Landforms and Land Development
Reading material from Larz T. Anderson: Planning the Built Environment, 2000

Landform – the form, structure, and character of the surface of the land

Landforms are usually the result of the interactions of various natural physical processes with the surface of the earth. These processes include stream erosion, wind erosion, glacial action, earthquakes, volcanic action, the freeze-thaw cycle acting on surface materials, the leaching chemicals from rocks and soils, and the deposit of wind- or water-born materials. These processes are usually (but not always) very slow.

Mankind also makes significant impacts on landforms through actions such as draining lakes and marsh areas, flooding lowland areas, massive grading operations, and diverting rivers. Man-made impacts on landform are usually very small in size, but very rapid when compared to the scale and pace of geologic change.

Landforms are important to designers because they often place substantial limitations on the location, intensity, and character of urban development. For example, in some areas it is difficult or expensive to build because of steep slopes, extensive rock formations, or the presence of water; in other locations, it is dangerous to build because of natural hazards such as flooding, landslides, earthquakes hazards or shoreline erosion.

On the other hand, landforms often identify opportunities because they may show locations that are most suitable for urban development, areas suitable for the exploitation of natural resources (through farming, mining, and forestry), or areas where the natural features are of such ecological importance or social value that they should be preserved.

How Landforms Affect Urban Development
Mountains and steep hillside – Roads and buildings are difficult and expensive to build in mountainous or steeply sloping hillside areas. Their construction is relatively expensive because of the cost of excavating the uphill section of a road right-of-way (ROW) or a level building site, and the cost of filling and compacting the downhill section. Aside from the economics of development, grading in hillside areas may have very serious adverse environmental impacts: it can cause severe sill erosion and can disrupt much vegetation.

Rock hillside areas may experience rockfalls, especially, in the freeze-thaw cycle of winter-spring. Avalanches may occur in areas with heavy snowfalls. Some soils tend to lose their cohesion when they are saturated with water. If they are on a steep hillside, the force of gravity pulls them downhill which may result in a landslide.

Vee-shaped valleys – The bottoms of these valleys usually have rivers or streams which pose flooding problems, and the steep sides of the valleys may be expensive building sites. Flash flooding is often a serious threat in these valleys.
**Flood plains** – Many plains are subject to periodic flooding, especially those located where there is no place into which the flood waters can drain. These areas are often suitable for agriculture but may be hazardous for urban development.

**Bare rock** – these include areas where the depth to bedrock is slight. Installation of underground utilities is difficult and expensive. Grading for level building sites or parking lots is expensive. In some cases, it may be more economical to leave the landform alone and build structures above it.

**Sand** – Wind blows sand around. You may find that sand intrudes on urban development and may cover it over as the years go by, or sand around and under the development may be blown away.

**Lakes** – It is possible but often expensive to build urban development on barges or houseboats. Or, piles can be driven down to a firm bearing soil (or to the point of resistance) and used for foundations, but that’s expensive, too. Installing underground (or underwater) utility lines is also a severe problem. Of course, there are environmental costs to be considered; they are usually significantly adverse.

**Marshes, bogs, and mud flats** – These have problems that are similar to those present in lakes, although the water is thicker in them. Some of these areas can be drained and developed, or filled and developed. Note, however, that areas which have water on their surface (seasonally or more frequently) are classified as “wetlands,” and most of them are considered to be valuable ecological resources. Current legislation places severe restrictions on how they may be used or modified.

**Shoreline areas** – Shorelines adjacent to the Pacific Ocean are sometimes inundated by tsunamis (“tidal waves”). On the Atlantic and Gulf coasts, hurricanes occasionally do great damage to shoreline development.

**Earthquake areas** –

- **Sites which are crossed by a fault zone** – Often, when an earthquake occurs, the land on one side of the fault moves, while the land on the other side of the fault does not. This plays havoc with any building foundations and underground utilities that straddle the fault line.

- **Sites which are not directly on, but are in the vicinity of, a fault zone** – These areas may experience severe shaking, which may cause substantial damage to above ground structures in the area. Underground utilities may be compressed and then stretched by the shaking motion, which may cause severe damage or failure.

