Integrated Environmental Planning
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CHAPTER 5

Landscape Inventory and Analysis

Information is a critical component of any decision-making process, and environmental planning is no exception to this rule. As demonstrated by Lein (1997), every decision-making body relies on information to exist, and the acquisition, processing, and dissemination of information are fundamental activities undertaken by planning agencies. Information can be considered a form of planning intelligence, and planning intelligence is a type of strategic decision support information that enables the environmental planner and the community to identify, understand, and manage the problems characterizing the planning area. This intelligence is derived from organized data and facts about the regional setting and those features that are of specific concern to planning. In this chapter the methods used to collect and organize this information, and the evaluation procedures employed to provide the "intelligence" needed to direct the environmental planning process, are examined.

Regional landscape inventory and monitoring

Inventory and monitoring are among the most basic tools that enable environmental planners to establish critical baseline information and measure change. Unfortunately, information pertaining to the natural environment has often been used in an *ad hoc* manner (Steiner, 1991). There is a tendency to collect only that information required to address a specific problem. That information, because it is specialized, is often disconnected from the larger concerns of the planning area and fails to satisfy more generic information needs. This results in a one-dimensional view of the landscape that does not support the ecological premise that everything is connected to everything else (Steiner, 1991). Yet, without providing a more systematic view of the landscape, "seeing" the connections between the natural elements of the landscape and gaining insight regarding their interaction is difficult to achieve. Furthermore, because environmental planning is based on an integrated view of the landscape, synoptic-scale data concerning the biophysical processes characterizing the region must be collected and analyzed to provide the baseline knowledge from which plans can be developed (Steiner, 1991). With these elements in place, the data gathered through inventory and monitoring activities helps to substantiate environmental planning and improves the credibility of the environmental plan. Deriving the information needed to reach this point, however, depends on the implementation and timing of programs developed to inventory and monitor the regional landscape.

An inventory, as its name suggests, is an itemized listing of current assets. If we consider the geographic area of a watershed, it would be necessary to have information pertaining to that area's geology, climate, land use, land cover, and vegetation, as well as a range of other factors, so that effect plans to manage the watershed can be drafted. Thus, whether in the context of environmental planning or with reference to the local retail department store, the inventory represents a basic accounting of the presence or status of important and valuable resources whose present disposition is unknown. Through the inventory process an understanding of these assets is acquired and their quality, quantity, condition, and location become known. As a preplanning mechanism, the inventory plays a vital role by providing the detailed overview of the region necessary before specific programs or policies can be drafted. In this role, the inventory describes the salient environmental variables that characterize the planning area, identifies their geographic extent, and carefully documents their important properties. Once completed, the inventory forms a baseline information source against which plans and programs can be evaluated, and provides a mechanism whereby the opportunities and constraints of the environment can be disclosed and recommendations can be offered to guide future development within the region.

For an inventory to be effective several organization questions need to be addressed. Taking each question in turn, they help to refine the methods used to develop the inventory and ensure its adequacy.

What to inventory?

Unlike our department store analogy with items arranged on stockroom shelves, the natural resource inventory is complicated by the multidimensional nature of the environment. The relevant factors to include in an inventory may be predetermined by local, state, or federal mandates. In other instances selection of the natural factors to inventory may require careful deliberation by the planner. Selecting the appropriate factors to inventory depends largely on purpose. In the majority of cases an inventory is conducted to give decision-makers a comprehensive and detailed understanding of the physical and human characteristics of the planning area. Using this information-base, environmental data can be employed directly in setting development options and priorities, identifying problems, and increasing general knowledge about the region that can be used by decision-makers.

Typically the dominating or prominent features of the landscape are chosen and described in a manner such that a decision-maker unfamiliar with the planning area can learn enough about its important qualities to ensure that plan development and implementation remains focused. Natural Factors given consideration in a resource inventory may include the follow items:

1 Habitats found within or adjacent to the planning area.
2 Major cultural resources found within or adjacent to the planning area.
3 Major land uses and related land-use activities found within or adjacent to the planning area.
4 Major land and resource ownership patterns and management responsibilities.
5 Major historic, prehistoric, and archaeological resources.

A comprehensive outline of the natural, cultural, and amenity resources that can typically be examined and subject to inventory are presented in Table 5.1. Describing each of the factors presented in the table may involve the production of statistical summaries, detailed maps documenting location and geographic arrangement, narrative summaries reviewing and explaining important features or relationships, photographs and other supporting graphic displays to enhance visualization of the planning area. Because the overriding goal of the inventory is to present data and information to improve understanding, anything not related to improving communication and the transfer of critical environmental knowledge should be avoided.

How to inventory

An inventory can be derived from a mix of primary, secondary, and tertiary sources. Consequently, data collection and data evaluation become critical phases in the inventory process. Perhaps the most important step in data collection involves identifying the boundaries that will delineate the

Table 5.1 Landscape factors subject to inventory.

