velocity of flow in feet per second,

n = coefficient of roughness,

r = hydraulic radius in feet,

s = slope of hydraulic gradient in feet per foot (although s should be the slope of the water surface, it can be the slope of the channel bottom for designs within the scope of this publication).

The equation below is used to determine r:

$$\mathbf{r} = \frac{A}{p}$$

where

A = area of cross section in square feet,

p = wetted perimeter or length, in feet, of cross section on which water impinges.

The roughness coefficient n takes into account not just roughness, but anything in a channel that might retard the flow of water. Vegetation, meanders, obstructions, etc., all affect channel flow. For designs within the scope of this publication, a value of n = 0.04 is commonly used if the channel has aged. Many tables used in channel design are based on that value. However, in determining a value for n, you should consider all retarding influences, not just aging. Select a value representing conditions that will exist after the channel has aged and that assumes the amount of maintenance you expect to do.

Generally, n tends to decrease as the hydraulic radius increases. Listed below are recommended values for n based on the hydraulic radius of the earth channels. You can use these values in solving Manning's equation if the channel has good alignment.

Hydraulic Radius	n
less than 2.5	.040 to .045
2.5 to 4.0	.035 to .040
4.1 to 5.0	.030 to .035
more than 5.0	.025 to .030

After determining V, calculate channel capacity, using the continuity equation:

Q = A x V

where

Q = capacity in cubic feet per second,

A = area of cross section in square feet,

V = velocity in feet per second (determined from Manning's equation).

The references listed below contain tables that will aid you in selecting n values and solving Manning's equation:

- King, Horace Williams, and Ernest F. Brater, HANDBOOK OF HYDRAULICS, 5th ed. New York: McGraw-Hill, 1977.
- Army Corps of Engineers. HYDRAULIC TABLES. 2nd ed. Washington, D.C.: U.S. Government Printing Office, 1944.
- Bureau of Reclamation, HYDRAULIC AND EXCAVATION TABLES. 11th ed. 1957. Reprint. Washington, D.C.: U.S. Government Printing Office, 1974.

Channel Depth

An outlet channel that receives water from subsurface drains should be designed to keep the normal water surface 1 foot or greater below the bottom of the subsurface drain (Fig. 4). The normal water surface is defined as the elevation of the usual low flow during the growing season. The clearance may be less where there are unusual site conditions or where adequate maintenance occurs.

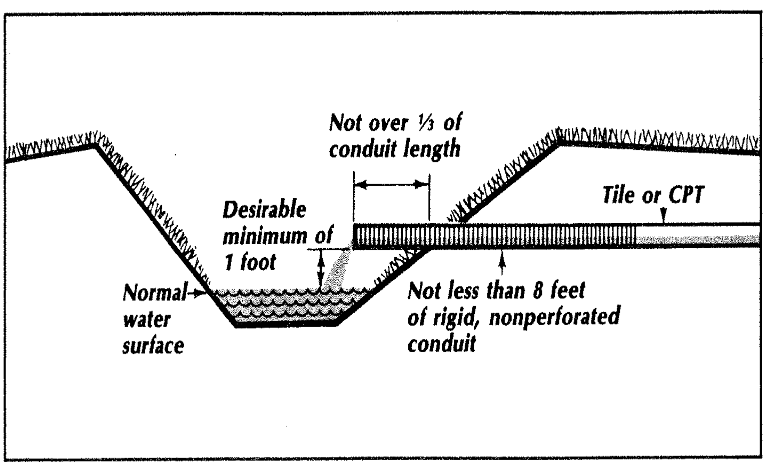


Figure 4. Entrance of a subsurface drain into an outlet channel.

Cross Section

The design cross section of the outlet channel should meet the combined requirements of capacity, velocity, depth, side slopes, and bottom width, and, if necessary, allow for initial sedimentation. The side slopes should he stable, meet maintenance requirements, and be designed according to site conditions. In silt, the side slopes should be no steeper than 2 to 1; in clay and other heavy soils, 1½ to 1; and in sands, peat, and muck, 1 to 1.

Construction equipment and maintenance requirements influence the width of the bottom of the channel and should be determined according to the conditions of the site.

Other Considerations

Location and Alignment

If possible, the outlet channel should be located near or parallel to field boundaries or property lines where it will not interfere with cropping patterns. It is even more desirable to place it along existing natural drainage courses to minimize excavation. Appropriate permits and easements must be obtained for constructing open channels across more than one landowner's property.

It is recommended that the channel be laid out in straight lines and gentle curves. Table 1 lists recommended minimum radii of curvature for channels without hank protection. Provide bank protection if changes in alignment are sharper than those listed in the Table 1.

Table 1. Minimum Radii of Curvature without Bank Protection

Width of Ditch Top --feet--	Slope --feet/mile--	Minimum Radius of Curvature --feet--	Approximate Degree of Curve
Small ditch	Under 3	300	19
(less than 15)	3 to 6	400	14
Medium ditch	Under 3	500	11
(15 to 35)	3 to 6	600	10
Large ditch	Under 3	600	10
(greater than 35)	3 to 6	800	7

Berms and Spoil Banks

Excavated soil may either be spread or placed in spoil banks along the outlet channel. If you place the soil in spoil banks, also leave a berm or flat area adjacent to the channel bank for the construction of roads and operation of maintenance equipment.

Berms will also prevent excavated material from rolling back into the channel and lessen sloughing of the banks by reducing heavy loads on them. Berms should be at least 10 feet wide, and, if the channels are over 8 feet deep, they should be 15 feet wide (Fig. 5A). Make sure that the side slopes of the spoil banks are stable and adequately shaped to permit establishment and maintenance of vegetation. Provide some means by which water can flow through the spoil and into the ditch without causing erosion.

On cropland it is often desirable to spread the spoil. Begin spreading at or near the channel bank or leave a berm as described above. If you begin spreading at the channel bank, carry the spoil upward at a slope no steeper than 3 to 1 to a depth no greater than 3 feet. From a point of maximum depth, the spoil should be graded to slope away from the channel no steeper than 4 to 1 and preferably 8 to 1 if the spoil is to be farmed (Fig. 5B).

Junctions of Lateral Ditches

Where there is a significant drop from a lateral ditch to the outlet channel, the lateral should be cut back on a level grade and then graded back on a slope (Fig. 6). The purpose of this level area is to store sediment and protect the channel until the lateral stabilizes. Excavate the lateral on a level grade flush with the bottom of the outlet ditch for a distance of 50 to 300 feet. Then, steepen the lateral grade from 0.5 to 1.0 percent until it intersects the normal grade of the lateral.

Where the drop from the lateral to the channel is too great to be controlled by the above method, you will have to provide structural protection.

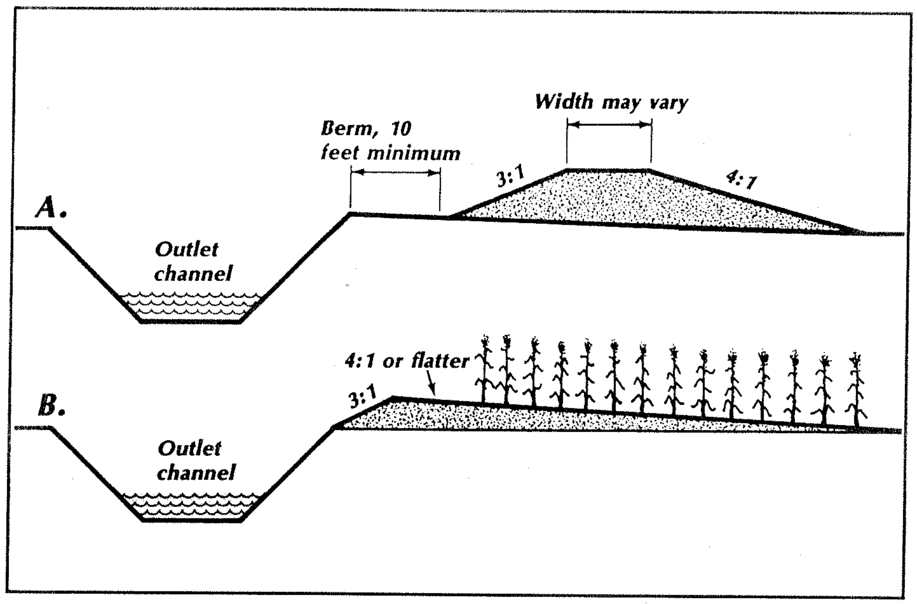


Figure 5. In drawing A, excavated soil (shaded area) has been placed in a spoil bank and a berm has been created. In B, the spoil has been spread without a berm. Spoil may be spread on either or both sides of an outlet channel.

Structural Protection

Ideally, surface water should enter the outlet channel only through lateral ditches graded to the bottom of the channel (Fig. 6A) or through stabilizing structures such as chutes, drop spillways, or conduits with proper inlets (Fig. 6B). These structures may be located at the entrances of lateral ditches, at the heads of outlet channels, or along the outlet channel at selected intervals.

Culverts and Bridges

Culverts and bridges across ditches should be designed for lengths and load produced by farm machinery, trucks and other vehicles. Culverts and Bridges should be evaluated for their impact on wildlife movement.

Culvert and bridge openings must be large enough to minimize reduction of ditch flow capacity. NRCS National Engineering Handbook Section 650 Chapter 3 - Hydraulics, has details on the design and installation of culverts for open ditches. Where bridges and culverts are not feasible, fords with suitable ramps for livestock and machinery may he used.

Recommended Design Frequencies for Bridges and Culverts*

State Highways	Q_{50} or as required by New York State Dept. of Transportation
County and Township	Q_{25} or as required by local government
Private Lanes or Roads	Q_5

* In no case should the capacity of bridges or culverts be less than the design capacity of the ditch.

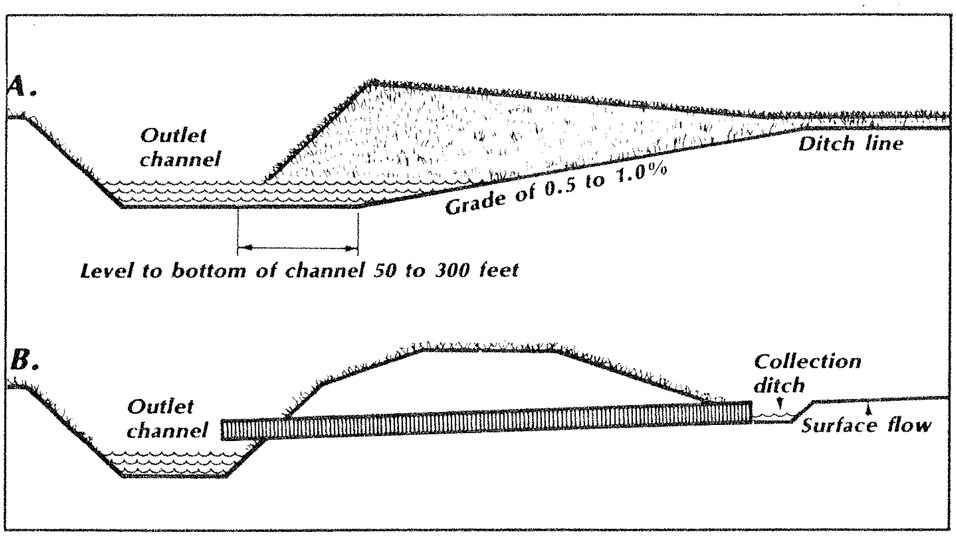


Figure 6. Drawing A shows a lateral ditch graded through a spoil bank to discharge directly into an outlet channel. Drawing B shows how a pipe can be used to move water through a spoil bank to an outlet channel.

Effects on Environment

Environmental impact from a drainage outlet includes temperature changes, flow quantity changes, and the potential for contaminants moving from the drained land. In most cases, you can build and maintain an outlet channel that will accomplish its purpose as well as maintain the temperature of the water. For example, if a dense tree canopy is situated on the site of the channel, you can carry out construction from just one side of the channel. The canopy remaining will shade the channel for at least part of the day. The favorable effects of the tree canopy will be to provide a windbreak; increase the fishery potential of the channel by keeping the water temperature lower than if the channel was not shaded; provide an area for wildlife between the cropped area and the water; and create a pleasing esthetic effect on land that might otherwise have been committed entirely to agriculture use.

To encourage bird habitat, delay mowing in the channel and on maintenance travel ways until the ground-nesting species of wildlife have departed, which is normally after the middle of July. Areas along the channel that are not used for travel, farming, or maintenance can be planted to shrubs, trees, or other plants that provide food for wildlife.

When open channels are constructed adjacent to wetlands, the effect of watertable drawdown needs to be considered. The Ellipse equation can be used to evaluate an appropriate setback distance. The major parameters impacting this setback distance include the appropriate drainage rate, the hydraulic conductivity of the soil, and the depth to the existing and planned watertables. A web based tool to solve this equation can be found at: http://www.wli.nrcs.usda.gov/technical/web_tool/Ellipse_java.html. Note that one of the parameters used in the ellipse equation is the effective radius. When applying this equation to a ditch, however, one must be sure to use the appropriate tabulated value.

Surface Drainage Discharges – The following aspects should be considered to reduce or control water quality impacts from surface drainage systems:

1) As discussed in the section on "Hydraulic Environmental Considerations" (p. 17xx), surface ditches should be designed to keep velocities below erosive levels.
2) Vegetation should be established and maintained in the ditch as soon as possible after construction or after cleanouts. Consider keeping the ditches permanently vegetated and maintaining a vegetative filter strip on each side of the ditch, especially where ditches approach the discharge outlet location.
3) Develop a good nutrient management and conservation plan for the contributing drainage area to avoid excessive nutrient, manure, or other chemical application rates, and to maintain a good residue cover.
4) Manure applications should be limited or avoided during saturated conditions and when soil is frozen, especially if vegetated filter strips have not been established.
5) Utilize surface water control structures to reduce peak discharges and provide some retention, or to provide some runoff control at non-critical times.
6) Incorporate constructed wetlands between the ditch and where a ditch may discharge directly to a stream.

Liquid Manure Applied to Systematic Surface Drained Fields – Fields or areas of fields that have systematic "surface drainage" systems (e.g. shallow surface drains spaced 100 – 200 feet apart – NRCS Surface Drainage-Field Ditch Practice Standard 607) are considered concentrated flow areas. However, if special precautions are taken, manure can be applied in the surface drains with minimal risk of surface runoff. This does not apply to the collector surface drains (mains) or drains bordering the fields. The following special manure application techniques shall be used:

1) Till the surface at least 3 to 5 inches deep prior to liquid manure surface application. Pre-till within 7 days of application.
2) Surface-apply liquid manure uniformly over the entire soil surface on the freshly tilled soil to allow the liquid manure to be absorbed into the soil surface.
3) For fields with no subsurface drainage, liquid manure can be injected directly without prior tillage.
4) Manure application rates should be adjusted to consider the most limiting factor and include the ability of the soil to accept, store and hold liquid manure, water and nutrients. The Nitrogen and Phosphorus Application Criteria for manure, Organic By-Products and Biosolids contained in NRCS Nutrient Management Standard 590 are to be followed to limit transport and leaching.

Maintenance

Maintenance of a drainage system is the key to lengthening its life and lowering operating costs. In any proposed drainage project, you should begin thinking about maintenance requirements as early as the design stage. We strongly recommend a systematic, annual inspection and maintenance program.

An operation and maintenance plan must be prepared for each channel system. Minimum requirements for operation, maintenance, and replacement shall be consistent with the design objectives. This includes consideration of fish and wildlife habitat, quality of the landscape, water quality, mitigation features, methods, equipment, costs, stability, function for design life, frequency, and time of year for accomplishing the work.

Seeding outlet channel banks to permanent cover will prolong the life of many channels by helping to stabilize the banks and by reducing weed infestations. Maintain a 10-foot grass strip along the channel to reduce erosion and provide access for maintenance. Brush and weeds reduce the velocity of water flowing in the channel, limiting its drainage capacity. Short-stemmed grasses are preferred since they provide a smooth surface for water. The grass on channel banks, berms, and spoil banks may occasionally need mowing. When you mow, be careful to avoid destroying wildlife. Brush and weeds can be controlled by herbicide sprays. Always check local, state, and federal regulations on the use of herbicides, and be sure to follow the instructions on the herbicide label. Outlets in postures should be fenced.

Aquatic weeds should be kept out of channel bottoms since weeds limit drainage by reducing flow rates and cause sediment deposition. Although these weeds can be controlled with herbicides, whether you may apply them will depend upon downstream uses of the water and your legal liability. Be sure to investigate your legal liability before applying herbicides. Sediment deposits and accumulations of debris should be removed from outlet channels to maintain their design capacity.

SURFACE DRAINAGE

Surface drainage is the removal of water that collects on the land surface. A surface drainage system consists of shallow ditches and should include land smoothing or land grading. This type of system is suitable for all slowly permeable soils and for soils with fragipans or clay subsoils.

The rate at which water is removed by surface drainage depends on several inter-related factors, including rainfall, soil properties, and cropping patterns. For most row crops, a surface drainage system should remove excess water within 24 to 48 hours. More rapid removal may be necessary for higher value truck crops.

Before designing a surface drainage system, you should make a topographic survey and develop a contour map of the area, using grid surveys, laser techniques, photogrammetric methods, or some combination of these. Keep copies of the contour maps, as-built plans, and profiles as a record of permanent improvements. These resources will he invaluable later when the ditches have to be reshaped or the channel regraded.

Components

A surface drainage system consists of an outlet channel, lateral ditches, and field ditches. Water is carried to the outlet channel by lateral ditches, which receive water from field ditches or sometimes from the surface of the field.

Plan a minimum number of field ditches located, where possible, at right angles to the lateral ditch and crop rows. It is essential that lateral ditches be deep enough to drain the field ditches completely enough to permit crossing by farm machinery. The minimum depth of lateral ditches is 1.0 foot. At points where lateral ditches enter the outlet channel, grade hack small overfalls on a nonerosive grade (Fig. 6A). If the outlet is too deep or some other problem makes it difficult to grade the overfall, install a chute, drop spillway, or pipe (Fig. 6B).

The cross section is usually trapezoidal or V-shaped, as shown in Fig. 7. Its minimum depth should be 6 inches for trapezoidals and 9 inches for V sections, each having a minimum cross sectional area of 5 square feet. Field ditches should ordinarily not be deeper than 1 foot where they are to be crossed frequently by farm machinery. Side slopes should be 8 to 1 to flatter for a trapezoidal section and 10 to 1 for V sections. Determine the capacity of the ditches according to curve B or C in Fig. 2. The minimum recommended design grade is 0.1 foot per 100 feet. Where the channel grade is less than 0.05 foot per 100 feet, ponding and siltation may occur.

Diversions may be included in a drainage system to prevent surface runoff from sloping land from reaching a flat or depressional area. Diversion ditches are located at the base of a slope to intercept and carry surface flow to an outlet. Their side slopes range between 2 to 1 and 4 to 1, and they should be kept in sod. To minimize overtopping of the diversion, design the ditch cross section to carry the runoff from a 10-year frequency storm of 24-hour duration.

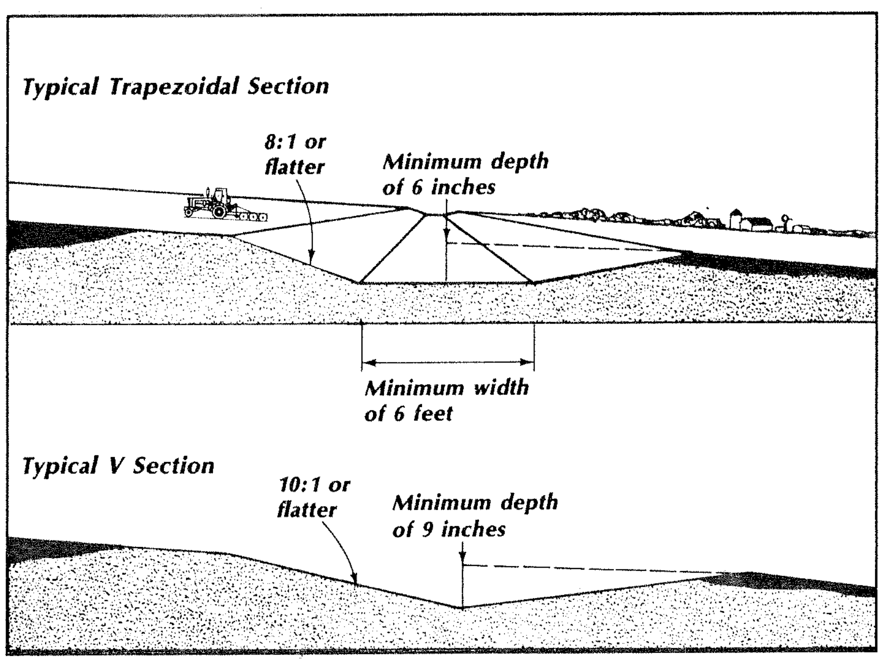


Figure 7. Two typical cross sections of a field ditch. Note how excavated soil (darker areas) from the ditch has been used to fill depressions and to shape land areas adjacent to the ditch.

