CHAPTER 4

Natural Factors in Environmental Planning

Environmental planning has been explained as a systematic attempt to integrate environmental and earth science information into the land-use and land development process. With this information in hand, the environmental planner strives to reduce the adverse effects of human-induced landscape change on both the social and environmental systems characterizing the planning area. The principal goal of this approach to planning is to identify alternatives that maximize human and environmental benefits while minimizing the entropic influences of land development programs. The distinguishing characteristic of the environmental planning approach is its focus on the utilization of environmental information to guide decision-making concerning land development and regional growth and change. In this chapter we will examine the type of environmental information critical to the environmental planning approach, and review the essential natural factors that guide environmental planning and decision-making.

The relevance of environmental information

Environmental information speaks to the myriad factors that define the physical landscape and impart an influence on the planning process. Integrating environmental information into this process, however, requires an understanding and sensitivity to the physical processes and patterns that shape the environmental system. Therefore, assessing natural systems and defining their role in critical environmental processes is a central activity for the environmental planner. Assessment begins with a search for information. Specifically, when natural factors are examined, the planner seeks and uses this information to help answer fundamental question regarding how the environment influences the resource potential of land and the appropriate direction change can take without adversely affecting the landscape. With respect to information search and assessment, for each variable that has been selected to characterize the environmental system, the planner would like to know whether a given environmental factor is relevant to the problem, what it explains, what influence it exerts on environmental and development processes, what specific information is needed to form a complete understanding of its significance, and how it is defined within the landscape system. Answers to these basic questions help to refine the salient features of the landscape and also identify the critical knowledge needed to effectively guide environmental planning. In addition, the natural factors selected for review aid planning by defining important earth-science controls that help to shape a more harmonious balance between human motivations and natural form. As Legget (1973) reminds us, when planning starts, the area to be developed is not the equivalent of a piece of blank paper ready for the free materialization of the ideas of the designer, but rather is an environment that has been exposed for a very long period to the effects of many natural modifying factors. Development of new communities or the charting of regional growth must take into account the fundamental organic and dynamic character of nature so that human progress may fit as harmoniously as possible into this setting.

The role of natural factors in planning

Within the mosaic of the landscape, a natural factor may be thought of as a physical property of the environmental system that connects in some way to a structural attribute of the systems that define human and social processes. This may be as simple as an expansive soil type affecting the integrity of a home's foundation, or may be more complex, such as a regional climate that induces upper-level thermal inversions that degrade ground-level air qualities. Another way to explain these physical and biological factors is to view them as natural resources that evidence the basic ecological premise that "everything is connected to everything else." Regardless of how they are conceptualized, natural factors define controlling variables whose form and consequence direct the balance between land-use activities, facilities, and the environment. Admittedly the environment is difficult to characterize succinctly simply because of its many defining attributes and the complex interrelationships that exist among them. While changes in the attributes that define the environment and their interrelationships describe a new state of the landscape system, there is always an element of uncertainty surrounding the precise implications of this new state and its relationship to basic human needs and expectations, and what change may mean to the future use of the landscape. Therefore, within the interwoven fabric of time, scale, and spatial variability, select characteristics of the environment serve as indicators and regulators of forces set into motion by human actions. From the simple clearing of trees to provide for housing to the accelerated erosion that is washed into a river as sediment, the balance of the natural system can be impacted. Therefore, for effective environmental planning, the planner must understand the fundamental characteristics of the landscape and learn how the land functions, changes, and interacts with the life it supports. This point has been eloquently stated by Marsh (1997).

Table 4.1 Landscape-shaping forces.

Wave action
Wind action
Glacial Action
Runoff:
- overland flow
- stream flow
- soil moisture
- groundwater

The landscape on which we plan is dynamic. Its form and features are constantly subject to change. As a process, change is driven by system events such as precipitation, soil formation, stream flow, and land use. These actors shape the landscape and direct the planner to not simply respond to patterns and features in a static setting, but to consider the processes and the dynamics of change that they reveal. Through observing the landscape, insight is gained regarding the processes that presently operate there (Marsh, 1997). Changes in these processes alter the functional character of the environmental system, and become recognizable to us as observable changes in landform, climate, soil, hydrology, vegetation. One of the critical tasks of the environmental planner, therefore, is to determine the formative processes that act on the landscape and what these processes mean with respect to present and future use. A listing of these is given in Table 4.1. Because these processes vary both geographically and over time, they produce terrain features that are subjected to differential forces that sculpt, weather, and shape the landform. This is our "blank sheet of paper," a page where the margins have been preset by natural forces that continue to act on landscape.

The patterns which evidence the relationship between natural factors and landscape evolution are held in a dynamic equilibrium as the stress of various driving forces applied to the landscape converges against the inherent resisting forces that strive to maintain balance. For most natural landscape a state of balance exists between the driving forces of water, wind, and human activity and the resisting forces that define the landscape's internal stability (Marsh, 1997). Only when there is an event powerful enough to exceed the strength of the resisting force will the landscape's balance be upset. In the majority of instances, landscapes are resistant to all but the most extreme events. There are exceptions to this general rule, particularly where balance is conditional on a specific feature of the environment. Therefore, recognizing conditional factors present in the landscape is critical to effective environmental planning: these factors induce change. Guiding land development in a manner that will not trigger or compromise the status of these controlling variables is essential. Ignoring them will lead to a series of potentially adverse consequences that can be traced directly back to the changes introduced by land development practices (Marsh, 1997). Therefore, identifying the important natural factors that influence land potential and knowing why they are relevant is an integral part of any plan targeted at achieving sustainable development, and an essential ingredient of the planner's professional knowledge.

A comprehensive discussion of the problem of environmental definition and description can be found in Canter (1996). Although this discussion is directed more toward the issues surrounding the environmental impact assessment process, the basic "what we need to know" knowledge outlined is common to the environmental planning problem as well. In general, the natural factors selected to form a baseline against which planning and change can be evaluated must serve three related functions:

1 They must aptly characterize the environment.
2 They must contain sufficient information to guide planning.
3 They must be pertinent to the goals that motivate environmental planning.

The critical natural factors that must be understood and applied in the environmental planning process may be placed into three general categories with specific attributes listed under each main heading. This outline, or inventory, looks like this:

1 **Physical environment**
  a) Geology
    1) surface and subsurface characteristics
    2) geomorphic controls
  b) Topography
    1) slope form
    2) slope composition
    3) slope stability
  c) Soils
    1) soil type – composition and texture
    2) soil properties
    3) geotechnical characteristics
  d) Hydrology
    1) surface-water characteristics
    2) watershed drainage patterns
    3) groundwater systems
    4) fool plain characteristics
  e) Climate
    1) regional and synoptic patterns
    2) microclimates
    3) extreme events
  f) Hazards
    1) earthquakes
    2) landslides
    3) subsidence
    4) drought
2 **Biological environment**
  a) Terrestrial ecosystems
    1) natural vegetation
    2) natural fauna
    3) community functions
    4) ecological functions
    5) biological resources
    6) sensitive habitats
    7) endangered species
  b) Environmentally sensitive areas
3 **Human environment**
  a) Demographic patterns
  b) Land use
  c) Physical infrastructure
    1) housing
    2) education
    3) public services
    4) transportation
    5) recreation
    6) utility systems
  d) Cultural resources

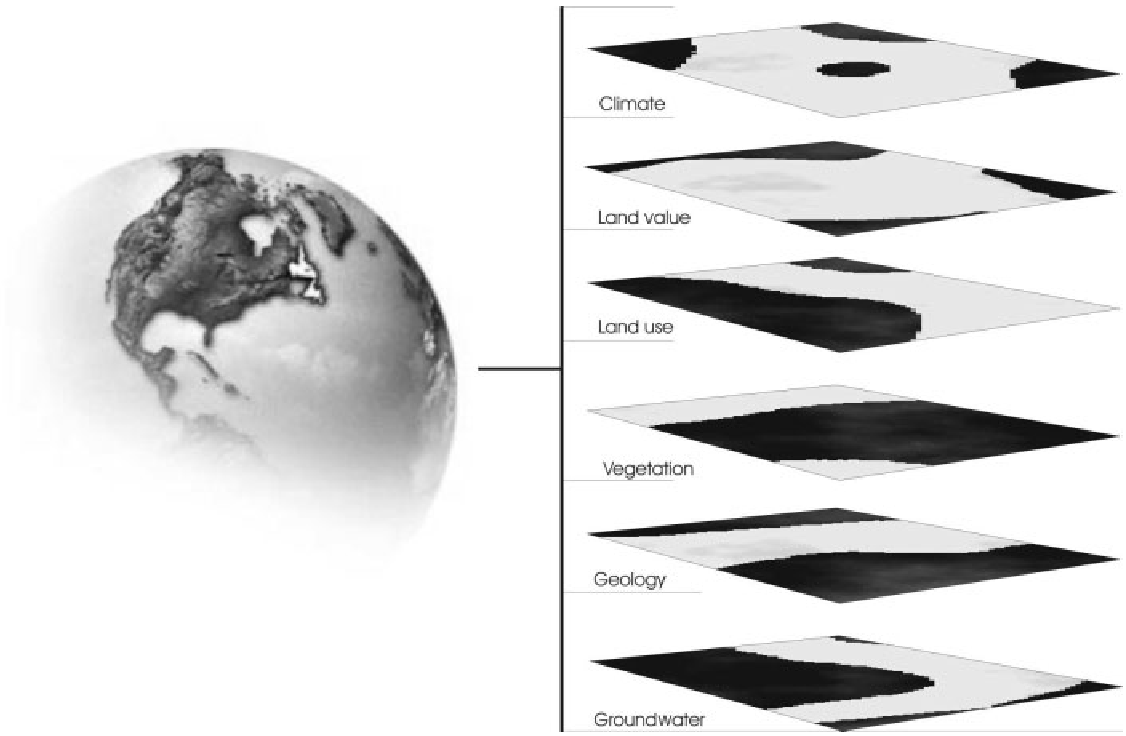

Fig. 4.1 The landscape/layer cake model.