Natural elements
Physiography: slope, drainage, unique features
Geology: bedrock formations, faults, fractures, slumps, slips
Soils: type, composition, permeability, erosion potential
Hydrology: drainage systems, springs, seeps, wetlands
Vegetation: plant associations, unique communities
Wildlife: habitats
Climate: temperature, precipitation, wind flow, humidity, evaporation

Cultural elements
Transportation: roads, rail lines, airports
Utilities: oil, gas, water networks
Structures & excavations: buildings, mines, dumps
Ownership: name, assessed value
Historical/archaeological: significant features and sites

Visual and aesthetic elements
Major viewsheds
Minor viewsheds
Scenic areas
Unique features
Points of interest

planning area and delimit the geographic extent of the biophysical and sociocultural factors that will be mapped and described. Although boundaries may be set by legislative goals, there is a hierarchical quality to an inventory that directs description and mapping through different levels of geographic scale and resolution. Generally, an inventory proceeds from a regional scale to a local level of detail. This hierarchical structure is used to place the planning area into its larger environmental context and to enhance the decision-maker's ability to see relationships that may exist between the planning area and the larger regional landscape. The drainage basin at the regional level and the watershed (or sub-basin) at the local level serves as the ideal natural delimiting feature for ecological planning and analysis (Steiner, 1991; McHarg, 1969). Recall that a drainage basin is identified by locating the drainage divides between channels of a particular order through the use of contour (elevation) data and runoff patterns. Since the drainage basin is delineated on the basis of physiographic and hydrologic criteria, it creates a practical reference for connecting natural and cultural attributes that facilitates system representations. The drainage perimeter has also been used to approximate ecosystem boundaries. By applying the drainage basin as the primary organizing spatial unit, data characterizing the natural, cultural, and amenity resources presented in Table 5.1 can be collected and mapped.

Cartographic treatment of inventory data is an important method of communication, visualization, and analysis by which the quality of the inventory can be determined in large part by the quality and accuracy of the maps created for display. Therefore, one of the more critical decisions that must be made early in the inventory process has to do with the selection of a base map and scale of representation. The base map will be used to anchor all the spatial information collected for the inventory. Factors that will influence the appropriateness of the base map include: (1) scale, (2) projection, (3) locational reference, and (4) medium.

1. **Map scale** – a map is a scaled representation of a portion of the earth's surface. The scale of a map is simply the ratio between map distance and earth distance. However, scale greatly influences the level of generalization required in order to represent geographic objects and directly controls the degree of detail that can be seen on a map. It is therefore essential that an appropriate scale is selected to that the representation of the surface can be as accurate as possible and the features and patterns of natural factors shown without unnecessary abstraction or generalization. Although the increased use of digital geographic information systems (GIS) has reduced some of the concerns regarding scale, every map product, whether stored in a machine environment or printed on paper, will posses a level of resolution (the smallest ground area that will be treated as an object that can be represented on the map) as a function of its scale that will direct how objects can be represented and symbolized.
2. **Projection** – the characteristics of a particular map are determined by the projection on which it is plotted. The retention of shape, equivalence, direction, or distance are important considerations when deciding upon the purpose of a map. Retaining one charac-

teristic generally results in the distortion of other potentially important characteristics. For mid-latitude regions, conic projections such as the Lambert or Alber's projection are commonly used on base maps, although other options are possible.

3 **Locational reference** – Before maps can be prepared that actually portray the locations of surface objects, a means of determining location must be selected. Locational systems can include latitude and longitude as well as more specific reference grids such as the Universal Transverse Mercator (UTM) grid system, or the State Plane Coordinate System.

4 **Medium** – traditionally mapped data were compiled and printed on paper or polyester film. While maps placed on these media are still very common and useful, the emergence of digital cartography and GIS together with the advent of the worldwide web (www), has introduced new source material for map compilation and display. Selection of map media must be taken into consideration since this simple decision will influence the ease of data storage, stability, accessibility, permanence, and ease of update and error correction. While inventory data may be collected from a variety of sources including field surveys and sampling, data are likely to be assembled and compiled into a digital form for computer storage and processing. For this reason, digital formats are preferred and provide greater flexibility when compared to traditional map media.

With a base map selected, the inventory can proceed as an exercise in data collection, data compilation, and geographic description and mapping. Since the inventory explains the first technical phase in the sequence on which planning depends, the compilation of inventory elements is directed by the information content of each data item. To be useful, it is essential that the information presented in the inventory meets three fundamental requirements (Gonzalez-Alonso, 1995). First, it must be comprehensive and gaps in the information should be avoided wherever possible. Secondly, the inventory must be systematic so that it can be applied easily. Lastly, the inventory must be multidimensional and give reasonable consideration to the totality of the significant environment.

The key decisions affecting how an inventory may be compiled relate to the choice of elements and the appropriate level of detail that will effectively communicate their importance. The important factors to consider when planning the inventory include: (1) the general characteristics of the planning area, (2) the objectives and socioeconomic implications of the inventory, (3) the size of the planning area, and (4) the availability and quality of data. With reference to information content, processing, and purpose, a resource inventory can be targeted at three interrelated levels:

- A reconnaissance level appropriate for describing regional patterns or elements that characterize large-scale regional trends.
- A semi-detailed meso-scale level oriented toward general planning questions with more specific data needs.
- A detailed site-specific level required for localized analysis involving siting decisions and the assessment of environmental impact.

Although exhaustive collection of information may not be required in all cases, concentrating on those elements that supply information that define the planning area makes it possible to map elements into homogeneous regions, and define elements in a clear and simple manner (Gonzalez-Alonso, 1995).