- **Site which undergo liquefaction** – When some soils contain substantial water, they may undergo “liquefaction” when shaken by an earthquake, causing them to act like a liquid for a brief period of time. This can result in slides or slumps of the soil, and destroy the foundations of any structures built on them.
The influence of landforms on the location of cities
The earliest cities appear to have been built in areas where it was easy to grow crops. This often meant that their locations were on or adjacent to the flood plains of rivers such as the Nile, Tigris, Euphrates and Indus.

Many of the North American cities were built in coastal areas where there were good harbors. The cities of Boston, New York, and Charleston are examples. Early inland cities are built at locations which are accessible by ships and barges using navigable rivers.

Later, as the interior of the country was being settled, canals were built to provide water-borne transportation. The alignment of these canals, of course, had to observe the local landforms. Most often they followed existing river beds and, when the river was no longer navigable, they had to avoid mountains and rock outcroppings. The growth of a number of cities in the United States was greatly accelerated by the construction of these canals.

The canal-building era in the United States was soon eclipsed by the railroad-building era, which started about 1830 and lasted into the 20th century. Rail lines strongly influenced urban growth in America: many cities that had good transportation (by water or rail) flourished; those without trended to stagnate or decline.

The location of rail lines, like the location of canals, has to observe the restrictions imposed by local landforms. Rail lines are generally built with a maximum grade of 1 percent, so they are most often found on level to gently sloping terrain, or following the alignment of river valleys which zigzag across the face of hillside areas, or cutting or tunneling through hills and mountains. Since rail-line locations are so strongly influenced by landforms, in many cases the locations of many cities were also influenced by landforms.

With the development of automobiles and trucks in the 20th century, it became feasible to locate large cities in areas not served by rail lines or waterways. It should be noted, however, that most cities which have major commercial or industrial uses relying on the shipment of heavy or bulk cargo must have access to rail or water-borne carriers. Cities that do not require bulk cargo shipments can now rely on highway transportation. (An example of this is the “Silicon Valley” metropolitan area in California.) We observe that today’s city location is far less restricted by landforms than it was 50 years ago. Nevertheless, we still select sites for city development where the landforms are friendly to urban development (such as on gently sloping plains that are not subject to flooding).

The influence of landforms on the forms of cities
Many city planners acknowledge that the forms of most cities are strongly influenced by economic considerations. At the same time, they also acknowledge that economic considerations are often strongly influenced by the character of local landforms.
For example, active centers in American cities are usually located in areas with good access; areas with good access are located where roads or rail lines can be built at a moderate cost. This rules out mountainous areas, lakes, and marshes for the locations of high-intensity urban uses.

Gently sloping terrain, which is well drained and has easy-to-build soils, is usually the most suitable for agricultural uses. Economic forces, if left to work in an unfettered manner in urban areas, trend to displace the very low-intensity uses (such as agriculture) with medium-intensity uses (such as subdivisions) which, in turn, may be outbid by high-intensity uses (such as business parks or shopping centers).

In North American cities, we can observe the interaction of economic forces with landforms. For example:
- Port development often takes place on level lands adjacent to navigable waterways.
- Central business districts are often found in areas that have good accessibility and fairly level building sites.
- Rail lines, freeways, and major streets are located where the terrain does not require excessive grades.
- Areas that are subject to occasional flooding are occupied by land uses which do not expose residents to danger and which, if inundated, do not incur an unreasonable economic cost. Land uses such as agriculture or parklands are sometimes found there.
- The slope of the terrain usually identifies which land uses are economically and environmentally suitable. Level terrain can accommodate many types of land uses; steeply sloping terrain is suitable for relatively few.
- The elevation above sea level of various sections of an urbanizing area may strongly influence the location and timing of land development because of constraints imposed by utility systems.

The constraints of landform, combined with economic forces, have had a noticeable effect on the forms of North American cities.

**Interpreting Topographic Maps**

The form of the earth’s surface is most commonly indicated through the inclusion of contours on a map. When these contours are shown, the map becomes a topographic map.