Taken together, the elements listed above define the landscape and can be conceptualized as series of themes or layers that relate and interact over time and space. When assembled into a composite view, these layers, as illustrated in Fig. 4.1, help to define the morphology of the surface and describe its form and functional characteristics. Through assessment these functional qualities become known, and supply the foundation information from which plans are made.

Assessing the physical environment

Assessment of the physical environment is conducted with several goals in mind. Perhaps the most important of these relate to the planner's need to understand how the physical environment exerts a controlling influence on the resource potential of land. From this perspective assessments are performed primarily to:

- Increase the efficiency of human investments.
- Minimize hazards to life and property.
- Protect water quality.
- Minimize soil erosion.
- Protect important aquifers and recharge areas.
- Preserve open space.
- Protect sensitive and unique natural areas.
- Identify potential development conflicts.

Because extensive knowledge of a site is essential before any proposed change can be entertained, assessment must emphasize the integration of natural factors into a definition of the total landscape. This holistic view enhances the identification of physical components and their interrelationships (Baldwin, 1985). While a detailed discussion of this topic is beyond the scope of this chapter, the major considerations that demand careful review can be examined, and the dominant control mechanisms, introduced by a selection of physical processes germane to the environmental planning approach, can be examined. From this general overview, the information needed to produce workable plans and to guide site-specific analysis can be better understood. We can begin our evaluation from the ground up, starting with the geologic environment.

Geologic controls

Geologic information provides the basis for understanding the physical processes that shape the planning area. From bedrock properties which form the fundamental definition of stability, to the landform building processes and the active agents of weathering, geology describes the stage on which development takes place. In the same context, the geologic environment also explains a set of properties that conspire to (1) constrain the scale and intensity of development proposals, (2) introduce hazard, and (3) produce limitations that restrict the feasibility of committing land to particular types of uses. For example, knowledge of rock types and the environments in which they have formed, as well as their responses to weathering, erosion, and tectonic activities, becomes critical to the task estimating site conditions (Johnson & DeGraff, 1988). If the underlying bedrock is unstable, should the addition of water increase its weathering, then certain land uses may not be suited to that location. Thus, knowledge of the regional geologic history of the planning area is of great value, since this information broadens interpretation of an area and the relationships that exist between features such as rock type, their physical properties, their structure and geographic distribution, and how these factors influence the appropriateness of a given development plan.

Rock type

Rock may be defined in one of two principal ways. Geologically, rock is a naturally occurring consolidated or unconsolidated material composed of one or more minerals. However, this definition also includes materials with physical properties that an engineer might consider to be soil. Therefore, engineering definitions of rock characterize it as a hard, compact, naturally occurring aggregate of minerals. In general the engineering properties of rocks are uniquely related to rock type (Johnson & DeGraff, 1988). This observation is particularly true when specimens are unbroken and intact. For this reason the name of the rock should provide information useful for engineering applications. For instance, in the example of most igneous and metamorphic rocks, mineralogy, texture, crystal size and structure are implicit in the name, as are the prevailing conditions at the time of the rock's origin. Not surprisingly, classification schemes for these rock groups are based logically on these variables. Sedimentary rocks, however, require more careful interpretation. The complex interaction of sedimentary environment, parent material, the detrital and/or soluble products of weathering, transporting mechanisms, lithification, and postdepositional changes preclude simple classification (Johnson & DeGraff, 1988). This fact carries important implications when one is estimating engineering properties based on the names and descriptions of sedimentary rock types.

Properties of igneous rock

Igneous rocks have silicate mineral compositions and interlocking textures (Johnson & DeGraff, 1988). Engineering classification of these rock types is based primarily on composition of crystal size. For comparatively recent igneous rock, mineralogy and texture combine to produce high strength and excellent elastic deformation characteristics. Thus, crystal size inversely affects strength. The emplacement mode of intrusive igneous rocks also has engineering significance, as does the origin of igneous extrusives. Knowing the boundary limit and rock type provides information on a variety of physical properties that may affect construction activities and slope stability, as well as the use of certain rocks as construction material.

Sedimentary rocks

Sedimentary rocks present the greatest challenges to planners and engineers. Because sedimentary rocks are the products of numerous marine, freshwater, and terrestrial environments, they exhibit a wide range of physical properties, lateral extents, and thicknesses. In general, attempts to classify sedimentary rock are complicated by the fact that grain size separates the rocks composed of detrital material, while composition separates rocks of chemical and organic origin. An important characteristic of all sedimentary rocks is stratification. Primary sedimentary structures such as bedding surfaces and cross bedding create discontinuities in addition to those formed by secondary structures such as joints and faults. Primary and secondary structures reduce rock-mass strength and may contribute to slope instability (Johnson & DeGraff, 1988). The physical properties of sandstone, shale, and limestone are also influenced by differences in compaction, composition, grain size range, texture, and the nature and amount of cementing material. Vertical and horizontal gradation into other sedimentary rock types may also be expected.

Metamorphic rocks

Metamorphism causes textural, structural, and mineralogical changes in the original rock, modifying its physical properties (Johnson & DeGraff, 1988). These modification may improve some engineering properties, while others may contribute to reductions in strength, slope stability, and abrasion resistance. Metamorphic rocks are classified primarily on the presence or absence of foliation. The significance of this attribute of metamorphic rock is that foliation degrades a rock's engineering properties.

Planning significance

The key to using geologic information effectively depends on the planner's ability to "see" where this information fits. The previous discussion of rock and rock types is important simply because most construction takes place on or into rock. Therefore, the engineering characteristics of the underlying rock will influence where specific structures are placed, how they are designed, and the methods used to build and maintain them. Any project involving the addition of great weight on the surface requires a detailed understanding of how rock will react under a variety of conditions. The planner must therefore obtain answers to several very basic questions pertaining to how the rocks involved will react when they are wet or dry, when they freeze and then thaw, when the dip of the rock is flat, gentle, or steep, or when they are subjected to earthquakes or large-scale subsidence. Since certain characteristics of rocks govern their stability, factors such as mineral composition, degree of weathering, the structure of the rock mass, the porosity and permeability of the rock, the depth to bedrock, and the depth to aquifer must be known. Each of these factors greatly influences the ease of excavation, foundation support, and other critical construction properties that will determine whether a building design, type, or placement is appropriate for a given site.

Weathering processes

Weathering defines a series of physical and chemical processes that are responsible for producing sediments that may lithify into sedimentary rocks or occur as engineering soils. When one is considering the appropriateness for a given development plan, perhaps the most important factor is the role weathering plays in altering the engineering properties of rock and rock masses. As an active process, weathering will influence all rock types, depending on their resistance, the type of weathering process involved, the environment to which the rock is subjected, the local climate, and time. Weathering processes can be either physical or chemical.

Physical weathering describes the mechanical breakdown of rock as the result of thermal expansion and contraction, unloading, hydration, and swelling. The most significant product of physical weathering are talus slopes and rock falls that originate from frost wedging and gravity movement of jointed rock masses. These features contribute to construction and maintenance problems and identify hazards to structures and facilities placed in proximity to locations where such processes are active.

Chemical weathering explains the decomposition of rock by chemical reactions that alter its composition. Chemical weathering processes include oxidation, solution, and hydrolysis. Of these agents, solution and hydrolysis are perhaps the most significant to the planner and engineer (Johnson & DeGraff, 1988). These forms of chemical weathering contribute to the weakening of rock and its gradual disintegration. Where active, these processes can produce massive failures at the surface, leading to the formation of sinkholes where underground support has given way. For example, the widening of joints in limestone and the development of caves are good examples of how solution alters subsurface properties.

Geomorphic controls

Geomorphology can be defined as the study of landforms. To the planner or engineer, the origin and nature of the landform is a key indicator of the processes that actively shape the land surface. These processes also provide important clues as to how the present land surface was formed and which geologic controls exert an influence on the location and scale of development. When examining the geomorphic characteristics of the landscape it is valuable to the planner to recognize that when observing the land surface, there exists a delicate balance or equilibrium between landforms and process, and the character of this balance is revealed by considering both factors as systems or parts of systems. In addition, the perceived balance between process and form is created by the interaction of energy, force, and resistance. Therefore, changes in driving forces and/or resistance may stress the system beyond the defined limits of stability. Furthermore, various processes are linked in such a way that the effect of one process may initiate the action of another.