Documenting the inventory

The data selected and collected in the inventory must be assembled into a format that will give decision-makers a clear indication of the landscape's significance and outline the main implications that should direct future use. Therefore, the inventory and the recommendations that grow from it provide a basis for subsequent analysis and for raising questions concerning specific features of the landscape, such as:

- its susceptibility to modification
- its stability
- its aesthetic qualities

- its conservation value
- its opportunities and constraints.

Based on these points, it can be seen that an inventory represents more than simply an exercise in data collection. It provides an initial assessment of site characteristics that allows the potential of an area to be critically examined. Therefore, to be useful, a detailed evaluation of each factor together with a series of planning recommendations should accompany the discussion. This form of cursory evaluation identifies the issues, concerns, possibilities, and limitations that are associated with each natural factor, and allows options to be entertained without specific goals or objectives in mind that might otherwise limit thinking.

With respect to documentation, the ultimate goal of an inventory is to produce an organized and concise review of the pertinent material that clearly describes the planning area in both a narrative and graphic form. An inventory is typically divided into five major sections beginning with an introduction and proceeding systematically through each thematic factor. A generic outline presenting the basic structure and contents of a natural resource inventory is given in Table 5.2. Each section in this document has a specific purpose and establishes the background needed to proceed to the sections that follow. The logic behind this design is simple. Beginning with the introduction, an overview of the planning area is offered and the purpose and scope of the inventory is explained. Information presented in the introduction establishes the site and situational context of the planning area and helps communicate a sense of place. With the general characteristics of the regional setting described, the decision-maker has a reconnaissance-level perspective of the planning area. Moving from this general overview, the section that follows can introduce the human and cultural factors that define the area, along with a brief historical treatment of the region to document its origins and suggest its evolution. In this section emphasis is also given to aesthetic qualities and known management problems that exist within the planning area. The problems identified in this section can include a range of social, economic, and environmental issues that should be recognized as the information in the inventory is interpreted. Using this discussion as a backdrop, this section of the inventory may conclude with a review of general planning recommendations that have been derived from the analysis of data inventoried. Although a more detailed treatment of these recommendations will follow later in the document, a general summary is presented here to help frame the material that is introduced in the sections to follow.

Table 5.2 General resource inventory contents.

I. Introduction
   a) site description
   b) purpose of inventory
   c) table of contents

II. History of Site and General Information
   a) land ownership patterns
   b) existing land use
   c) aesthetic qualities and special features
   d) general planning recommendations

III. Natural Site Conditions
   a) geology
   b) vegetation
   c) soils
   d) hydrology
   e) climate
   f) wildlife habitat

IV. Summary of Planning Recommendations
   a) review of planning considerations
   b) recommended uses
   c) development constraints
   d) other limitations

The next major section of the inventory can be considered to form the heart of the document. In this section the detailed information pertaining to the natural site conditions selected for examination are presented. While the sequence or order may vary, generally a “ground-up” approach is used. This approach allows the environmental factors that define the planning area to unfold in a manner that facilitates an understanding of factor interactions and interrelationships.

The final substantive section of the inventory contains recommendations regarding the present state and the potential concerns surrounding each factor. This section is critical to the success of the inventory, particularly if it is to have value as a basis for goal-setting and plan-making. Recommendations address the particular types of use, pattern of development, design concerns, and locational constraints that where identified during the inventory and analysis process. The concept of a constraint is particularly important to this purpose. Constraints can explain environmental limitations evident with respect to a given factor, from expansive soils, flood risk, slope instability, and sensitive habitats, to historic sites, cultural amenities, and areas of scenic value. Each constraint is documented and the overall developmental suitability of the planning area for future use is described in relation to how each factor imparts its influence. Although recommendations are merely suggestions, they often identify important alternatives that can be better accommodated by the site given its biophysical and socioeconomic characteristics. Moving the inventory into a more coherent expression of opportunity or constraint directs our attention to the methods of land evaluation and analysis.

Land evaluation and analysis

A large tract of land is being considered for some form of use. The question is what use is best suited for that area. This is the general question that guides the land evaluation process and the methods that have been developed to assess the "fitness" of land for development. However, numerous environmental factors influence the development process and require careful evaluation. From topography, surface drainage, climate, and soil, to the incidence of natural hazard, and disease, a range of environmental characteristics affect the current as well as the future state of the landscape system and impart some direct influence on the land use placed at a given location. Consequently, there are considerable benefits to be realized from a simultaneous assessment of the landscape factors critical to the sustainable use of the planning area. The regional landscape inventory is the first phase in this more comprehensive process of landscape evaluation.

Drawing from the fundamental principles that (1) land should be used for the purposes for which it is best suited and that (2) land of high value for an existing use should be protected against changes that are difficult to reserve, the natural environmental factors that define the regional landscape are subjected to six interpretative stages that when completed yield an expression of the optimum configuration of land use within the planning area (McRae & Burnham, 1981). The stages defining this evaluative process are illustrated in Fig. 5.1. By definition land evaluation is the process of estimating the potential of land for alternative uses (Dent & Young, 1981). Through this evaluation process a comparison is made between the requirements of specific types of use and the resources offered by the environment to support them. Fundamental to the evaluation procedure is the widely understood fact that differing land uses will define differing requirements. Since nearly all human activities use land to some degree, the opportunities and limitations of this increasingly scarce resource must be translated into a form that can aid decision-making (McRae &