Contour lines on topographic maps connect points on the land surface that have the same vertical elevation.

Contour intervals are the vertical distances between contours. For example, if one contour shows the elevation of 560 feet and the adjacent contour is 565 feet, then the contour interval is 5 feet.
Contour lines usually show the elevation in feet or meters above a datum plane, which is usually (but not always) mean sea level.

The ground elevation is usually noted on every fifth contour line. It is good practice to show this fifth contour in a bolder line than the intervening four contour lines in order to increase the legibility of the map.
There is no standard contour interval for all topographic maps. The interval may range from 3 inches for land surveys in Arizona deserts to 100 feet for maps of the rugged sections of the Rocky Mountains. It is essential to identify the contour interval of a topographic map as one of the first steps in its interpretation.

**Characteristics of contours**

- All points on a contour line have the same elevation
- Contour lines never cross other contour lines except where there is an overhanging cliff, a natural bridge, or a pierced or arched rock.
- Contour lines never split
- When contour lines are relatively close together, they indicate a change of vertical elevation of the earth’s surface in a relatively short horizontal distance, often indicating a steep slope.

![Figure 2.3 Contours indicating a steep slope](image1)

![Figure 2.4 Contours indicating a moderate slope](image2)

Figure 2.3 is a map of a hypothetical terrain that has a fairly steep slope, made evident from the spacing of the contours. One can tell from the scale of the map that there is about a 25-foot change of elevation in a distance of 100 feet; this is a generally considered to be a fairly steep slope.

When the contour lines are far apart, they indicate that there is little change in surface elevation in a given horizontal distance and that the surface is relatively flat.

Figure 2.4 illustrates some terrain which has a gentle slope indicated by the widely spaced contours. Here you will observe a 5-foot change of elevation in a distance of 100 feet, usually considered to be not steep.
Figure 2.5 Contours indicating a moderate slope

Figure 2.6 Contours indicating ridges and valleys

Figure 2.5 illustrates the same gently sloping terrain that was shown in figure 2, but it has closely spaced contours. This is because the contour interval on the map is only 1 foot rather than 5 feet. The lesson to be learned here is that it is important to check the contour interval of the topographic map, as well as its visual character of the contours, when you are evaluating how steep the terrain is.

Figure 2.6 illustrates terrain that has ridges and valleys.

Valleys are always indicated by contours that point uphill. Within a valley, the contour lines run up the valley on one side, often turn at a watercourse, and run back down on the other side.

Ridges have contour patterns that are somewhat similar in their general appearance to those of valleys, with this major exception: contours in valleys usually have a distinctive “V” shape, with the apex of the V occurring at a watercourse (such as a stream). Ridges, on the other hand, usually have contours that are more in the shape of a rounded “U”; they rarely have the V form. This distinction is the result of geologic processes, primarily from the eroding effect of precipitation falling on the surface of the earth.

Contour lines that enclose an area occur only around elevated areas such as the tops of hills, or around depressed areas such as sinkholes and craters.
Figure 2.7 illustrates a hilltop with its typical closed contours. When mapping a hilltop, it is good practice to provide the spot elevation of its highest point.

Depressions in the surface of the earth are also indicated by concentric closed contours. It is good practice to indicate the spot elevation of the lowest point of the depression and use “hachure” marks on the downhill side of the contour (fig 2.8).

The Direction of the Flow of Water over Terrain

In which direction does water flow? There are two answers to this question. The first, and most obvious, is that water flows downhill. The second is that water flows downhill at right angle to the contour lines of the hill. That is, water runs straight downhill; it never flows diagonally across the face of a uniform slope. This bit of information is important to remember when making studies that involve the flow of water, as is often required when preparing plans for water supply, flood control, storm drainage, soil erosion, or many environmental protection programs.

