SECTION 1B
SITE PREPARATION

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1B.1 INTRODUCTION

The presence of water over and under a building site impacts the way foundations perform. Maintaining a consistent level of soil moisture is desirable. The best way to affect the consistency of the soil moisture is by limiting the incursion of unplanned water onto the building pads. For this reason, civil engineers and others design plans so that surface, and in some cases underground, water will flow away from building foundations.

1B.2 GRADING PLANS

To protect the building pad from surface water, each project must be sculpted and compacted to direct drainage away from buildings and other structures. The activities necessary to accomplish this are called *earthwork*. Before concrete can be poured and structures built, the land must be prepared to provide a strong base. A civil engineer specializing in soils should be assigned to determine the characteristics of the soil, evaluate the potential for groundwater impacts and recommend construction methods to be used to provide the base for the structures. If the site is in a mountainous area or an area subject to earthquakes, a geologist or geologic engineer should also be contracted to evaluate risks and make recommendations for protection against landslides and earthquakes.

1B.3 THE SOILS REPORT

An investigation of the soils should be made for every site and a report made. The investigation should be made by a qualified civil engineer specializing in soils science. The soils engineer will visit the site, take soils samples, and make borings at various locations. The cores resulting from the borings show the underlying strata. A three-dimensional view of the layers of earth and rock can be projected from the cores. Although subsurface conditions cannot be described with absolute certainty, the unknowns are reduced and much useful information is provided.

The different types of soil and rock on the site are identified. A series of tests are performed on the soils to determine their strength, plasticity, potential for liquefaction, and permeability (See Section 2A). The depth of groundwater is also provided. The level of groundwater varies with the time of year and the character of the previous rainy seasons. If the seasons have not been typical or there is historical evidence that groundwater is a problem, further investigation is indicated.

The information provided will be useful to the architect and structural engineer in designing the structures, to the site engineer in designing paved surfaces and slopes, and to the contractor charged with grading the site. If subsurface conditions change abruptly under a proposed structure location, it may be necessary to excavate existing earth to provide a consistent earth foundation beneath that structure, or to design different foundations for different parts of the structure.

The report should describe maximum allowable slopes. The allowable slope is based on the *angle of repose* for the soil on the site. The angle of repose is the angle between horizontal and the slope of a heaped pile of the material. Using a steeper slope could result in slope failure or landslide. The *slope* is described as the unit horizontal distance necessary for each unit of vertical distance (Fig. 1B.1). The slope described as 2:1 indicates two horizontal units to for every vertical unit. (The same slope is defined as 1:2 vertical to horizontal in the metric system). These slopes will be used between areas or pads of different elevations.

The relative compaction requirement should be included in the soils report and is important to the site engineer. Typically, the engineered base for structures in the field must have 90 to 95% relative compaction. That is, the soil must be compacted to 90 to 95% of the maximum dry unit weight from laboratory tests. Compaction testing methods are described later in this book.

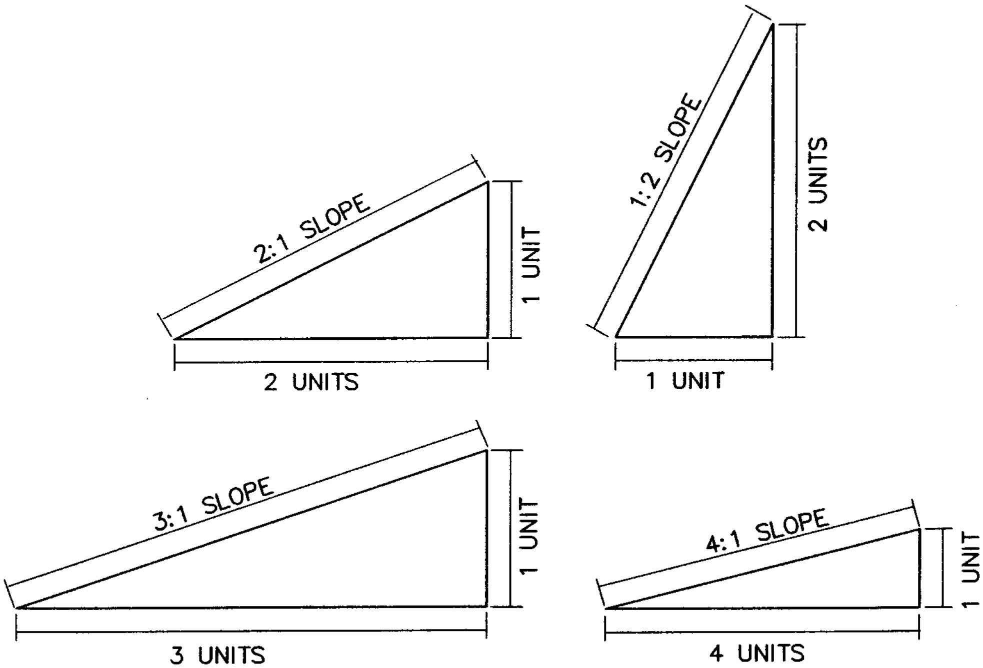

FIGURE 1B.1 Slopes are described by the number of horizontal units for each vertical unit.

TABLE 1B.1 Earthwork Calculation

	Cut (yd^3 or m^3)	Fill (yd^3 or m^3)
Pads and parking	4780	4080
Compaction	0	700
Organic material	320	
Stockpile for landscaping		320
TOTAL	5100	5100

The natural earth in place may not be sufficiently compacted, in which case more earth will be required to fill the same space after compaction. A clear demonstration of this can be seen by filling a cup loosely with sand and clearing off the excess sand level with the top of the cup. If you then tap the cup several times, the sand will compact, and the cup will no longer be full. The same is true for earthwork.

All sites require some excavation and some embankment to provide level pads. If the earthwork is measured in cubic yards for design and estimation purposes, more than a cubic yard of excavation will be required for each cubic yard to be filled. The percentage difference, expressed as a portion of 1, is called the *compaction* or *shrinkage factor*. The soils report should give a shrinkage factor and may describe the optimum moisture needed and construction methods and equipment to be used to accomplish the recommended compaction. The relationship used to determine the amount of earth needed to compensate for shrinkage is shown here.

$$V_R = \frac{V}{100} - S \tag{1B.1}$$

where V_R = volume of compacted earth (fill) required, yd^3
V = volume of uncompacted earth (excavation), yd^3
S = shrinkage factor

Not all soil found on a site will be suitable for construction of the building pad. Humus soil must be removed before construction is begun. The soils report should describe the depth of the unsuitable soil and whether it can be stockpiled and later used for landscaping and on nonstructural areas of the site.

It is desirable to have the grading plan designed so that excavation and fill on a site will *balance*. The earthwork on a site is said to balance when no import or export of material is required to create the building pad. To accomplish a balance, a volume of earth to allow for shrinkage must be included in the calculations (see Table 1B.1). Where the native soils have poor structural qualities or are expansive, the soils report may recommend importation of soils better suited to providing a subbase for structures.

1B.4 THE GEOLOGIC REPORT

Peoples lives and property can be destroyed very quickly by landslides and earthquakes; therefore, hillside areas of existing or potential landslides should be identified. Once a previous or potential landslide area is identified, recommendations can be made to avoid the risky areas. In some cases, areas of potential landslides or of soil creep can be used if certain precautions are taken or the structures are designed to accommodate the problems.

Earthquakes can be a threat to life and can damage or destroy structures. There are two primary ways that earthquakes cause damage. One is through the lateral forces created when the earth moves. This is a structural engineering problem. The other cause is that some soils liquefy during the ground shaking. These soils and their depths must be identified so that foundations can be designed to withstand liquefaction.

The geologist will research the geologic history of the site, study aerial photographs, perform soundings to determine subsurface densities, and dig trenches across suspected earthquake faults and ancient landslides. Earth cores will also be extracted and studied. With this information, recommendations can be made as to areas where structures are at risk and possible mitigation methods must be taken.