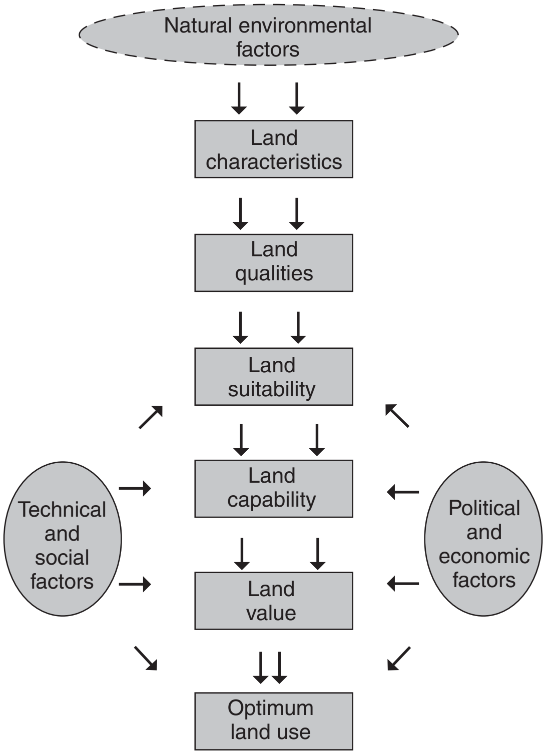

Fig. 5.1 The general method of land evaluation.

Burnham, 1981). Land evaluation is the methodology designed to achieve this objective.

As a general methodology, land evaluation can be conducted directly by trial and error, or indirectly through the application of an analytical approach that attempts to explain or predict land performance under specific categories of use. The logic that makes land evaluation possible relates to the fact that land varies in its physical and human-geographic properties. Therefore, this inherent variation should affect land use, suggesting that given a proposed use, some land areas are more appropriate in physical and/or economic terms. This observable variation is in part systematic with definite and knowable causes. Because causal influences can be known, the variation, whether expressed in physical, political, economic, or social terms, can be mapped. Furthermore, the behavior of the land when subjected to a given use can be predicted with some degree of certainty, depending on the quality of data and the depth of knowledge relating land to land use. Hence land suitability for various actual and proposed uses can be systematically described so that decision-makers can apply these predictions to guide their decisions.

Providing this specialized information is the function of land evaluation and information becomes a key ingredient in this process. Typically three sources of information are required: (1) land, (2) land use, and (3) economics. Land data is obtained directly from the natural resource inventory. Information regarding the ecological and technical requirements of various land-use types is acquired from the subject areas that have developed applied and theoretical knowledge related to each category. Economic data may not be necessary if the results of an evaluation are needed to address purely physical issues; then only general economic and social patterns are required. However, if the results are required in strict economic terms, then data on specific costs and prices is needed (Dent & Young, 1981). These data needs coupled with the observation that direct evaluation methods tend to be of limited value unless large amounts of data can be collected, support the use of indirect evaluation techniques (McRae & Burnham, 1981).

As an analytic tool, a land evaluation may be presented in terms that are qualitative, quantitative, physical, or economic (Dent & Young, 1981). A qualitative evaluation is one in which the suitability of land for alternative purposes is expressed in qualitative terms only. For example, observation of land areas based on soil, slope, and distance criteria may suggest that a given land area, because of its soil type, steepness of slope, and distance from major roads, may be of marginal value for a particular type of crop production. Therefore, the use of terms such as highly, moderate, or marginally suitable or not suitable when considering a specific type of use imply qualitative judgments have been made to place land into one of these categories. Typically, qualitative evaluations are employed mainly at a reconnaissance scale, or as a preliminary to more detailed investigations. While the results of this type of land evaluation may be highly generalized, it permits the integration of many environmental, social, and economic factors.

Quantitative physical evaluations provide numerical estimates of the benefits to be expected from the use of land. Quantitative evaluation is most frequently carried out as the basis for economic evaluation, where results are expressed in terms of profit and loss. Here, monetary values are applied to data from quantitative measures to obtain cost expressions and to derive profit and loss treatments of inputs and outputs. However, Dent and Young (1981) note that an economic evaluation is not strictly confined to profit and loss considerations. Other consequences such as the environmental or social can be included and combined with economic data as a basis for decision-making.

Regardless of the type of evaluation conducted, the goal of evaluation is to predict change and to provide better insight concerning the consequences of a development plan. Thus, as a planning tool, land evaluation becomes a necessity wherever changing the landscape is contemplated (Dent & Young, 1981). Prediction, in this context, directs attention to the concept of suitability. Generally, all land evaluation procedures attempt to express this idea and relate it either qualitatively or quantitatively to alternative types of land uses. Therefore, given different forms of use, with varying environmental opportunities and constraints, land evaluation methods strive to produce an expression of suitability that can be used to direct how land should be utilized. Using this expression, a comparison is made between the requirements of the contemplated land use(s) and the qualities of the land that are present to support it. The suitability of land can be assessed and expressed in several ways. Three of the more common include: (1) capability, (2) suitability, and (3) value. A variety of analytic techniques have been introduced to perform regional landscape analysis and land evaluation that apply these terms as a control which directs the future use of land resources (McAllister, 1986; Anderson, 1980; Steiner et al., 1994; Davidson, 1992).