A Useful Tool for Reading Maps

An engineer’s scale is often used as an aid in reading maps. This is a “ruler” which is usually triangular in cross section and slightly over 12 inches in length. The standard markings on an engineer’s scale are 10, 20, 30, 40, 50, and 60 divisions per inch. The scale can therefore be easily used to measure maps that have a linear scale which is one of these figures (such as 50 feet to the inch) or a multiple of one of them (such as 500 or 5,000 feet to the inch). Engineer’s scales are also available for use with metric-scaled maps and drawings. These are similar in size and shape to those described above, but their scales are marked in representative fractions such as 1:500, 1:1,000, and 1:2,000.

USGS Maps
The basic source for topographic maps in the US is the United States Geological Survey (USGS), which is a division of the U.S. Department of the Interior. The USGS produces topographic maps that cover the entire United States. Each map is bounded by parallels of latitude and meridians of longitude. The maps are most frequently those in the 7 ½-minute series. These are often referred to as “quadrangles,” “quads,” or topos.” In this series of maps, most of the maps cover 7 ½ minutes of latitude and 7 ½ minutes of longitude, at a scale of 1:24,000. The sheet size of each quad for areas on the mainland of the United States is typically about 22 x 28 inches.

These maps are available at USGS offices, and from many local distributors such as bookstores and mountaineering supply stores. Other series of maps produced by the USGS include those at scale of 1:100,000, 1:250,000, 1:500,000, and 1:1,000,000. These maps are readily available directly from the USGS and infrequently from local private distributors.

The USGS maps contain three basic types of data: cultural features (such as roads, railroads, cities, and towns), water features (such as lakes, rivers, streams, and major intermittent channels), and topographic relief (shown with contour lines and spot elevations). The contour intervals vary from map to map depending on the scale and terrain of the country. Many of these maps include additional information such as woodland areas, limits of urbanized areas, highway classifications, and the boundaries of major public land areas.

For some areas, the USGS has prepared “orthophoto” quads. These are black-and-white aerial photographs which have been processed so that they are distortion-free, and are printed at a scale of 1:24,000 with the same boundaries as the 1:24,000 topographic maps. The current practice of the USGS is to produce orthophotos in digital form rather than as a conventional photographic image. The digital format, which is supplied on a compact disk (CD-ROM) for a computer, allows the user to instruct a computer to print out the image at a scale which suits local needs.

In addition to using USGS topographic maps, at a scale of 1 inch = 2,000 feet, many cities have their own topographic maps prepared. These maps are typically at a scale of 1 inch = 100 or 200 feet.

**Measuring Mapped Land Areas**

1. Using a planimeter
2. Using a computer-aided design and drafting (CADD) program
3. Using geometric figures to approximate mapped areas
4. Using gridded overlays

**Method 4:**
1. Prepare a grid pattern on a sheet of transparent film (such as clear acetate or mylar)
2. Lay the gridded sheet on top of the mapped area to be measured.
3. Count the number of grid cells that cover the mapped area.
4. Multiply the number of grid cells counted by the area that each cell represents; this will give an approximation of the size of the mapped area.

**Figure 2.10. Grids for Measuring Areas on a Map at Scale 1" = 2,000'**

- **GRID SIZE 200' x 200'**
  (EACH GRID CONTAINS 40,000 SQ. FT., OR 0.918 ACRES)

- **GRID SIZE 500' x 500'**
  (EACH GRID CONTAINS 250,000 SQ. FT., OR 5.74 ACRES)

- **GRID SIZE 1,000' x 1,000'**
  (EACH GRID CONTAINS 1,000,000 SQ. FT., OR 22.96 ACRES)
Constraints of Slope on Land Development

Slope is defined as the slant or steepness of the terrain. In most planning and engineering work, slope is usually expressed in terms of percent. Percent of slope is the change in vertical elevation between two points divided by the horizontal distance between the two points. (Note that horizontal distance is different from the distance measured along the sloping surface of the land.)

![Figure 3.1 Alternative methods of describing slope](image)

Slope is almost never described in terms of angular degrees. In construction work, slope is often described in terms of the ratio of the horizontal run to the vertical rise, such as a “2-to-1 slope.” Figure 3.1 illustrates the interrelationship of various methods of describing slope.