Patterns

The two main types of surface drainage patterns are random and parallel. Each includes lateral ditches that permit water to flow from the drainage system to a suitable outlet. The pattern you choose depends upon the soil type and topography of the land.

Random

The random ditch pattern is adapted to slowly permeable soils having depressional areas that are too large to be eliminated by land smoothing or grading. Field ditches connect the major low spots and remove excess surface water from them. They are generally shallow enough to permit frequent crossing by farm machinery. Soil from the ditches can be used to fill minor low spots in the field.

Field ditches should extend through most of the depressions, as shown in Fig. 8, to assure complete drainage, and they should follow the natural slope of the land.

Parallel

The parallel ditch pattern is suitable for flatter, poorly drained soils that have numerous shallow depressions (Fig. 9). In fields that can he cultivated up and down slope, parallel field ditches are installed across the slope to break the field into shorter units of length and make it less susceptible to erosion. The field should be farmed in the direction of the greatest slope. Dead furrows are neither desirable nor necessary.

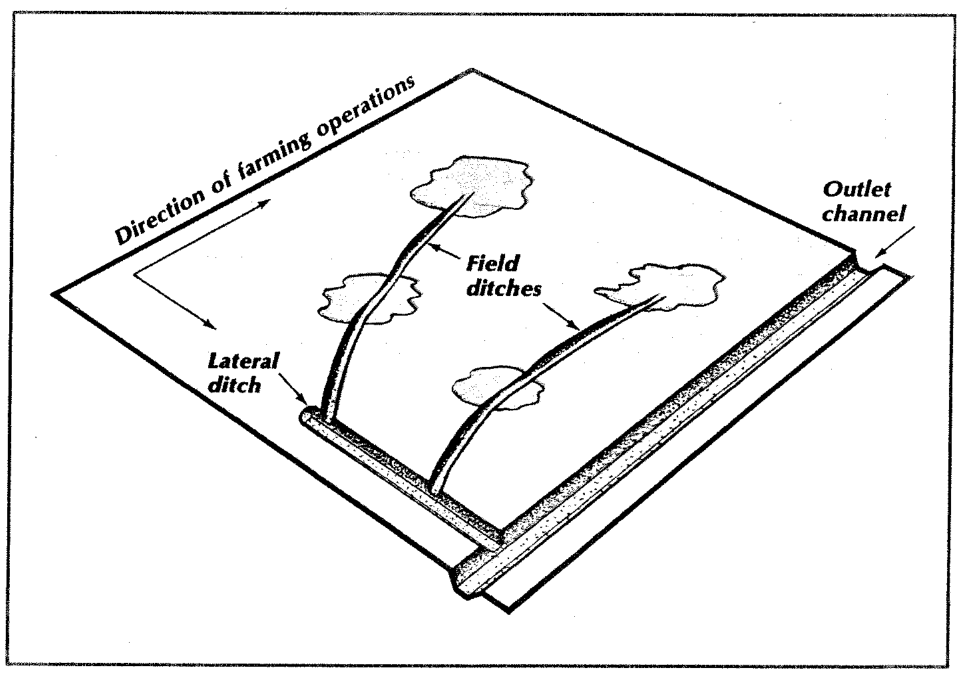


Figure 8. Random ditch pattern for surface drainage.

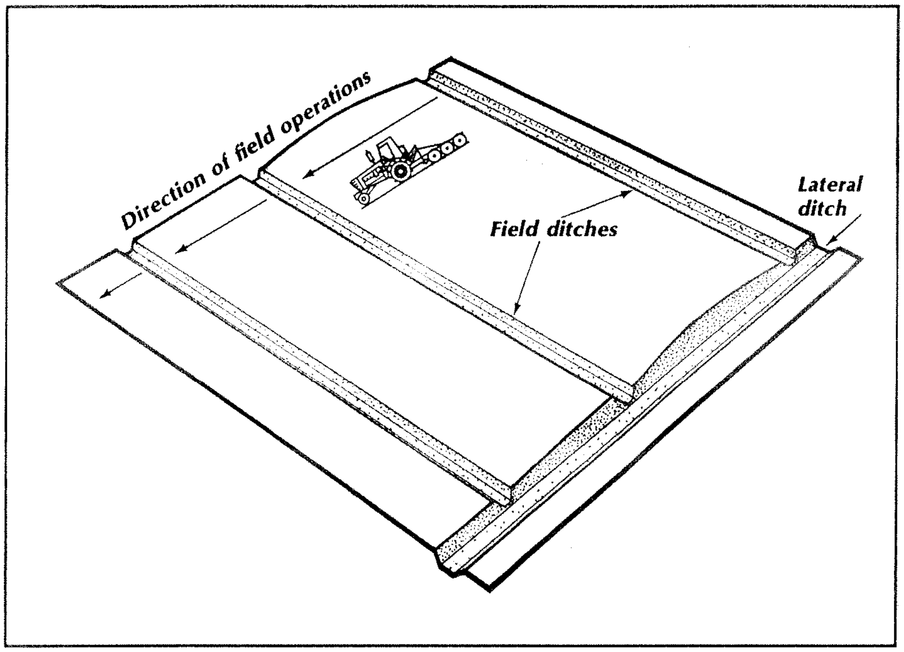


Figure 10. Parallel ditch pattern for surface drainage.

Although the ditches must be parallel, they need not be equi-distant. The spacing between them depends upon the permissible length of row drainage for the soil type and upon the amount of earth and the distance it must be moved to provide the amount of earth and the distance it must be moved to provide complete row drainage. The maximum length of the grade draining to a ditch should be 660 feet.

The success of a surface system using a parallel pattern depends largely upon proper spacing of the parallel ditches and the smoothing or grading between them. During the grading operation, fill all depressions and remove all barriers. Excavated material from ditches can also be used as fill for establishing grades.

Design Criteria

Ditches for drainage of common field crops are usually designed to remove runoff water from the drainage area within a 24-hour period following an ordinary rain. Some surface flooding of the land during this period is permissible.

Some high-value and specialty crops require a more rapid rate of removing runoff water to prevent crop damage. For these crops, a 6 to 12 hour removal interval may be necessary during the growing season.

The degree of removal is determined by the "drainage coefficient," which is the rate of water removal per unit of area used in drainage design. For subsurface drainage systems, the drainage coefficient usually is expressed in inches removed in 24 hours. For surface drainage, the coefficient is usually expressed in terms of flow rate per unit of area, which varies with the size of the area.

For designing drainage areas with average slopes less than 25 feet per mile, use the following drainage curve designations:

	Truck Crops	Grain Crops	Pastureland
*Zone 1	B	C	D
*Zone 2	$\frac{B+C}{2}$	$\frac{C+D}{2}$	D

For designing drainage areas with average slopes more than 25 feet per mile, use the following drainage curve designations or consult a qualified engineer for appropriate values:

	Truck Crops	Grain Crops	Pastureland
*Zone 1	A	B	C
*Zone 2	B	C	D

**Zone 1 - Includes all counties outside Zone 2.*

**Zone 2 - St. Lawrence, Franklin, Clinton, Jefferson, Lewis, Herkimer, Hamilton, Essex, Warren, Fulton, Saratoga, and Washington Counties.*

After selection of appropriate drainage curves, determine runoff for design from Pig. 2.

Determine the size of ditch necessary to obtain required capacity.

Shaping the Surface

Grading

Land grading (also termed precision land forming) is the reshaping of the surface of land with tractors and scrapers to planned grades. Its purpose is to provide excellent surface drainage although the amount of grading will depend upon the soil and costs. To do a good job of land grading, you need a detailed engineering survey and construction layout.

To assure adequate surface drainage, eliminate all reverse surface grades that form depressions. The recommended surface grades range from 0.1 to 0.5 percent and may be uniform or variable. The cross slopes normally should not exceed 0.5 percent. Minimum grade limits should include a construction tolerance that will permit the elimination of all depressions either in original construction or in postconstruction touchup. Reverse grades can be eliminated with relative ease in a field that has minimum grades of 0.2 percent. Unusual precision in construction is required to eliminate reverse surface grades in fields that have 0.1 percent and flatter grades.

Land grading is hampered by trash and vegetation. This material should be destroyed or removed before construction and kept under control while the work is being done. The fields should he chiseled before construction if there are hardpans. The field surface should be firm when it is surveyed so that rod readings taken at stakes will reflect the true elevation. Do not grade fields when they are wet because working wet soil impairs the physical condition of the soil.

Smoothing

Land smoothing removes irregularities on the land surface and should be done after land grading and may be useful in other situations. Special equipment such as a land plane or land leveler is used. The purpose of land smoothing is to improve surface drainage. The smoothing operation may ordinarily be directed in the field without detailed surveys or plans, although grid surveys may be needed for some critical parts of the field.

A smoothing operation consists of a minimum of three passes with a land leveler. Make the first two passes on opposite diagonals as noted in Fig. 10 and the last pass in the direction of cultivation. Either before or after the final land smoothing operation, chisel fields to loosen the cut surfaces and to blend the fill material with the underlying soil. The finished surface should be free from minor depressions so that runoff will flow unobstructed to field or lateral ditches.

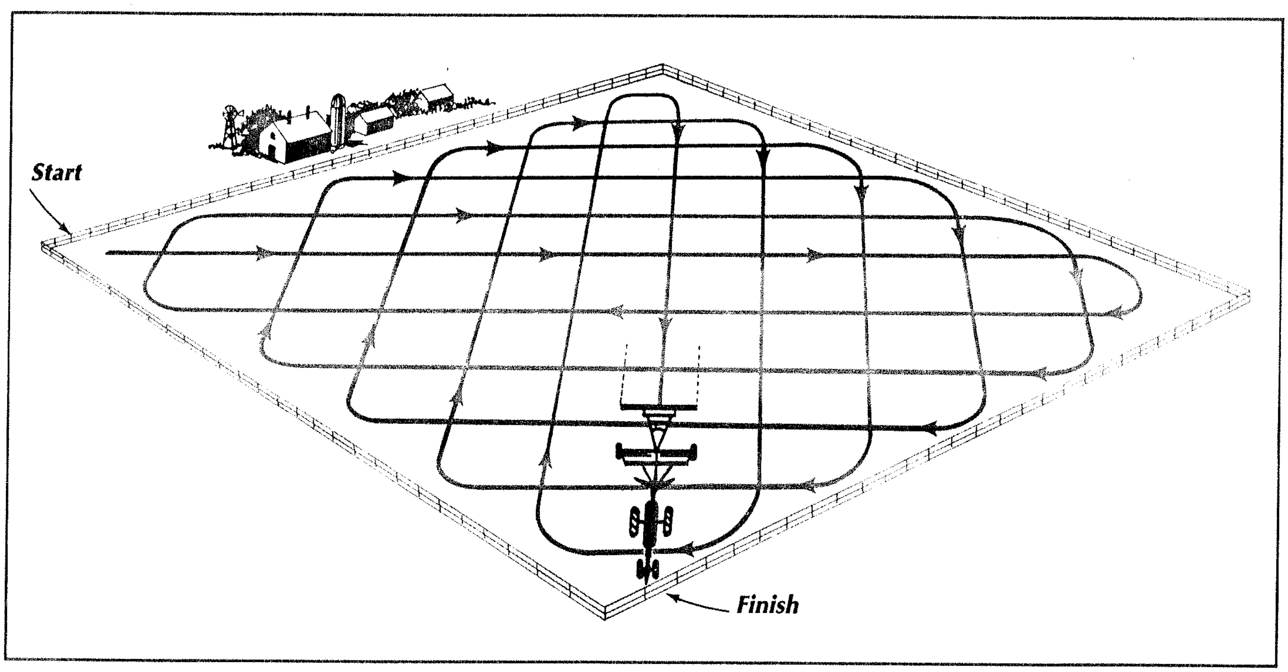


Figure 10. Suggested procedure for a land smoothing operation.

Maintenance of Surface Drainage Systems

It is important to adopt a good maintenance program. Plowing, planting, cultivating, and harvesting operations often create ridges that disturb the surface and disrupt intended drainage. In addition, wind and water erosion may provide further disturbance. It is recommended that after each field plowing, a land plane or large heavy drag be used to regrade the area. One pass should be made along each diagonal. This operation will facilitate settlement in the fill areas, erase all scars on the land surface caused by field operations and provide a good seed bed.

Maintenance requirements may justify flattening side slopes. Ditch side slopes which may be used with various maintenance methods are given in Table 2 below.

Table 2.
Ditch Side Slopes for Use with Various Maintenance Methods

Type of Maintenance	Usual Recommended Minimum Side Slopes	Remarks
Mowing	3:1	Flatter slopes desirable for ordinary farm wheeled tractors. Special equipment may be used on steeper slopes.
Grazing	2:1 or flatter 1/2:1 or flatter	For ditches greater than 4 feet deep, use ramps. For ditches less than 4 feet deep, use ramps.
Dragline	1:1	Suitable for use in stable soils on ditches greater than 4 feet deep.
Blade Equipment	3:1	Flatter slopes desirable.

Key Maintenance Tips

Field Ditches – Shallow field ditches on cropland lose their capacity as tillage equipment passes. Annual cleanouts are usually required. Farm tractors with mounted blades or scrapers are ideal for cleanouts.

Vegetative Treatment – In cropland a vegetative filter strip is desirable on each side of the watercourse. Tillage operations should be performed in a manner that maintains the filter strip. Lime and fertilize ditch banks and filter strips when treating adjoining areas or as needed to maintain cover.

Controlling Vegetative Growth

Mechanical – Mowing is a common method of controlling undesirable vegetation. Since ditch banks and berms are a favorite habitat for many wildlife species, the timing of maintenance mowing is very important. Delay mowing until after the principal rearing season has passed.

Depending on the vegetation and climatic conditions, undesirable vegetation can be controlled by mowing about every two to five years. A good practice is to mow one side one year and the other side on alternate years.

Grazing – Controlling growth of vegetation by grazing requires very careful management. Too often livestock damage the desired vegetation and ditchbanks by trampling. Drainage ditches in pastures or adjacent to barn yards and feed lots should be fenced.

SUBSURFACE DRAINAGE

Subsurface drainage is used where the seasonal high watertable limits agricultural productivity or otherwise restricts the use of the soil. Subsurface drainage is applicable where the soil is permeable enough to allow economical spacing of the drains and productive enough to justify the investment. A subsurface drain will provide trouble-free service for many years as long as it is carefully planned, properly installed, constructed of high-quality materials, and the outlet is maintained.

Components

A subsurface drainage system consists of a surface or subsurface outlet, and sub surface main drains and laterals. Water flows into the outlet via gravity from the main drains, which receive water from the laterals. Submains are sometimes used off the main drain to collect water from a subset of laterals.

The system will function only as well as its outlet. When planning a subsurface drainage system, make sure that a suitable surface or subsurface outlet is available or can he constructed. Where a surface outlet channel is used, all subsurface drains emptying into the outlet should be protected against erosion, against damage that occurs during periods of submergence, against damage caused by ice and floating debris, and against entry of rodents or other animals.

An older subsurface outlet used for a new subsurface drainage system should be free from breakdowns, fractured tile, excessive sedimentation, and root clogging. It must be deep enough to intercept all outletting main drains and laterals and have sufficient capacity to handle the flow. It must also be deep enough to provide the minimum recommended cover for all drains newly installed or intercepted.

If no suitable free flowing gravity outlet is available and it is not practical to improve an existing ditch, you might consider using pump outlets.

Site Considerations

In planning a subsurface drainage system, you need to determine the topography of the site to be drained, keeping in mind the depth limitations of the trenching machines and the amount of soil cover required over the drains. The amount of surveying you must do to obtain topographic information depends on the lay of the land. Where the slope of the land is obvious and has a constant gradient, only a limited amount of data is needed to locate the drains. A topographic survey is necessary, however, for flat and slightly undulating land since it is not as obvious where drains ought to be located to assure gravity flow. Enough topographic information needs to be obtained so that the entire system can be planned before installing it. Planning the job without first gathering enough data often results in a poorly performing or piecemeal system that may eventually be very costly.

The type of subsurface drainage system you install depends to a large degree upon the soils in the area to be drained. Knowing the soil types also helps you anticipate special drainage problems. To identify the soils, refer to soil maps that are available at local offices of the Natural Resources Conservation Service. You can supplement the map information by taking soil borings and digging test pits. Once the soils have been identified, refer to the section on the Soil Moisture Management Groups for the drainage recommendations.

Also in planning a subsurface system, keep in mind that some trees have an aggressive rooting system for obtaining water. Trees such as willow, elm, soft maple, and cottonwood should be removed for a distance of approximately 100 feet on either side of a perforated subsurface drain line. Most other species of trees, except possibly, fruit trees, should be removed for a distance of 50 feet. If the trees cannot be removed, plan to re-route the line or to use nonperforated tubing or tile with sealed joints throughout the root zone of the trees.

Environmental Effects

The quality of subsurface drainage water discharge depends on how water flows through the soil and how the drained land area is used. Subsurface drain discharges are increasingly being scrutinized regarding their impacts on downstream water quality.

Preferential Flow Considerations

In general, two types of water flow occur through soil, often referred to as matrix and preferential flow. Matrix flow is where drainage water percolates through smaller pores in the soil, thus contacting and mixing with most of the soil. The numerous small and variable size pores act like a filter and also promote the exchange (i.e., sorption, de-sorption) of materials between the water and the soil. Preferential flow is where a significant amount of percolating water flows through the larger pores in the soil, or through the more permeable parts or layers of the soil, which reduces the amount of water-to-soil contact. Preferential flow is often referred to as ‘by-pass’ flow because excess water at the surface can easily flow down through the soil without contacting very much of the soil, almost acting like a miniature surface inlet. Consequently, preferential flow to tile may cause the tile discharge to have similar water quality characteristics as surface runoff. Soil management such as no-till or improving soil health may tend to increase the prevalence of preferential flow in soils.

Subsurface drainage water collected from a pristine land area may be used as a source of bottled drinking water. However, where the drained land is used for agriculture, the drainage discharge reflects the nutrients and pesticides commonly used to optimize production. Since nitrate-nitrogen ($NO_3^{-}N$) is dissolved in the soil-water, any excess can leach to the tile drain via both matrix and preferential flow. However, nutrients like ammonium-nitrogen and phosphorus, bacteria, and most herbicides/pesticides prefer to attach to soil; so these are usually removed or at least reduced significantly during matrix flow, but still may reach the drain when the flow is mostly preferential. Since manure can be applied at different liquid-solid contents and can be applied to the surface or the subsurface, the variations in manure application methods can influence whether manure contaminants will be transported to subsurface drains. Several studies have shown that liquid manure applications on soils exhibiting preferential flow can result in rapid contamination and elevated levels of nutrients and bacteria in the drain discharge.

Control Methods to Reduce Water Quality Impacts from Subsurface Drainage Discharges

The following aspects should be considered to reduce or control water quality impacts from subsurface drainage systems:

1) Develop a good nutrient management and conservation plan for the area to avoid excessive nutrient, manure, or other chemical application rates.

2) Manure applications should be limited or avoided during saturated conditions when the drains are flowing, and during early spring periods when snow is melting and the ground is thawing.
3) Locate the drain outlet to discharge into a vegetated watercourse, and not directly into a perennial stream.
4) Evaluate the soil type for preferential flow tendencies. Soils with the Subgroup C - Clayey designation in the "Soil Moisture Management Groups" index will be most likely to exhibit preferential flow. Where drainage is provided for these soils, liquid manure applications to these areas should be limited to a rate of 5000 gallons per acre per application and incorporated, and drains should be monitored up to 10 days thereafter for any contaminated discharge. Tile plugs should be made available in the event of any contaminated discharge, or one or more of the following additional control methods should be implemented.
5) Utilize subsurface water table or drain discharge control structures to provide retention and to provide discharge control at non-critical times. In sloping fields, several structures may be necessary to avoid tile blowouts, typically a structure for each 3 foot drop in elevation. Where possible in new installations, subsurface drainage laterals should be installed along the field contour, whereby zones could then be controlled with a structure on the collector main.
6) Incorporate a gravel or bio-based material filtering media at the drain outlet instead of having a direct pipe discharge outlet.
7) Incorporate constructed wetlands between the subsurface drain discharge to avoid discharge directly to a stream.