Methods of landscape assessment

Techniques for regional landscape evaluation and analysis are general tools that assist with the task of assembling a large number of important landscape variables into an expression that can be used to direct decision-making. Through integration, data from diverse sources can be interpreted, evaluated, and communicated in a manner that guides the process of choosing among alternatives and identifying optimal patterns that maximize benefits and reduce or avoid costs. More importantly, these techniques complement the method of regional landscape analysis applied in environmental planning. This method, derived from the procedures outlined previously by McHarg (1969) and Steinitz (1977), define a combination of procedures which form a model that describes the general process. The four main phases of this model are as follows:

1 *Inventory* – describing the compilation of data on natural environmental conditions to serve as critical baseline information on which further analysis may draw.
2 *Data interpretation* – explaining the process of categorizing inventory data to define patterns and trends.
3 *Data synthesis* – defines the combination of data through the use of specific analytic techniques and models to derive expressions of suitability or constraint.
4 *Plan formulation* – explaining the integration of land evaluation and ecological assessment results into the policy-making process.

Connecting data to the plan is accomplished through the application of one or more evaluative (analytic) techniques. With each technique adopted, certain assumptions or conventions are assumed that influence how well a given method can be applied and its results interpreted (McAllister, 1986). When one is conducting an assessment of a plan or design, assessment typically implies that a comparison is being made between two states, one of which is the condition that will result from implementing the plan. The effect of the proposal can be examined by comparing:

1 The original state existing before the action was taken, referred to as the baseline state.
2 The state that would have evolved in the absence of the action.
3 A goal or target state.
4 The ideal state.

The appropriateness or suitability of a proposal, therefore, relates to how well the various states compare. Thus, given baseline conditions, one asks how closely the goal state, ideal state, and the "non-action" state agree.

Not all assessment methods provide the same level of comparison. Generally, differences among methods are revealed by the way they address concerns related to the categorical descriptions used to estimate and report natural factors and effects, the manner by which magnitude and significance of change is estimated, and the procedures used to derive ratings intended to indicate the relative importance of each factor. With reference to the description of factors included in the selected methodology, the fundamental rule for selecting categories is that they must be mutually exclusive and exhaustive. Concerning the question of magnitude and significance, mathematical or statistical procedures are considered to be the most reliable means of estimation. However, in both cases, assessment relies heavily on the use of expert judgment. This is particularly the case in situations where: (1) scientifically valid procedures are lacking, (2) data needed to implement a procedure does not exist, or (3) where cost factors prohibit the use of certain procedures. The question of measurement can be addressed in a number of ways. First, the notion of rating implies either a subjective or quantitative ordering of a variable. Therefore, one distinction considers the source of the rating. Ratings can be derived from a variety of sources: measurable physical characteristics, monetary values, or expert judgment (McAllister, 1986). Finally, rating type describes the general approach that was used to scale qualities, quantities, or effects. Four scaling methods frequently applied in environmental assessment include (1) simple, (2) constant, (3) scaled value weight, and (4) rescaled weight. The general characteristics of these rating schemes are summarized in Table 5.3. A more detailed discussion of these approaches can be found the McAllister (1986).

Table 5.3 Characteristics of land rating schemes.

Scaling method	Characteristics
Simple rating method	A set of guidelines or standardized procedures are followed in assigning judgmental importance scores
Constant value weight	Rating applied to each unit of a given type of impact
Scaled value weight	Derived from a mathematical function, they are used to avoid possible inaccuracies of constant weights
Rescaled impact weight	Scaled weights adjusted by expert judgment; used to overcome factor dependencies problems

Recognizing the distinctions that exist among various assessment techniques available helps the planner identify the approach that will produce the most meaningful results. In general an assessment technique should be:

- **Systematic** – any technique must be systematic to ensure that the results it provides are replicable.
- **Simple** – the techniques selected should not be overly complex.
- **Quick** – the techniques must be able to generate useful results within a reasonable length of time.
- **Inexpensive** – the techniques should not impose unnecessary costs.
- **Legally acceptable** – the techniques should conform to the various legal and administrative requirements to which it is subject.
- **Comprehensive** – the techniques should be capable of incorporating all of the relevant factors important to the decision-maker.

While strict adherence to these points may not be possible in all situations, they focus attention on the practical aspects of the analysis problem and offer some insight to help evaluate whether a certain technique is feasible or not. The methods available to the environmental planner fall within four broad categories: (1) methods of land capability analysis, (2) methods of developmental suitability analysis, (3) methods of carrying capacity analysis, and (4) methods of land evaluation and site assessment. Each of these techniques is reviewed below.

Land capability analysis

Land capability analysis is a technique designed to classify land units based on their ability to support general categories of use. The term capability has specific meaning in this context. When used in reference to land, capability implies that a given area, due to its inherent characteristics, may be qualified for a specific type of use (i.e. agriculture, open space, urban). Determining the qualifications land must possess to be considered appropriate relies on relating the land area to a set of environmental factors that influence how well a given land use will perform. The environmental factors typically employed in capability analysis include soil erosion potential, susceptibility to flooding, climate, and slope stability, together with other factors that stand to degrade the utility and productivity of land. The analysis of land capability, therefore, requires an evaluation of the degree of limitation posed by permanent or semi-permanent attributes of land to one or more land uses (Davidson, 1992). The logic guiding analysis is comparatively simple. Capability is based on the premise that as the degree of constraint increases, land should be allocated to lower categories or less intensive forms of use. Although this technique was originally developed to assist with agricultural planning and designed to help identify agricultural land uses that would not contribute to environmental degradation, the concept of capability is flexible enough to permit broader interpretations.