The geologic report should also identify groundwater conditions. If the water table is near the surface, it can create problems for structures. The geologist can make recommendations as to the scope of the problem and make suggestions for removing the water so that it will not adversely affect the structures.

1B.5 HILLSIDE SITES

On hillside sites, earthwork is usually significant. Earth is excavated from one area of the site and placed on another in order to create a level pad or pads for the foundations. Where there will be high cut or fill slopes, benches are usually required in the slope. The benches will stop falling rocks and earth and will be used to intercept and redirect overland drainage. Benches are also required in existing sloped ground that will be covered by an embankment (Fig. 1B.2).

The natural slope is first scraped clean of any organic material, then cut into benches. The vertical distances between benches and the width of the benches will be determined by the characteristics of the soil, widths needed to operate equipment, and what the finished slope will be. Benches so employed in fill slopes are usually sloped at 1% into the hillside and have a key in the bottom bench to connect the soil masses.

1B.6 EXISTING TOPOGRAPHY

Of prime importance in understanding the various elements of the grading plans as well as the other aspects of design is the concept of elevations. When the term *elevation* is used, it may refer to an ac-

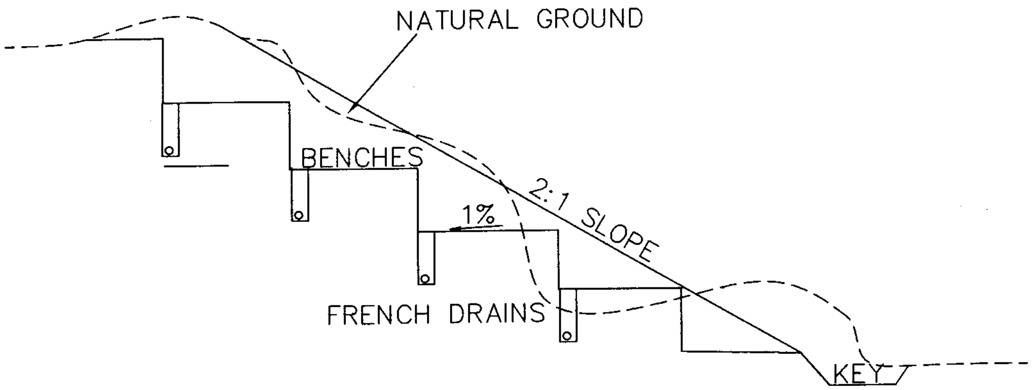

FIGURE 1B.2 Benches.

tual elevation (vertical distance in feet or meters above mean sea level), or it may refer to a vertical distance above an assumed elevation. Although the dimension of the elevation is in feet or meters, it is customary to show elevations without a dimension.

All plans using elevations should have a *benchmark* (BM). The benchmark is a vertical reference point. The benchmark may be a brass disk set in concrete by the U.S. Geological Survey (USGS) or some other agency, and tied to mean sea level, but it can be anything that has a permanent elevation that can be referenced. Some jurisdictions require that all plans be referenced to their standard benchmarks or USGS benchmarks. At this writing, USGS maps and benchmarks are in English units (feet), except for some of the 1:100,000 maps produced in 1991 and 1992. Whether the elevations are in feet or meters will be clear from information provided on the map.

On projects where there is no existing benchmark in the vicinity, the surveyor may establish a benchmark using some permanent feature such as a top of curb or manhole cover and give it an arbitrary elevation high enough so that no point related to the project will have a negative elevation. This point then has an assumed elevation and elevations are given to elements needed to design and build the plan in reference to that benchmark. What is important is that all the vertical relationships among the design elements is established. There are areas where the land is below sea level and will have negative elevations, but when an assumed elevation is to be used for the benchmark, negative elevations should be avoided.

Care should be taken when using elevations from existing plans. The benchmarks used to design different projects are often taken from different sources, so the relation between elevations on the projects will not be true. The elevation for a physical object taken from one benchmark may be different from an elevation for the same object taken from another benchmark, unless the two benchmarks refer to a common benchmark. Even then, there may be some differences due to the degree of precision or errors. Where two or more sets of existing plans are to be tied together, it may be necessary to establish a *benchmark equation*. An example is

Rim elevation for sanitary manhole on Main Street at Spring Street 139.68 from Tract 5555
= 140.03 from Tract 5560

In this case, if elevations for Tract 5560 are to be used on the new project, but ties must be made to objects in Tract 5555, 0.35 (140.03 – 139.68) must be added to all elevations taken from Tract 5555.

Before design is begun on the grading plan, elevations should be shown wherever they must be considered in the design. This includes elevations for existing and proposed:

1. Natural ground
2. Ditch flow lines within project boundaries and outside a sufficient distance to show the limits of the *drainage basin* (described later in this section) contributing drainage flows to the project
3. Tops of curbs at
   a. Property lines
   b. Beginnings and ends of horizontal curves
   c. Beginnings, ends, and high or low points in vertical curves
   d. High and low points in street center line profiles
   e. Points beyond the property line as necessary to show the grade of the street so that smooth transitions can be made.
4. Existing streets being met at connections and as necessary to show the grade of the street so that smooth transitions can be made
5. The bases of trees and other amenities to remain

In most cases, the topographic map will have been produced through the use of photogrammetry, and most of this information will be available on the map. The engineer must determine how far beyond the limits of the project topography is required before ordering the topographic map.

Lines connecting points of equal elevation are called *contours* (Fig. 1B.3). They are usually plotted for even elevations of 1, 2, or 5 feet (0.3, 0.6, or 1.5 m). Where the terrain is very flat, the one foot contour interval is used and intermediate elevations are spotted where the slope between contours is not uniform. In steep terrain, the contour interval may be 5 feet (1.5 m), 10 feet (3 m), or

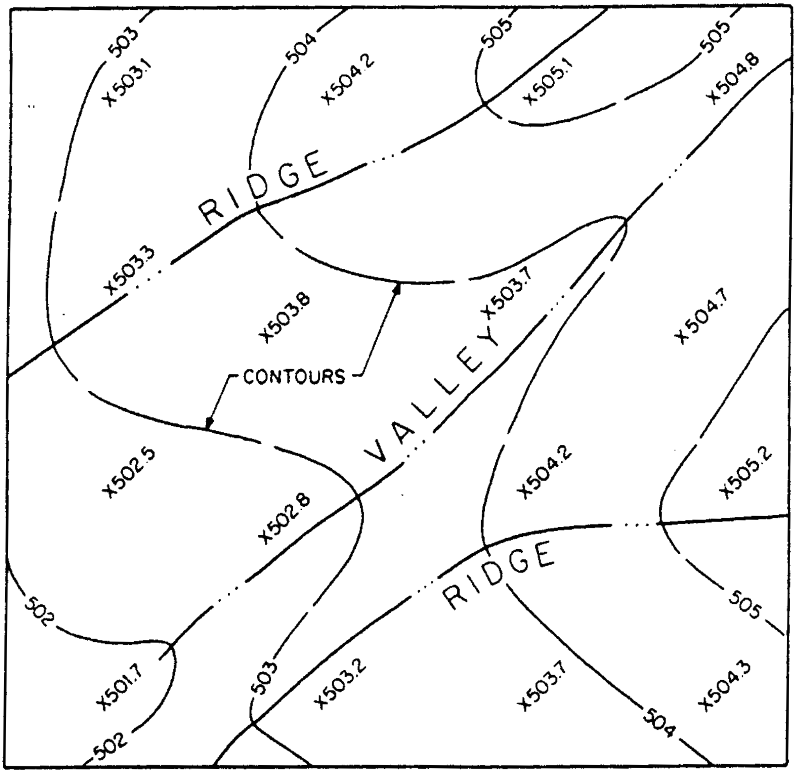

FIGURE 1B.3 Contours.

even greater. The steeper the slope, the closer the contours will be. Therefore, rather than fill the map with contour lines, a greater interval is used.