Additional guidance can be obtained from "Supplemental Manure Spreading Guidelines to Reduce Water Contamination Risk During Adverse Weather Conditions" found on, http://nmsp.css.cornell.edu/publications/winterspreadingguidelines.pdf

Patterns

Because subsurface drainage is used primarily to lower the water table or remove excess water that is percolating through the soil over a general area, the drains are placed in a pattern usually determined by the topographic characteristics of the area. If the soil is homogeneous and on a level slope, the water table is lowered at about the same rate and over a similar distance on both sides of the drain. Where a drain is placed on soil slopes that exceed about three percent, the water table is preferably lowered to the upslope side. Flow from the drains is generally intermittent unless the drains intercept deeper groundwater seep discharge.

Four basic patterns are used in the design of subsurface drainage systems. Select the pattern that best fits the topography of the land that can be located near enough to the sources of excess water, and that is suited to other field conditions. The four basic patterns are illustrated in Figure 11.

Random

The random pattern is suitable for undulating or rolling land that contains isolated wet areas. The main drain is usually placed in the swales rather than in deep cuts through ridges. The laterals in this pattern are arranged according to the size of the isolated wet areas. Thus, the laterals may he arranged in a parallel or herringbone pattern or may he a single drain connected to a submain or the main drain.

Parallel

The parallel pattern consists of parallel lateral drains located perpendicular to the main drain. The laterals in the pattern may he spaced at any interval consistent with site conditions. The parallel pattern of laterals can be in any direction on flat, regularly shaped fields and on uniform soil. For uniformly and long sloping soils where the predominant land slope exceeds about three percent, the parallel laterals should be placed across the slope. Variations of this pattern are often combined with others.

Herringbone

The herringbone pattern consists of parallel laterals that enter the main at an angle, usually from both sides. The main is located on the major slope of the land, and the laterals are angled upstream on a grade. This pattern is often combined with others to drain small or irregular sloping areas or to take advantage of intercepting cross-slopes. Its disadvantages are that it may cause double drainage (since two field laterals intercept the main at the same point) and that it may cost more than other patterns because it contains more junctions. Nevertheless, the herringbone pattern can provide the extra drainage needed for the less permeable soils that are often found in narrow depressions.

Double Main

The double main pattern is a modification of the parallel and herringbone patterns. It is applicable where a depression, frequently a watercourse, divides the field in which drains are to be installed. This pattern also is sometimes chosen where the depressional area is wet because of seepage coming from adjacent and higher ground.

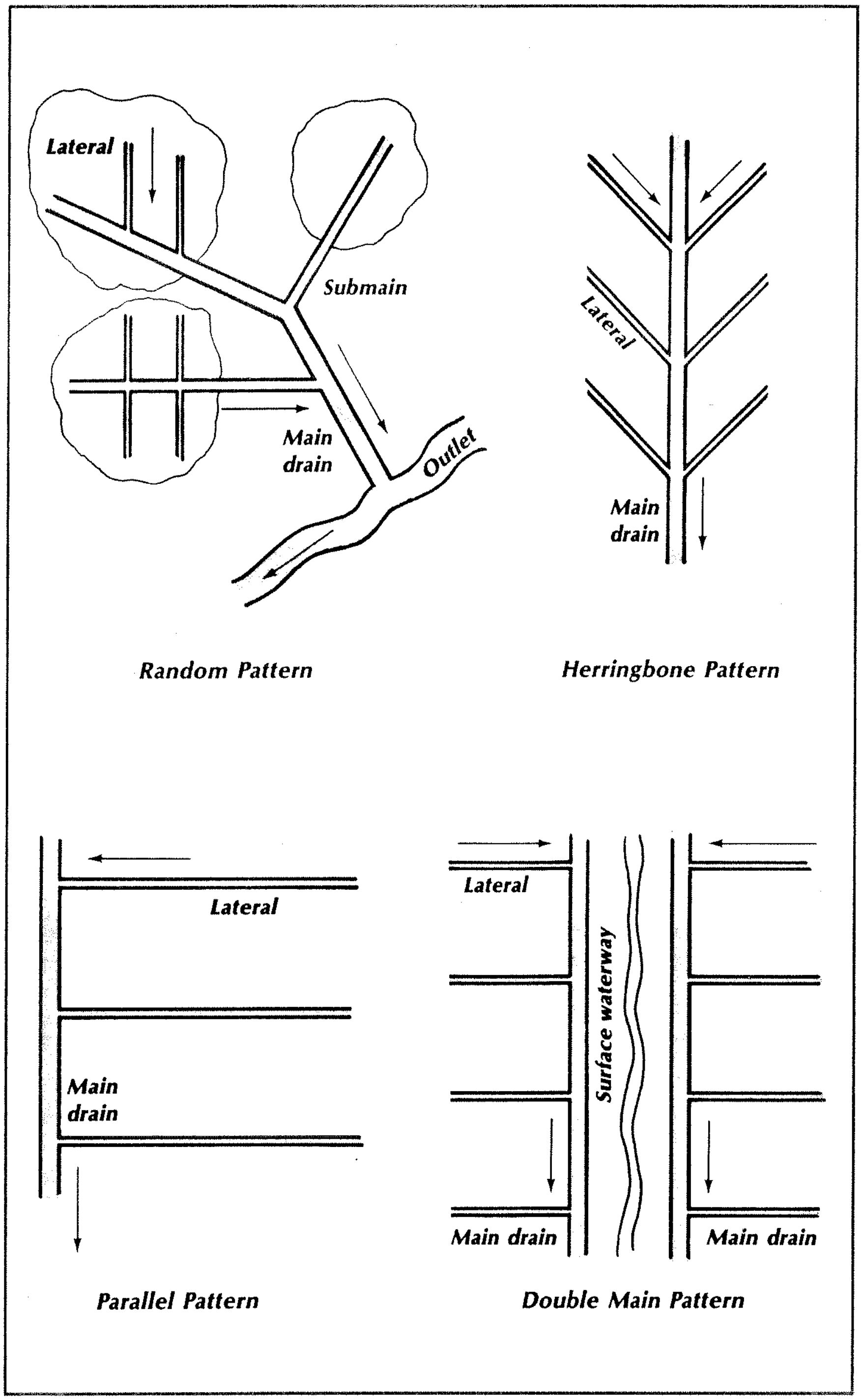


Figure 11. Basic patterns for subsurface drainage systems (the arrows indicate the direction of water flow).

Placing a main on each side of the surface waterway or depression serves two purposes; the main intercepts the seepage water, and it provides an outlet for the laterals. If the depression is deep and unusually wide and if you place only one main in the center, you may have to make a break in the gradeline of each lateral before it reaches the main. By locating a main on each side of the depression, you can keep the gradeline of the laterals more uniform. It's also important to avoid placing a main subsurface drain in the center of a surface waterway because the combined flows and hydraulic pressure can result in channel erosion and wash-out of the main.

Materials

Material specifications for drain conduits benefit both the drainage contractor and landowner. These specifications enable manufacturers to maintain uniformity in their products, thus giving buyers some assurance that the products will be strong and durable and perform adequately in drainage systems. The materials used for subsurface drainage include clay, concrete, bituminized fiber, metal, plastic, and other materials of acceptable quality. Current specifications for these materials can he obtained from the American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.. The ASTM designations for these specifications are listed on the following page and in Section IV of the Technical Guide, which is prepared by the Natural Resources Conservation Service. Use these or federal specifications in determining the quality of a conduit.

Clay Drain Tile

In ASTM C-4, Standard Specification for Clay Drain Tile and Perforated Clay Drain Tile, clay drain tile is divided into four classes according to its physical test requirements: standard, extra-quality, heavy-duty, and extra-strength. Standard drain tile is satisfactory where the tiles are laid in trenches of moderate depth and width and where the tile will not be exposed to severe conditions. Use extra-quality, heavy-duty and extra-strength tile where conditions are expected to be severe. (Load requirements are discussed under the "Design" section.)

To be rated standard, clay drain tile that is 3 ½ to 12 inches in diameter must have a minimum crushing strength of 800 pounds or more per foot of length (Table 2a). The tile must have an absorption rate not exceeding 13 percent for an average of five tiles. To be rated extra-quality, clay drain tile that is 3 ½ to 14 inches in diameter must support at least 1,100 pounds per foot by the three-edge bearing test and have an absorption rate of not more than 11 percent. To be rated heavy duty, clay drain tile that is 3 ½ to 6 inches in diameter must support at least 1,400 pounds per foot by the three-edge bearing test and have an absorption rate of not more than 11 percent. To be rated extra strength, clay drain tile that is 3 ½ to 6 inches in diameter must support at least 2,000 pounds per foot by the three-edge bearing test and have an absorption rate of not more than 11 percent.

A few points to keep in mind about clay drain tile are that color and salt glazing are not reliable indicators of tile quality, that clay tiles are not affected by acids or sulfates, and that low temperatures normally will not damage clay tile, provided that it is properly selected for absorption and carefully handled and stored during freezing weather. To reduce chances for damage due to freezing, do not string out or stack clay tiles on wet ground during periods of freezing and thawing.

MATERIALS FOR SUBSURFACE DRAINAGE

Material	Specification
PLASTIC	
Corrugated Polyethlene Pipe and Fittings 3-6 in.	ASTM-F-405 a/
Corrugated Polyethlene Pipe and Fitting 8-24 in.	ASTM-F-667
Polyvinyl Chloride (PVC) Sewer Pipe and Fittings	ASTM-D-2729
Polyvinyl Chloride (PVC) Sewer Pipe and Fittings	ASTM-D-3034 type PSM
CLAY	
Clay Drain Tile and Perforated Clay Drain Tile	ASTM-C-4
Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated	ASTM-C-700
Vitrified Clay Pipe, Test Methods	ASTM-C-301
CONCRETE	
Concrete Drain Tile 4-36 in.	ASTM-C-412
Concrete Pipe for Irrigation or Drainage	ASTM-C-118
Concrete Pipe, Manhole Sections, or Tile, Test Methods	ASTM-C-497
Nonreinforced Concrete Sewer, Storm Drain and Culvert Pipe	ASTM-C-14
Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe	ASTM-C-76
Perforated Concrete Pipe	ASTM-C-444
Portland Cement	ASTM-C-150
OTHER	
Asbestos-Cement Storm Drain Pipe	ASTM-C663
Asbestos-Cement Nonpressure Sewer Pipe	ASTM-C-428
Asbestos-Cement Underdrain Pipe	ASTM-C-508
Asbestos-Cement Pipe, Test Methods	ASTM-C-500
Laminated—wall bituminized fiber pipe, physical testing of	ASTM-D-2315
Styrene Rubber (SR) Plastic Drain Pipe and Fittings	ASTM-D-2852
Corrugated Aluminum Pipe for Sewers and Drains	ASTM-B-745B
Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains	ASTM-A-760

Source: Subsurface Drain (606), National Handbook of Conservation Practices, can be obtained from National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, VA 22161, (703) 487—4600.

a/ ASTM specifications can he obtained from the American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.

Table 2a. ASTM Physical Test Requirements for Clay Drain Tile

Internal diameter, inches	Minimum crushing strength, lb/linear ft[a]		Maximum absorption, percent[b]	
	Average of five	Individual	Average of five	Individual
Standard				
3 ½	800	680	13	16
4	800	680	13	16
5	800	680	13	16
6	800	680	13	16
8	800	680	13	16
10	800	680	13	16
12	800	680	13	16
14	840	720	13	16
15	870	740	13	16
Extra-quality				
3 ½	1,100	990	11	13
4	1,100	990	11	13
5	1,100	990	11	13
6	1,100	990	11	13
8	1,100	990	11	13
10	1,100	990	11	13
12	1,100	990	11	13
14	1,100	990	11	13
15	1,150	1,030	11	13
16	1,200	1,080	11	13
Heavy-duty				
3 ½	1,400	1,260	11	13
4	1,400	1,260	11	13
5	1,400	1,260	11	13
6	1,400	1,260	11	13
8	1,500	1,350	11	13
10	1,550	1,400	11	13
12	1,700	1,530	11	13
14	1850	1,660	11	13
15	1,980	1,780	11	13
16	2,100	1,890	11	13
Extra-strength				
3 ½	1,400	1,260	11	13
4	1,400	1,260	11	13
5	1,400	1,260	11	13
6	1,400	1,260	11	13
8	2,140	1,920	11	13
10	2,200	1,980	11	13
12	2,420	2,170	11	13
14	2,640	2,370	11	13
15	2,800	2,620	11	13
16	3,000	2,700	11	13

[a] Minimum crushing strength was determined by the three-edge bearing test. The number of freezing and thawing cycles for extra-quality and heavy-duty tile is 48 (ASTM designation C 4).
[b] Maximum water absorption was determined through 5 hours of boiling.

Concrete Drain Tile

Concrete drain tile of high quality will give long and satisfactory service under most field conditions. There are four classes of concrete drain tile:

1. **Standard-quality** tile is intended for land drainage of ordinary soils where the tiles are laid in trenches of moderate depth and width. Tile of this quality is not recommended for use where internal diameters in excess of 12 inches are required.

2. **Extra-quality** tile is intended for land drainage of ordinary soils where the tiles are laid in trenches of considerable depths or widths, or both.

3. **Heavy-duty, extra-quality** tile is intended for land drainage of ordinary soils where the tiles are laid in trenches of large depths or widths, or both.

4. **Special-quality** tile is intended for land drainage where special precautions are necessary for concrete tile laid in soils that are markedly acid or contain unusual quantities of sulfates, and where the tile are laid in trenches of considerable depths or widths, or both. example, (a) where the tile is laid in soils that are markedly acidic (pH below 6.0) or that contain unusually high quantities of sulfates, or (b) where the tile is laid in trenches of considerable depth, width, or both.

ASTM standard specification C-412 lists the physical test requirements for each of these classes (Table 3).

Table 3. ASTM Physical Test Requirements for Concrete Drain Tile

Nominal inside diameter, inches	Minimum crushing strength, lb/linear ft[a]		Maximum absorption, percent[b]		Wall thickness, inches
	Average of five	Individual	Average of five	Individual	
Standard Quality					
4	800	700	10	11	---
5	800	700	10	11	9/16
6	800	700	10	11	5/8
8	800	700	10	11	3/4
10	800	700	10	11	7/8
12	800	700	10	11	1
Extra-quality (Heavy-duty extra quality)					
4	1,100 (1,300)[b]	990 (1,170)	9	10	½
5	1,100 (1,300)	990 (1,170)	9	10	9/16
6	1,100 (1,300)	990 (1,170)	9	10	5/8
8	1,100 (1,400)	990 (1,170)	9	10	¾
10	1,100 (1,500)	990 (1,260)	9	10	7/8
12	1,100 (1,750)	990 (1,350)	9	10	1
14	1,100 (1,870)	990 (1,580)	9	10	1 1/8
15	1,100 (2,000)	990 (1,690)	9	10	1 ¼
16	1,100 (2,250)	990 (1,800)	9	10	1 3/8
18	1,200 (2,250)	1,080 (2,030)	9	10	1 ½
20	1,330 (2,500)	1,200 (2,250)	9	10	1 5/8
22	1,460 (2,750)	1,320 (2,470)	9	10	1 ¾
24	1,600 (3,000)	1,440 (2,700)	9	10	2
26	1,730 (3,250)	1,560 (2,930)	9	10	2 1/8
28	1,870 (3,500)	1,680 (3,150)	9	10	2 3/8
30	2,000 (3,750)	1,800 (3,380)	9	10	2 ½
32	2,130 (4,000)	1,920 (3,600)	9	10	2 5/8
34	2,270 (4,250)	2,040 (3,820)	9	10	2 7/8
36	2,400 (4,500)	2,160 (4,050)	9	10	3
Special Quality					
4		1,100[d]	8	9	½
5		1,100	8	9	9/16
6		1,100	8	9	5/8
8		1,100	8	9	¾
10		1,100	8	9	7/8
12		1,100	8	9	1
14		1,100	8	9	1 1/8
15		1,100	8	9	1 ¼
16		1,100	8	9	1 3/8
18		1,200	8	9	1 ½
20		1,330	8	9	1 5/8
22		1,460	8	9	1 ¾
24		1,600	8	9	2
26		1,730	8	9	2 1/8
28		1,870	8	9	2 3/8
30		2,000	8	9	2 ½
32		2,130	8	9	2 5/8
34		2,270	8	9	2 7/8
36		2,400	8	9	3

[a] Standard and extra-quality drain tile that meets these strength requirements is not necessarily safe against cracking in deep and wide trenches.
[b] The values in parentheses are the crushing strengths for heavy-duty, extra-quality tile.
[c] Where tile will be exposed to sulfates, use sulfate-resistant cement.
[d] For crushing strengths greater than or equal to those listed, use tile with increased wall thickness, stronger concrete, or reinforcing.

Plastic Drain Pipe

High-density polyethylene (PE) is the most commonly used material for corrugated plastic drains in the United States. Polyvinyl chloride (PVC) is more commonly used in Europe. ASTM F-405, Standard Specification for Corrugated Polyethylene (PE) Pipe and Fittings, contains specifications for 3- to 6-inch corrugated polyethylene pipe (Table 4). ASTM F-667, Standard Specification for Large Diameter Corrugated Polyethylene Pipe and Fittings, includes specifications for pipe that is 8 to 24 inches in diameter.

Table 4. ASTM Physical Test Requirements for Corrugated-Plastic Tubing from 3 to 6 Inches

Physical Property	Standard Tubing	Heavy-Duty Tubing
Pipe stiffness at 5 percent deflection, psi	24	30
Pipe stiffness at 10 percent deflection, psi	19	25
Elongation, maximum percentage	10	5

Plastic pipe is not affected by acids and chemicals normally found in the soil at the drainage depth. Plastic may become stiff and brittle at very low temperatures or lose some of its stiffness when exposed to the sun on a hot day. But the sensitivity of plastic to temperature is a problem only while the pipe is being hand led. Temperature ceases to be a problem once the pipe is installed and buried. If you install plastic pipe during unusually cold weather, consult the manufacturer for advice on handling the pipeunder those conditions.

Design

The purpose of drainage is to lower the water table far enough below the ground surface that it will not interfere with plant root growth. The degree of drainage required depends upon the maximum allowable height of the water table, the minimum rate at which the water table must be lowered, or the maximum allowable duration and frequency of ponding. The designer of the subsurface drainage system should select the degree of drainage that will fit the various crop requirements of the site.

Drain Size

One of the first steps in determining drain size is to select the drainage coefficient, which is the rate at which water is to he removed from an area. It is a value selected to provide adequate drainage for future crops and is expressed in inches per 24 hours (see Table 5).

Table 5. Drainage Coefficients for Subsurface Drains

Degree of Surface Drainage	Drainage coefficient, inches of water per day	
	Mineral Soil	*Organic Soil*
Field crops		
Good surface drainage	3/8 to ½	½ to ¾
Blind inlets	½ to ¾	½ to 1
Surface inlets	½ to 1	½ to 1½
Truck crops		
Good surface drainage	½ to ¾	¾ to 1½
Blind inlets	¾ to 1	¾ to 2
Surface inlets	1 to 1½	2 to 4

Where field ditches or watercourses provide adequate surface drainage, the drain age area for which you are choosing a drainage coefficient need only include the area that will be drained by subsurface drains. If the slope of the field is less than 0.2 percent, choose the higher of the drainage coefficient ranges listed in the table.

Where the surface drainage is not adequate and surface-water or blind inlets (see page 58) must be used to drain depressions, the drainage coefficient must be relatively high so that the drains can remove runoff from the entire watershed of the depressional area. An exception can be made where the depressions are small, as long as surveys are available and the volume of the potholes can be determined accurately. In that case, the drains should be able both to remove water at the appropriate drainage coefficient from the land area that needs drainage and to remove the water in the potholes within 24 to 48 hours.

The size of the drain depends not only upon the drainage coefficient, but also upon the size of the area to be drained, the grade of the drain, and the internal roughness of the pipe. The main should be large enough to drain all areas in the watershed that need drainage at the appropriate drainage coefficient It should also have a free outlet and be deep enough to provide an outlet for all laterals to he installed.

To determine the size of plastic drains, refer to Chart A in Figure 12; for clay and concrete tile, use Chart B in Figure 12. First, find the appropriate drainage coefficient at the bottom right corner of the chart. In the column above the coefficient, find the acreage that will be drained by the subsurface drain. Next locate the point at which a horizontal line through your acreage would intersect a vertical line through your drain grade or slope (horizontal axis). This point indicates the size of the drain and the velocity of water moving through it when it is flowing at capacity. The minimum cleaning velocity is 0.5 feet per second for drains not subject to the entry of fine sand or silt and 1.4 feet per second where fine sand or silt may enter. The rate of discharge information can be used in determining drain size at design slopes.