It is important for the urban planner to be able to visualize various categories of land slope. In many areas, the following slope categories are considered meaningful and appropriate:
0 – 3 percent   flat
3 – 10 percent   moderately sloping
10 – 15 percent  hillside
15 – 30 percent  steep hillside
over 30 percent  very steep

The Concepts of Slope Analysis

Within the framework of our contemporary economic system, there are certain slopes (and ranges of slopes) upon which certain types of construction can be most economically undertaken (that is, on some slopes, the cost of construction to meet the requirements of a specific urban land use will be minimized). This cost of construction, as reflected in the consumer cost, includes not only the cost of structures but also the costs of site preparation, site development, utility services, and the provision of necessary drainage facilities, access roads, and parking spaces.

By classifying the ground slopes in an area, a slope analysis of the area can be determined. This slope analysis can provide guides to the land uses and patterns that could exist in the area if economy in physical construction, based on ground slope qualities, were the only influence on urban form and structure. Obviously, this is not the only influence; slope analysis by itself does not determine urban form and structure.

A graphic slope analysis is essential when planning an urban area. Such an analysis can indicate subareas within which certain land uses should be avoided, if possible, because of high development costs. It can also identify those subareas within which land development can be most economically undertaken, if other factors appear to indicate that development for these uses is desirable or mandatory.

A slope analysis is often the first physical planning study undertaken when urban development on a vacant site, or the expansion of an urban area, is contemplated. This slope analysis is often accepted as the basic study which, to a great degree, determines the future uses of land. The determinations of economically feasible land uses, by the nature of the landform, is then modified by the application of social, economic, and other goals and constraints; however, the form of the land is usually the first consideration made in an urban planning site analysis.

A graphic slope analysis commonly consists of a topographic map on which the terrain is divided into a number of distinct “slope categories.” For example, all terrain which has a slope between 1 and 3 percent is outlined on the map and identified as being in that particular slope category. On the same map, terrain in other slope categories (such as from 3 to 5 percent and from 5 to 10 percent) is also identified and marked.

The Effect of Slope on Land Use

Experience in the construction of cities has shown that, for each slope category, there are some uses of land that are particularly suitable. There are some that are impractical because of the economic cost of construction. Table 3.1 indicates the uses that are
generally considered appropriate for each slope category. Note, however, that the information given here is not to be considered as the ultimate and universal truth. In many cases, where there is a strong social motivation, and an economic ability and a willingness to pay for added costs of construction, the limitations of land slope can usually be overcome.

In doing so, however, consideration should be given to ecological impacts. Sloping terrain is difficult to develop without disrupting the natural setting, and has the potential for causing serious erosion problems; the steeper the slope, the greater the threat.