The surveyor or photogrammetrist should have marked an elevation wherever there is a break in the slope. Therefore, it should be safe to assume that the ground between elevations slopes evenly. Though contours are used primarily to illustrate existing topographic conditions, *contour grading* can be used to show proposed finished contours. During preliminary stages of design, the contours as they will exist when the construction is complete can be drawn as a graphic illustration of the concept. Exact contours can be drawn during the design phase to be used for earthwork calculations and to show drainage patterns.

Cross-sections are used extensively in designing grading plans. Figure 1B.4 shows an example. Elevations on the natural ground are plotted to scale in a line perpendicular to, and measured distances from, some reference line. When the points are connected, they represent the cross-section of the natural ground. Then elevations at break points in the finished plan are plotted along the same line. The elevation at the edge of the finished lot usually does not meet the existing ground but is above or below it. This point is called the *hinge point*. From this point, a slope is designed based on the slope recommended in the soils report. The slope will probably be between 1:1 and 4:1. That slope will be extended until it connects to the natural ground. That point is called the *catch point*.

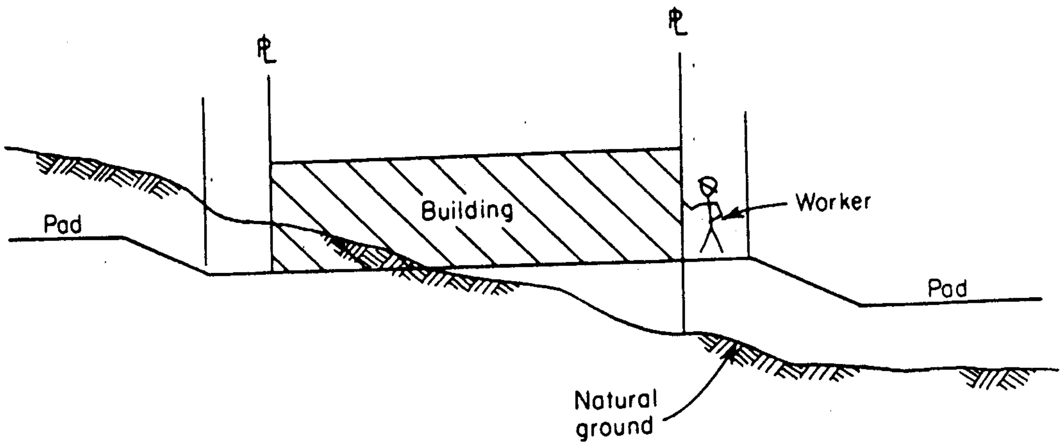

FIGURE 1B.4 Cross-section.

1B.7 DETERMINING THE BUILDING PAD

The grading plan must be designed with an understanding of the drainage criteria. The storm drainage and overall design are coordinated with the grading plan. On hilly or complicated sites, the first step may be a preliminary contour grading plan. Usually, street profiles are existing or have been designed and proposed top-of-curb elevations or edge of pavement elevations calculated and transferred to the grading plan. This information is essential for designing the site grading.

There are three types of residential lot grading plans (Fig.1B.5):

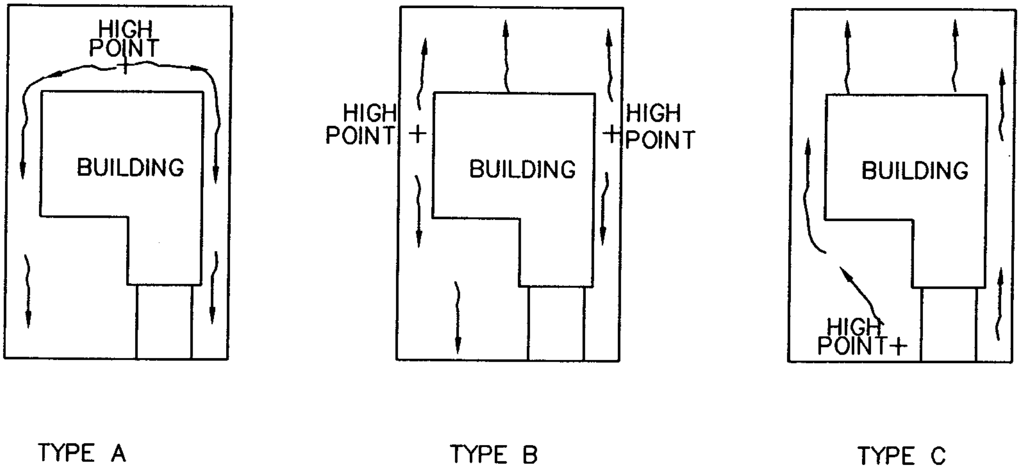

FIGURE 1B.5 Types of drainage.

Type A—All the overland drainage on the lot is directed to the street at the front of the lot.

Type B—Drainage on the front half of the lot is directed to the street in front, and drainage on the back of the lot is directed to a street, alley, or ditch in the back of the lot.

Type C—All drainage is directed to the back of the lot.

Some jurisdictions allow only Type A drainage. Where type B or C is allowed, a ditch or other drainage facility must be designed for the back of the lot. Storm drainage easements must then be acquired to take the drainage across adjacent properties. All lots crossed with a ditch or underground system for storm drainage must be provided with a private storm drainage easement. On hillside sites where much of the site will be left natural, a ditch may be required at or near the property line to prevent storm water that falls on one property from crossing adjacent property.

On residential and simple commercial/industrial sites, the elevations of the pads should be selected so that they will drain to the front of the property. This will save the complications of draining storm water over adjacent properties or the cost of installing storm water inlets.

1B.7.1 Building Pads with No Storm Water Inlets

The criteria for selecting the building pad elevations where there will be no drainage inlets within the lot are:

1. The pad must be high enough above the lowest top-of-curb elevation at the front of the property to accommodate a drainage swale around the building with a slope of at least 1%. Often, the size of the lot and slope in the street are consistent, so a constant amount can be added to the lower top of the curb to establish pad elevations.
2. The pad must be designed so the grade on the driveway does not exceed 15% up or 10% down to the garage floor. Steeper grades may result in the undercarriage of cars scraping and damaging the car or the driveway. Flatter driveway slopes should be used wherever possible. A drainage swale must be provided in the driveway in front of the garage where the garage is below the street.

   When the building setback distance and driveway length are consistent in a subdivision, a consistent maximum elevation difference for a building pad can be calculated. The elevation difference for a driveway up should be calculated using the top of the curb on the lower side of the driveway. The elevation difference for a driveway down should be calculated using the top of the curb on the higher side of the driveway. The driveway slope is a function of the length of the driveway as well as the elevation difference. Where flexibility is allowed for the building setback, the driveway slope can be made less steep by making the driveway longer.
3. The widths of slopes between pads and surrounding features are affected by the vertical distances between them. It is necessary to verify that the slopes do not occupy so much space on adjacent lots that the level pad becomes too small to be useful or whether retaining walls will be required. Typically, building pads on residential sites where fences may be built extend to five feet beyond the property line before sloping down to the adjacent pad.
4. Vertical differences between adjacent pads of less than 0.5 ft (0.15 m) should be avoided. It is simpler to build three adjacent pads at one elevation and a fourth pad 0.6 ft (0.18 m) different, than to build three pads each 0.2 ft (0.06 m) different.

On subdivisions that are fairly level, the high point of the swale will be at or near the center of the back of the building (Fig. 1B.6). On subdivisions that are built on hillsides, the high point of the swale will be moved toward the high side (Fig. 1B.7). On lots with narrow side yards, a system of area drains and underground piping may be needed (Fig. 1B.8).

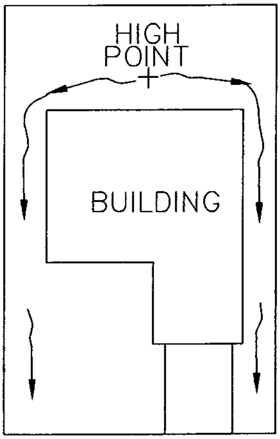

FIGURE 1B.6 Type A drainage on level tract lot.