With these conditions understood, we can see that the landscape explains a pattern where erosion and transport agents combine with weathering processes to create characteristic forms such as valleys, ridges, fans, moraines, dunes, and so forth. The principal agents responsible for these unique forms are water, ice, wind, and mass wasting. Thus, insight regarding the geologic structure of the surface can be gained through the careful examination of landforms and the drainage patterns over them. For the planner, a set of questions can be posed with respect to the geomorphology of the planning area that help improve knowledge of form and process and clarify their planning implications (after Cooke & Doorkamp, 1990):

- Which forces define the present geomorphic situation, and underscore its present-day problems, hazards, and resources?
- What is the nature and rate of geomorphic change at present, and how stable is this landscape?
- What will happen to geomorphic processes if the area is developed?

We can examine a sample of geomorphic agents to help shed light on these questions.

The role of drainage

One of the more useful indicators of surface and subsurface characteristics under similar conditions of climate is drainage density and pattern. For example, when viewed from a map or aerial photo, lower density or more widely spaced drainage channels indicate subsurface drainage through thick, permeable soils, or through karstic limestone terrain when compared with greater drainage density or less permeable soils and bedrock units (Johnson & DeGraff, 1988). Drainage patterns also tend to help define rock types and geologic structure (Way, 1978).

Typically, drainage patterns are classified either by their density and dissection or texture, or by the type of pattern form they exhibit. Drainage texture is defined in three principal ways:

1 *Fine-textured* – indicates high levels of surface runoff, impervious bedrock, and soils of low permeability.
2 *Medium-textured* – describes conditions where the spacing of first-order streams is less than fine textured, and the amount of runoff is medium when compared to that associated with fine or coarse textures

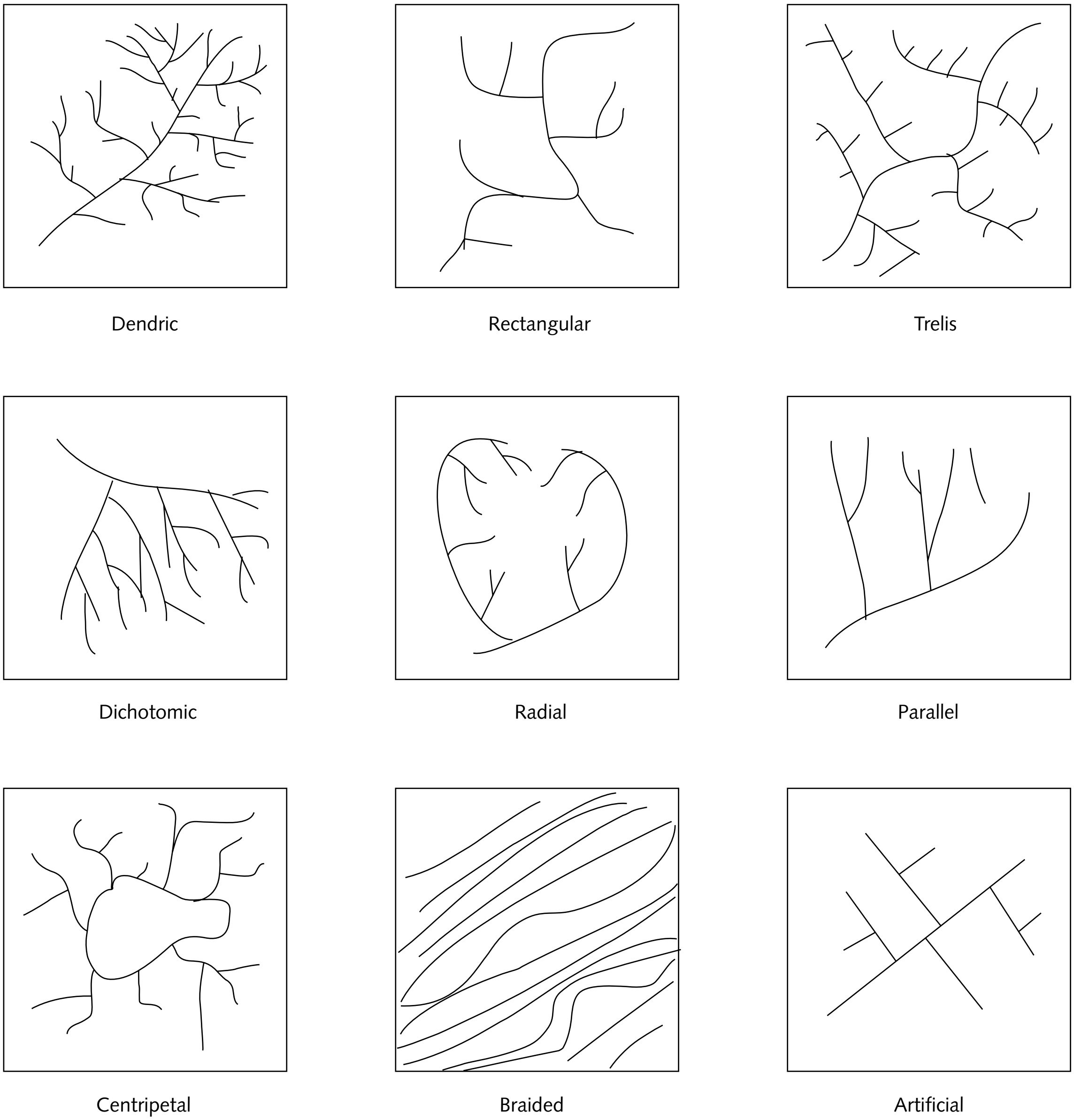

Fig. 4.2 Characteristic drainage types.

3 *Coarse-textured* – indicates a more resistant bedrock which may be permeable and forms coarse, permeable soils.

In addition to drainage texture, drainage pattern is also a useful indicator of landform structure and process. There are 23 major descriptions of drainage types. These categorizations encompass the entire pattern of water flow, including gullies or first-order area of channelized flow, the tributaries, and the major channels which may be depositing eroded materials, to form surficial water-laid landforms. The main patterns classified according to this scheme are illustrated in Fig. 4.2. Each of the patterns shown can indicate the presence of specific rock types, soil materials, rock structures, and drainage conditions. An excellent

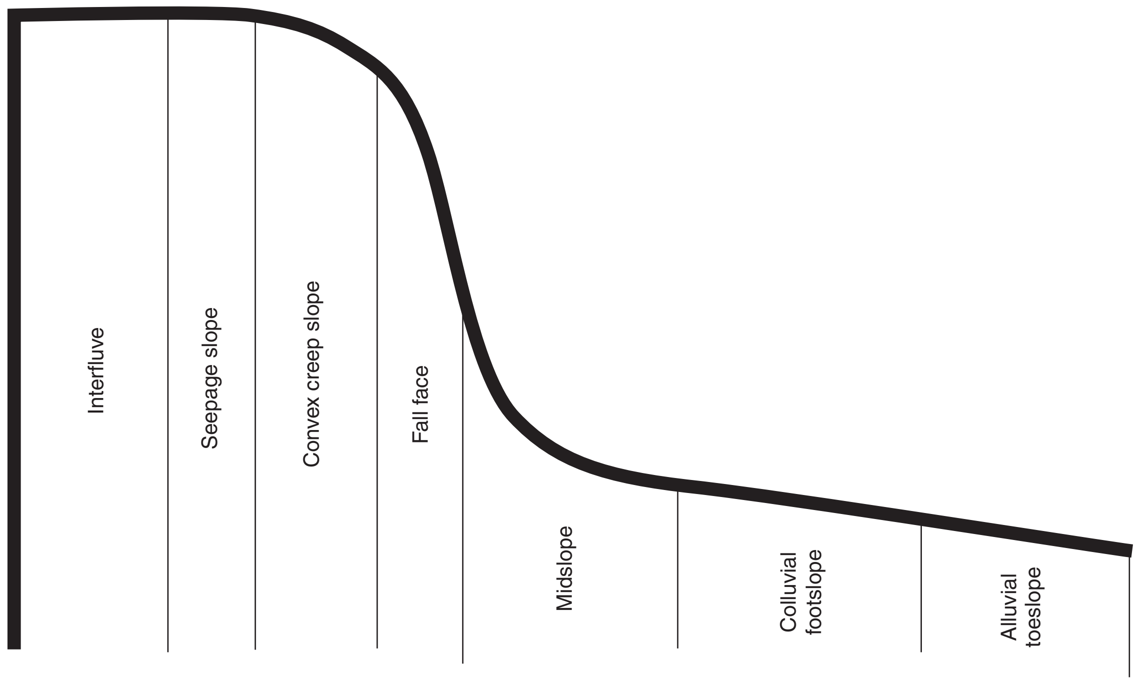

Fig. 4.3 Generalized slope characteristics.

description of the planning significance of the drainage patterns illustrated in Fig. 4.2 can be found in Way (1978).

When the planner is assessing the geologic environment, his or her search for information revolves around a series of questions that not only define critical information needs but also point to the geologic factors that should be used to form an inventory of the planning area (Flawn, 1970):

- What part of the planning area is most suited for the desired future land-use need?
- Where in the planning area are excavation costs high and where are they low?
- Where in the planning area are there highly corrosive earth materials?
- Where in the planning area do earth surface processes represent risk or hazards?