<table>
<thead>
<tr>
<th>Slope Category: Under 1/2%</th>
<th>Almost no land uses are feasible in this slope category because of the problems of surface drainage of rain. There are some exceptions, of course, such as rice paddies, orchards where irrigation is done by flooding basins around the trees and, of course, flood control basins.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>Large-scale, linear production uses. (Slopes greater than this either interfere with production line methods or increase construction costs.)</td>
</tr>
<tr>
<td>Commerce</td>
<td>Expensive due to drainage problems.</td>
</tr>
<tr>
<td>Residence</td>
<td>Expensive due to drainage problems.</td>
</tr>
<tr>
<td>Roads</td>
<td>Expensive due to drainage problems. Dangerous due to standing water, fog, and ice.</td>
</tr>
<tr>
<td>Airports</td>
<td>Expensive due to drainage problems. Dangerous due to standing water, fog, and ice.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Picnic areas and informal, small-group field sports. (Difficult ground drainage and expensive artificial drainage systems make provision for organized or intensive sport-recreation use expensive.)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Truck crops in flood plain areas, general farming, elsewhere. Excellent for crops grown using flood irrigation methods.</td>
</tr>
<tr>
<td>Slope Category: 1 to 3%</td>
<td>Moderate and small plants without extensive linear production; trucking terminals; warehouses (3% grade the upper limit for uninhibited trucking operations).</td>
</tr>
<tr>
<td>Industry</td>
<td>Commercial developments of all types, specially well suited to large-scale shopping center development and parking lots (good natural drainage, easy slopes, easy truck and auto access).</td>
</tr>
<tr>
<td>Commerce</td>
<td>All types (single-family, multifamily, townhouse, high-rise), but 2% minimum grade needed in areas where ground frost is probable.</td>
</tr>
<tr>
<td>Residence</td>
<td>In any pattern. Slopes of this category impose no limitations on the geometry of the road system.</td>
</tr>
<tr>
<td>Roads</td>
<td>All types (best slope, drainage good, easy grades, no inhibition of operations by standing water or ice).</td>
</tr>
<tr>
<td>Airports</td>
<td>Moderately inexpensive railroad construction.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Playgrounds and playfields, intensive picnic, intensive informal field sports, camping (sufficiently flat for organized field sports, yet sufficiently sloped for good natural drainage). Must have slope over 2% where ground frost is probable.</td>
</tr>
<tr>
<td>Agriculture</td>
<td>General farming.</td>
</tr>
<tr>
<td>Slope Category: 3 to 5%</td>
<td>Intensive, small-scale industry with minimum trucking needs (truck access difficult and perhaps impossible with icing).</td>
</tr>
<tr>
<td>Industry</td>
<td>Small-scale, individual commercial structures. (Parking areas must be terraced.)</td>
</tr>
<tr>
<td>Commerce</td>
<td>Single- and multifamily residences; townhouses; high-rise apartments (with terraced parking lots or parking garages).</td>
</tr>
<tr>
<td>Roads</td>
<td>Truck roads must run parallel with, or diagonal to, the contours; high-speed roads similarly limited.</td>
</tr>
<tr>
<td>------------</td>
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</tr>
<tr>
<td>Airports</td>
<td>Often feasible, but runways and taxiways should not have a slope in excess of 2%; this means running them parallel with or diagonal to the contours.</td>
</tr>
<tr>
<td>Railroads</td>
<td>Must run parallel with or diagonal to the contours. Switching and marshalling operations are difficult.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Playgrounds and playfields, picnic areas; informal field sports; camping; golf courses; nature trails; natural hiking areas.</td>
</tr>
<tr>
<td>Agriculture</td>
<td>General farming.</td>
</tr>
</tbody>
</table>

**Slope Category: 5 to 10%**

<table>
<thead>
<tr>
<th>Industry</th>
<th>Intensive, small-scale industry on slopes up to 7%. (Truck access becomes difficult and expensive when the slope exceeds 7%.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commerce</td>
<td>Small-scale, individual, commercial structures on slopes from 5 to 8% (with virtually no parking demand or, if provided, in parking garages). Economic construction practically precluded on sites with slopes over 8%.</td>
</tr>
<tr>
<td>Residence</td>
<td>Detached, single-family residences, townhouses, and multifamily residences are all feasible, but parking lots must be terraced, or parking garages must be provided.</td>
</tr>
<tr>
<td>Roads</td>
<td>Truck roads and high-speed roads must run parallel with or diagonal to the contours. In areas of slope over 8%, road routing is virtually dictated by the terrain. The topography creates serious problems of access from the road to the abutting properties, due to the cut and fill of the roadway.</td>
</tr>
<tr>
<td>Airports</td>
<td>Usually economically impractical, unless you can find a long ridgetop that parallels the prevailing wind direction, and which can be levelled without excessive expense.</td>
</tr>
<tr>
<td>Railroads</td>
<td>Must run virtually parallel with the contours, but even then creates serious embankment problems and high costs.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Golf course, picnicking, camping, hiking. (Large, level fields, such as tennis courts or football fields, are expensive to construct and may be environmentally damaging.)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>General farming. (Care must be taken for erosion control.)</td>
</tr>
</tbody>
</table>