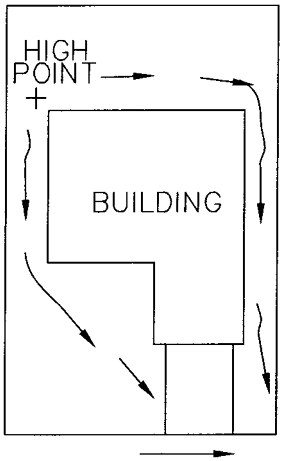

FIGURE 1B.7 Type A drainage on hillside tract lot.

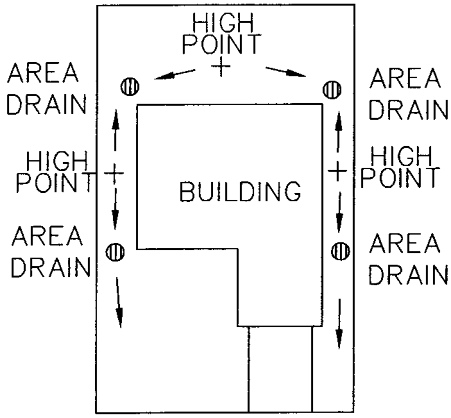

FIGURE 1B.8 Type A drainage with area drains.

1B.7.2 Building Pads with Storm Water Inlets

The elevation of building pads for commercial, industrial, multifamily residential, and single family detached buildings where drainage inlets will be provided is determined as follows:

1. The pad must be determined so that the areas surrounding the pad slope away from the building.
2. Building codes require that the *protective slope*, unless paved, must be at least 0.5 feet below the elevation of the finished floor. The protective slope is the earth against the outside of the foundation
3. The *storm water release point* should not be more than 1.0 ft (0.3 m) above any on-site storm water inlet. The *drainage release point* is that elevation and location where the runoff will leave the property if all the on-site storm water inlets fail to function.
4. The appearance of the building with respect to the street and other surroundings should be considered. If the buildings are much different in elevation from adjacent buildings and improvements, they will look out of place.

The size of the building pad should be designed to extend beyond the building a distance recommended by the soils engineer. Usually, the minimum distance outside the foundation to provide room to work for construction equipment and personnel is 5 ft (1.5 m). A greater distance may be required to provide for foundation support. The pad elevation should be at least 0.2 ft (0.6 m) higher than is necessary to satisfy the other criteria.

1B.8 SITE DRAINAGE DESIGN

On lots within new subdivisions, the runoff for individual lots will be designed to collect and discharge runoff for that lot alone. Normally, collection of off-site runoff reaching the subdivision will be collected and discharged along the boundary of the subdivision. Individual lots must have a swale or ditch within the lot with a drainage flow line around the building to the street or, on very compact lots, to area drains.

1B.9 SURFACE DRAINAGE

Designing storm drainage systems requires an understanding of *hydrology* (the science of the natural occurrence, distribution, and circulation of the water on the earth and in the atmosphere), *hydraulics* (the science of the mechanics of fluids at rest and in motion), and drainage law. Understanding the elements of the design of storm facilities and their coordination with surface improvements and underground utilities is essential. Drainage law varies from location to location and from time to time, so local drainage laws must be investigated and applied.

The purpose and focus of this chapter is for construction and protection of foundations, so hydrology and hydraulics will not be discussed here; however, there is a brief discussion in Section 1B.14. Determining the volume of storm water and subsurface water to be handled on-site should be determined by a qualified civil engineer or hydrologist. The storm water reaching the site is often generated by a very large area outside of the project site. Storm water reaching the site from areas off-site must be intercepted and safely routed away from the structure foundations. This can be accomplished with swales or ditches and storm water inlets. The amount of runoff and location determines the design of ditches.

When the runoff being handled is very small, and the ditch is less than 100 ft long, a simple note, "Grade To Drain," at the flow line of the ditch on the plan, may be sufficient for construction. Where the volume of runoff is low, slopes should be at least 1%. A flatter slope may become uneven in time.

An unlined ditch with a slope that is steep will erode and can threaten the property improvements. The maximum allowable slope depends on the volume of runoff and the type of soil. If the soil is sandy, the maximum limit for the slope of an unlined ditch should be 2.5%. If the soil is compacted clay and the flow is less than one cubic feet per second (cfs), the slope can be as steep as 6%.

Higher volumes of runoff will require lining the ditch. Where erosion will be a problem, the ditch can be lined with any of a number of materials, such as asphalt, concrete, Gunite, or cobblestone. Economics, velocities, and aesthetic will indicate which choice is best. A minimum slope of 0.3% should be used for concrete-paved ditches. Successful construction of a flatter slope is doubtful.

The cross-section of the ditch must be designed to fit the circumstances and accommodate the flow (see Fig. 1B.9). A "V" ditch is most economical to build. If the ditch is located where people

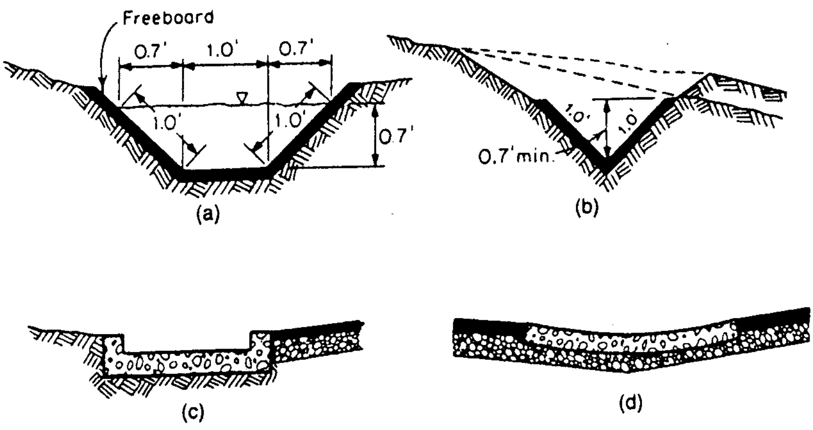

FIGURE 1B.9 Types of ditches: (a) trapezoidal; (b) V ditch; (c) flat-bottomed; (d) curved-bottomed.

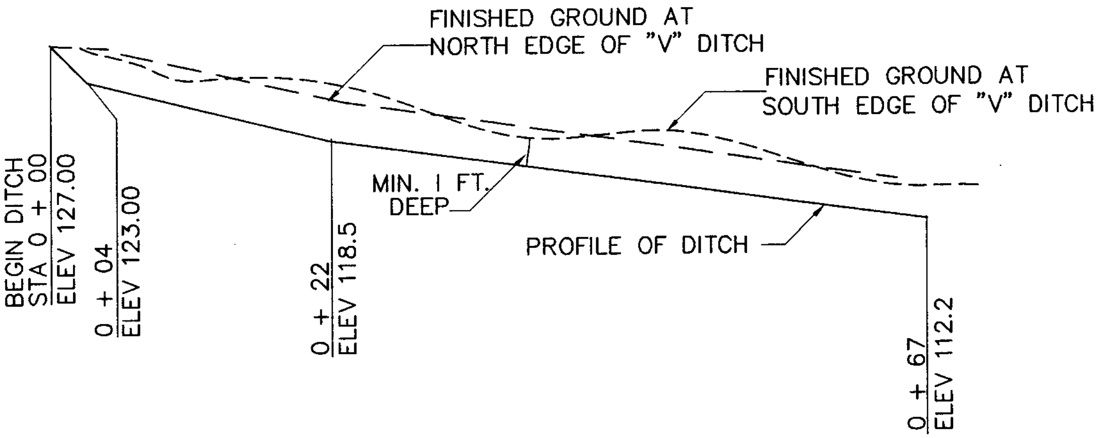

FIGURE 1B.10 Ditch profile.

are likely to step into it, a shallow, flat-bottomed, or curved ditch is better. If the ditch is to carry a large volume of runoff, a trapezoidal ditch is more efficient.