The smallest drain generally recommended for laterals is 4 inches. A drain 3 inches in diameter may be installed in certain locations where the grade is 0.2 percent or more for clay and concrete tile and 0.3 percent for corrugated plastic pipe. Because of difficulty in achieving uniform grade the drain should be a minimum of 5 inches in diameter for a system with short laterals in sandy soils. Normally, 6 inches is the minimum diameter for drains located in organic soils and for main lines. For a subsurface system that contains tile lines exceeding 10 inches in diameter, it is preferable to use 2 or greater lengths to maintain alignment.

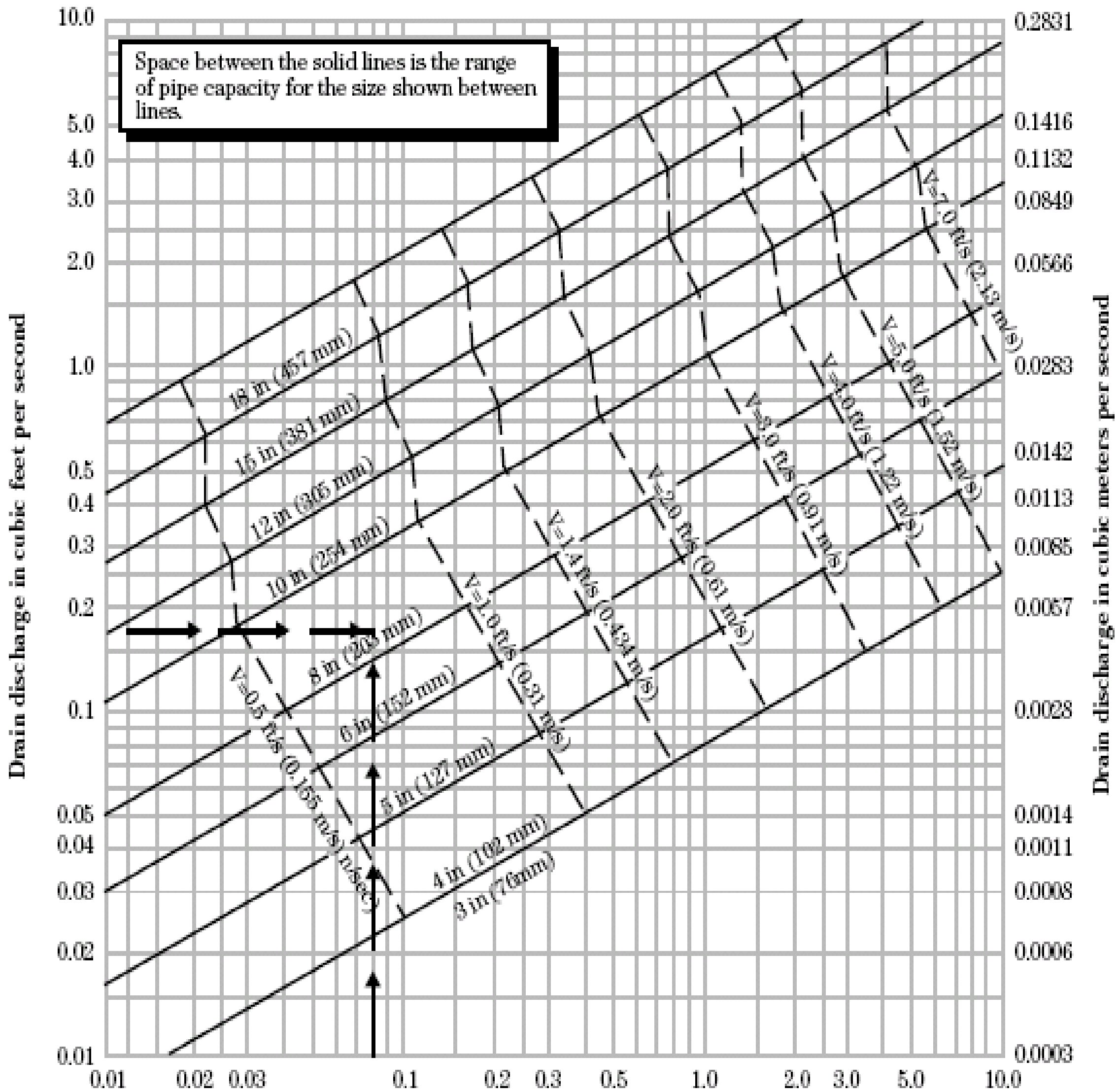
Drain Length

The length of lateral drains made of corrugated plastic drain pipe and concrete and clay drain tile should not exceed the values given in Table 6, assuming that the drains are spaced 100 feet apart and that the drainage coefficient is 3/8 inch. To determine drain length for other drainage coefficients and lateral spacings, multiply the length listed in Table 6 by the appropriate adjustment factor listed below for different coefficients and spacing.

If coefficient is:	Factor is:
¼ inches	1.50
3/8	1.00
½	.75
¾	.50
1	.38

If spacing is:	Factor is:
20 feet	5.00
30	3.33
40	2.50
50	2.00
60	1.67
66	1.52
70	1.43
80	1.25
100	1.00

Chart A



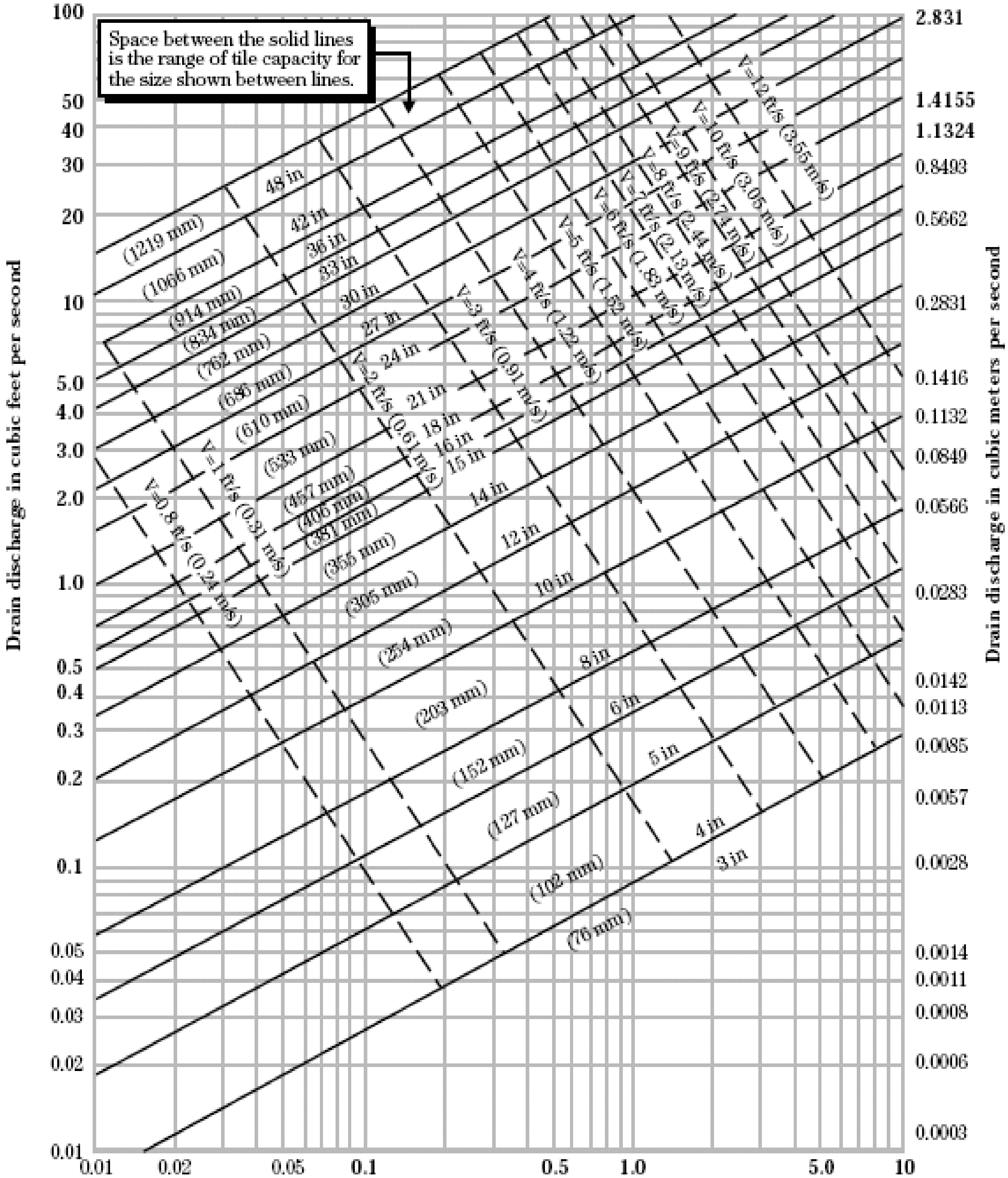
Drain grade = hydraulic gradient
Percent = ft per 100 ft, or m per 100 m
V = velocity in ft/s (m/s)

3 to 8 in (76 to 203 mm) : n = 0.015
10, 12 in (254, 305 mm) : n = 0.017
15, 18 in (381, 457 mm) : n = 0.02

(Source-ASAE Standard EP260.4)

Figure 12. Use chart A to determine the size and capacity of plastic drain tubing and chart B of clay and concrete drain tile. The range of capacities (rates of discharge) for each size are indicated by the space between the blue diagonal lines. **V** is velocity in feet per second. The coefficient of roughness values (n values) used in developing this chart were 0.015 for 3- to 8-inch tubing, 0.017 for 10- to 12-inch tubing, 0.02 for tubing greater than 12 inches in diameter, and 0.013 for all sizes of clay or concrete tile.

Chart B



Drain grade = hydraulic gradient
(Percent = ft per 100 ft, or m per 100 m)
V = velocity in ft/s (m/s)
(Source-ASAE Standard EP260.4)

Table 6. Maximum Lengths of Corrugated Plastic Pipe and Clay and Concrete Drain Tile

Grade, Percent	Drain Diameter			
	3 inches	4 inches	5 inches	6 inches
	(feet)			
Corrugated plastic pipe				
0.05	470	1,000	1,800	2,800
0.1	660	1,400	2,600	4,000
0.2	830	1,900	3,600	5,500
0.3	1,000	2,300	4,300	6,600
0.5	1,400	3,000	5,800	8,800
Clay and concrete tile				
0.05	520	1,160	2,100	3,450
0.1	750	1,650	3,000	4,900
0.2	830	2,200	4,100	6,900
.03	1,100	2,700	5,000	8,300
0.5	1,660	3,600	6,600	10,800

NOTE: It is assumed that the drainage coefficient is 3/8 inch per day and that the spacing between drains is 100 feet.

Drain Grade and Velocity

When possible, subsurface drains should be placed at uniform depths. The range of grades on which they can be placed depends to some degree upon the topography of the land. The grade should be great enough to prevent silting hut flat enough to prevent flow from exceeding the allowable velocity and subjecting the drain to excessive pressure. Too much flow would cause erosion around the drain. The grade should be as great as possible on flatlands. But you should not sacrifice adequate drain depth to Increase the grade. The minimum grades of small drains are listed in Table 7.

Wherever the grades of drains are flatter than the minimum, take these precautions to reduce the amount of sediment:

- Make sure that the system has a free outlet so that backwater conditions will not further reduce velocity.
- Provide sediment traps and clean systems (see page 55).
- Provide breathers and relief wells (see pages 57 to 58) to vent the drain and to assure maximum flow.
- Protect the entire system from sedimentation by using filters and envelopes (pages 59 to 60) to prevent movement of the drain blinding materials.

Table 7. Minimum Grades of Small Drains

Inside diameter (inches)	Minimum grades for drains not subjected to fine sand or silt		Minimum grades for drains where fine sand or silt may enter	
	Tile	Tubing	Tile	Tubing
	(percent)			
3	0.08	0.10	0.60	0.81
4	0.05	0.07	0.41	0.55
5	0.04	0.05	0.30	0.41
6	0.03	0.04	0.24	0.32
NOTE: The minimum grades listed here were determined at full flow.				

For long laterals and main drains, the maximum velocity should he limited to those listed below, assuming that no protective measures are provided.

Maximum Velocity Limitation

Soil Texture	Velocity, ft./sec.
Sand and sandy loam	3.5
Silt and silt loam	5.0
Silty clay loam	6.0
Clay and clay loam	7.0
Coarse sand or gravel	9.0

If protective measures do prove to he necessary, use one or more of the following:

For clay or concrete tile:

- Use tile uniform in size and shape with smooth ends.
- Lay the tile to secure a tight fit. The inside section of one tile should match that of the adjoining tile.
- Wrap open joints with tar-impregnated paper, burlap, or special filter material such as plastic sheets, fiberglass fabric, or properly graded sand arid gravel.
- Select the least erodible soil for blinding.
- Tamp soil carefully or use a drain with water-tight joints.

For corrugated plastic pipe or continuous pipe:

- Completely encase perforated drains with a filter material (see pages ???) made of plastic, fiberglass, or a like material, or use a properly graded sand and gravel filter.
- Use non-perforated corrugated plastic pipe or continuous pipe with taped or leak-proof connections.

Drain Spacing and Depth

The spacing and depth of drains influences the groundwater level between drains after a rain. Good drainage lowers the water table to at least 12 inches below the ground surface in the first 24 hours after a rain and to approximately 21 inches 48 hours after a rain. Incorrect spacing and depth could result in water remaining in the fields after 24 to 48 hours, significantly affecting crops (see Figure 13).

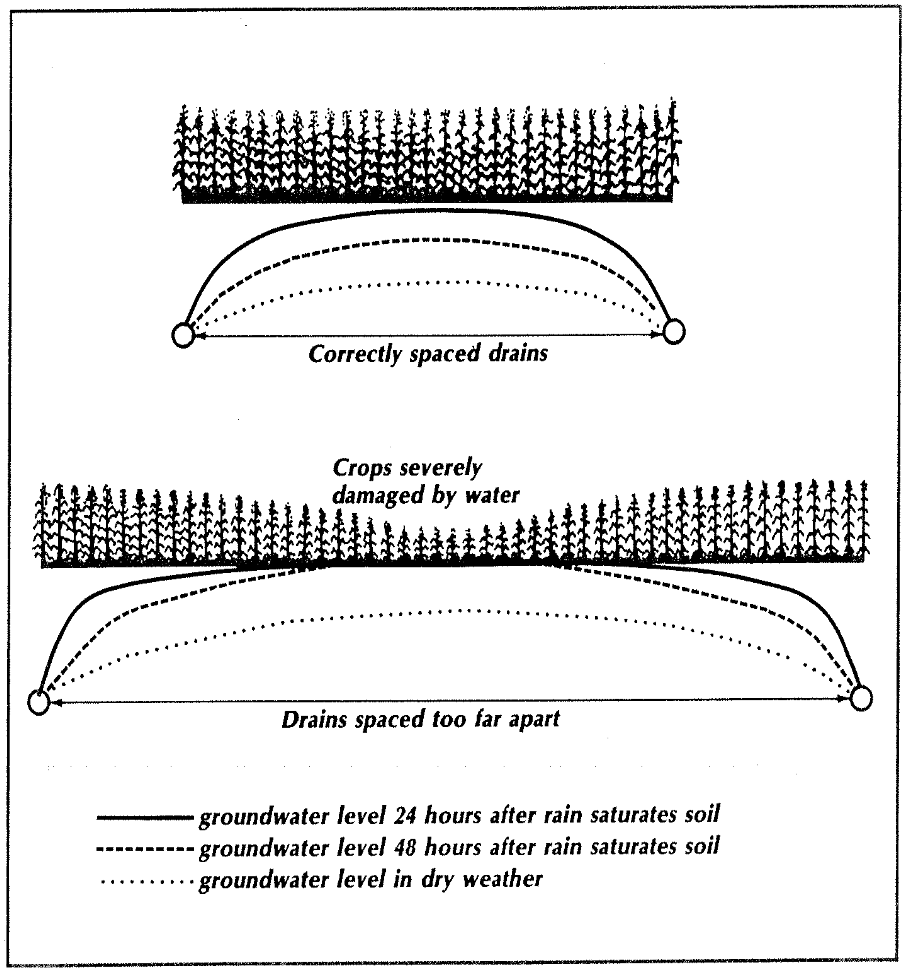
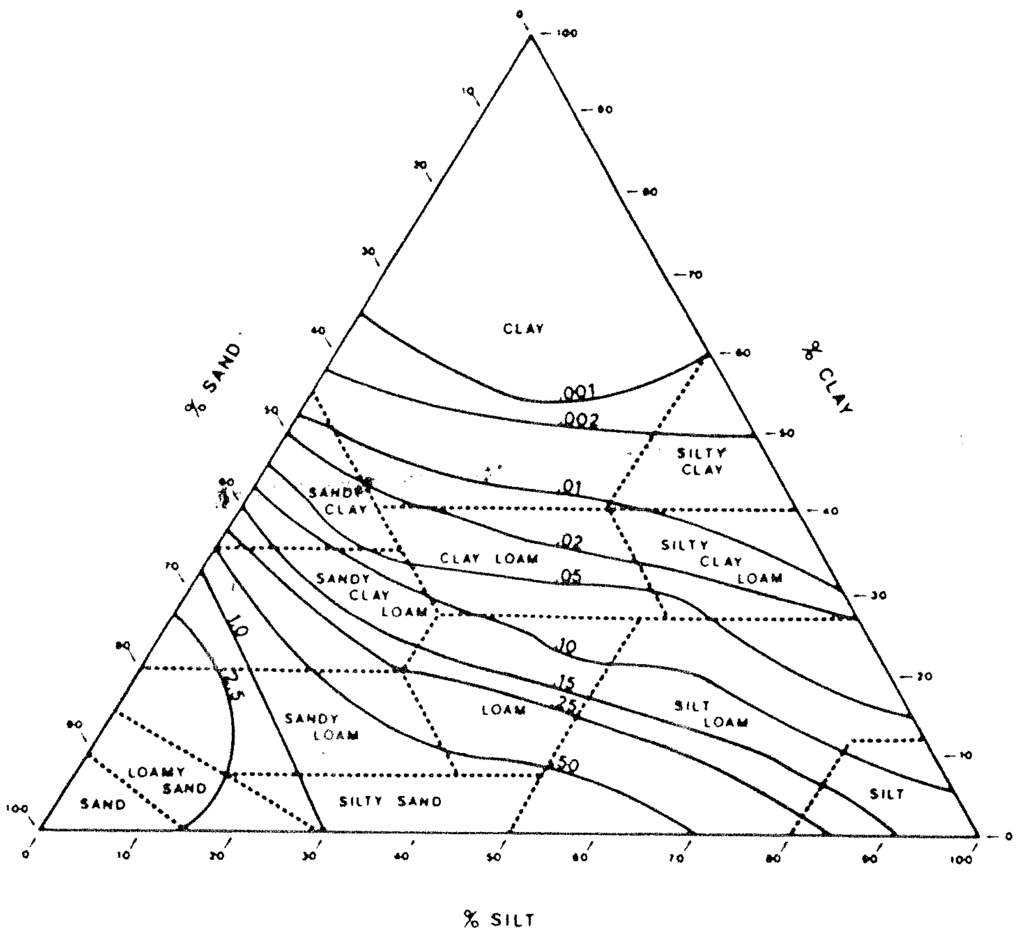


Figure 13. *The effect of drain spacing upon groundwater level and crop damage.*

The spacing and depth required to keep the water table at the desired level are influenced by the permeability of the soil, depth to the barrier, the amount and frequency of rainfall, seepage, capillary movement, and topography. Spacing and depth also influence each other. In general, you should increase the lateral spacing the deeper you place the drain. Spacing and depth recommendations are given in the drainage guidelines (pages 5 to 16) for specific soils. If your soil is not listed in the guidelines, keep in mind the following general principles about drain spacing and depth.

Drains in rapidly permeable soils should be spaced 200 to 300 feet apart, while those in moderately rapidly permeable soils should be placed 100 to 200 feet apart. Where soil permeability is moderate, spacing should he 80 to 100 feet apart. In slowly permeable or moderately slowly permeable soils, drains should be spaced 30 to 70 feet apart or 60 to 80 feet apart, respectively.