Topographic controls

Topography forms the basic definition of the form and character of the terrain. Considered synonymous with the concept of relief, topography defines the overall configuration of the landscape. Perhaps the most important expression of topography to the environmental planner is slope (Fig. 4.3). Aside from its influence on the use and capability of land, slope exerts substantial controls on runoff, ground stability, and erosion. Slope, defining the inclination of a landform from the horizontal, can be expressed in several ways:

- Steepness of slope – defined by the vertical gradient as interpreted from the contours of a topographic map.
- Length of slope – the physical distance from the head to the toe of the landform.
- Percent of slope – the ratio of slope defined as a function of elevation over distance expressed as a percentage.
- Slope gradient – the maximum rate of change in altitude.
- Slope angle – the angle of inclination from the horizontal.
- Slope form – the morphology or shape of the slope.

- Slope composition – the earth and rock material that constitutes the landform.
- Slope stability – the inherent resistance of the slope to failure.

The need to consider slope in planning is the direct result of the realization that slope not only imposes limitations on the use of land, but that modern development practices have contributed to a misuse of sloping land. Misuse of slope occurs in two fundamental ways (Marsh, 1997):

1 The placement of structures and facilities on slopes that are unstable or potentially unstable.
2 The disturbance of stable slopes resulting in failure, accelerated erosion, and ecological deterioration of the slope environment.

There are three common disturbances that contribute to the majority of slope-related problems. These include (1) mechanical cut and fill where the gradient and length of slope is reshaped by construction, (2) deforestation, where in hilly terrain urbanization, agriculture, and extractive industries encourage the removal of vegetation that alters the hydrologic regime and stability of slopes, and (3) drainage alterations resulting from the construction of buildings on slopes which change slope equilibrium and the surface and subsurface flow of water.

Slopes are among the most common landform and although most appear to be stable and static, they should be viewed as extremely dynamic and evolving systems (Keller, 1988). Because of their dynamic nature, slope stability is a major concern in planning. There are a number of ways in which sloped earth materials may fail and move or deform. Several of the more pronounced are flowage, sliding, falling, and subsidence. The variables that influence downslope movement include factors such as the type of slope movement, the material composing the slope, the rate of rock movement, and the amount of water present on the slope (Keller, 1988).

Slope stability

Depending upon the type of movement – creeping, falling, sliding, or flowing – and the kind of material involved – rock, earth, or mud – mass movements can vary considerably in their shape, rate, extent, and effect on surrounding areas (Griggs & Gilchrist, 1977). Understanding slope stability issues is paramount for effective planning. In general, the nature and extent of slope stability can be explained by examining forces on slopes in relation to 6 interrelated factors:

1 type of earth material
2 slope characteristics
3 climate
4 vegetation
5 water
6 time.

Slope forces

The propensity for downslope movement is defined by the interplay between a set of driving forces that tend to move earth materials down a slope and the set of resisting forces that act to oppose downslope failure. The most common driving force is the downslope component of the weight of the slope material. This factor includes anything superimposed on the slope, such as vegetation, fill material, or buildings (Keller, 1988). The most common resisting force is the shear strength of the slope material acting along potential slip planes. According to Griggs and Gilchrist, the shear strength of a material is defined as the maximum resistance to failure. This quantity can be described in relation to:

1 Internal friction due to the interlocking of granular particles, and
2 Cohesion due to the forces that tend to hold particles together in a solid mass.

Thus, as slopes become steeper, the shear stress (defining the force of gravity lying parallel to a potential or actual slippage) exerted on surface material increases as the downslope pull of gravity increases. A number of internal and external factors can affect the balance between these forces. External factors affect the stress acting on a slope, while internal factors act to alter the strength of slope material. Critical external factors include:

- Change of slope gradient – where an alteration in the angle or degree of slope may degrade internal resistance to downslope forces.

- Excess loading – where the addition of weight at the head of a slope can destabilize internal equilibrium conditions.
- Change in vegetative cover – where the removal of vegetation can effect the overland and subsurface flow of water.
- Shocks or vibrations – where energy waves can effectively shake slope material.

Important internal factors that require careful review include:

- Change in water content.
- Groundwater flow.
- Weathering.
- Slope angle.

Characterizing slope

Slopes may be characterized in a number of ways, and a variety of graphical devices have been developed to help visualize slope information. Perhaps the most basic method to visualize slope is by means of a slope profile. A slope profile is constructed from the contour lines displayed on topographic maps. Interpretation of the profile permits a general categorization of slope form (Marsh, 1997). A more useful device for assessing slope and making judgments regarding slope characteristics is the creation of a slope map. The purpose of such a map is to graphically indicate each slope and place slope characteristics into a classification system to order and highlight their significance. The general sequence of steps needed to manually produce a slope map using a topographic map can be outlined as follows:

1. Determine the slope classes that will be used to order slopes, e.g., 0–10%, 11–25%, >26%.
2. Note the contour interval and scale of the base map, e.g., 40-foot interval, with a scale of 1 inch to 2,000 feet (1 : 24,000).
3. On one edge of an index card or similar durable medium, carefully inscribe five tick marks at 400-foot intervals (note that 40/400 = 10%). Identify this scale as 10%.
4. On another edge of the index card inscribe another series of ticks at 160-foot intervals (40/160 = 25%). Identify this scale as 25%.
5. Only these two classes need to be marked on the card, since any area where the contours are closer together than 160 feet would be over 25%.
6. Using the base map delineating the planning area, locate areas of 10% slope by placing the appropriate card scale at right angles to the contour. At each location where the contour lines and scale marks coincide, place a mark on the base map. If the distance between contours is greater than 400 feet (each index mark), placing a mark on the base map is unnecessary, since this area would be less that 10% and still fall within the same slope class. By connecting the marks placed on the base map and the perimeter contour, the outline of areas with slopes between 0 and 10% can be delimited.
7. Following the same procedure explained above in Step 6 for the remaining slope classes completes the preparation of the slope map.
8. Each of the classes mapped should be symbolized according to a color or shading scheme that permits sound cartographic representation of the slope information and enhances visual interpretation of slope data.

The manual method of slope mapping using index cards tends to be a tedious and labor-intensive process. Fortunately much of the drudgery has been taken out of slope mapping by the widespread availability of digital elevation models (DEMs) and use of specialized routines found within the toolbox of leading geographic information systems (GIS) software. Whether hand drawn or produced via a GIS, slope maps are an important way of communicating critical information regarding the nature of slope in the planning area.

Soil considerations in planning

Soils describe a transitional environment juxtaposed between the lithosphere and the biosphere/atmosphere complex. Although soils are frequently overlooked as a major factor in planning analysis, their influence on the design and sustainability of land uses is noteworthy. One possible reason that may account for the lack of concern for soils in planning has to do with the contrasting definitions used to explain soils and soil characteristics. Soils are the natural bodies in which plants grow. They underlie the foundations of houses, factories, and commercial establishments, and determine whether these foundations are adequate. They serve as the beds upon which roads and highways are constructed and influence the life expectancy of these features. Soils are also used to absorb and filter waste from sewage systems. Therefore their importance is indisputable, although a simple definition of what they are may remain elusive.

Soil refers to the loose surface of the earth and can be explained as: (1) a medium for plant growth, (2) a mantle of weathered rock, or (3) an engineering material. Under these differing conceptual views, soil may be defined simply as unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by a series of genetic and environmental factors. The dominant influences on soil are

- Parent material – the bedrock properties from which soils are derived.
- Climate – the thermal and precipitation regimes that influence weathering and biological processes.
- Macro- and micro-organisms – which assist in modifying soil composition.
- Topography – characterizing slope and indirectly influencing rates of erosion.

Each factor, acting over time, produces a soil that differs from the material from which it was derived in several ways, including its physical, chemical, and biological properties and characteristics (Fig. 4.4).

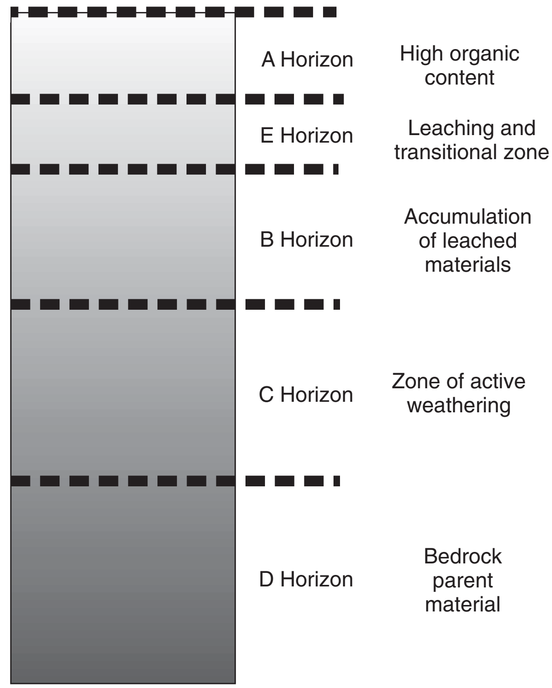

Fig. 4.4 A typical soil horizon.