The design of the ditch may be shown entirely on the cross section by showing a minimum depth below existing ground for the flow line of the ditch. The grading contractor can then cut the ditch without needing survey stakes for vertical control. If the design requires more exact vertical control, the flow line profile elevations should be shown on the grading plan or the plan view of the construction plans at grade breaks. The engineer should draw the existing ground and proposed flow line profile and perform the necessary calculation to verify that the ditch will perform as needed.

To design the ditch profile, the existing ground line profile at the centerline or finished ground line profiles at the edges of the ditch are first drawn. A line roughly parallel with and below the lowest ground line profile (Fig. 1B.10) is drawn. The ditch profile must be below the ground at least as much as the ditch is deep. That is, if the ditch is one foot deep, the flow line profile must be at least one foot below the natural ground everywhere at the edge. Otherwise, the ditch will come out of the ground. There should be no more breaks in the profile than are necessary to accommodate the changes in the ground line profile. If the cross slope is steep or erratic, it may be necessary to draw cross-sections at critical points to verify that catch points will be within the property or within a reasonable distance. When the ditch profile is drawn, the slopes must be calculated all along its length.

For each section of the profile, the difference in elevations at the beginning and end of the section is divided by the length of that section. These calculations are continued until the grades all along the profile have been established.

Designing the shape and slope of the ditch is an iterative process. A slope and cross-sectional area including some freeboard for possible wave action or hydraulic jumps is designed. The capacity is determined using the *continuity equation* and *Manning's equation* (described in Section 1B.14) and that cross-sectional area and slope. After comparing the designed capacity to the required capacity, the ditch is redesigned to provide greater capacity or a more economical design.

1B.10 STORM WATER INLETS

At the low point in the ditch, the runoff is collected and routed underground or discharged into an approved waterway. To collect the runoff for removal in an underground system, *storm water inlets* (SWI) are used. Inlets are also referred to as drop inlets (DI), flat grate inlets (FGI), catch basins

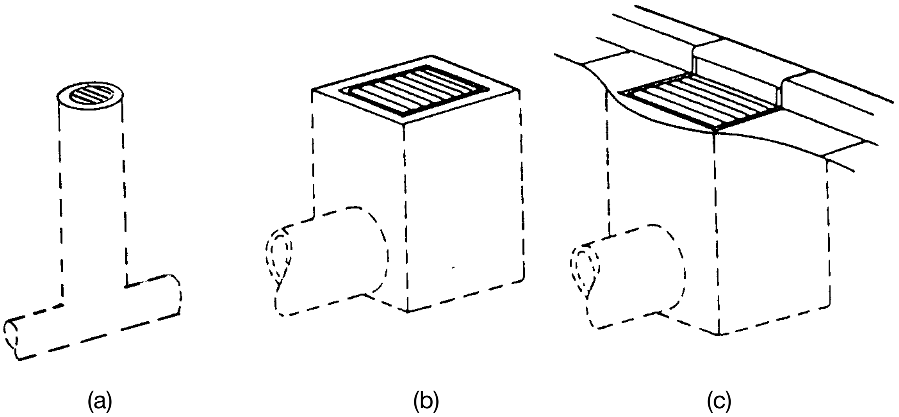

FIGURE 1B.11 Storm water inlets. (a) Area drain; (b) field inlet; (c) catch basin.

(CB), or area drains (AD). The terms "drop inlet" and "flat grate inlet" usually refer to inlets in a large open area such as in a field or parking area. The term "catch basin" usually refers to a storm water inlet located in a street or other area in conjunction with a curb. Area drains usually are small inlets placed in landscape areas.

1B.11 SUBSURFACE DRAINAGE STRUCTURES

A common method for removing ground water is the use of *French drains* (Fig. 1B.12). French drains are ditches in which permeable material is placed then covered with earth or improvements. The permeable material is wrapped in a geotextile to keep silt out. Groundwater moves into the

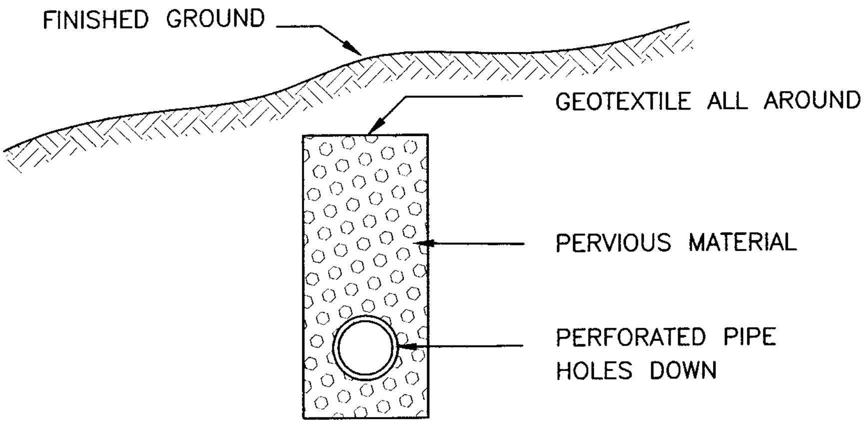

FIGURE 1B.12 French drain.

ditch because the water can move through the permeable material more easily than through the surrounding soil. A perforated pipe (PP) is placed in the ditch with the holes down at a slope designed for the expected flow. Hydrostatic pressure forces the water into the perforated pipe. The perforated pipe is then connected to the underground drainage system at a pipe or storm water inlet.

These French drains are constructed behind and flush with retaining walls to safely remove ground water to protect against damaging hydrostatic pressure, and basement walls to protect against the incursion of moisture. They are also constructed in excavation and embankment benches (Fig. 1B.2) to intercept, collect and remove ground water. The buildup of subsurface water can lubricate interfaces of soils, causing landslides or mud flows if the ground becomes saturated.

1B.12 HIGH WATER TABLES

Treatment of high water tables that can impact the stability of the building pads and thus the foundations is a more complicated matter. In some cases, a thick permeable base may be sufficient, but design responsibility for this condition should be given to soils and structural engineers. A simple, French drain type of mitigation would not be sufficient. In some cases, a matrix of French drains or wells may be recommended to cause draw-down (Fig. 1B.13) of the groundwater.

1B.13 LANDSCAPING PROBLEMS

Consideration must be given to the landscaping design. In clay soils, uneven soil moisture caused by sequential irrigation can cause uneven pressure and heaving. For this reason, if landscaping is to be placed next to the foundation, the clay soil should be removed and replaced with more permeable soil. An alternative might be to provide for simultaneous, even irrigation, but that approach is risky because of inevitable breakdowns of irrigation systems.

Existing trees are often an amenity to be preserved and protected. Where buildings and other structures are to be built in close proximity, an arborist should be consulted. The arborist will make recommendations so that the construction does not damage the tree so much that it has to be re-

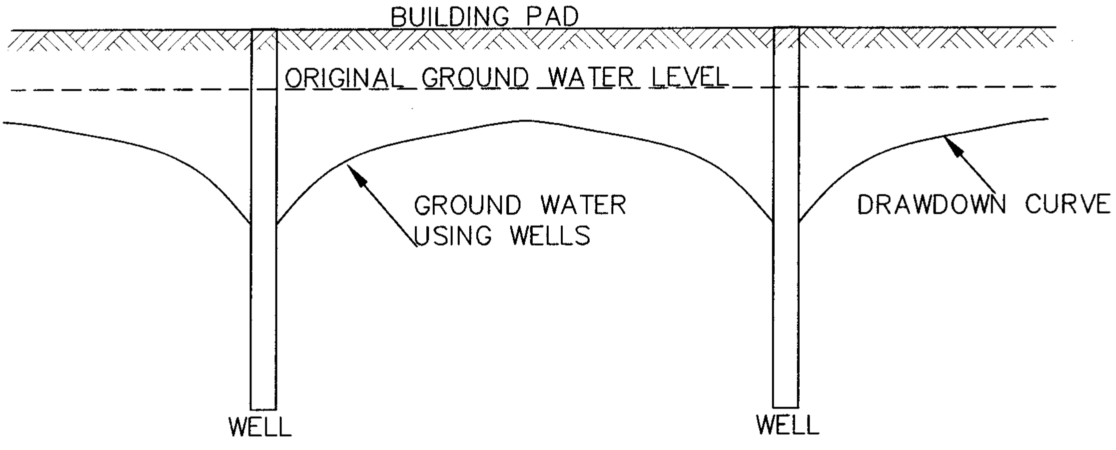

FIGURE 1B.13 Drawdown curves.

moved after the construction has taken place and to determine if the roots of the trees are likely to reach into and damage the foundation substructures (refer to Section 7B).