There are two principal ways whereby land capability can be assessed. One example is through the use of categorical systems. Categorical systems are implemented by testing the values of appropriate soil and site properties against criteria for a set of land-use categories. Site conditions are compared against these evaluative criteria and if the minimum criteria are not met, then the land area in question automatically falls to the next class and the process repeats until a match is identified. Land characteristics are then tested against less stringent criteria as the evaluation process continues through the classification system until a category is identified where all the criteria are satisfied. A second means of deriving an estimate of land capability is through the use of parametric systems. Parametric systems apply mathematical formulas to combine site properties into a quantitative expression. Although parametric systems differ in respect to the factors that are included for mathematical manipulation, three general approaches are common:

1. Additive systems of the form $P = A + B + C$
2. Multiplicative systems of the form $P = A \times B \times C$
3. Complex systems of the form $P = A\ (B + C) \times D$.

In each of the examples listed above, P is the parametric rating or score and A, B, C, and D represent soil and site properties. The basic features of categorical and parametric approaches are examined below.

Capability classification

A variety of land capability classification techniques have been introduced (Davidson, 1992). Perhaps the best known of these is the USDA method formalized by Klingebiel and Montgomery (1961). The USDA method employs a three-tier structure in its classification system:

- **Tier 1, Capability Class** – the top level in the classification with a total of eight classes defined and labeled I to VIII inclusive, indicating the degree of limitation in descending order of severity.
- **Tier 2, Capability Subclass** – indicating the type of limitation encountered within the class, these subclass designations identify limitations such as erosion hazard, climate, fertility, or excess water that restrict the use of land. The limitations recognized at the subclass level are:
  Subclass e (erosion), defining soils where susceptibility to erosion is the dominant limitation.
  Subclass w (excess water), explaining conditions of poor soil drainage, wetness, high water table, and overflow as the dominant limitation.
  Subclass s (soil), describing soils that have limitations associated with shallowness, low moisture-holding capacity, or salinity.
  Subclass c (climate), identifying land where climatic conditions limit land use.
- **Tier 3, Capability Unit** – a subdivision of the subclass where the variation in degree or type of limitation is similar across soil type. Thus within the same narrow range of environmental conditions, capability units define land areas that share a similar response to management and improvement practices.

Soil and climate limitations in relation to the use and management of soils are the basis for differentiating capability classes. Assigning land areas to capability units, capability subclasses, and capability classes is conducted on an evaluation of 8 environmental factors. These are summarized in Table 5.4. The assignment process itself is based on a series of assumptions that have been discussed in detail by Klingebiel and Montgomery (1961). When carefully applied to a well-defined problem, land areas falling within one of the eight classes can be described and mapped accordingly (Davidson, 1992):

- Class I: soils with few limitations that restrict their use.

Table 5.4 Criteria used for placing soils into capability classes.

1. Ability of the soil to give plant response to use and management based on organic matter content, ease of maintaining nutrients, percentage base saturation, cation-exchange capacity, parent material, water holding capacity
2. Texture and structure of the soil to the depth that influences the environment of roots and the movement of air and water
3. Susceptibility to erosion
4. Soil permeability
5. Depth of soil material to layers inhibiting root penetration
6. Alkalinity
7. Physical obstacles
8. Climate

- Class II: soils with some limitations that reduce capability.
- Class III: soils with some severe limitations that require special management.
- Class IV: soils with very severe limitations that restrict certain activities and require special management.
- Class V: soils with little or no erosion hazard but with other limitations that restrict extensive activities.
- Class VI: soils with very severe limitations and that are unsuitable for cultivation and restrict use to pasture and range.
- Class VII: soils with very severe limitations that make them unsuited to cultivation and restrict use to woodland or wildlife.
- Class VIII: soils and landforms with limitations that preclude their commercial viability and restrict use to recreation, aesthetic, or watershed purposes.

Implementing the USDA method is largely subjective since the criteria for establishing class limits are not generally specified. Therefore, the technique can be considered a formal representation of expert-technical judgment. Although the results can be useful, the advantages and disadvantages associated with land capability classification must be well understood in order to guide its appropriate application. The strengths and limitations of the USDA method have been examined by McRae and Burnham (1981) and are summarized in Table 5.5. Problems related to imprecision and subjectivity must be balanced, however, by the flexibility such categorical systems offer. Flexibility of use has contributed to the design of similar measurement frameworks in Canada, Great Britain, and the Netherlands, each modeled after the USDA approach (Davidson, 1992).

Table 5.5 Advantages and disadvantages of the USDA system.

Advantages:
- Division into small number of ranked categories is easily understood
- Qualitative and suggests realistic approach given knowledge limitations
- Versatility
- Easily applied
- A general-purpose classification system
- Stresses adverse effects of poor management
- Useful way of relating environmental information
- Results easily displayed on maps

Disadvantages:
- Subjective
- Interactions between limiting factors difficult to express
- Division into too few categories overgeneralizes conditions
- Implied ranking suggests true land value
- Fails to include socioeconomic factors
- Emphasizes limitations rather than land's positive potential
- Difficult to use where reliable soil information is lacking

Parametric methods

Dividing land into a small number of categories that are mutually exclusive and supposedly exhaustive imposes an artificial structure that does not correspond well with the variability inherent to complex environmental interactions. By relaxing the need for discrete classification and replacing nominal categorization of land with continuous scale assessment, more realistic results can be obtained (McRae & Burnham, 1981). Applying parametric techniques in a land capability analysis involves:

1 Establishing a land unit to assess.
2 Obtaining the required data.
3 Developing the appropriate measurements for that data.
4 Translating the raw measured data into a coding or rating scale.