To the planner, the physical properties of soil greatly influence its suitability with respect to the many land uses that may be placed on top of or into its structure. In addition, the rigidity and supporting power, drainage and moisture-storing capacity, plasticity, ease of penetration by roots, aeration and retention of plant nutrients are all intimately connected to its physical condition (Foth, 1978). Several of the more salient properties of soil with particular relevance to the land development problem include:

- **Soil composition** – refers to the materials that make up a soil. There are four primary constituents of a soil: mineral particles, organic matter, water, and air. Mineral particles comprise 50% to 80% of the volume of most soils. Mineral structure allows the soil to support its own weight as well as that of water and buildings placed overlying the soil. A soil's mineral composition helps to define its bearing capacity, a quantity that describes a soil's resistance to penetration from a weighted object. Organic composition can vary widely in soils. Generally, organic particles provide a weak structure with poor bearing capacities. Thus, soils with high organic content tend to compress and settle differentially under road beds and foundations. Furthermore, when dewatered, these soils may undergo substantial volume losses through decomposition and wind erosion.
- **Soil texture** – refers to the fineness or coarseness of the soil expressed relative to particle size. In more specific terms, texture characterizes the relative proportions of sand, silt,

and clay. The rate and extent of many physical and chemical reactions important to plant growth are governed by texture, since it determines the amount of surface on which these reactions can occur (Foth, 1978).

- **Soil structure** – refers to the aggregation of its primary particles (sand, silt, clay) into compound particles which are separated from adjoining aggregates by surfaces of weakness. Therefore, the structure of the different horizons of a soil profile is an important characteristic of the soil, as are its color, texture, and chemical composition. Structure tends to modify the influence of texture relative to the presence of moisture and air, the availability of plant nutrients, and the actions of micro-organisms and root growth.
- **Soil moisture and drainage** – A soil's water content will vary with particle size, topography, texture, and climate. Water can occur in two principal ways in either mineral or organic soils:
  1) Capillary water – a form of molecular water held in the soil by cohesion among water molecules.
  2) Gravity water – characterizing liquid water moving in response to gravitational forces. This downward flow accumulates in the subsoil and underlying bedrock to become groundwater.

Drainage properties of soil typically related to gravity, water, and the capacity of a soil to transmit water downward. Three important factors help define soil drainage and also serve as critical determinants of land-use suitability:

1 Infiltration capacity – which refers to the rate at which water penetrates the soil surface. Infiltration capacity is greatly influenced by the structural stability of the upper horizons of a soil. Other factors such as organic matter content, soil texture, soil depth, and the presence of impervious soil layers help to refine the infiltration capacity rate.

2 Permeability – refers to the rate at which water transfers through a given volume of material. The permeability rate of a soil defines the ability of the soil to transmit water. Permeability can influence decisions relating to the location and design of septic-tank systems, the size of terrace ridges, and the slope of terrace channels for erosion control, as well as the suitability of land for agricultural uses.

3 Percolation – explains the rate at which water in a soil pit or pipe placed into the soil is taken up by the soil. Percolation results in leaching, which can deplete a soil of certain nutrients. Typically, when the amount of precipitation entering a soil exceeds the water-holding capacity of the soil, losses by percolation will occur. Percolation losses in a soil are affected by the amount of precipitation, its distribution, runoff, and evaporation, and the overall character of the soil.

Other important qualities of soil relevant to the environmental planning problem include:

1 Corrosivity, which varies with soil acidity, texture, drainage, electrical conductivity, and the presence of corrosive agents such as sodium or magnesium sulfate.

2 Shrink–swell potential, which defines the interlayer expansion of silicate clays, particularly of the semetic and vermiculite units, given changes in water content.

3 Depth to bedrock, a characteristic describing the distance through the soil mantel before soil bedrock is encountered.

4 Heightened erodability, which describes the ease with which soils may be detached and moved by water, wind, ice, or gravity.

Each of these soil variables introduces limitations that restrict or redirect the use of land and determine its relative fitness for development.

Soil-related planning issues

There are a number of concerns that the planner must factor into the decision-making process when interpreting soil information and reviewing sites for various development proposals. For example, organic soils are highly compressible under the weight of structures and tend to decompose when drained. In the case of mineral soils, texture and drainage are important factors. Generally, coarse-textured soils present the fewest limitations; however, as clay content increases, drainage and shrink–swell potential pose constraints for development. Perhaps the most pressing concern in planning with soils is the issue of erosion. Soil erosion is both a natural process and one accelerated by human activity. As an active process, the wearing away of the land surface by water, wind, ice, or poor land management practices can assume many different forms. A series of the descriptions used to characterize different types of erosion has been offered by Foth (1978), and includes:

- Accelerated erosion – erosion much more rapid than normal natural geologic erosion, primarily as a result of the influence of people or animals.
- Geologic erosion – the normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of landforms and the build-up of flood plains and fans.
- Gully erosion – the erosion process whereby water accumulates in narrow channels and over short time periods, and removes the soil from these narrow areas to considerable depths.
- Natural erosion – wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate and vegetation, undisturbed by humans.
- Normal erosion – the gradual erosion of land used by people that does not greatly exceed natural rates.
- Rill erosion – an erosion process in which numerous small channels of only several inches in depth are formed.
- Sheet erosion – the removal of a fairly uniform layer of soil from the land surface by the overland flow of water.
- Splash erosion – the spattering of small soil particles caused by the impact of raindrops on very wet soils.

Soil erosion remains among the most significant problems in land management and environmental planning. Because virtually all land uses contribute directly or indirectly to the process, erosion is pervasive and results in direct monetary losses as well as a range of indirect costs or effects, such as (1) increased sedimentation and clogging of streams and channels, (2) heightened flood frequency and risk, (3) land degradation, and (4) reduced water quality. These considerations place a premium on developing methods to control and reduce the soil erosion risk.

Table 4.2 Erosion control strategies.

Site selection practices
Reducing soil exposure
Structural control methods
Land-use management

Erosion control

Erosion can be controlled effectively if (1) study and planning precede any kind of land surface alteration, and (2) a set of basic principles are followed. Several methods have been shown to be effective, particularly with respect to urban development. A selection of these control strategies is listed in Table 4.2. The methods outlined are based on three guiding principles that can be applied to any development proposal. First, ensuring that environmentally appropriate sites have been selected for the proposed development. Secondly, taking steps to reduce the area and duration of exposure of soil to erosion. Lastly, adopting measures to mechanically retard runoff, or trapping the sediment removed from a site. Following these recommendations and integrating them into development plans can reduce the adverse effects typically associated with soil erosion.

Climatic and hydrologic considerations

Climate and planning

The effects of land use and land cover on local climate have been well documented (Lein, 1989). The question for the planner to consider is not simply the relationship between land development and climate, but the larger issue of how climate can introduce opportunities for and constraints on sustainable development. To understand climate's role in sustainable planning one need only begin with the influence climate has on thermal patterns, air pollution dispersion, energy efficiency, and human comfort, and the ways in which these factors can be modified by the form and material structure of the land surface. Gaining this appreciation for climate in planning begins with a review of the fundamental principles that determine and control local climate, and the properties of the climate the stand to be modified by changes at the surface.

Climate can be defined as the aggregate of atmospheric conditions involving heat, moisture, air movement, and their extremes, measured over periods of months to years (Henderson-Sellers & Robinson, 1986; Hidore & Oliver, 1993). Of the various scales by which climate may be examined, two of the more pertinent to the environmental planner are (1) the synoptic or mesoscale and (2) the microscale. Climate at the synoptic scale describes the regional patterns and processes that form unique characteristics associated with distinctive geographic features such as mountains or valleys and explain regional controls that dominate or influence atmospheric conditions. Here, the seasonal fluctuations of major pressure systems and the physical controls of climate within the mesoscale environment exert influences that give rise to distinctive climatic regimes such as lake-effect characteristics, thermal inversions, summer drought patterns, and convective circulation complexes (intense thunderstorm cells). Local, microscale climates are defined by environments where specific topographic and land-cover arrangements and configurations exert moderating influences on the pattern established by the dominating synoptic controls. Examples of these small-scale patterns include forest climates, urban climates, and climates that are topographically induced.

Regardless of scale, an important means of characterizing climate is through the mechanisms that direct the exchange and budgeting of heat energy between the surface and the atmosphere. Here, the input of solar radiation that drives the climate system is subject to a series of transfer mechanisms that redistribute this flux and in the process produce fundamental climatic regimes. This budgeting of solar radiation is also a very useful way to explore the effects of surface change on the disposition of climate at global to local scales. The flux of energy at the surface can be expressed symbolically by the relation

$$R_n = (Q + q)(1 - \alpha) + I\downarrow - I\uparrow \qquad (4.1)$$

Where:

R_n = net radiation
Q = direct solar radiation
q = diffuse solar radiation
α = surface albedo
$I\downarrow$ = atmospheric counter-radiation (long wave)
$I\uparrow$ = terrestrial radiation (long wave).