1B.14 DRAINAGE FLOWS

Understanding the elements of the design of storm facilities and their coordination with surface improvements and underground utilities is essential. Determination of drainage impacts on a site should be prepared only by a civil engineer specializing in land development or a hydrologist. For inexperienced persons to make these determinations can be worse than ignoring the impacts. Describing the formulas and techniques used are described here for information only.

1B.14.1 Hydrology

A formal study of hydrology includes complicated concepts of weather forecasting, storm water runoff, and stream flow routing, as well as the determination of groundwater characteristics. Fortunately, however, for the small areas that are ordinarily involved in land development, the rational formula provides a conservative flow rate that can be used for designing storm water facilities. It is questionable whether areas as small as city lots or any area less than a square mile can be accurately determined using the rational formula but it is the method most commonly used for lack of something better. For projects where the drainage basin affecting the project is larger than 320 acres (120 ha), hydrologists should be brought in and other methods used. The rational formula is given in Eq. 1B.2.

$$Q = kCIA \tag{1B.2}$$

where Q = flow rate (cfs or m^3/s)
k = is a factor to account for units:
Imperial 1.008 cfs, per ac, in/h
S.I. 0 .0286 m^3/s, per ha, mm/h
I = rainfall intensity (in/hr or mm/hr)
A = area (acres or hectares)

The *intensity* factor (I) in the rational formula is the rate of rainfall over the area in inches per hour. This factor can be taken from an intensity–duration–frequency (IDF) chart (Fig. 1B.14) supplied by the responsible agency or the weather bureau for the area specific to your project. To find the intensity from the chart, you must know the return period. If the return period is 100 years, the rate of rainfall given is of the most intense storm expected during a 100 year period. This is called a "100 year storm" or a "100 year event." If the return period is 10 years, the rate of rainfall is of the most intense storm expected to occur during a 10-year period and is called a "10 year storm." The larger the interval, the greater the intensity. The jurisdiction responsible for flood control will dictate what return period to use.

The *duration* (D) is the amount of time it takes for a drop of rain to travel from the most distant point in the drainage basin (described below) to the point (ditch, swale, or storm water inlet) for which the drainage quantity is being calculated. This is called the *time of concentration* (t_c). There are complicated formulas to determine the time of concentration. One that is used to approximate the time of concentration for a pear-shaped basin is the Kirpich equation, which can be used for the time of concentration for overland plus channel flow.

$$t_c = 0.0078\left(\frac{L}{S^{0.5}}\right)^{0.77} \tag{1B.3}$$

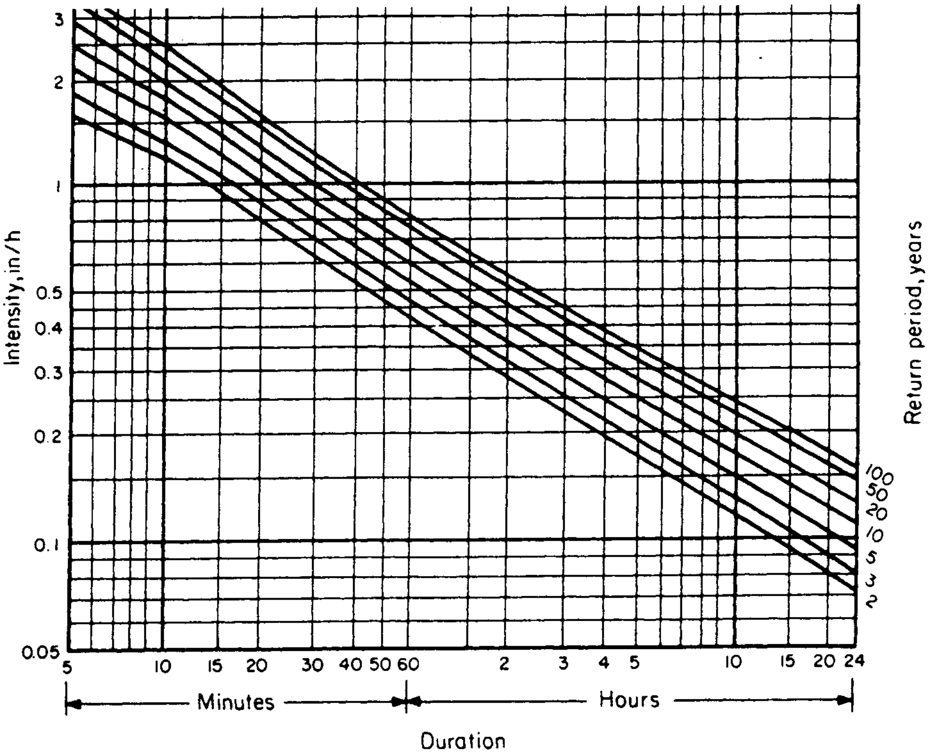

FIGURE 1B.14 IDF Chart for San Jose, CA.

where t_c = time of concentration (min)
L = horizontal projected length of the watershed (feet or meters)
$S = H/L$, where H is the difference in elevation between the most remote location in the watershed and the point of concentration (feet or meters) and L is the horizontal length between those same two points

This formula can be used when determining the time of concentration for existing large, off-site, pear-shaped drainage basins adjacent to the subdivision.

For *small-scale* hydrologic problems, an estimate of the duration is adequate. If the distance or the runoff travel time is from the rooftop to the swale, ditch, or storm water inlet, a duration of 10 to 15 min can be used. Here the most distant point in the drainage basin is judged to be the rooftop. The swale, ditch or storm water inlet is the drainage structure. The time of concentration increases as the drop of rain continues downstream.

When you have the return period and duration, the intensity can be read from an IDF chart (Fig. 1B.14). For example, if the return period is 5 years, find it on the right-hand side of the chart. The 5 is at the end of a diagonal line. Now, find the duration of 15 min at the bottom of the chart. Follow the vertical line representing 15 min until it intersects the diagonal line for the 5 year return period. The intersection falls about halfway between the horizontal lines for 1 and 1.5 in/hr (38 mm/hr). The resulting intensity is 1.25 in/hr (32 mm/hr) as read from the left side of the chart. Notice that as the duration becomes longer, the intensity diminishes. The reason for the decrease in intensity is that peak intensity is seldom sustained for long. The average intensity is less for longer periods of time.

TABLE 1B.2 Typical Runoff Coefficient (C) Values for 5- to 10-Year Frequency Design

Description of area	Runoff coefficients
Business	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential	
Single-family areas	0.30–0.50
Multiunits, detached	0.40–0.60
Multiunits, attached	0.60–0.75
Residential (suburban)	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Streets	
Asphaltic	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.85
Lawns, sandy soil	
Flat, 2%	0.05–0.10
Average, 2 to 7%	0.10–0.15
Steep, 7%	0.15–0.20
Lawns, heavy soil	
Flat, 2%	0.13–0.17
Average, 2 to 7%	0.18–0.22
Steep, 7%	0.25–0.35

Source: Warren Viessman, Jr., Terrence E. Harhaugh, and John W. Knapp, *Introduction to Hydrology,* Intext, New York, 1972, p. 306.