Soils which are slowly and moderately permeable are more difficult and costly to drain. Close drain spacings are required yet slight spacing adjustments can significantly affect installation costs and drainage performance. For these soils, a more careful site analysis is generally beneficial, so spacing recommendations can be made which minimize drainage installation costs and still provide satisfactory drainage. A site analysis for these soils should include measurements or a determination of the soil's permeability. A commonly used method of measuring permeability in the field for drainage purposes in the auger hole hydraulic conductivity method. While other measurement methods are available, this measurement method is the most straight and easiest to use. It is very similar to percolation tests which are used for septic leach field determinations, only the method works in reverse. Basically a hole of 2 to 6 inches in diameter is augured to a depth slightly below the planned drain depth. In soils without structure this hole is usually cased with a perforated pipe. The water level in the hole is allowed to come to equilibrium which may take a day for the slowly permeable soils. The equilibrated height of the water level is measured and then the water in the hole is bailed or pumped out. The rate at which water refills the hole is measured and the information is used to calculate the permeability. Further details of utilizing this method are available in Chapter 2 "Drainage of Agricultural Land', in Section 16 of the Soil Conservation Service National Engineering Handbook. Since the auger hole test can be performed only when water tables are close to the surface, the seasonal changes in water table depth do not always allow for the test to be conducted in a timely manner. If measurement of permeability cannot be made directly, then attempts should be made to estimate the permeability from the soil texture. The following diagram can be used for this purpose.



Estimated relationship between soil texture and saturated hydraulic conductivity.
(Values shown are m/d)

NOTE: This chart should only be used when actual field measurements are not available changes in soil porosity will require adjustment of these average values.

After the permeability is determined, the drain spacing can be calculated from the Ellipse equation. For further information about utilizing this equation refer to a web based tool to solve this equation at: http://www.wli.nrcs.usda.gov/technical/web_tool/Ellipse_java.html. These equations can also be used to determine the lateral drainage effect on existing wetlands.

With respect to general principles for depth, drains in moderate to moderately permeable mineral soils in humid areas should be installed at a depth of 3 to 5 feet. At this depth, the drains will lower the water table to not less than 2 to 4 feet. Because the upward capillary action is limited in very sandy soils, the drains should be no deeper than 4 feet. In slowly permeable clay soils, the rate of lateral water movement does not increase with depth. Therefore, the drain is usually placed approximately 1 foot below the desire water table.

The depth of drains also depends upon conditions other than those mentioned above; the depth of frost penetration, for example. If possible, place drains below the frost line to obtain optimum year-round drainage and to prevent damage to the line.

To protect a well-bedded subsurface drain in a mineral soil from breakage or excess deflection of flexible tubing by heavy equipment, make sure that the drain has a minimum coverage of 2 feet. Where 3-inch drains are used both for drainage and sub-irrigation of shallow-rooted crops, the minimum depth may he 1.5 feet if heavy machinery is not used in the crop area. The minimum depth of cover in organic soils should be 2.5 feet for normal field Levels after initial subsidence to a minimum, the depth of cover should be increased to 3 feet. The outlet should be deep enough for the lateral drain to have adequate grade and cover. When it is impossible to provide minimum cover for protection, use metal or some other continuous high-strength pipe.

Live loads should be added to soil loads in the determination of depth. Table 8 shows the percentage of wheel loads transmitted to the drain. After determining load requirements, select the class of tile or pipe that will meet the requirements.

Table 8. Percentage of Wheel Loads Transmitted to Underground Drains

Backfill depth over top of drain, feet	**Trench width at top of drain**						
	1 foot	**2 feet**	**3 feet**	**4 feet**	**5 feet**	**6 feet**	**7 feet**
				(percent)			
1	17.1[a]	26.0	28.6	29.7	29.9	30.2	30.3
2	8.3	14.2	18.3	20.7	21.8	22.7	23.0
3	4.3	8.3	11.3	13.5	14.8	15.8	16.7
4	2.5	5.2	7.2	9.0	10.3	11.5	12.3
5	1.7	3.3	5.0	6.3	7.3	8.3	9.0
6[b]	1.0	2.3	3.7	4.7	5.5	6.2	7.0

a These percentages include both live load and impact transmitted to 1 lineal foot of drain.

b Live loads transmitted are practically negligible below 6 feet.

Plastic drain pipe should be installed in such way that it does not deflect more than 20 percent of its inside diameter. The maximum trench depths for tubing that is buried in loose, fine-textured soils are listed in Table 9. Because the maximum depths listed in the table are based on a limited amount of research, they should he used with caution. Keep in mind, too, that these values are based on certain assumptions about corrugation design and pipe stiffness (which may not be the same for all commercial pipe) and about soil conditions. Because the variation in these characteristics, you may need to increase or decrease the maximum depths listed in Table 9.

The maximum allowable trench depths for drain tile are listed in Table 10.

Table 9. Maximum Trench Depth for Tubing
Buried in Loose, Fine-Textured Soil

Nominal diameter of tubing, inches	**Quality of tubing**	**Trench width at top of tubing**			
		12 inches	**16 inches**	**24 inches**	**32 inches**
		(feet)			
4	Standard	12.8	6.9	5.6	5.2
	Heavy-duty	a/	9.8	6.9	6.2
6	Standard	10.2	6.9	5.6	5.2
	Heavy-duty	a/	9.5	6.6	6.2
8	Standard	10.2	7.2	5.6	5.2
	Heavy-duty	a/	9.8	6.9	6.2
10		---	9.2	6.6	6.2
12		---	8.9	6.6	6.2
15		---	---	6.9	6.2

Source: Adapted from Fenemor, A.D., B.R. Bevier, and G.O. Schwab. 1979. Prediction of deflection for corrugated plastic tubing. Transactions of the ASAE 22(6): 1338-1342.

a/ Tubing of this diameter or less and of this quality can be buried at any depth.

Table 10. Maximum Allowable trench Depths for Drain Tile

Crushing strength, lb/linear ft[a]	Tile diameter, inches	Trench width at top of tile							
		18 in.	21 in.	24 in.	27 in.	30 in.	36 in.	42 in.	48 in.
		(feet)							
800	4, 5, 6	9	7	7	7	7	7	7	7
800	8	9	7	6	6	6	6	6	6
800	10	10	7	6	5	5	5	5	5
800	12	-	7	6	5	5	5	5	5
840	14	-	-	6	5	5	5	5	5
870	15	-	-	6	5	5	5	5	5
1000	6	19	9	8	8	8	8	8	8
1000	8	19	9	7	7	7	7	7	7
1100	4, 5, 6	25+	11	9	9	9	9	9	9
1100	8	25+	11	8	7	7	7	7	7
1100	10	25+	11	8	7	6	6	6	6
1100	12	-	11	8	7	6	6	6	6
1100	15	-	-	8	7	5	5	5	5
1150	15	-	-	9	7	6	5	5	5
1200	12	-	14	9	7	6	6	6	6
1200	16	-	-	10	8	7	5	5	5
1200	18	-	-	-	8	7	5	5	5
1250	4, 5, 6	25+	16	11	11	11	11	11	11
1300	4, 5, 6	25+	18	11	11	11	11	11	11
1300	8	25+	18	11	8	8	8	8	8
1300	18	-	-	-	9	7	5	5	5
1350	8	25+	22	11	9	9	9	9	9
1400	4, 5, 6	25+	25+	12	10	10	10	10	10
1400	10	25+	25+	12	9	8	8	8	8
1400	15	-	-	13	9	8	6	6	6
1450	4, 5, 6	25+	25+	13	11	11	11	11	11
1500	8	25+	25+	14	10	9	9	9	9
1500	12	-	-	14	10	8	7	7	7
1550	10	25+	25+	15	11	9	8	8	8
1600	4, 5, 6	25+	25+	16	12	12	12	12	12
1600	8	25+	25+	16	11	10	10	10	10
1600	10	25+	25+	17	11	9	9	9	9
1600	14	-	-	17	12	8	7	7	7
1650	15	-	-	19	12	10	7	7	7
1700	8	25+	25+	25	12	11	11	11	11
1700	12	-	-	25	12	10	8	8	8
1700	16	-	25	25	13	11	8	7	7
1700	18	-	-	-	13	11	8	7	7
1750	15	-	25	25	14	11	8	7	7
1800	8	25+	25+	25+	14	11	8	8	8
1800	12	-	25+	25+	15	11	8	7	7
1800	18	-	-	-	15	11	8	7	7
1850	14	-	-	-	15	11	8	8	8
2000	4, 5, 6	25+	25+	25+	19	14	14	14	14
2000	8	25+	25+	25+	19	12	12	12	12
2000	10	-	25+	25+	19	13	10	10	10
2000	18	-	-	-	20	14	9	7	7

NOTE: In the calculation of trench depth, soil weight was assumed to be 120 pounds per cubic foot and the safety factor to be 1.5.

[a] Crushing strength was tested by the three-edge-bearing test.

To prevent overloading in deep and wide ditches, you may want to construct a subditch, either with a trenching machine or by hand, in the bottom of a wide ditch that has been excavated by a bulldozer, dragline, power shovel, or backhoe. It is now the width of the subditch measured at the top of the drain that influences the allowable load; the width of the excavation above that point is relatively not important. It is a good idea to backfill deep trenches in several stages to allow time for settlement between fillings.

Interceptor Drains

An interceptor drain can be used in areas that are wet because of seepage from adjoining highlands. The drain is also used to intercept seepage or water that flows in a pervious layer on top of an impervious subsoil stratum.

Proper location of an interceptor drain is very important. An interceptor drain is usually buried at about the upstream boundary of the wet area. The drain is installed at approximate right angles to the Flow of groundwater and intercepts a seep plane in the soil profile (Figure 14). Adequate field investigations must he made to determine the amount of seepage and to identify seep planes. You can locate seep planes by making backhoe test pits or taking soil borings.

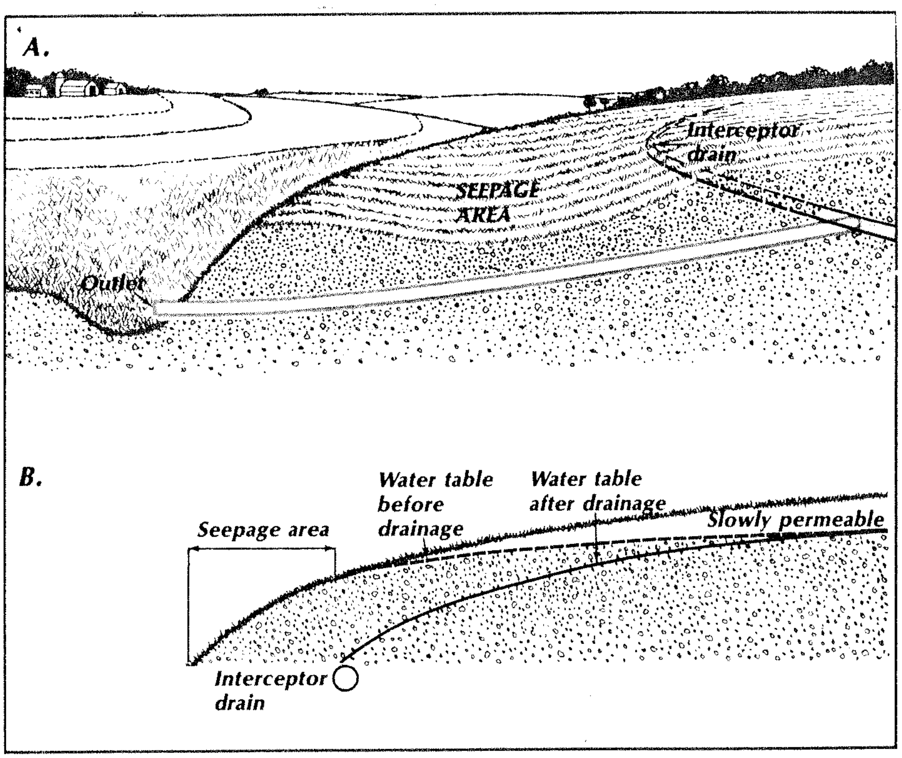


Figure 14. Drawing A shows an interceptor drain installed at the upstream boundary of a seepage area. Drawing B is a side view showing how an interceptor drain lowers the water table above an impervious area and usually eliminates the seepage area.

An interceptor drain must intercept the seep plane continuously, have adequate soil coverage, and be on a continuous grade toward the outlet. The drain is usually located one-half to one times its diameter deep in the impervious layer or seepage plane.

One or two properly spaced interceptor drains will usually dry up a wet area. The flow will often he continuous throughout much of the year. In a steeply graded depression or draw, the layout may consist of a main or submain located in the draw or to one side of it and interceptor lines located across the slope on grades slightly off contour.

To determine the size of an interceptor drain for a particular set of conditions, refer to the list below, which contains inflow rates for various soil textures. Measure or estimate the discharge of flowing springs and the direct entry of any surface flow through a surface inlet or filter. Add that figure to the rate of inflow. If the interceptor lines are being installed on sloping land, increase the inflow rate by 10 percent for slopes of 2 to 5 percent, by 20 percent for slopes of 5 to 12 percent, and by 30 percent for slopes of more than 12 percent. Once you have deter mined the drain size, using Figure 13. For interception areas where there is considerable seepage, the minimum drain size should be 6 Inches.

Soil Texture	**Inflow Rate, per 1,000 ft. of line cu. ft./sec.**
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

Changing the Direction of Drains

You can change the horizontal direction of drain lines by several means. Curve the trench gradually on a radius of curvature that the trenching machine can dig while still maintaining grade. The joint spacings for tile should be no more than 1/16 to 1/8 inch. Use manufactured bends or fittings, or use junction boxes where drain lines make an abrupt change in direction or where two or more large drains join.

Special Components

Drainage Water Management Controls

Drainage water management is the practice of using a water control structure in the main (or submain) drain to raise the drainage outlet to various depths. This allows farmers to have more control over drainage, keeping the water table depth at a more beneficial level for yield and water quality while providing drainage during critical periods. The outlet is:

- Raised after planting and spring field operations to store water that could be used by the crop in midsummer and potentially boost yields. (Figure 15)
- Lowered so the drain can flow freely before field operations such as planting or harvest. (Figure 16)
- Raised again after harvest until early spring to limit drainage outflow and to reduce nitrate loss. (Figure 15)

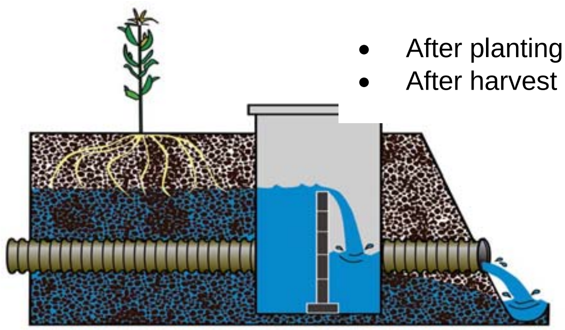


Figure 15: The outlet is raised after planting (to store water for crops) and after harvest (to improve water quality).

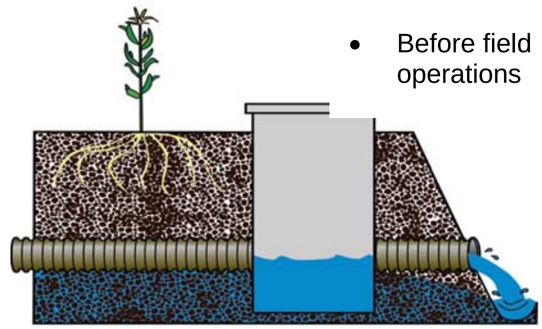


Figure 16: The outlet is lowered a few weeks before field operations such as planting and harvest to allow the field to drain more fully.

Some design considerations for drainage water management are:

1) The field should be flat (generally less than 0.5% to 1% slope) so that one control structure can manage the water table within 1-2 feet for 20 acres or more.
2) You must be able to manage the drainage without impacting adjacent landowners.
3) The practice can be used with any drain spacing; however any yield effects are likely to be greatest with narrow drain spacing.
4) If a new drainage installation is being planned for a field, drains should be designed to run along the contours, so each control structure can control the maximum possible area of the field.

More design information regarding drainage water management is available in NRCS Conservation Practice Standard 554.

Where drain discharges may have detrimental water quality effects on the receiving water body, treatment of the drainage water prior to discharge may need to be considered. One approach to treating this discharge is with the use of a bio-filter structure as shown in Figure 17. Another approach to provide some water quality treatment is to provide a setback for the tile outlet so that some water treatment may take place in the open channel shown in Fig. 18. An outlet setback provides additional advantages for management and control because there is opportunity for observing and evaluating the discharge, and to potentially collect and further treat the discharge.

Figure 17: An in-line bio control structure.

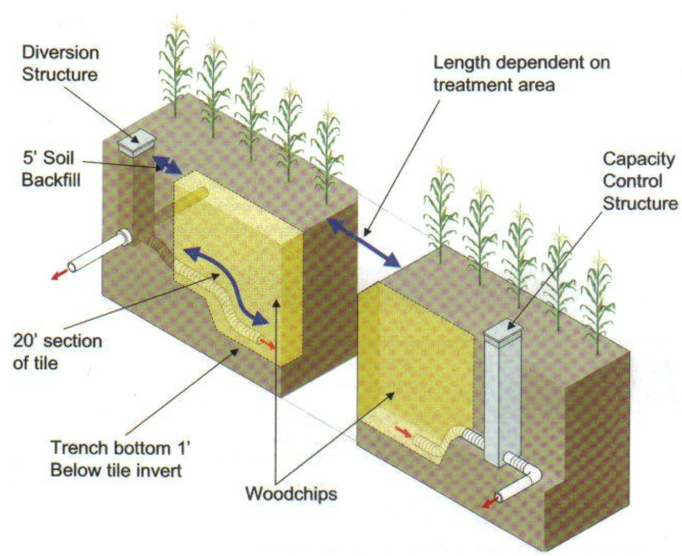
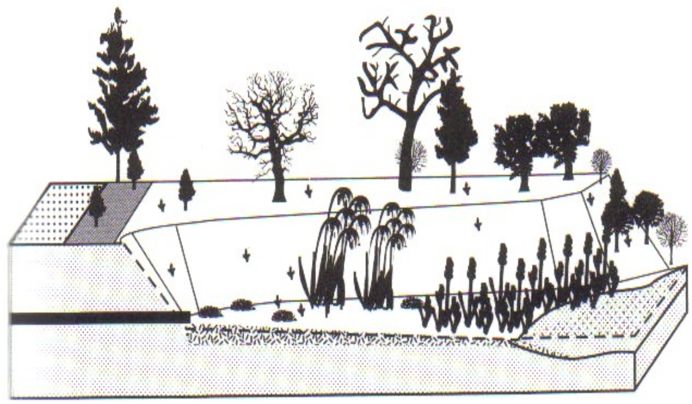


Figure 18: A tile outlet setback.



To protect drains from erosion and undermining, install outlet pipes on the end of all drains that outlet into an open ditch.

Assuming that no surface water enters the ditch at the drain outlet, the most practical and economical protection is a length of continuous pipe that does not have perforations or open joints. The pipe should be long enough (a minimum of 8 feet) to ensure that no seepage will occur around the drain and cause erosion at the outlet. The pipe should be of durable material to with stand weathering and maintenance and should have capacity equal to or larger than that designed for the main drain.

At least two-thirds of the pipe should be embedded in the bank to provide the required cantilever support. The flow line of the outlet pipe should he at least 1 foot above the normal water surface in the outlet ditch (Figure 4). A pipe projecting into the ditch can either be damaged or destroyed by floating ice and debris or cause a serious ice jam. Where this possibility exists, the pipe should be recessed into the ditch bank (as shown in Figure 19) and protected with riprap. Where there is not enough soil cover at the outlet, use one of the methods shown in Figure 20 to protect the drain.

Figure 19: Recessed outlet pipe.