As suggested by the above relationship, the concept of balance is critical to understanding the climate system. Because the only energy input to the system is solar radiation, this extraterrestrial short-wave flux entering the earth atmosphere system must, on an annual basis, be balanced by an equal amount of energy leaving the system. Thus, as shown in equation 4.1, the radiant energy available to drive climate (R_n) is the product of the energy reaching the surface directly or after diffusion by clouds in the atmosphere ($Q+q$), reflection off the surface ($1-\alpha$), and transfer from the surface to the atmosphere and from the atmosphere back to the surface. Any change in these terms will change the value of R_n and alter climate. The implications are subtle, but they form the basis for understanding human-induced climate change. Therefore, promoting human activities that may alter the composition of the atmosphere may result in changes in the quantity and quality of radiation reaching the surface. Once at the surface, land cover can redirect the quantity of radiation reflected off the surface. Changes in the quantity of radiation at the surface will change the rate of terrestrial radiation, and so on. If atmospheric scattering and absorption are included along with surface and atmospheric storage, the fundamental balance relationship can be expanded to produce a more complete description:

$$R_n = R_g(1 - \alpha) - \Psi_c - \Psi_a + \beta_c + \beta_a + \Delta_s + I\downarrow - I\uparrow \qquad (4.2)$$

Where:

R_g = global radiation
α = albedo
X_c = reflection by clouds
X_a = reflection by aerosols
β_c = absorption by clouds
β_a = absorption by aerosols
Δ_s = absorption by the surface
$I\downarrow$ = atmospheric counter-radiation
$I\uparrow$ = terrestrial radiation.

Given the net radiation input at the surface, the balance of energy is achieved for a specific surface by a series of transfer functions that define the energy conservation equation for the surface:

$$R_n = H + LE + \Delta G \quad (4.3)$$

Where:

H = sensible heat flux
LE = latent heat flux
G = surface heat flux.

The significance of the relationships expressed above it that they identify the processes involved in forming climate at scales of interest to the environmental planner. They also suggest pathways whereby changes at the surface can modify climate processes and alter surface conditions. For example, changing surface vegetation and exposed soil to asphalt and concrete will change surface albedo, alter the flux of latent heat by removing vegetation, and increase sensible heat flux from the surface. Each of these deviations from the original conditions presents new microclimates and can contribute to a redistribution of solar radiation. While such microclimatic alterations appear to be subtle and insignificant, they have been shown to carry important implications in site planning and design (Douglas, 1983). These include:

- The way in which the walls and roofs of buildings and concrete paved surfaces behave like exposed rock materials and display high heat capacities, conductivities, and evidence an ability to store and reflect heat energy at rates greater than that for natural surfaces.
- The way in which the additional surface areas of buildings with large vertical faces create exchanges of energy, mass, and momentum.
- The input of artificial heat generated by machinery, vehicles, and heating and cooling systems.
- The way in which a large extent of impervious surface removes precipitation quickly and alters moisture and heat balances by reducing evaporative processes.
- The ways in which the injection of pollutants and dust into the atmosphere modifies radiation and energy-balance processes.

Based on these examples, as the surface is transformed from a natural to a functional state, development modifies the ambient energy balance, air circulation, and evaporative processes through the introduction of multiple reflection and absorption patterns, rough and uneven surface forms, and by altering vegetative cover. Modification also results from the addition of sources of heat, dust, and pollutants that intensify as the pace of human activity increases. The significance of these changes will vary with prevailing synoptic scale controls, yet the ground-level consequences to human comfort, human health, and energy efficiency have been well documented. The examples presented above also suggest that the natural advantages or amenities associated with climate that guide siting and design may be degraded as the intensity, scale, and pattern of development promotes continued modification.

Hydrologic factors

The process description used to explain climate's role in planning is also a convenient way to characterize the hydrologic regime and how it influences the planning process. Consideration of the hydrologic regime directs attention to the variables that define the hydrologic cycle. Perhaps the most comprehensive treatment of hydrologic cycle and related processes with specific reference to environmental planning can be found in Dunne and Leopold (1978).

The hydrologic cycle can be represented symbolically as

$$P = E \pm T \pm R \pm I \pm \Delta S \qquad (4.4)$$

Where:

P = precipitation
E = evaporation
T = transpiration
R = runoff
I = infiltration
S = soil-moisture storage.

According to this relation, the input of precipitation at the surface is balanced by a series of output or transfer mechanisms that redistribute water back through the earth/atmosphere system. In a manner similar in concept to the surface-energy balance, any change in the variables on the right-hand side of the equation will alter the availability and movement of water within the planning area. However, as built form replaces natural landscape, the movement of water is actually influenced by two interrelated hydrologic systems: (1) the human-modified hydrologic cycle and (2) the human-created water supply and water removal system (Douglas, 1983). These contrasting expressions of water, when coupled with the removal of vegetation, the addition of impervious surfaces, the alteration of soil qualities, the modification of drainage, and the utilization of both surface and subsurface water introduced by land development practices, generate a series of hydrologic effects such as:

1 A change in total runoff at the surface.
2 An alteration of peak flow characteristics.
3 A decline in the quality of water.
4 Changes in the hydrologic amenities associated with rivers, lakes, and streams.

Add to these documented effects changes introduced by the network of water collecting, treating, transmitting, and distributing systems created to provide for development. With these active systems, water is abstracted, relocated, and discharged in a manner that can upset the total hydrologic balance of a watershed (Douglas, 1983). Therefore, recognizing the hydrologic implications of land use and land-cover change on the balance, inflow, transfer, and outflow of water is an integral step in planning sustainable urban systems. However, with *any* alteration of the surface, a change in the natural hydrologic cycles can be anticipated. The most noteworthy surface changes include the clearing of forested lands, the overgrazing of land, and the introduction of impervious surfaces.

As suggested by the processes involved, as the composition of the surface changes, the rates of evaporation, transpiration, infiltration, and runoff will deviate from their expected condition. Through the transformation of land from natural to urban use the planner can anticipate:

- Decreased infiltration – with the addition of impermeable surface, less ground area is available to allow water to percolate into the soil.
- Increased runoff – with increases in impermeable surface, overland flow will accelerate.
- Accelerated erosion – with faster rates of overland flow the erosion potential of the surface will increase.
- Altered flood regimes – with changes in infiltration, runoff, and erosion, sedimentation and flooding will be more common and contribute to urban flood problems and ponding.

Although these concerns are often viewed individually, they are highly interrelated and serve to illustrate the importance of examining both direct and indirect effects as land-cover changes are contemplated.

Biotic and ecological considerations

The ecological approach to planning is predicated on a detailed understanding of ecological process and the interrelationships that exist between geology, soils, climate, and hydrology and the structure and function of the ecosystems that define the planning area. Although the ecological approach to planning is widely advocated, distilling the essential knowledge of ecosystem processes required to produce ecologically sound plans remains a challenge (Steiner, 1991; Park, 1980; Peck, 1998; Sukopp et al., 1995). Much of the problem associated with ecological planning stems from the fact that urban landscape design continues to operate on the premise that ecological processes are either non-existent in cities or have little relevance to the issues of design and form (Hough, 1995). Ecological processes, however, provide an indispensable basis for planning if the planner recognizes the significance of basic ecological principles. Fundamental ideas such as the dependence of one life process on another; the interconnected development of living and physical processes on the earth; the continuous transformation and recycling of living and nonliving materials, define elements of a self-perpetuating biosphere that sustains life and directs the form of the physical landscape. These same elements become central determinants of the form underlying all human activities as well.

Ecosystem planning

The ecosystem has become the fundamental unit of study in ecology and represents a concept that is of great value to all aspects of environmental planning. It is here, at the ecosystem level, where the ecological approach begins. For our purposes, an ecosystem can be defined simply as a self-regulating association of plants and animals interacting with one another and their nonliving environment in a well-defined geographic area. Self-regulation is a key concept in this definition, and serves as the starting-point for achieving sustainable development goals. Through the arrangement of the various living elements of the system, the relationships they assume together with the nonliving elements that characterize the physical and chemical factors that form an environment, a structure, pattern, and flow is established which moves matter and energy through the system. This idea, while rudimentary, is all too easy to overlook as development pressures encourage change at the surface.

The components that comprise an ecosystem include

1. Producers – defining plants that convert sunlight into chemical energy through photosynthesis.
2. Consumers – describing animals that feed directly or indirectly on producers, which can be further divided into more specialized groups that explain their particular role or function:
   - Herbivores – animals that feed on plant material.
   - Carnivores – animals that feed on other animals.
   - Omnivores – animals that feed on either plants or animals.
   - Decomposers – organisms that break down waste plant and animal material and return nutrients to the soil.

When diagrammatically represented, these components form a fundamental system structure that can be used to illustrate key functional relationships. The defining elements of an ecosystem are connected by a flow of energy as the input of solar radiation is transformed into a new energy source that enters the food chain and cycles through the system. Other elements cycle through the system as well. These nutrient cycles include the carbon, nitrogen, and phosphorus cycles, and serve to reinforce the concept of self-regulation and support the dynamic balance ecosystems achieve over time.