Table 5.6 Calculation of the Storie Index Rating System.

Index parameters:
Factor A – Rating based on characteristics of physical profile
Factor B – Rating based on surface texture
Factor C – Rating based on slope
Factor X – Rating based on other site conditions

Index calibration:	**Percent**:
Soil type X – brown upland soil with shale parent material and depth to bedrock at 90 cm	Factor A = 70.0
clay loam texture	Factor B = 85.0
rolling topography	Factor C = 90.0
moderate sheet erosion	Factor X = 70.0

Index rating:
SIR = 0.70 × 0.85 × 0.90 × 0.70 = 0.37 or 37 %

Source: Adapted from McRae and Burnham (1981).

5 Performing the desired mathematical combination of measured properties.
6 Applying the resulting scores to the entire planning area.

A selection of additive, multiplicative and complex schemes has been reviewed in detail by McRae and Burnham (1981). Perhaps the most widely known parametric method is the Storie Index Rating System (Storie, 1978). This multiplicative system computes a land-quality rating index based on the general relation

$$SIR = A \times B \times C \times D \qquad (5.1)$$

Where:
A = character of the soil profile
B = texture of surface soil
C = slope
D = miscellaneous factors (i.e. drainage, alkalinity).

Ratings for each factor are provided and expressed as percentage scores in Storie (1978). An example of the scores applied in a hypothetical calculation are shown in Table 5.6.

As with the categorical approach, parametric systems possess important advantages and disadvantages that should be understood before these methods are applied. The main advantages of these systems when compared to categorical methods include:

- reduced subjectivity
- ease of adaptation
- attractive simplicity
- amenability to computer manipulation.

The main limitations are related to concerns surrounding

- misleading impressions of accuracy
- calibration difficulties
- parameter inconsistencies.

An alternative means of evaluating land shifts the focus from capability to the concept of developmental suitability.

Developmental suitability analysis

Developmental suitability may be defined as the "fitness" of a given tract of land for a well-defined use (Steiner, 1983). When compared to the concept of capability, suitability explains the condition where a singular use is described that is the most appropriate use for a site in the landscape. Therefore, while capability narrows the search for alternative land uses that may be "qualified," suitability refines this search further to identify the single use that fits with the environmental conditions present at a given location. To illustrate this important terminological distinction, consider the example of a county that is exploring options for currently undeveloped land areas. The county wishes to identify what uses might be appropriate and seeks workable alternatives. Through the application of land capability analysis, broad categories of general land use are identified that suggest where land may be qualified to support urban, agricultural, and recreational uses. Within each of these categories, developmental suitability analysis is performed to determine which specific types of urban, recreational, and agricultural uses are the most appropriate. Thus within the general land-use category of urban, suitability analysis can suggest which areas may best support residential, commercial, or industrial forms of development.

Variations in the degree of suitability are determined by the relationship, actual or anticipated, between benefits and the required inputs associ-

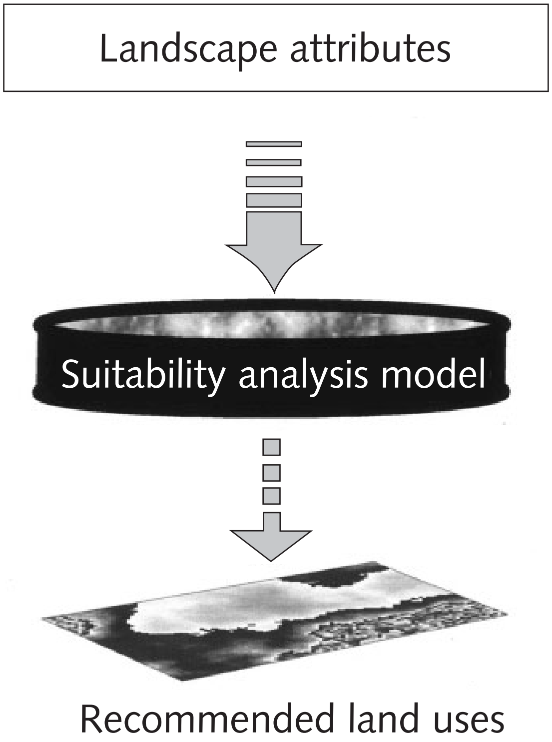

Fig. 5.2 The suitability analysis "filter."

ated with the use in question for the tract of land under consideration (Brinkman & Smyth, 1973). Focused on the concept of suitability, effective analysis depends on the techniques that make systematic use of environmental information and relate the condition of the environment to the activity it is proposed to accommodate (Ortolano, 1986). In this context, suitability analysis can be looked upon as a filter, where land-use requirements are passed through an environmental screen. Land uses passing through this screen can be considered the most suitable for the site under consideration (Fig. 5.2).