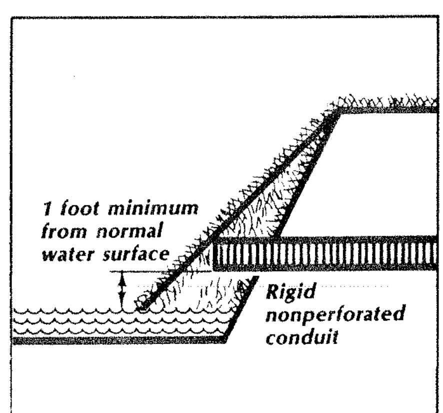
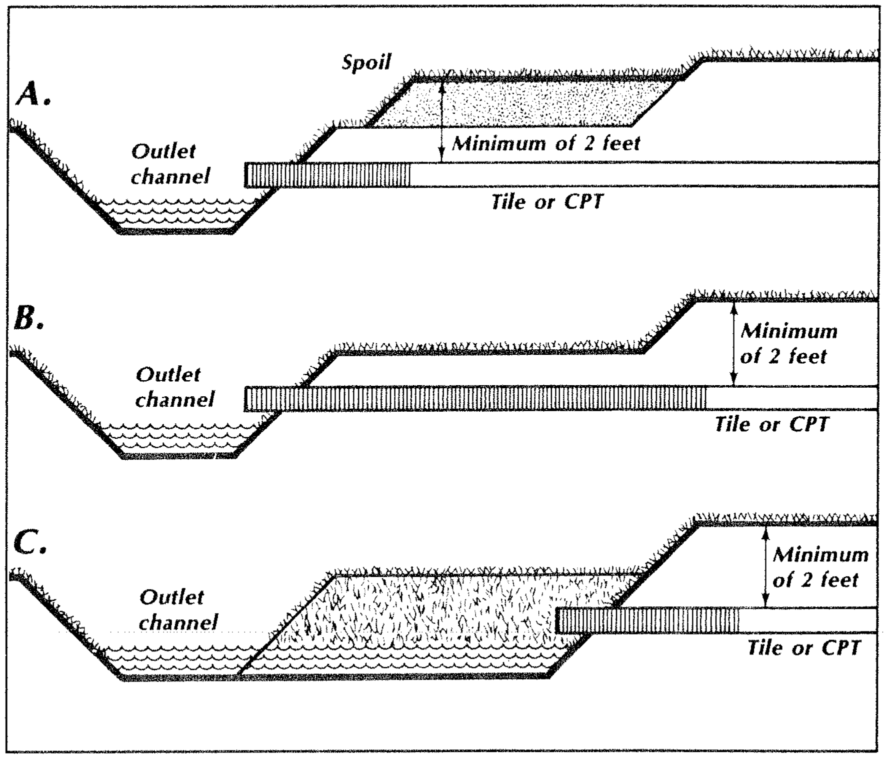
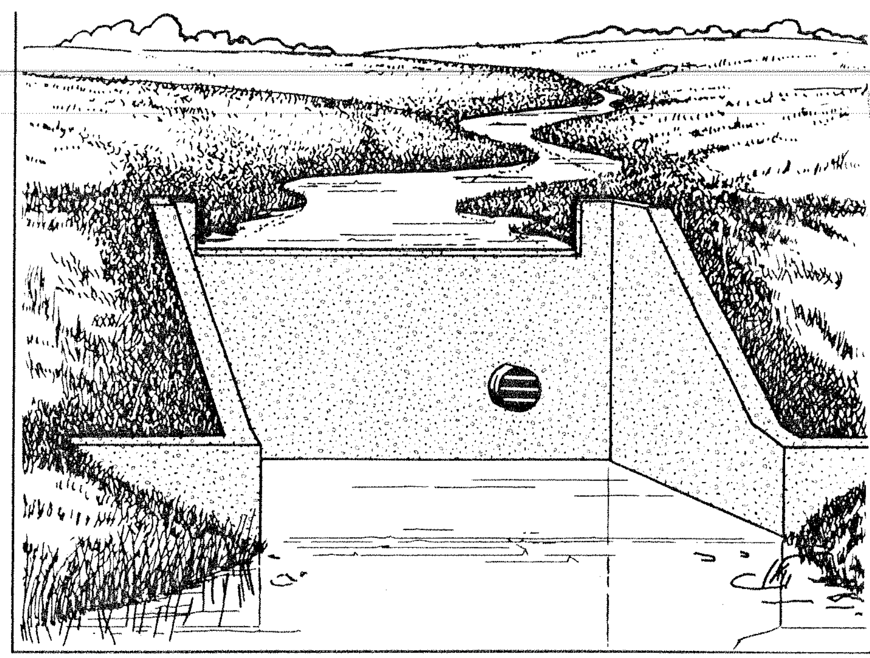


Figure 20: These drawings show three methods for protecting drain outlets where there is not enough soil cover (less than 2 ft.). In drawing A., fill is placed over the drain to provide the minimum soil cover; in B, a metal pipe is extended through the section where soil cover over the drain is less than 2 ft.; and in C, a ditch is excavated back to where the cover over the drain is more than 2 ft.



Where surface water does enter the ditch at the drain outlet, some type of structure should be installed to lower the surface flow safely to the ditch (Figure 21). If there is no spoil bank, a straight-drop spillway is generally the best type of structure. But if there is a spoil bank and enough temporary storage for surface water, it is usually more economical to install a pipe drop-inlet. Sometimes you can move the drain outlet out of the waterway or divert the surface water to another location at least 60 to 75 feet away and lower the surface flow into the ditch over a sodded chute.

Figure 21: Straight drop spillway used to protect subsurface drain entering channel.



Animal Guards

Animal guards such as rods, flap gates, and finger-type flap gates should be used on the outlets of all drains that are accessible to small animals (Figure 22). Fixed pins are suitable for lines that do not have surface-water inlets. Insert the pins horizontally through the end of the outlet pipe, not more than 1½ inches apart. Check the outlet frequently to be sure that roots and other debris carried through the drain do not block the openings between pins.

Fixed pin guards are not suitable for lines that do have surface-water inlets because the guards can easily become plugged up by the small material that continually washes through them. For those lines, use flap gates made of noncorrosive material. Flap gates should be placed well up into the outlet pipe so animals cannot easily get their nose underneath them.

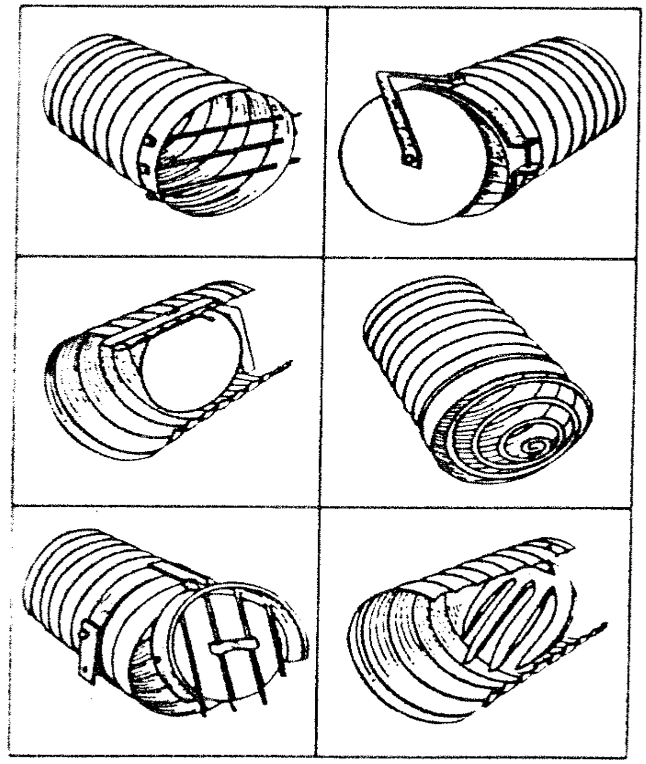


Figure 22: Animal guards.

Drain Crossings

Where subsurface drains cross under waterways or other ditches, the conduits should be watertight and strong enough to withstand the loads put on them. Design conduits that pass under roadways to withstand the expected loads and fleet the requirements of the appropriate railroad or highway authority (Figure 23). (Tables 9 and 10 list the maximum allowable trench depths for tile and tubing, and Table 8 gives the percentages of wheel loads transmitted to underground drain.) Be sure to obtain written permission to construct drains under roads from the responsible road official. Protect shallow drains in depressional areas and near outlets against damage by farm and other equipment and by freezing and thawing.

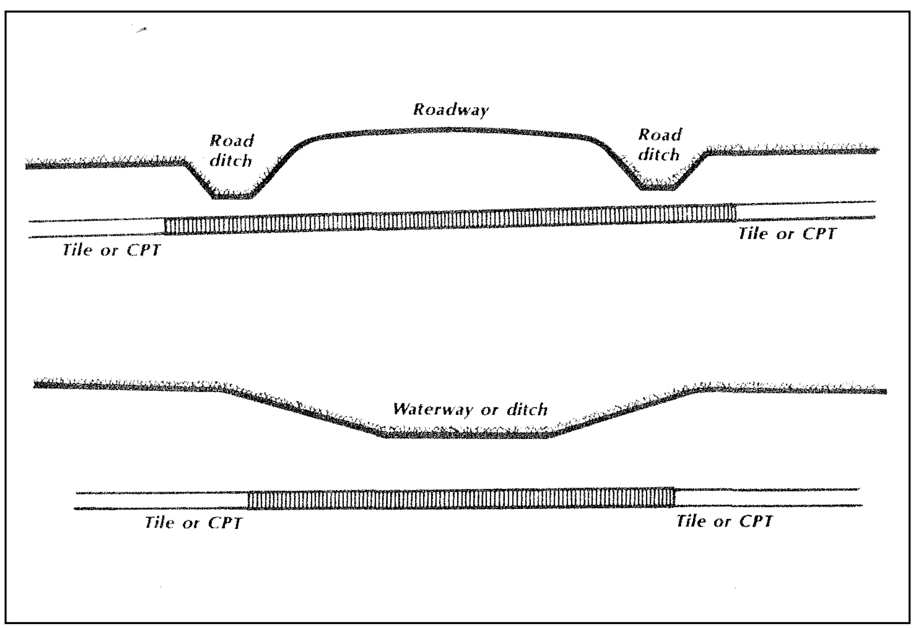


Figure 23: Drains that cross under roads, waterways, or ditches should be constructed of metal pipe, extra-length sewer tile with cemented joints, or drain tile encased in 4 inches of concrete.

Junction Boxes and Sediment Traps

Junction boxes are used where two or more drains join at different elevations or where a drain changes direction abruptly. They can also serve as sediment traps, which are placed downstream from surface-water inlets to catch sediment and trash entering the line. Locate junction boxes in permanent fence rows or in non- cultivated areas. Be sure that the capacity of the outlet drain equals the combined capacity of the incoming drain lines and that the elevation of the outlet drain flow line is at the same level or below the flow line of the lowest incoming drain (Figure 24). Place the junction box cover above-ground to provide easy access for inspection. In cultivated fields, the top of the box should be at least 18 inches below the ground surface. Sediment traps need to he inspected and cleaned frequently.

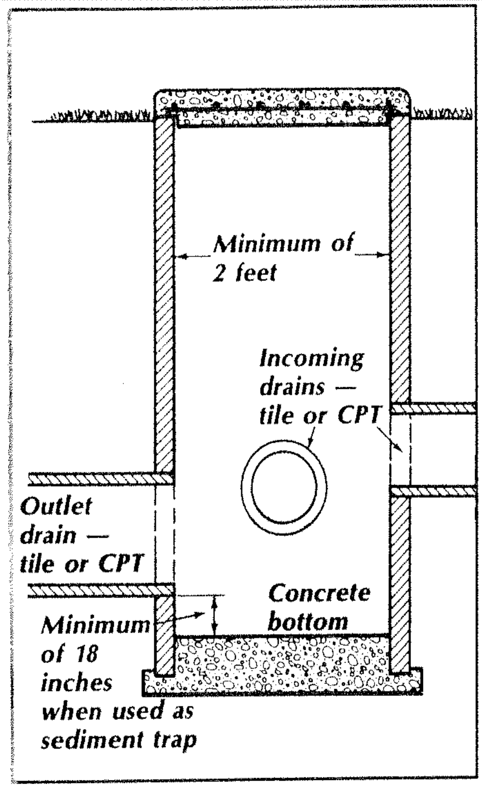


Figure 24: Junction boxes and sediment traps should be constructed of materials that have adequate strength and durability to carry the applied loads.

Pressure Relief Wells

A well relieves pressure in drain lines that might otherwise cause them to blow out. A relief well can be constructed by placing a T connection in the line and fitting a riser vertically into the T (Figure 25). The riser should outlet at the ground surface; the exposed end should be covered with heavy wire mesh or grating. The size of the riser should be equal to or greater than the diameter of the line. Locate relief wells where the drain line might become overloaded for short periods. This is more apt to occur where there is a change from a steeper to a flatter grade and where there are surface inlets. Relief wells should he considered where grade changes exceed four (4) percent and/or where clay tile are used in erosive type soils.

Pressure relief wells that are intended to function frequently (as with underground outlets that carry surface water from terraces or other temporary impoundments) should he designed to keep the hydraulic gradeline as low as possible, preferably below the ground line. This may be best achieved by outletting near the gradeline of a grassed waterway or surface drain.

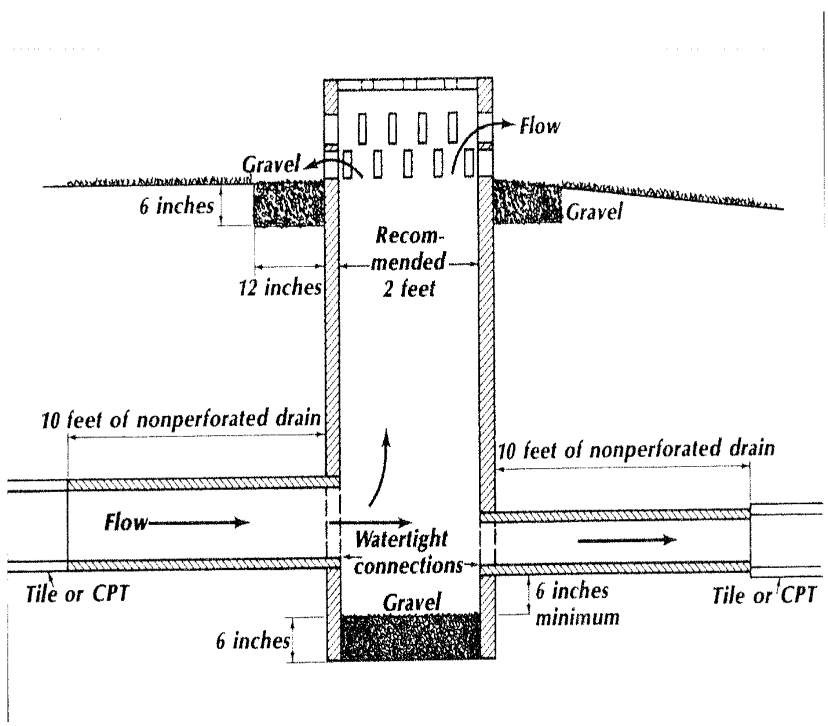


Figure 25: Relief wells relieve pressure in drain lines. They are typically used where tile outlet terrace systems connect to drainage mains.

Connections

Manufactured connections should he used for joining two tile lines at a junction. If connections are not available, the junction should he chipped, fitted and sealed with cement mortar.

For drainage systems constructed of corrugated plastic tubing, use manufactured fittings at all joints, at all changes in direction where the radius of the center line is less than three times the diameter of the tubing, at changes in diameter, and at the end of the line. All connections must be compatible with the tubing. If certain fittings are not available, hand-cut holes are acceptable, provided that they are reinforced with cement mortar or other material that will make the joint tight. When making the connection, be careful not to create a means of obstructing flow or catching debris inside the conduit or allowing soil to enter the line.

Mains should be laid deep enough to permit the centerlines of the laterals to be joined at or above the centerline of the main.

Breathers or Vents

Breathers, sometimes referred to as vents, can be constructed as shown in Figure 26. They allow air to enter the drain for the purpose of venting the line. Breathers are usually installed where the line is longer than 1/4 mile or where the line changes from a flat to a steep grade and full flow occurs in the line with the flat grade.

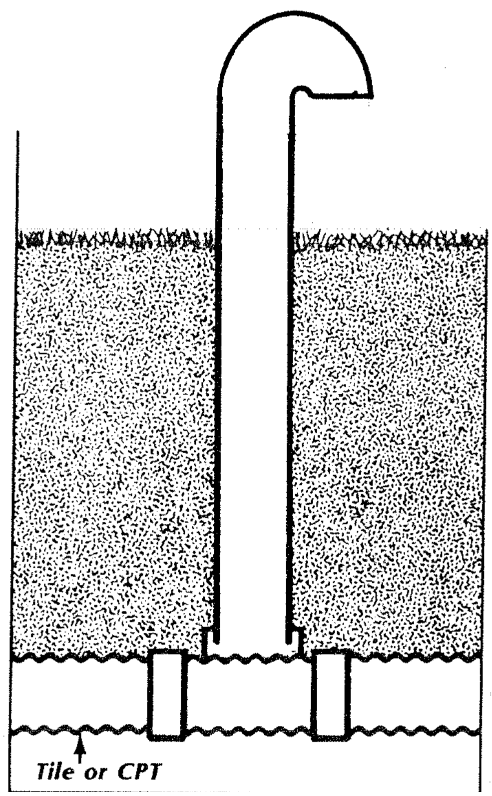


Figure 26: Breathers or vents allow air to enter drain line.

Exposed material needs to have resistance to ultraviolet light and fire. The riser should be 4 inches in diameter for 15-inch and smaller drain lines and 6 inches for drain lines that are 18 inches or larger. Cover the top of the riser with a heavy wire-mesh screen or some type of perforated cap.

Blind Inlets

Blind inlets remove both surface and subsurface water. They are most useful in open fields because they do not hinder farming operations. Since blind inlets remove impounded water at a much lower rate than surfacewater inlets, the former should not he used where there is a large amount of impounded water.

Described below is one method of constructing a blind inlet. Fill a section of the trench around and up to about 6 inches above the drain with stone, gravel, crushed rock, or a combination of these materials (see the section on envelopes, page 69.) Grade the material upward from coarse to fine to within approximately 12 inches of the ground surface and cover the material with topsoil. To increase the intake of water, especially in areas where silting is a problem, use pea gravel, small stones, or coarse sand instead of topsoil (Figure 27). You can also construct the blind inlet of graded gravel. The length of time for which the blind inlet will be useful depends upon the care with which it is installed, the fill material, and the amount of sediment that reaches the inlet, and the degree of disturbance by cultivation.

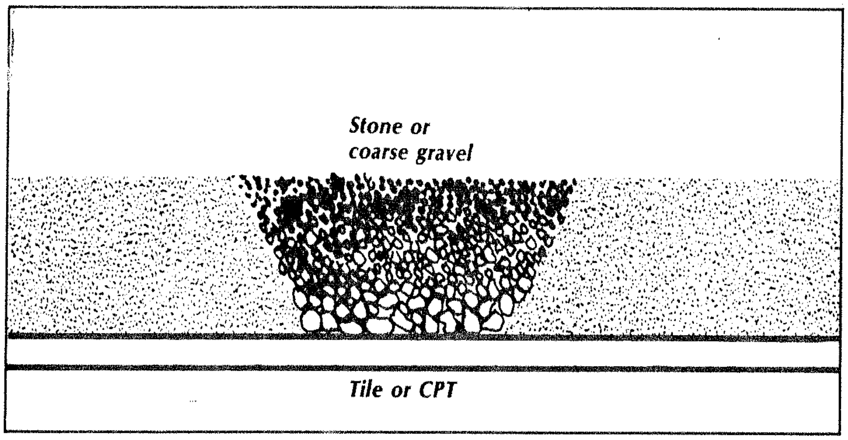


Figure 27: Blind inlets remove both surface and subsurface water and are suitable where there are relatively small amounts of impounded water.

Surface-Water Inlets

Surface-water inlets allow surface water to enter subsurface drains (Figure 27 and 28). The potential water quality impacts of adding surface water to tile drainage lines needs to be considered when adding surface inlets. Maintaining a filter area and manure free area around the inlet may be required for CAFO plans and recommended for all installations. Because of the high cost of carrying surface water in buried drains, inlets are recommended only for draining low areas where it is not feasible to install a surface drainage system. If you have to use surface-water inlets, place nonperforated tubing or conduit on each side of the riser. Since surface-water inlets may be a source of piping, erosion or crushing in a drainage system, you might consider offsetting the inlet to one side of the line to reduce the hazard to the main line (Figure 29).

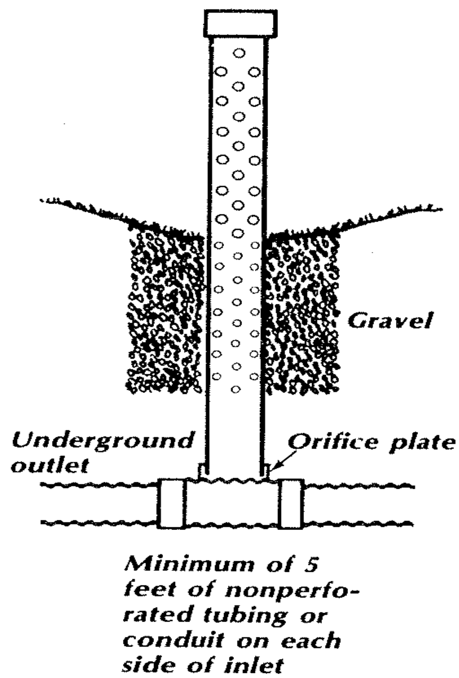


Figure 28: A surface-water inlet connected directly to a subsurface drain line. Typically the length of the riser is 5 feet.