The runoff coefficient (C) in the rational formula (Eq. 1B.2) represents the amount of water running off as a proportion of the total amount of precipitation falling on the area. Of the precipitation that reaches the ground, some will percolate into the soil, some will be taken up by the vegetative cover, some will evaporate, and the remainder will run off. For buildings, runoff coefficients range from 0.70 to 0.95. That is, 70 to 95% of the precipitation falling on the building will run off. The responsible agency may provide a table of coefficients to use. The coefficient reflects the type of soil, type of vegetative cover, and the evenness and degree of slope. Typically, the area will consist of more than one type of cover. In that case, a weighted average should be used.

The area (A) in the rational formula (Eq. 1B.2) is the area of the drainage basin. A drainage basin or watershed is that area of land from which drainage contributes to a particular waterway. Several drainage basins are illustrated in Fig. 1B.15. Ridges W, X, Y, and Z and swales A, B, and C are shown. Drainage basin A is bounded by ridges W, X, and Y and contributes storm water to swale A. Drainage basin B is bounded by ridges Y and Z; water falling there contributes to swale B.

To determine the amount of runoff reaching the point of concentration at A, the drainage basin

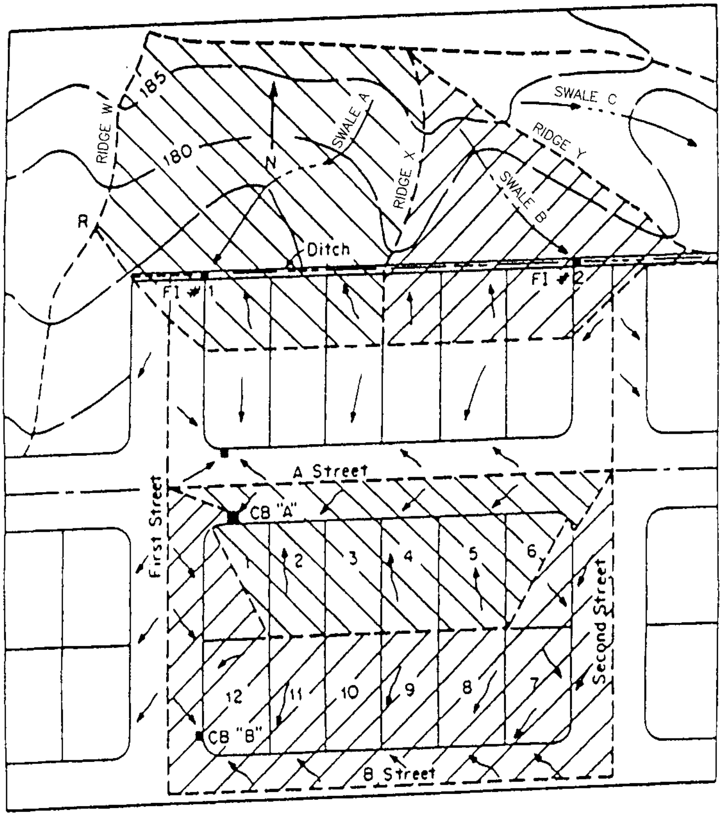

FIGURE 1B.15 Drainage basins in a developed area.

contributing to that point in the swale (waterway) is delineated. Water flowing overland follows the steepest route. The flow line of the steepest route will always be perpendicular to the contours. The land is steepest where the contours are closest. To delineate the drainage basin contributing to a particular point, trace the flow line from point A up the contours at right angles (Fig 1B.15) to the ridge lines. For most projects, the specific project topography will not cover a sufficient area. USGS maps are typically used to determine the drainage basins that will impact the project.

Drainage basins in a developed area are shown in Fig. 1B.15. One drainage area is bounded on the north by the crown on "A" Street, on the south by the lot line between lots 2 through 5 and 8 through 11, and on the east and west by ridges through lots 1 and 6. This drainage area is collected at catch basin "A" (CB "A"). Catch basin "B" collects water from the area bounded by the ridges described above through lots 1 to 11 and by the crowns on First Street, Second Street, and B Street.

The first step in drainage system design is to develop the grading plan. On-site surface drainage basins are created to direct runoff to ditches and storm water inlets. Six of the lots shown in Fig. 1B.15 will interface with existing drainage basins along the northerly tract boundary. In this case, the lots will be graded so that the northern half of each lot drains north and the southern half of each lot drains to A Street. First and Second Streets slope south. Two of the drainage basins established when the lots are constructed this way are delineated in Fig. 1B.15. The storm water falling on the basins will collect in the ditch along the northerly tract boundary and be picked up by fields (FI) #1 and #2.

The ditch here must be designed to accommodate the off-site drainage basins to the north as well. At the northwest corner of the tract, the basin is limited by the point from which the water flows. Water falling south of point R flows south and will not reach the site. Therefore, the limit of the basin is as shown. Once the boundaries of the drainage basins have been defined, their areas can be calculated. If the drainage basin is irregular, use of a planimeter may be the quickest way to determine the area. Convert the area to acres before putting it into the rational formula. Once the quantity of runoff (Q) has been established, the size and type of drainage facilities can be designed. Drainage will run from the high point in the ditch or swale profile to the low point, where an area drain or other drainage facility must be located.

1B14.2 Hydraulics

The understanding of hydraulics for flow in ditches and pipes for the simple situations covered in this section relies only upon the rational formula, the continuity equation, and Manning's equation. The continuity equation simply says the quantity passing a particular location in a pipe or other channel depends upon the cross-sectional area of the flow at that location and the velocity. In other words, the bigger the pipe and the faster the flow, the more flow will pass. The equation is:

$$Q = VA \tag{1B.4}$$

where Q = quantity of flow (cubic feet per second, cfs)
A = area of the cross-section of the flow, square feet, ft^2)
V = velocity, feet per second, fps)

Manning's equation gives the velocity (V). Manning's equation is:

$$V = \frac{0.486}{n} R_H^{0.67} S^{0.5} \tag{1B.5}$$

where n = coefficient of friction
R_H = hydraulic radius
S = slope (ft/ft or m/m)

The slope is taken from the ditch or pipe profile. The n is referred to as Manning's n and is a friction factor for the roughness of the pipe or channel. The value of n to use may be dictated by the responsible jurisdiction. Otherwise, 0.010 can be used for PVC (polyvinyl chloride) pipe and 0.013 can be used for concrete, reinforced concrete, or vitrified clay pipe (CP, RCP, or VCP). Values of n for other materials are given in Table 1B.3. The smoother the conduit, the smaller the value of n is. From Manning's equation (Eq. 1B.5), we see that the smoother the pipe used, the greater is the velocity, thus capacity, produced.

R_H in the equation is the *hydraulic radius*. It accounts for the effect of friction on the flow. The value of R_H is expressed in Eq. 1B.6.

$$R_H = \frac{a}{p} \tag{1B.6}$$

where R_H = hydraulic radius
a = cross-sectional area of the flow (ft^2)
p = wetted perimeter (ft)

The wetted perimeter (Fig. 1B.16) is the length measured on the cross-section that will be wet when the ditch or pipe is flowing at the design capacity.

TABLE 1B.3 Values of n to Be Used with Manning's Equation

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Polyvinyl chloride (PVC) pipe	0.009	0.0 10	0.011	
Smooth brass and glass pipe	0.009	0.010	0.011	0.013
Smooth, lockbar and welded "OD" pipe	0.010	0.011*	0.013*	
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Vitrified sewer pipe	{0.010 0.011}	0.013*	0.015	0.017
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Glazed brickwork	0.011	0.012	0.013*	0.015
Brick in cement mortar; brick sewers	0.012	0.013	0.015*	0.017
Canals and ditches				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033*	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged earth channels	0.025	0.0275	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubber sides	0.028	0.030*	0.033*	0.035
Natural stream channels				
1. Clean, straight bank, full stage no rifts or deep pools	0.025	0.0275	0.030	0.033
2. Same as 1, but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as 3, lower stages, more ineffective slopes and sections	0.040	0.045	0.050	0.055
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	0.015*	0.016
Corrugated metal pipe	0.025*	0.025*	0.025*	0.025*
Wood stave pipe	0.010	0.011*	0.012	0.013
Plank flumes				
Planed	0.010	0.012*	0.013	0.014
Unplaned	0.011	0.013*	0.014	0.015
With battens	0.012	0.015*	0.016	
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Dressed-ashlar surface	0.013	0.014	0.015	0.017
Semicircular metal flumes, smooth	0.011	0.012	0.013	0.015
Semicircular metal flumes, corrugated	0.0225	0.025	0.0275	0.030
5. Same as 3, some weeds and stones	0.035	0.040	0.045	0.050
6. Same as 4, stony sections	0.045	0.050	0.055	0.060
7. Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150

*Values commonly used in designing.