**Slope Category: 10 to 15%**

<table>
<thead>
<tr>
<th>Industry</th>
<th>Economically impractical.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commerce</td>
<td>Economically impractical, except for unusual, specialized shopping areas to serve &quot;planned-unit developments.&quot; (Parking areas must be terraced or in structures.)</td>
</tr>
<tr>
<td>Residence</td>
<td>Hillside subdivision for single-family homes (which take special design if terrain is not graded to form building pads). Townhouse construction is economically impractical. Apartment construction is often feasible, especially when a &quot;cluster design&quot; is utilized. Special care must be taken in the design of access roads and parking areas for apartments.</td>
</tr>
<tr>
<td>Roads</td>
<td>Any road design takes special care in this terrain. All types of roads can be constructed, but at greater economic and ecological cost than is experienced for roads built in more level areas.</td>
</tr>
<tr>
<td>Railroads</td>
<td>Same as in slope category 5 to 10%, but problems are more severe.</td>
</tr>
<tr>
<td>Airports</td>
<td>Economically impractical.</td>
</tr>
<tr>
<td>Recreation</td>
<td>Hiking, camping, picnicking. Sports which require level play areas (such as playfields) are economically impractical. Golf courses are unplayable.</td>
</tr>
</tbody>
</table>
A slope analysis is an analysis in map form of the natural slope of an area, noted in percentages. A topographic map and an engineer’s scale are needed to prepare a slope analysis.

Percent of slope is the ratio of the vertical rises of land to the horizontal length of that rise (a rise of 1 foot in 100 feet is a 1 percent slope; 5 feet in 50 feet is a 10 percent slope; etc.).

In order to analyze slopes and record the analysis in map form, two operations are necessary. First, a classification system of useful slope divisions must be selected. The system which is usually employed depends upon the character of the terrain being analyzed.
When the terrain is generally quite flat, the following slope categories are often used:
0 – 1 percent
1 – 3 percent
3 – 5 percent
5 – 10 percent
10 – 15 percent
over 15 percent

When the terrain is generally quite hilly, these categories are often used:
0 – 5 percent
5 – 10 percent
10 – 15 percent
15 – 30 percent
over 30 percent

The first step in the preparation of a slope analysis is to inspect the topographic map, consider the output requirements of the slope analysis, and then decide what slope categories you should use. If detailed information about buildable area is required, you should have a fairly refined analysis of the land areas between 1 to 20 percent slope. If the purpose of your slope analysis is to compute water runoff from a drainage basin, you would probably choose to use quite a different set of slope categories for your analysis.

You should be aware of the following:
- Only on rare occasions will there be justification for more than six slope categories
- The more slope categories you include, the greater the number of measurements you must make, and the longer it will take you to complete the slope map.
- The degree of accuracy of may topographic maps, and the number of judgment decisions required in making slope analyses, lead one to prefer generalized slope maps with few categories, rather than detailed slope maps with many categories.

The second step is to prepare a graphic aid called a slope scale. This is a sort of ruler which shows the distances between contours for each slope classification. It is constructed to the scale of the map and according to the contour for each slope classification. It is constructed to the scale of the map and according to the contour interval of the map.

A slope scale is constructed in the following manner: for every slope category in the selected classification system, a corresponding horizontal distance between contours must be found and marked off along a straight line. Each distance must be marked off at the scale of the map being used.

It is an easy task to calculate the horizontal distance between contours when the percent slope of the terrain and the contour interval are both known. We know, by definition, that:

\[
\text{percent slope} = \frac{\text{vertical rise} \times 100}{\text{horizontal distance}}
\]

Transposing elements of this equation, we can show that:
\[ \text{horizontal distance} = \frac{\text{vertical rise} \times 100}{\text{percent slope}} \]

If we substitute in this equation the contour interval (the vertical distance on the terrain represented between two adjacent contour lines on the topographic map), we get:

\[ \text{horizontal distance between contours} = \frac{\text{contour interval} \times 100}{\text{percent slope}} \]

**Example #1**
Given: Contour interval = 2 feet
Slope of terrain = 7 percent
Find: Horizontal distance between contours

From the preceding equation:

\[ \text{horizontal distance} = \frac{\text{contour interval} \times 100}{\text{percent slope}} = \frac{2 \text{ feet} \times 100}{7} = 28.57 \]

To make a slope scale which identifies terrain with a slope of 7 percent, one need only to make a scale on which two tick marks are spaced 28.57 feet apart, using the scale of the map to be analyzed. (We would actually use the figure of 29 feet, because of significant figures.)