Surface-water inlets not projecting above the surface should be protected with a cone grate (often referred to as a "beehive"). The cone grate tends to float flood debris, preventing it from closing off the entrance.

Metal pipes and other durable materials with holes or slots may be used as inlets. Flow control devices may he necessary to limit the amount of water entering the drain. Ways of limiting water flow are to install an orifice plate near the bottom of the inlet, or restrict the diameter of the connecting conduit. Where it is likely that a substantial amount of sediment will enter the surface-water inlet, it is advisable to construct a sediment trap.

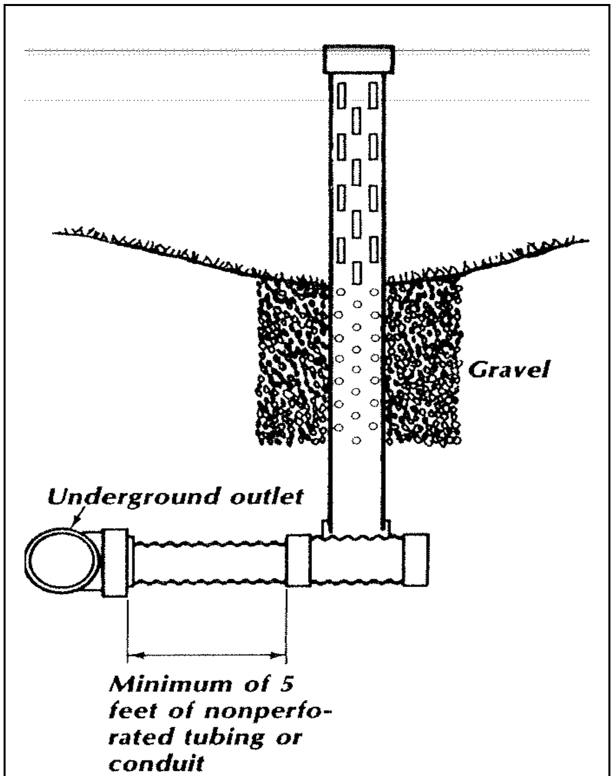


Figure 29: A surface-water inlet offset from the subsurface drain line to reduce potential damage to the line.

Filters and Envelopes

The need for a filter or envelope depends upon the characteristics of the soil material at drain depth and the velocity of flow in the conduit. Filters may he required in sand, silt, and some organic soils to prevent sediment from accumulating in the drain. A filter is required where the base material is uniform, fine to medium sand and where flow reaches such high velocities that it moves the sand into the drain.

Filters may be sand and gravel envelopes or manufactured filter material. Most of the presently available, artificial, prefabricated filter materials, such as fiber glass, spun-bonded or knitted synthetic fabrics, and plastic filter cloth, act as protective filters. With time, however, these materials may partially clog and decrease flow into the drain. Manufactured filters should have openings of sufficient size and enough strength, durability, and permeability to provide constant filtering of the soil material and to protect the drain throughout the expected life of the system. Make sure that the manufacturer of the material has certified it for underground use. During installation the material should span all open joints and perforations without being stretched excessively. Be careful not to damage the material during installation. Any damaged areas should be replaced before backfilling.

Installing envelope material around subsurface drains provides them proper bedding support and improves the flow of groundwater into the drain. Where it is not feasible to form a bedding groove for plastic drain tubing, envelope material can be substituted for bedding. The minimum thickness of the envelope may vary from 3 to 6 inches, depending on the type of equipment used to install the material and the availability of the gravel material. For all envelope designs, if the trench is wider than the specified width of the envelope, the trench must be filled on both sides with bedding material, or a gravel envelope so that no space is left between the drain and the walls of the trench.

Figure 30 shows various ways of placing envelope materials around drains. Although gravel envelopes are not normally designed to be filters, they do act as partial filters because their gradation is better than that of the base material.

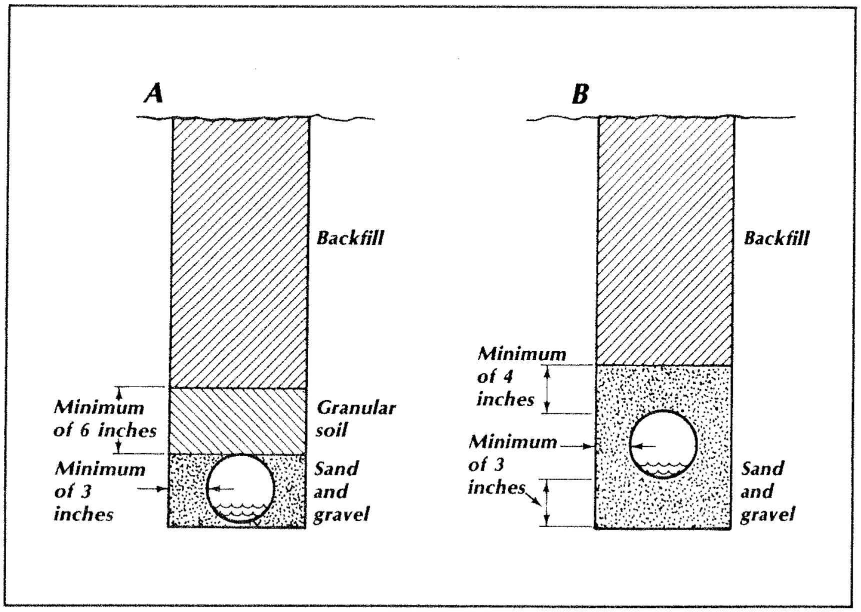


Figure 30: Two ways of placing envelope materials around drains. In drawing A the sand and gravel envelope supports the drain; in B the envelope acts as a filter. If fine particles are present in the soil, the envelope should be designed as in drawing B.

Preinstallation Considerations

In order for a subsurface drainage system to perform properly, it must be installed correctly. Assuming that the system is well designed and constructed of high-quality materials, proper installation will greatly reduce maintenance and pro long the life of the system.

Plans and Records

Ideally, all construction should follow a definite plan that has been prepared in advance by the designer of the system specially for the drainage contractor. The plan should include profiles and construction notes for all mains and submains and a map showing the locations, sizes, and grades of all lines and other components of the system. The map also should show physical features so that components of the system can be readily located in the future for repairs and maintenance. The location of buried cables, pipelines, or other utilities also should be noted (long before construction begins, the owner should obtain any necessary permission or easements that might be required to cross the land of private owners, highways, railroads, etc.).

The contractor should carefully examine the plan before work is begun and should not proceed with installation until the public utilities have marked the exact location of any buried obstacles at points where drains are to be constructed. As the work proceeds, the contractor should be careful to note on the plan and map any modifications in the design that are necessitated in the field, especially any changes in grade. Once the job is completed, the contractor should give the landowner the plan and map showing the system exactly as it was installed in the field. We recommend that the owner file one copy of the plan with the legal papers for the land and keep a working copy with the farm records.

If a drainage system is designed in the field, the designer, with the help of the contractor, should prepare a final, as-constructed plan with notes for the landowner.

Inspection of Materials

The contractor should inspect construction materials before and during installation. All materials should be satisfactory for the intended use and should meet the requirements described in the section of this publication on quality of materials (page 37) and any additional requirements of the owner. Reject any defective or damaged clay or concrete drain tile; remove defective or damaged sections of plastic tubing. Make sure that the perforations in the plastic tubing are of the proper size.

Storage of Materials

Drainage materials should be protected from damage during handling and storage. The storage area should be dry, well drained, and free of rodents, vegetation, and fire hazards. It should have a protected floor (peagravel or cement) and adequate security.

Take more precautions to protect plastic tubing. Where rodents could be a problem, we recommend that you use end caps. Tubing with filter wrap should either be stored inside or placed in protective bags. Since tubing can be harmed by excessive exposure to ultraviolet rays, protect it from sunlight when it is to be stored out side for a long period. To protect coils or reels of tubing from damage and deformation, lay them flat when they are stored for extended periods. Coils of tubing should be stacked no more than four high; reels should not be stacked.

Tree Removal

Before installation begins, remember to remove willow, elm, soft maples, cotton wood, and other water-loving trees that grow within approximately 100 feet of the planned drainage lines. All other species of trees, with the possible exception of fruit trees, should be removed for a distance of 50 feet. If it is not possible to remove trees or to reroute the line, use a nonperforated line with sealed joints throughout the root zone of the tree or trees. Grade is normally maintained by the use of targets or electronic, optical grade control devices (lasers).

Small and gradual variations from grade can be tolerated, providing the line still has adequate capacity after the variations. No reverse grade should be allowed, If the trench is excavated below the designed grade, it should be filled to grade with gravel or well-pulverized soil and tamped enough to provide a firm foundation. The bottom of the trench should then be planed and shaped to grade.

Safety

Observe safety standards for persons and machines. Persons working in trenches should be protected from cave-ins (especially when trenches exceed four (4) feet depth), and they should not work alone. Moving parts of machinery should he protected by proper guards. Persons observing the work should not be permitted to come close to the excavating operation.

Trench Method of Installation

Constructing the Trench

Construction of the trench should begin at the outlet and proceed upgrade. Align trenches in such a way that the drain can be laid in straight lines or in smooth curves. The width of the trench at the top of the drain should be the minimum required to permit installation and enable the bed to support the load on the drain, however, there should be at least 3 inches of clearance on either side of the drain.

Tile should he bedded in an earth foundation that is shaped to fit the lower part of the tile. The foundation can be shaped in this way with most trenching machines. If the trench is dug with a backhoe, it will have to he hand graded and shaped to fit the tile.

For corrugated plastic tubing a specially shaped groove must he made in the trench bottom if the design does not call for a gravel envelope. The groove provides side and bottom support to the lower part of the tubing and provides a means of controlling alignment during installation. The grove may be in the shape of a semicircle, trapezoid, or a 90-degree **V**. A 90-degree V groove of sufficient depth is recommended for 3- to 6-inch tubing. However, if the tubing is installed on a steep grade, shape the bottom of the trench to closely fit the tubing.

The groove for tubing can be formed or cut in a number of ways. With all methods, some type of a forming tool is attached to the shoe of the trenching machine or to the backside of a backhoe bucket. One method is to install a forming tool on the bottom of the shoe and use pressure to form the bedding groove. Another method is either to install a device on the front of the finishing shoe that will plow out the groove during the trenching operation or to attach special shaping cutters to the trenching wheel. The latter methods minimize soil compaction and do not reduce permeability as much as the first method.

Figure 31 shows the dimensions of a 90-degree V groove. The depth at which 3- to 6-inch tubing is set in the groove will vary according to the size of the tubing.

Diameter[a] (D)	r (D/2)	X (0.707r)	Y (0.293r)	Z (0.414r)
		inches		
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 diameters, which are assumed to be 20 percent greater than inside diameters.

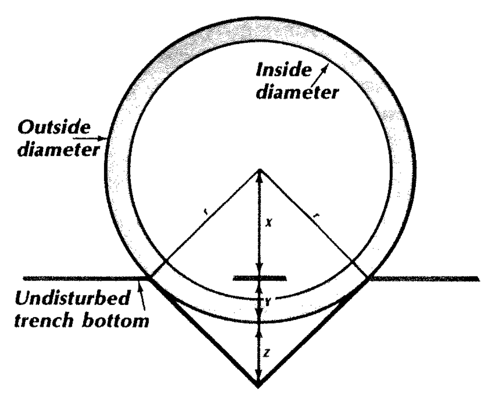


Figure 31: Dimensions for a 90-degree V groove for corrugated plastic tubing.

If the drain is to be laid in a rock-cut, the trench should he overexcavated to a depth of 6 inches below grade level; this space should be filled with graded sand and gravel or well-pulverized soil and tamped enough to provide a firm foundation. Then, the bottom of the trench should be shaped and leveled to grade. The trench should be filled with designed bedding or envelope material to the top of the rock-cut.

Where the trench bottom is unstable, as in fine sandy soils or in soils containing quicksand, be extremely careful to keep sediment from entering the drain and to provide a firm foundation for the drain. When draining these types of soils, consider the following suggestions:

- Install the drain only when the soil profile is in the driest possible condition.
- Place stabilizing envelope materials under the drain.
- Cover the remainder of the drain with an envelope material.
- Use nonperforated tubing self-sealing sewer pipe, or continuous rigid pipe where there are small pockets of noncohesive soils less than 100 feet in length.
- If the drain is tile, be sure that the joints are snug.
- If tubing is used, take precautions to prevent it from floating.

If you find unstable soil at the trench bottom, you can remove and replace it with suitably graded foundations and bedding of processed stone or processed gravel, which will act as an impervious mat into which the unstable soil will not penetrate. The depth of the processed material depends on how unstable the soil is in the trench bottom. Install the foundation and bedding material in layers of no more than 6 inches, and compact. If the foundation contains large particles that create a hazard to the drain, provide a cushion of acceptable bedding material between the foundation and the drain.

Where stabilizer materials do not furnish adequate support, the drain should be placed in a 90-degree, rigid V, prefabricated foundation cradle in which the top of the V equals the outside diameter of the drain. Each section of the cradle must pro vide rigidity and continuous support throughout the entire length of the cradle. Occasionally, it is necessary to place the cradle on piling; drive pairs of posts along the edge of the cradle into solid material to provide the required support.

If the soil in the trench wall is unstable, the trench sidewalls may cave in and cause tubing failure. This problem may arise where excavation is below groundwater level or in saturated sand. Unstable trench walls may also cause misalignment of tile lines. Where there are unstable trench sidewalls, you should protect the tubing or tile by some means until the drain has been properly laid and blinded. In some cases, the trencher shield behind the shoe can be made longer to protect a greater length of the trench during construction. To install drains in unstable soils, use a fast-moving trencher or trench drain plow that can maintain continuous forward motion while disturbing the soil as little as possible.

<u>Installing the Drains</u>

Listed below are some guidelines to follow when installing drains:

- Remove all soil or debris inside drains before installation.
- Make sure the drain is free from clinging wet or frozen material that could hinder laying the drain on grade.
- Begin laying tile or tubing at the outlet and progress upgrade. If possible, place the drain inside the shoe casing of the trencher during the trenching operation.
- Automatic drain-laying devices are acceptable, provided that they can lay the drain according to the requirements stated in this publication.

- Lay tubing in the groove and tile on a firm bed that is free of loose soil on the planned grade.

- Hold plastic tubing in position on grade immediately after installation by careful placement on blinding material.

- Where lengths of plastic tubing are to be joined, cut the ends square and remove all ragged or burred edges. Use a plastic coupling to secure the ends of the tubing in proper alignment and to prevent the joint from separating during installation.

- Before work is suspended for the day, blind and backfill all drains laid in trenches.

- Close any open ends tightly with an end plug.

- Use continuous pipe within 100 feet of trees.

Any stretch that occurs during installation of tubing will decrease its 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 tubing at the time it is installed, the amount and duration of drag that occurs when the tubing is fed through the installation equipment, and the stretch resistance of the tubing. Tubing should not be stretched so much that its stiffness is reduced to less than the minimum allowable pipe stiffness. Stretch, which is expressed as a percentage increase of length, should not exceed 5 percent. The use of a power feeder is recommended for all sizes of tubing.

The internal wall temperature of plastic tubing can reach 150°F. or more when it is strung out in a field on a hot, bright day. The ability of corrugated poly ethylene tubing to resist deflection is reduced by about 40 percent when its temperature rises from 70° to 100°F. and by about 50 percent when it increases from 70° to 120°F. Therefore, it is essential that the contractor take precautions in hot weather to keep sharp heavy objects from striking the tubing and to prevent excessive pull on the tubing during installation. The tubing will regain its strength when its temperature returns to that of the surrounding soils, which usually occurs five minutes or less after installation.

The stiffness of tubing increases and its flexibility decreases as its temperature is lowered. Rapidly uncoiling tubing in cold weather stresses it excessively and may cause it to crack. The tubing may also have a tendency to coil in cold weather; it is then difficult to lay flat and must be handled with extra care. Ask the manufacturer for recommendations on handling the material in hot or cold weather.

When plastic tubing floats in water during installation, it is difficult to get blinding material around and over the tubing without getting the material underneath it and causing misalignment. You can prevent floating by holding the tubing in place until blinding is completed.

<u>Blinding</u>

Blinding is the placement of bedding material consisting of loose, mellow soil on the sides and over the top of the drain to a depth of 6 inches. The bedding material must permit water to reach the drain easily. Except in areas where chemical deposits in and around the drain area are a problem, the bedding material should be friable top soil or other porous soil. Fine sand should not be placed directly on or around the drain. In soils with low permeability where blinding with soil is not adequate, a suitable envelope should be used. Blinding is not necessary where the drains are placed in sand and gravel filters or envelopes.

A number of blinding methods have proven to be acceptable. Some contractors consider blinding so important that they place the material by hand around and over the drain. There are a number of mechanical blinding devices that can be mounted on the trencher. These devices take material from near the top of the trench and place it around and over the drain. Their main advantages are that they blind the drain immediately after laying it, use the most suitable blinding material that is readily available, and reduce labor requirements.

All drains should be blinded immediately to maintain alignment and to protect them from falling rocks, ditch cave-ins, and backfill operations.

Blinding immediately also will help maintain proper alignment of tubing in the groove and protect it when the remaining excavated material is placed in the trench. Careful soil placement on both sides of the tubing is necessary to provide good side support, which will reduce deflection of the tubing. Hold tubing in place in the trench until it is secured by blinding. This step is especially important when water is in the trench and when the air temperature is below 45°F. Under those conditions, you may want to increase the quantity of blinding material.

No stones or other hard objects should be allowed to come into contact with the drain. These objects apply point loads and may cause the drain to fail. Blinding provides protection for the drain during the backfilling operation when the impact of rocks and hard clods could damage it. All lines should be carefully inspected for grade alignment and other specifications before backfilling.

<u>Backfilling</u>

At the conclusion of each day's work, the end of the drain line should be stopped and the trench backfilled to prevent sediment or debris from entering the line in case of rain. Backfilling should be done even sooner if there is a chance of heavy rain or freezing temperatures. The upper end of each drain should be tightly covered with a manufactured plug or equivalent material.

Various methods can be used to move the remaining excavated material back into the trench and mound it up and over the trench to allow for settlement. These include graders, bulldozers, and auger and conveyer methods. The backfill material should be placed in the trench in such a manner that displacement of the drain will not occur. It is preferable to place the material on an angle so that it flows down the front slope. Avoid large stones, clods, and heavy direct loads during backfill operations. If you are installing tubing on a hot day and the tubing feels warm to the touch (100°F.), delay the backfilling until the tubing reaches the soil temperature.

Trenchless Method of Installation

In the trenchless plow method, tubing is placed at a prescribed depth in an open channel beneath a temporarily displaced wedge or column of soil. The trenchless plow constructs a smooth-bottomed opening in the soil, maintains the opening until the tubing has been properly installed, and then surrounds it with permeable material.

The plow blade is designed to lift and split the overburden as it moves forward. The lifting action causes a deformation and disruption of the soil upward and outward at an angle on both sides of the plow blade. The slot should be fissured and loosened rather than compacted. The size of the shoe and drain-placing attachment should conform to the outside diameter of the tubing.

Critical Depth

The way the trenchless plow moves through the soil influences whether the slot wall is fissured or compacted. When a plow 3 to 5 inches wide working at a relatively shallow depth of 3 feet or less in dry soil, the soil is broken loose from the base of the plow, heaves forward and upward ahead of the tine, and falls back around the tubing as the plow moves on. This type of disturbance creates cracks and fissures without causing compaction. The same plow working at much greater depth of 6 to 7 feet in dry soil may tend to compress the soil sideways, causing it to become compacted and reducing its permeability. Between these two extremes of working depth there is a certain depth, termed critical depth, where the transition between one type of soil disturbance and the other occurs. This critical depth is the maximum depth at which the trenchless plow can work without causing compaction around the tubing. The critical depth depends upon the forward inclination of the tine, the tine width, the soil moisture content, and the soil density.

In a uniformly compact, dry seedbed, the critical depth will he approximately 15 times the tine width. As the surface layers become very dry and strong or if the soil is of low bulk density and contains large air-filled pores, the critical depth will he reduced to about 10 times the tine width. You can sometimes lower the critical depth by loosening the surface layers of the soil to a depth of 8 to 16 inches in a strip approximately one and one-half times the working depth of the plow. The shallow tining can he done as the plow "returns empty" before the next run. An alternative is to use a double-pass system. The first pass with the plow is made at approximately two-thirds the final depth. Where the critical depth is above the working depth, using a wider tine and loosening the soil surface will reduce the draft force, often by a substantial amount.