Our review of basic ecology carries several important implications and points to the information needs the planner will require to effectively balance development with sustainable environmental functioning. First, the functioning of an ecosystem reveals that the plants and animals defining its structure participate in a complex flow of energy that supports and perpetuates the system. To facilitate this flow each organism has a niche that defines all the physical, chemical, and biological factors that it needs to survive and reproduce. This niche includes considerations such as an organism's:

- Food niche – the specific foods that compose a species' diet.
- Habitat niche – the environment that the species inhabits.
- Reproductive niche – the pattern and characteristics of species' ability to regenerate.
- Physical and chemical niche – environmental elements required to sustain the species.

Plans and development proposals will alter niche relationships that can affect whether or not a given organism can find the food it requires and the habitat it needs, mate successfully, and acquire the other factors it needs to survive. These effects can be very subtle and reveal their effects after long periods of time have elapsed, or they can result from major and immediate disruptions and redirections in the quality and quantity of energy flowing through the components in the system. In either case this pattern introduces a disturbance which affects the stability of the ecosystem and ultimately degrades its resource potential. At this point in out brief discussion it must be recognized that natural ecosystems, due to their many interdependencies and interrelationships, are invariably richer in species and more stable that those artificially developed. The urban pattern superimposed onto the natural landscape defines an ecosystem contrived by people. All of the facilities and arrangements of its parts are for human use. The material and energy flow arrives from well beyond the boundaries of a given urban complex. Furthermore, being "artificial," interdependencies are missing and the system is not self-regulating or self-sustaining.

The contrast between these two systems, the natural and human, together with the disturbance development introduces as interrelationships are severed by the implacement of built forms, suggests that land development processes will change the biotic community. However, because every environment has some recovery potential and level of adaptability, the effects on the natural system will vary in terms of intensity and duration.

The complexity and variability of ecosystems and their response to disturbance is further complicated by the fact that planning focuses on landscape and not on ecosystems. This distinction is important, since the landscape is almost always highly heterogeneous and can include such diverse elements as fields, woods, marshes, towns, and corridors (Gordon & Forman, 1983). For example, in a suburban area, a cluster of landscape elements such as a residential tract, a patch of woods, a commercial area, and an open, grassy field would define a pattern replicated throughout the landscape, whereas a different cluster of ecosystems would be found in adjoining agricultural fields, or between a sandy, forested plain and a riparian corridor (Gordon & Forman, 1983). The landscape is therefore an area where a cluster of interacting ecosystems is repeated in similar form. Consequently, basic ecological principles pertaining to energy flow, nutrient cycles, niche concepts, balance, and successional dynamics of ecosystems provide a useful backdrop for a more landscape-directed focus. This focus is provided by the developing science of landscape ecology.

Landscape ecological planning

The application of landscape ecology theory has had a pronounced influence on environmental planning (Foreman, 1998; Foreman & Gordon, 1986), and there is growing interest in using landscape ecology as a scientific base for land-use decision-making (Hersperger, 1994). Two reasons may be cited to account for its appeal: (1) landscape ecology gives emphasis to the interface between humans and environment, and (2) landscape ecology recognizes the importance of change as a fundamental feature of the landscape. A landscape-ecological approach to environmental planning, therefore, tends to be more focused on the nature of spatial change and the functional connections between biophysical and sociocultural processes and agents of change.

According to the principles of landscape ecology, the landscape system shares three important characteristics: structure, function, and change (Hersperger, 1994; Foreman & Gordon, 1986). For the most part, structure describes the spatial relationship between the distinctive ecosystems or elements present in the landscape. The main landscape components that define a landscape's spatial structure are patch, corridor, and matrix. The overall landscape is therefore the synthesis of these basic parts, while the distribution of energy, materials, and species in relation to the size, shape, number, type, and arrangement of each differentiate the pattern. Accordingly, patch, corridor, and matrix can be explained as functions of factors such as origin, shape, size, connectivity, porosity, edge, heterogeneity, and configuration. Function defines the ecological processes at work in the landscape. Explaining function requires an understanding of how energy, water, mineral nutrients, plants, and animals move across landscapes composed of various combinations of structural features. Key factors used to define function include the relative structural attributes of the landscape, flow gradients (locomotion, diffusion, mass flow), and scale. Coupled to these qualities are the natural processes and human actions that influence landscape evolution on the larger scale. Because function influences structure and structure influences function, their interaction forms the logical basis for causal analysis. In this context, change is the product of the relationship between function and structure expressed over time. Change, therefore, implies temporal analysis and can be measured (or quantified) as an alteration in either structure or function. Subsequently, change, or its absence, is typically expressed in relation to stability. Thus, natural and human disturbances together with the natural processes that direct ecosystem development form the driving forces of change.

The concept of a disturbance and the methods developed to compare landscapes under differing levels of modification provide essential information to the planner: particularly with respect to issues related to conservation, biodiversity, and the development of sustainable land-use patterns. Generally, all landscapes are defined by a common geomorphic origin and a common disturbance regime. A disturbance regime describes the sum of types, frequencies, and intensities of disturbances through time. The disturbance itself is considered to be something that causes a community of ecosystem characteristics, such as species diversity, nutrient output, biomass, and vertical or horizontal structure, to exceed or drop below its homeostatic range of variation (Gordon & Foreman, 1983). Geomorphic processes such as uplift, erosion, aeolian action, and deposition produce physiographic units, which, in the absence of human activity, contain various natural disturbances. Landscapes modified by human activities are changed by new disturbances induced by humans. Examples include agricultural activities and urbanization. These human disturbances differ according to landscape and are superimposed onto natural disturbances and geomorphic settings, resulting in landscapes that vary widely and form distinct boundaries.

Comparing landscapes along a gradient from lesser to increasing levels of human modification can be accomplished by examining critical ecological attributes. These attributes have been summarized by Gordon and Foreman (1983) and include:

- *Horizontal structure* – In natural landscapes subjected to minimal human disturbance, horizontal structure shows little contrast. Primary breaks result from natural disturbances and from geomorphology. As human modification increases, sharp delineations between ecosystems become more numerous. This includes the proliferation of straight lines in the landscape, forming the borders between ecosystems and corridors crossing ecosystems. The dominant human imprint on structure involves: (1) increases in contrast, and (2) increases in linearization and rectangularization.
- *Stability* – Natural landscapes display considerable potential energy in the form of biomass, yet they are also stable. With increased modification, potential energy and stability decrease.
- *Thermodynamic characterization* – Although ecosystems vary in degree of thermodynamic openness, natural landscapes generally are more closed than modified landscapes. Modified landscapes receive a large external supply of nutrients and fossil energy. Human activity tends to increase openness of energy and nutrient cycles, which accounts for one of the principal ways by which human actions stress or modify the stability of the landscape.
- *Chorology* – describes the processes and results of species dispersal. In natural landscapes dispersion of reproductive structures is rather viscous. Managed forests and grasslands produce more fluid chorologic systems, while at the end of the modification gradient, the most human-influenced land-

scapes provide special opportunities for cosmopolitan species.

- *Minimal grain* – defines the minimal land area in which nearly all species of a community are found.
- *Net production* – characterizes the balance between photosynthesis and respiration. In natural landscapes the annual balance of plant production is close to zero. With increasing management, a positive net production is realized; however, in urban landscapes net production declines and can be negative.

Other critical factors to consider when examining disturbance patterns include nutrient cycling, tactics, phylogeny, and type of resistance.

Although landscape ecology offers theory and empirical evidence to help understand and compare different spatial configurations, few land-planning principles based on this knowledge have emerged (Foreman, 1998). One useful idea that has developed out of the landscape ecology school is the "aggregate-with-outliers" principle discussed by Foreman (1998). According to this principle, when considering the spatial allocation of land uses, care should be taken to:

1 aggregate land uses;
2 maintain corridors and small patches of nature throughout the developed area;
3 geographically arrange outliers of human activity along major boundaries.

From this simple beginning, several landscape qualities can be maintained and incorporated into plans as a basis for design. By so doing the overall functioning of the landscape as sustainable habitat can be enjoyed and a balance can be achieved between human use of the landscape and the natural processes at work there. A selection of qualities identified by Dramstad et al. (1996) include:

- **Large patches of natural vegetation:** are ecologically important because they: (1) protect aquifers, (2) protect low-order stream networks, (3) provide habitat for large home-range species, (4) support viable population sizes of interior species, (5) permit natural disturbance regimes in which species evolve and persist, and (6) maintain a range of microhabitat proximities for multihabitat species.
- **Grain size:** The average area of all patches in the landscape affects many ecological factors. A landscape containing a variance in grain size (coarse and fine grain) is an important configuration.
- **Risk spreading:** Reducing the adverse consequences of limited diversity by encouraging a greater mix enhances sustainability.
- **Genetic variation:** Providing strains with resistance to disturbance and responding to environmental change by facilitating re-establishment.
- **Boundary zone:** Boundary zones between land uses are often suitable for outliers. When located along boundary zones, outliers do not perforate and destroy the advantages of large patches. The curvilinearity of boundaries also reduces barrier effects and mimics the results of natural processes.
- **Small patches of natural vegetation:** Small patches or outliers of natural vegetation are valuable throughout the developed area. Small patches are a significant supplement to large patches in that they: (1) serve as stepping-stones for species dispersal, (2) provide habitat and stepping-stones for species recolonization following local extinctions, (3) provide heterogeneity in the matrix that decreases wind and water erosion, (4) contain edge species with dense populations, and (5) maintain high species densities.
- **Corridors:** Natural vegetation corridors enhance important natural processes such as species and surface-water movement, while corridors of diverse fine-scale land uses result in efficient human and multihabitat species movement.