Source: Adapted from E. F. Brater and Horace King, *Handbook of Hydraulics,* McGraw-Hill, New York, 1976, pp. 7–22.

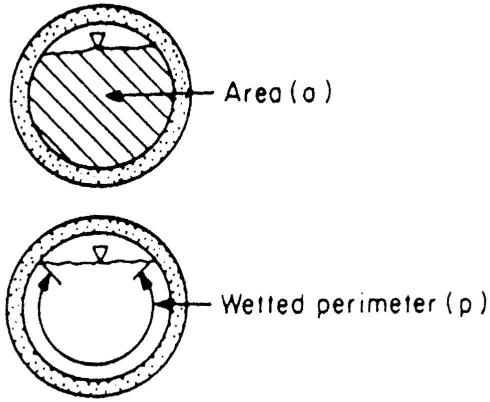

FIGURE 1B.16 The wetted perimeter, $R_h = a/p$.

Using the continuity equation and Manning's equation, the quantity can be calculated. For design purposes on simple projects, pipes can be assumed to be flowing full. Assuming that the pipe is flowing full yields a conservative capacity because when a pipe is full, the increased fiction offsets the increased cross section. Maximum capacity occurs when the height of the flow is at 0.8 the diameter of the pipe.

The sectional area required is compared with the area the pipe ditch section designed provides. If the cross-sectional area of the ditch or pipe is larger, the design will work; if not, using a larger cross section, or a steeper or smoother slope will provide greater capacity. This procedure is repeated using the new V, R_H, and/or S (Fig. 1B.17). If the ditch is long or lined and the section is much larger than necessary, the cross-section should be made smaller, and thus the ditch made cheaper. Here again, if the design of the cross-section is changed, a new cross-sectional area and a new wetted perimeter must be determined and R_H recalculated.

1B.15 DRAINAGE SYSTEMS

Simple residential lots should not require drainage *systems* involving swales, ditches, storm water inlets, and pipes. For larger or more complex sites, a system must be designed. The design involves use of a sophisticated hydraulics software or a time-consuming design procedure.

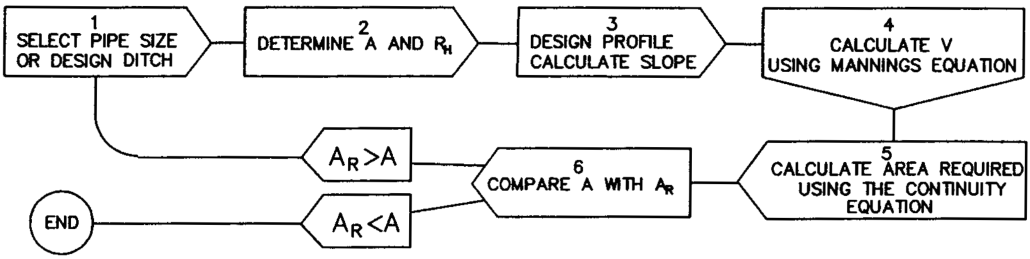

FIGURE 1B.17 Drainage design flow chart.

1B.15.1 Small Sites

On small lots with area drains or other facilities, pipe sizing can be determined easily. In most cases, the pipe size is determined by what makes sense for maintenance—eight to twelve inch diameter pipes will be minimum acceptable for large commercial/industrial sites and four to six inch diameter PVC pipe for single family detached sites. This information can then be used to determine R_H and n The minimum slope as determined by the elevation of the *outfall* (location where the runoff is released into a storm drain or other watercourse) and the finished slope of the land. The value of V can be determined with this information. That value is then used in the continuity equation (1B.4). The quantity of runoff (Q) can be determined using the area of the entire site and the minimum slope to be used. That gives the minimum cross-sectional area for ditches and pipes. Any ditch or pipe that has a greater cross-sectional area or steeper slope than the one used in this exercise will be sufficient to handle the runoff. On small sites, the minimum pipe sizes and slopes usually have much more capacity, as determined by maintenance concerns that are determined by hydraulic considerations.

1B.15.2 Large Sites

The choice of size and slope of ditches and pipes is made based on hydraulic factors, the criteria of the responsible agency or client, criteria affecting the design of the profile as described earlier, and the cost of material and trenching. Although providing for a single drainage basin is simple, providing for multiple basins served by a piping network is complicated. A storm drainage system calculations form is included here (Fig. 1B.18). When filled out correctly, the pipe sizes, slopes, and flow velocities are shown.

The calculations can be made with the use of a spread sheet, as illustrated in Fig. 1B.18, and a computer spread sheet. Once the form has been prepared, it can be used repeatedly by simply replacing data in the appropriate cells while being careful to not affect the formulas. Additional columns can be added for pipe inverts and cover. Hydraulic grade-line calculations can also be included in additional columns. The only problem with making your calculations in this way is that it is easy to accidentally corrupt one of the formulas without realizing it, so unusual care must be taken. Extra care must be taken as well to analyze the results visually to catch any errors.

Filling out the form must be coordinated with design of the profile and may have to be done more than once to coordinate with other criteria. Filling out the form is complicated. Normally the first t_c to use will have additional flow time between where the drop of rain enters the gutter and where it enters the inlet. Flow time can be calculated using the equation

$$t = \frac{l}{60\ V} \tag{1B.7}$$

where t = flow time (min)
l = length (ft) (or m)
V = velocity (fps) (or m/s)

Once the runoff reaches the storm water inlet or ditch, time becomes cumulative. That is, you must calculate the amount of time it takes the flow to travel from the first point of concentration to the second point of concentration and then add that time to the beginning time. Time is added with each leg of the system. This is important because the intensity decreases with time and the IDF chart must be revisited and the intensity determined for each section of the system. Where more than one pipe comes into a point of concentration, the longest time of travel is used.

The area (A) and value for the runoff factor (C) must also be recalculated if the terrain being crossed is inconsistent. With the use of a computer spread sheet or hydraulics software, several alternative slopes and pipe sizes can be examined to determine the most efficient ones.

Point of concen-tration	t_c (min.)	C	I (in/h)	A (ac.)	Total Q (Ft^3/s)	Diameter D (Ft)	Circum-ference Wetted Perimeter	Pipe area (Ft^2)	Hydraulic Radius (R_H)	Slope (Ft/100Ft)	Velocity (Ft/s)	Length (Ft)	Q=VA Capacity (Ft^3/s)
A	B	C	D	E	F	G	H	I	J	K	L	M	N

FIGURE 1B.18 Storm drainage calculations form.

Once the pipe sizes and slopes are determined, the profiles can be designed. Again, the design is an iterative process as shown in Figure 1B.17. The design is further complicated by the constraints of the outfall elevation (invert) and other pipes or underground obstacles that must be crossed. The profile calculation should be begun at the outfall. Of course each down-stream section of pipe must be the same size or larger than the section before, and if there is an abrupt change of slope from steep to shallow, an inlet or manhole must be constructed to account for possible hydraulic jumps.

1B.16 CONCLUSION

Site design should be prepared by a qualified civil engineer experienced in land development, with the help of a soils engineer, and information provided in following sections. In some cases, geologic engineers and, where existing trees are in close proximity to foundations, an arborist should be consulted. The surface of the land is sculpted to direct overland and underground flows away from foundations. The building pads are constructed to certain minimum standards of compaction and structural strength before foundations can be constructed. When the building pad has been constructed to meet specifications, the design of the foundations becomes the responsibility of the structural engineer.