Soil Condition

Because soil texture and moisture vary considerably, the soil disruption patterns caused by the trenchless plow will vary. The zone of disturbed soil extends upward and outward at various angles from the vertical, depending on soil conditions, depth, and plow geometry. Soils ranging from sands to clay-loam have properties that permit them to be fractured very readily by the plow. In fact, when the surface layer of these soils is loose, it tends to flow down behind the tubing just as it would during a blinding operation. Wet soil that has high clay content is more likely than other soil types to develop soil structure and compaction problems. Both radial and surface compact ton can occur where tubing is installed in heavy clay soils or wet soil. High-clay soils that are dry, however, can he fractured and fissured to a high degree, facilitating movement of water to the tubing.

Plows do not appear to be affected as much by rocks as are trenchers. In areas where rocks are a problem, the operator should flag any rocks he comes across so that they can later be inspected and removed if necessary. A plow will tend to push smaller rocks aside and move around the larger ones. When large rocks are encountered above or near grade, the plow tends to bounce over them, disrupting the tubing grade. If a rock deflects the plow upward a small distance, an alert operator will, where the slope permits, make a small adjustment in grade from that point on the avoid leaving a hump in the line that would have to be corrected later. If there is an adverse deviation in grade, the point of deviation should be marked. The tubing should be excavated at that point and the grade corrected. The grade should be con trolled automatically by means of a laser.

Blinding

To keep the tubing on grade, trenchless plows should be fitted with a device that brings blinding soil over the tubing as it is placed. Where the surface layer is loose, it will flow down freely behind the tubing boot and cover the top of the tubing. This cover is desirable as long as the surface material is highly permeable and stable, but siltation could occur if the surface material is very fine. If a filter is used, a covering of medium to coarse sand around the tubing could enhance inflow.

Maintenance

Although subsurface drainage systems do not require extensive maintenance, the maintenance that is required is extremely important. If the subsurface drains are working, water will stand in the field for only a short time after a heavy rain. If water stands for a few days, the drain may be partly or completely blocked. With drainage systems that have inspection wells or sediment traps, be sure to check the amount and rate of flow at these structures and at the outlets after a heavy rain. A change in flow may indicate that there is a blockage somewhere in the line. Regular inspection of the drainage system is essential. Prompt repair of any drain failure will keep the system in good working order and prevent permanent damage to it.

Outlet Ditches

Many subsurface drainage systems fail because the outlet ditches are blocked. If the outlet ditch is filled with sediment, a survey should be conducted to determine how much cleanout work will be required. You should also find out whether some type of conservation practice could be used on the contributing watershed to reduce soil movement.

Surface Inlets

Poorly constructed surface inlets are subject to severe damage and require frequent repair. Because inlet covers often become sealed with trash, they should be checked frequently. Clean the covers after a heavy rain and replace them carefully. If a cover is removed, trash can enter and block the line.

Blowouts

Repair holes over subsurface drains at once. Otherwise, large amounts of soil may wash into the lines and block the entire system. Holes form where a drain is broken or where joints or slots are too wide. If the tile is broken, replace it. If the joint is too wide, place tile bats (pieces of broken tile) over the joint to prevent soil from washing into the line. To repair crushed or punctured corrugated plastic tubing, cut the damaged segment from the line and replace it with new tubing, using the manufacturer's couplers.

Sediment

Sediment traps can he used for subsurface drains that are laid in fine sand or silty soils. If the traps are cleaned periodically, they will keep soil from filling the lines. Clean the traps every few days just after the lines are laid because at first sizable quantities of fine soil will wash in through the joints between tiles or through perforations in plastic tubing. After one freezing and thawing cycle, soil will wash in more slowly, and you will need to check the traps only once or twice a year. You can gain access to drainage lines and flush them through the inspection wells.

Tree Roots

Willow, elm, soft maple, cottonwood, and other water-loving trees that grow within approximately 100 feet of the drain should be removed. Maintain a clearance of 50 feet between the drain and other species of trees.

Ochre Accumulations

Ochre, which is an iron oxide, may block the drain when iron in solution moves from the soil to the drain and accumulates there. The process by which ochre accumulates may be chemical, microbial, or both. Ochre usually enters drains through organic soils but has been known to occur in other soils as well. There is no fool-proof solution (except construction of open ditches) to the ochre problem. Jetting the drain with an acid solution has proven successful in some areas, but that remedy is very costly. There is also no easy field method of determining whether ochre accumulation is apt to be a problem in the future for specific sites.

Computer Aided Drainage Designs

The computer technology revolution has brought about a number of useful software programs which can assist with designing drainage systems. Some software programs take field data and provide topographic maps for drainage planning and for land forming operations. Other software programs allow one to plan the entire drainage layout, pipe sizes, grades, etc., and print out lists of materials needed. On-site evaluations and the collection of field data such as elevations, location of outlet, and the soils permeability are still necessary to provide the proper input data for the software programs. The computer programs make generalized assumptions where input data is incomplete and this could sometimes lead to inadequate designs. SUBDRAIN, DRAIN (AGE SYSTEM) DESIGN, and LANDRAIN are three examples of computer aided drainage design software packages which are commercially available.

There are also several drainage design tools which evaluate long term weather records and soil parameters to determine the frequency of poor drainage conditions. These computer programs will evaluate the levels and probability of risk when different drain spacings are used, estimate crop performance under these conditions, and determine the most profitable design alternative. DRAINMOD is the most popular of these programs and is available to SCS personnel. These programs are cumbersome to use, at least initially, because of the amount of input data required and their complexity and ability to be not very user friendly. Nevertheless, these computer tools are becoming more accessible and can provide designs which are the most economical in the long term. For further information on computer applications for drainage, contact Cooperative Extension or Natural Resources Conservation Service personnel.

PUMPING PLANTS

Where it is impossible or uneconomical to install outlets for drainage, drainage pumping plants can be used to remove excess surface water or groundwater. Pumping plants are also used where outlets are adequate except during prolonged, periods of high water.

In solving drainage problems that involve pumping, take into account the capacity of the drainage system outlet, the capacity of the pump, its location and type, and the size of the sump. Determine the cost of all practical solutions. To be economically feasible, a pumping plant must be designed in such a way that annual operation costs are low. A pump that costs relatively little to install but has a high annual cost of operation may not he the most economical.

A preliminary survey will determine the condition of the drainage outlet and help you decide whether pumping is required. A drainage system with a pumping plant that is designed into the system will usually function much more efficiently than one to which the pump is added later when the outlet is found to be inadequate.

The pumping plant must be designed to pump enough water to provide adequate drainage against the total head expected. (Total head considers all possible sources of resistance, from elevation to friction to couplings and joints.) Because pumping plants that are designed to pump surface runoff are complex and expensive, as much surface runoff as possible should be diverted from the site of the plant. Where surface or flood waters are likely to inundate the site, dike protection must also be planned.

Selecting a Site

The pumping plant should be located where it can best serve its purpose. In choosing a location, consider the stability of the foundation material, accessibility for servicing, proximity to sources of power, and susceptibility to vandalism. In areas where ample sump storage is available, the pumping plant should be located so as to take maximum advantage of the storage. Select a location that will permit safe discharge into the outlet with a minimum of construction outside the diked area. If possible, locate the plant in a place that is readily accessible in all types of weather.

The requirement of a stable foundation is an important aspect in selecting a location. Before deciding upon a site, make borings to ensure that the location has the best foundation and that it meets as many of the other site requirements as possible.

Selecting Pumps

In selecting a pump, consider the type, characteristics, capacity, total head, the kind and source of power, shape and size of pump, housing, and method of operation. Pumps used for pump drainage are in the high-volume, low-head class. This class includes axial-flow propeller pumps and certain centrifugal pumps. Determine pumping volumes and heads carefully since friction factors become critical at settings other than those recommended by the manufacturer.

Electric power permits automatic operation and eliminates the need for daily fueling or servicing. Usually, a 10-horsepower motor is the largest that can be used on single-phase, 230-volt lines. Larger motors can he operated on three-phase power, which is available in some areas, or where phase converters can be used on single-phase power lines. If you plan to use electric power for pump drainage installations, consult the power supplier for suggestions and recommendations as to the best arrangement. If electric power is not available, you can operate the pump with diesel, gasoline, or LP gas stationary power units. Belt or power takeoff drives can he used to couple farm tractors to the pump. The size of the pump depends upon the total head and the quantity of water pumped. The rated size is usually designated by the diameter of the pipe column at the discharge end of the pump. The design column velocity in the discharge pipe may range from 7 to 12 feet per second, with the highest efficiency usually occurring at values of 8 to 10 feet per second.

Pump Capacity

The required capacity of pumping plants can he determined from drainage coefficients applied to the area served, empirical formulas, a study of existing installations, or direct analysis using hydrologic procedures. The capacity of pumping plants for drainage areas of up to 1 square mile can be determined from applicable drainage coefficients (Table 5) or computed through hydrologic procedures. Hydrologic procedures should always be used whenever the drainage area exceeds 1 square mile. If you determine pump capacity from the drainage coefficient, use the following equation:

$$\mathbf{Q = 18.9 \times C \times A}$$

where

Q = pump capacity, gallons per minute (GPM),
C = drainage coefficient (inches per 24 hours),
A = area of the watershed (acres).

Regardless of the method, be sure that the pump capacity is no less than the minimum values suggested below. Where only subsurface drainage water is pumped, the capacity of the pump should he no less than the maximum capacity of the drainage system plus 20 percent. When both subsurface and surface water are to be pumped for field crops, the pump should have the capacity to remove 1 inch of water from the contributing drainage area in 24 hours. When special or high-value crops are to be grown, the pump should be able to remove 1½ to 4 inches of water in 24 hours, depending upon how much runoff water can be stored in the ditches and watershed and upon the degree of protection desired. Where seepage is a problem, select a pump with additional capacity.

Power Requirements

The power required to achieve the designated pumping rate depends upon the head against which the water must be pumped and the efficiency of the plant. The horse power required to move a given quantity of water against a specific head can he calculated with this formula:

$$\mathbf{HP = \frac{Q \times H}{3{,}960 \times e}}$$

where

HP = horsepower required to move the water,

Q = pump capacity (GPM),

H = total head (feet), which includes the difference in elevation between inlet water level and discharge water level as well as friction losses in the pump and fittings.

e = efficiency of the unit (equal to the pump efficiency times the drive efficiency; pump efficiency varies from 50 to 75 percent and drive efficiency from 90 to 100 percent).

The horsepower you determine with this formula will be the continuous-duty requirement. For electric motors, this figure will be the nameplate rating. For internal combustion engines, the minimum engine size will be the calculated horse power plus the power required to operate accessories.

Before installing the pumping system, estimate the daily cost of pumping to complete a cost-benefit ratio. If the source of power is an electric motor, you can use this information in making the computations:

1 horsepower/day = 7.9 kilowatt hrs/day

Water Storage

To prevent the motor from starting too frequently, you must provide space for temporary storage of water. In small areas an enclosed sump or pump bay may be enough storage. Enclosed sumps can he constructed from silo staves, manhole blocks, or a series of large sewer or metal pipe sections. For large subsurface drainage systems where subsurface water must be pumped, an open ditch or large pit is usually the best type of storage.

For automatic operation, provide enough water storage so that the maximum number of operation cycles will he limited to 10 per hour. Estimate the required storage using these formulas:

$$\textbf{active storage (cubic feet)} = \frac{\mathbf{Q \times 2}}{\mathbf{N}}$$

$$\textbf{storage area in sump (square feet)} = \frac{\mathbf{Q \times 2}}{\mathbf{N \times d}}$$

where

Q = pump capacity (GPM),
d = the depth (in feet) of storage or distance between water levels that will start and stop pump operations,
N = cycles per hour.

The amount of active water storage must be greater for manually operated pumps than for automatic ones. The amount also depends upon the number of times the operator is willing to start the pump. Where the number of starts is limited to two a day, estimate the active storage desirable using these formulas:

$$\textbf{active storage (cubic feet)} = \mathbf{Q \times 25}$$

$$\textbf{storage area in sump (square feet)} = \frac{\mathbf{Q \times 25}}{\mathbf{d}}$$

where

Q = pump capacity (GPM),
d = the depth (in feet) of storage or distance between water levels that will start and stop pump operations,
N = cycles per hour.

The depth of storage (or distance between the water level at which the pump starts and at which it stops) should be about 2 feet for sumps and 1 foot for ditches. This depth reduces changes in the operating characteristics of the pump caused by changes in water level. Sumps should have a paved base and weep holes in the walls. The base provides a solid foundation for the sump wall and supports the weight of the pump and sump cover. Weep holes prevent flotation of the sump.

Pump Bay

The sump or hay should be designed after the pump has been selected. Be sure to provide proper clearance and submergence in the pump bay for the pump you select (most manufacturers make recommendations for these dimensions), and protect the pump and motor from flooding at all times. See Figure 32.

Operation and Cycling

Although pumping is cyclic in design, the electric motor used to power a pump should have a continuous load rating to take care of sustained water inflow. Electric motors can easily be controlled by float switches. An internal combustion engine will have to he controlled manually for certain periods, or it can he made automatic by some kind of throttle or clutch control. Automatic safety cutouts will eliminate the need for an operator during most of the time the engine is running. Safety cutouts (based on engine temperature, engine oil pressure, or pump pressure) should be attached to any engine that is to be left running unattended for any length of time.

Trash Racks

Provide trash racks or protective screening to prevent floating debris from entering the sump and damaging the pump. The velocity of flow through the rack should not exceed 2 feet per second. Recommended spacing for trash rack bars is 3/4 inch for a pump 16 inches in diameter, 1 to 1½ inches for diameters 18 to 24 inches, and 2 inches for ones 30 to 42 inches.

The trash rack should be shaped so that it can easily be cleaned by hand, or it should be equipped with mechanical cleaners. If the pump is too small for trash racks, use galvanized basket strainers to prevent small gravel and debris from entering the sump. For more details on the design of pumping plants, refer to Chapter 7, "Drainage of Agricultural Land," in Section 16 of the Soil Conservation Service National Engineering Handbook.

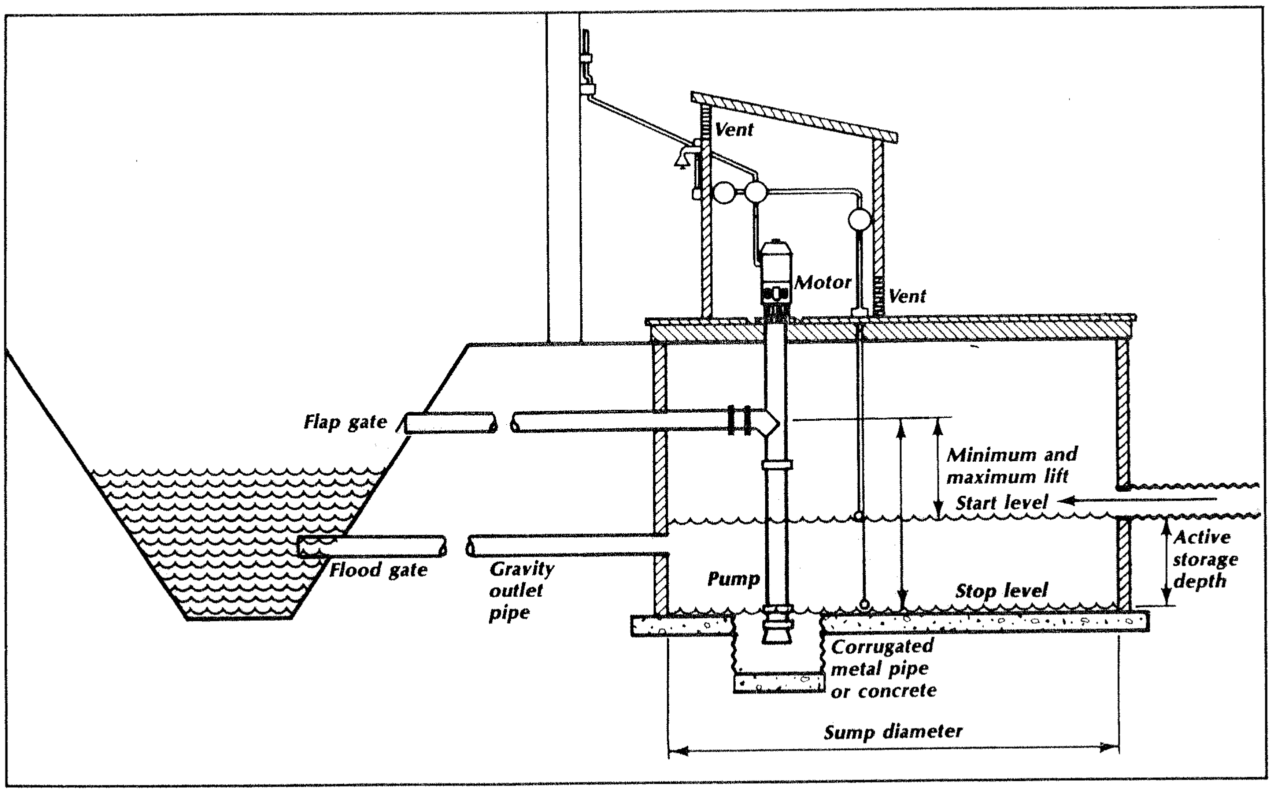


Figure 32. Drainage Pumping System

BASIC TERMINOLOGY

Backfilling	Placement of excavated soil in the trench after blinding has been completed.
Bedding	The earth foundation of the trench together with the select material around and over the drain, including envelope and filter material where used.
Berm	Strip or area of land, usually level, between the spoil bank and the edge of a channel or ditch.
Blind Inlet	Constructed by backfilling the trench for a length of 10' to 15' with crushed stone or pea gravel.
Blinding	Placement of select soil around a drain to prevent damage or misalignment when the trench is backfilled and to allow water to flow freely to the drains.
Coefficient of roughness	Factor expressing the frictional resistance to flow of a channel surface or a drain interior.
Connection	Fittings used to join two drain lines.
Continuous pipe	Extended length of pipe without perforations or unsealed joints.
Deflection	Decrease in vertical diameter of tubing, often influenced by loading.
Ditch	Constructed open channel for conducting water. See Drain.
Diversion	Channel constructed across the slope for the purpose of intercepting surface runoff.
Drain	Conduit below the ground surface for removal of surplus ground or surface water. See Ditch.
Drainage area	Area from which drainage water is collected and delivered to an outlet. Sometimes referred to as the watershed area for a particular drain.
Drainage coefficient	The depth of water, in inches, to be removed from an area within 24 hours.
Drainage system	Collection of surface ditches or subsurface drains, together with structures and pumps used to collect and dispose of excess surface or subsurface water.
Field ditch	A graded ditch generally crossable with field equipment for collecting excess water from a field.
Grade or gradeline	Degree of slope of a channel or natural ground.
Inspection well	Opening to surface in drain line to permit observation of flow conditions.

Interceptor line drain	Surface ditch or subsurface drain, or a combination of both, designed and installed to intercept flowing water. Also, a line used to intercept several lines to keep the number of crossings at highways and similar locations to a minimum (also called collector lines).
Junction	Point of intersection of two or more surface ditches or subsurface drains.
Lateral ditch	Principal channel or ditch that conducts drainage water from the field ditches to an outlet channel.
Lateral drain	Secondary drain that collects excess water from a field.
Main drain	Principal drain that conducts drainage water from the lateral drains and submains to an outlet.
Outlet channel	Channel constructed primarily to carry water from manmade structures such as drain lines, surface ditches, diversions, and terraces.
Pipe	A continuous length of nonperforated conduit typically used to protect an outlet or to provide additional structural strength.
Pipe drop inlet	Type of surface water inlet, fabricated from pipe materials, which lower surface water to a ditch bottom.
Pumping plant	One or more pumps, power units, and appurtenances for lifting drainage water from a collecting basin to a gravity outlet.
Slope	Degree of deviation of a surface from the horizontal, usually expressed in percent or a ratio of horizontal to vertical (i.e., 4:1).
Slot	Perforations in plastic tubing. Also, the opening in the ground created by the trenchless plow as it lays the tubing.
Spoil bank	Soil excavated from channel, ditch, or other site and placed along the excavation site.
Stretch	The increase in length of the tubing caused by tension forces during installation. It is expressed as a percent increase of the length prior to installation.
Submain	Branch drain of f the main drain which collects discharge water from laterals or from the field.
Tile	Drains made of burned clay, concrete, or similar material, in short lengths, usually laid with open joints to collect and carry excess water from the soil.
Tubing	A flexible drain that gains part of its vertical soil load-carrying capacity by lateral support from the surrounding soil.
Watershed	Total land area above a given point on a stream or waterway that contributes runoff to that point.