Incorporating these concepts into the physical landscape plan, however, requires a set of guidelines or a model planners can follow. As a direction for environmental planning and design, the "aggregate-with-outliers" model has been shown to possess several significant ecological benefits (Turner, 1989; Foeman, 1998). A range of benefits to human populations has also been suggested. These include:

- Providing a wide range of settings.
- Developing fine-scale areas where jobs, homes, and schools can be located in close proximity.
- Enhancing the efficiency of human movement along corridors.
- Introducing natural vegetation back into the development pattern.
- Providing for specialization within aggregated built-up areas.
- Enhancing visual diversity in the landscape.

Natural hazard considerations

Any review of the physical environment discussed within the context of planning would not be complete without a treatment of those physical processes and variables that represent hazards. While a more detailed discussion of hazard and risk assessment is presented later in Chapter 6, here, an outline of natural hazards and their basic characteristics is provided in order to: (1) identify critical environmental processes that produce hazards, (2) describe their salient properties and relationships, and (3) integrate environmental hazards into the planning process.

The concept of a natural hazard is somewhat misleading when removed from a human-centered view of the environment. Processes typically identified as natural hazards are nothing more than natural processes or events that have always been present in the landscape. These processes only become hazards when humans choose to occupy the same geographic location where such occurrences are common. Therefore, to a large degree the naturalness of these hazards becomes a philosophical and psychological barrier that can be difficult to reconcile when attempting to minimize their adverse effects. Further complicating the treatment of natural hazards is the observation that although natural hazards destroy property and often take human lives, they also perform vital environmental functions (Keller, 1988). For this reason understanding the nature of events that pose a hazard carries important implications that should influence environmental planning.

A list of natural events that can be assigned a hazard designation would include:

1 Geologic and geomorphic events:
   - Avalanches
   - Earthquakes
   - Erosion
   - Landslides
   - Tsunami
   - Volcanic eruptions
2 Climatic events:
   - Drought
   - Floods
   - Hurricanes
   - Tornadoes
   - Blizzards
   - Hailstorms
   - Severe thunderstorms
   - Fog
   - Heat waves
3 Biological processes:
   - Infestations
   - Fungal diseases
   - Bacterial diseases
   - Viral diseases

Detailed treatments of the nature and mechanisms that form these events can be found in the natural hazard literature (Murck, 1996; Blaike et al., 1994; Handmer, 1990). With specific reference to each of the processes listed above, several critical factors must be known if the environmental planner is to adequately address the nature of the hazard. Seven of the more essential descriptions of hazards include:

1 **Frequency** (interval and seasonality) – defines the time interval between events. Certain hazards have a definite seasonality associated with their occurrence, while others display temporal frequencies influenced by causal factors that operate from tens to thousands of years.
2 **Intensity** – describes the relative impact of the event as a function of its magnitude and local vulnerability.
3 **Duration** – explains the length of time the event is active. Some events are short-lived and may last for only a few seconds. At the opposite extreme are events such as drought that may least for several years.

4 **Spatial extent** – characterizes the size of the geographic area affected by the event.
5 **Exposure** – defines the population and infrastructure in proximity to the hazardous event that stands to affect it.
6 **Vulnerability** – explains the level of risk associated with the event given the pattern of exposure.
7 **Magnitude** – measures the physical power of the event as determined by a widely used metric such as the Richter scale for earthquakes, or the Fugitta scale for tornadoes.

Provided with this information, the planner has a clearer understanding of the physical processes that are active in the planning and which of those processes pose a hazard. Above all, this information serves as critical input to procedures used to evaluate both the present levels of exposure and vulnerability and future levels of risk associated with planned land-use changes. Information on the nature of hazards also greatly affects design considerations, building codes, densities, and the future allocation of sensitive land uses in zones that evidence hazards.

Physical systems and design

The preceding review of the natural factors that define the foundation knowledge that drives environmental planning serves to illustrate the importance of integrating earth-environmental science data into the process of making plans. The rationale supporting this form of integration is stated eloquently by McHarg (1969):

> To learn of the evolution of the physical and biological processes is an indispensable step towards the knowledge one needs before making changes to the land; but it is far from enough. It is as necessary to know how the world "works." Who are the actors and how do they respond to the environment, to physical processes and to other creatures?

Ecological processes are therefore more than a planning philosophy, they provide the basis for planning and design if balance and harmony with nature are to be maintained. Central concepts such as the dependence of one life process on another; the interconnected development of living and physical processes of earth, climate, water, plants, and animals; the continuous transformation and recycling of living and nonliving materials, are more than the elements of a self-perpetuating biosphere, they are the central determinants of all human activities on the land (Hough, 1995).

Successful integration of the driving forces of urbanization with ecology is achieved through the design process. As suggested by Hough (1984), design is by definition a problem-solving activity and a mechanism that fosters integration. Design directs connections between disparate elements to reveal potentials that might not otherwise be apparent. To this end, several principles can be noted that, when brought together with the social and economic objectives which propel planning, effectively guide plan design and frame natural environmental factors as active decision criteria critical to the evaluation of development strategies (Hough, 1984).

Process

Processes are dynamic. The form of the landscape is the consequence of the forces that give rise to it; geological uplift, and erosion of mountains; the hydrologic cycle and the forces of water; plants, animals, and humans living the land. The form of the landscape, therefore, reveals its natural and human history, and the continuing cycles of natural processes that steadily influence its morphology. Understanding the dependence of form on process and recognizing that human and natural processes are constantly at work modifying the land illustrates the need to incorporate a process orientation into design. This prerequisite places design in the role of initiating purposeful and beneficial change, with ecology and people as its foundation.

Economy of means

The idea behind this principle has been stated in several different ways, yet each conveys the same general meaning. From the principle of least effort to the notion that small is beautiful, the economy-of-means principle encourages design to achieve the maximum output from the minimum input. This suggests that simplicity, while a relative term, and balance with natural process should be common to any planning solution.

Diversity

In a purely ecological context, diversity implies richness and is used to express either the number of species in a given area or the genetic variability within a single species. If health can be described as the ability to withstand stress, then diversity may also be used to imply health (Hough, 1989). Diversity also suggests choice and a mixture of features from which selections can be made, be those land uses, employment opportunities, lifestyles, or landscapes. In design terms, diversity translates as the creation or preservation of a mixture of settings that can enhance interest and aesthetic appreciation, and stimulate social health.

Environmental connectedness

In an ever-urbanizing world there is a need to maintain a sense of connectedness with the environment. The natural environment provides one of the most appropriate, flexible, and diverse settings for connecting people to place. The constant and direct experience of how the environment works, assimilated through the daily exposure to and interaction with the landscape, should be a priority of design. There is nature in the city that can be amplified through design, and a need exists to give emphasis to the natural systems that operate in the urban landscape.

Change as constructive process

The natural tendency in planning, particularly with respect to environmental planning and design, is to focus attention exclusively on designs that minimize destruction of environmental resources. Although the minimal-impact approach is the obvious response to human-induced change, it suggests an acceptance of negative values (Hough, 1984). This position can inhibit more creative solutions that develop from ecology-based design. Thus, design needs to approach the question of how human development processes can contribute to the environments they change. Change becomes a positive force capable of enhancing the landscape through habitat-building, recycling wastewater, storm water conservation, and other related methods. In this way development manages and reuses the resources it draws on. Development becomes more than simply something superimposed onto the landscape, it becomes linked to existing natural processes.

The natural factors discussed in this chapter and the design principles that grow out of them draw the environment firmly into the planning process. However, knowledge of the environment has to be supported by the acquisition of site-specific environmental information and methodologies that can evaluate that information in relation to the problems confronting the planning area. Landscape characterization and assessment applies what we have learned in this chapter and connects us to alternatives that guide the future use of the landscape. In the next chapter the issues and methods that direct land evaluation and the characterization of the landscape are examined.

Summary

To successfully integrate environmental concerns into the environmental planning process, the planner must possess a basic understanding of the environmental processes active in the planning area. With this information, the planner can better comprehend the importance of critical environmental features and discern the influence they have on qualities of the built environment. This chapter presented a review of the fundamental "what I need to know" information pertaining to the salient natural factors that direct environmental planning. Beginning with the geologic environment and culminating with an overview of natural hazard considerations, the role of each factor in landscape design and the dynamics of the processes involved were identified. Because development is more than simply the superimposition of built form onto the landscape, how development becomes linked to existing natural processes becomes a central question to resolve in order to maintain environmental sustainability.

Focusing questions

Why assess the physical environment of the planning area; what significance does this assessment convey?

In what ways do the natural factors reviewed in this chapter exert controlling influences on development?

How does one plan within the context of a dynamic physical environment?

In what ways does environmental process suggest options to direct and form the design of development proposals?