**Example #2**
Given: Map scale of 1 inch = 200 feet
Contour interval = 5 feet
Find: Distances ("X") on the slope scale for 1 percent, 3 percent, 5 percent, 10 percent, and 15 percent slopes.

\[ \text{distance"X"} = \frac{\text{contour interval} \times 100}{\text{percent slope}} \]

We can make a simple table, as illustrated in table 3.2

<table>
<thead>
<tr>
<th>Slope (percent)</th>
<th>Equation for distance “X”</th>
<th>Distance “X”</th>
<th>Length on slope scale, when map scale is 1 inch = 200 feet (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(5 \times 10)/1\</td>
<td>500</td>
<td>2.50</td>
</tr>
<tr>
<td>3</td>
<td>(5 \times 100)/3\</td>
<td>167</td>
<td>.83</td>
</tr>
<tr>
<td>5</td>
<td>(5 \times 100)/5\</td>
<td>100</td>
<td>.50</td>
</tr>
<tr>
<td>10</td>
<td>(5 \times 100)/10\</td>
<td>50</td>
<td>.25</td>
</tr>
<tr>
<td>15</td>
<td>(5 \times 100)/15\</td>
<td>33</td>
<td>.17</td>
</tr>
</tbody>
</table>

Preparing the last column is not really necessary. It is easier just to use an engineer’s scale to mark off the distance "X"s directly on the slope scale, using the appropriate map scale.
Figure 3.2 illustrates two different methods of making a graphic slope scale for the figures developed in Example #2. The upper diagram shows a 3 x 5 inch card with different slopes marked on each edge. The lower diagram shows how the slope marks can be combined on one edge of the card.

**Form “A” (with separate scales)**

**Form “B” (with combined scales)**

Figure 3.2 Slope scales for a topographic map (1 inch = 200 feet)

**Specific Steps in Making a Slope Analysis**

Using your slope scale, mark on a topographic map the areas that are in each slope category. For example, mark all locations where the contours indicate a slope of exactly
5 percent. Next, mark all the locations where the slope is exactly 10 percent. Using this procedure you will have identified all those areas that are between 5 and 10 percent in slope, and they should be labeled as such. You can then proceed to mark the locations where the contours indicate a slope of exactly 15 percent, and then label those areas that lie between the 15 percent mark and 10 percent mark as having a slope of between 10 and 15 percent. This process is continued until all the lands in the various slope categories have been identified.

When marking the contours, hold the slope scale as close to right angles to the contours as you can; do not measure diagonally. (An exception to this rule is made when you are using your slope scale to lay out the route of a road, and you are given an exact grade that the road must follow.)

When you find an area on the map where you cannot measure the slope of the terrain because either the upper or the lower contour is missing, you may choose to leave the area blank. This often occurs on hilltops and valley floors.

After you have identified the slope of all areas on the map (other than those for which you have insufficient information), the next step is to “rationalized” the boundaries of the slope areas (round out the boundaries of the slope areas so that they enclose logical areas, rather than strange-shaped areas which have angular boundaries).

Preparing a Slope Map for Display

A second copy of the topographic map should be obtained and the rationalized boundaries of the slope areas should be traced onto it. This can best be done on light table, although you can do almost as well by holding the two maps together in front of well-lit window.

The “rationalized” map should then be colored, using a carefully selected range of colors. The lightest colors are generally used to indicate the flattest areas; the strongest colors are used to indicate the steepest areas. It is preferable to use colors in the same general color family (such as pinks-to-red), light-greens-to-dark-greens, and tons-to-browns) when illustrating features on a map that have some obvious relationships.

Figures 3.3, 3.4, and 3.5 give examples of the steps involved when preparing a slope map using the techniques outlined above, other than the map coloring.
Figure 3.3 A basic topographic map

Figure 3.4 A topographic map marked to show boundaries between slope categories
Figure 3.5 A slope map with rationalized slope boundaries