Identifying the potential opportunities or constraints of a site requires selection of those landscape attributes that would support or influence the functioning and sustainability of the activity under consideration. A variety of techniques have been proposed to perform a suitability assessment (Hopkins, 1977; Fabos, and Caswell, 1977). Traditionally, selected landscape attributes are depicted in map form and combined cartographically so that when viewed collectively they provide insight into the type of use intrinsically suited to that location. This generalized procedure for conducting a developmental suitability analysis has been described by Lein (1990). In nearly all cases, obtaining an expression of suitability becomes a function of the analyst's associative logic when relating landscape qualities as indicators of constraint to a specific developmental design. As noted by Lein (1990), this method of analysis contributes to the common practice of compiling a series of data maps each representing a selected environmental theme or variable, interpreting a combined pattern, and drawing conclusions from their composite profile. However, the practical limitations of complex manual overlaying operations, coupled with the inability to consistently confirm the results obtained through visual inspection of superimposed map surfaces, gave way to alternative procedures (Hopkins, 1977; Steiner, 1983; Bailey, 1988).

At present, 7 general approaches to developmental suitability analysis have been introduced (Table 5.7). With some variations, an algorithm is typically applied to a set of environmental variables and produces an expression of suitability through either direct or implied mathematical operations. The environmental variables selected for inclusion in the suitability algorithm are assigned some type of value, rating, score, or weight. Using these numerical approximations of fitness, developmental suitability is derived as a function of cross-factor addition or multiplication of these numerical expressions as dictated by the respective algorithm. The cross-factor results are then assembled into an arbitrarily derived classification scheme to allow a portrait of developmental suitability to take form (Lein, 1990).

Several algorithms are available to assist with the analysis of developmental suitability, and most have been extended to take advantage of the map-data processing capabilities of a geographic information system. Six common methods have been reviewed extensively in the environmental planning literature: (1) the Gestalt method, (2) the method or ordinal combination, (3) the linear combination method, (4) the nonlinear combina-

Table 5.7 General methods for developmental suitability analysis.

Method	Description
Gestalt method	Determination of suitability classes through field observation, air photo interpretation, or topographic maps without consideration of individual environmental factors
Ordinal combination	Mapping the distribution of land types, subjectively rating their suitability, then physically overlaying each map to describe a composite suitability profile
Linear combination	Rating and weighting environmental factors, then applying an algorithm to produce a mathematical expression of "fitness"
Nonlinear combination	Use of a nonlinear function to combine ratings into a suitability score
Factor combination	Modification of the Gestalt method to accommodate interdependence among factors
Clustering	Application of statistical clustering algorithms to find natural grouping among environmental variables
Logical combination	The use of rule and heuristics to assign suitability scores to environmental factors

tion method, (5) the Rules of Combination method, and (6) statistical grouping techniques (Hopkins, 1977; Anderson, 1980; Lein, 1990). While the intent of each technique is to provide an objective measure of suitability, each of the procedures introduced tends to be based on a common set of assumptions. First is the assumption that landscape factors are independent. This implies that environmental parameters do not share functional relationships. We know, however, that landscape variables are greatly interdependent. Next is the assumption that mathematical properties hold when assigned values are compared across factor levels. Here, the implication is that adding or multiplying variables creates mathematically valid results. We understand, however, that three times soil does not equal slope. Another important assumption is that rating or scoring schemes can be applied uniformly across factor levels. Finally, it is generally assumed that subjectively derived weights are flexible given changing environmental conditions.

These assumptions, however, lack absolute validity. This fact tends to frustrate the "scientific" aspects of suitability assessment and implies that the majority of combinatorial techniques are invalid when viewed critically or insufficient if used as the sole means for expressing developmental constraint. Of course, if these or similar techniques are invalid or flawed, then why are they used in practice? There are several responses to this question. First, it is important to recognize that environmental planning is as much an art as it is a science. Therefore, while we may strive to develop analytic tools that embrace the rigor and objectivity of pure science, our reality is a blend of imprecise concepts coupled with environmental relations that defy exact quantification (Lein, 1993b). Consequently, techniques that perform composite landscape assessments should not be looked upon as a calculus of certainty, but rather as simplifying tools that reduce the complexity of the planning problem to a more manageable set of conditions. By keeping this point in mind, the planner may apply these techniques and use technical judgment effectively within its proper context. Suitability analysis, though conducted using addition, multiplication, or some other logical operation on a set of environmental conditions, is not an exercise in mathematics. Instead it characterizes an algebra involving symbol manipulation whose logic must be clear and explicit to ensure that its results are interpreted correctly. For this reason, developmental suitability analysis represents an expert judgment method of evaluation (McAllister, 1986). As an exercise in the guided use of expert judgment, the general methods used to express suitability and form a geographic pattern of landscape opportunity and constraint can be examined.

Gestalt methods

The Gestalt concept when applied to development suitability analysis requires consideration of the landscape as a whole rather than as an assemblage of elements. Homogeneous regions are determined through observation using data sources that characterize the landscape in its entirety, such as aerial photographs, topographic maps, or field observations. From these sources, an expression of suitability forms from a three-step process:

1. The study area is partitioned by implicit judgment into homogeneous land units based on the interpretation of landscape patterns.
2. A table is created that verbally explains the effects or constraints that will occur in each of the regions should the potential land use be located there. Each land unit is then evaluated and a relative score or grade is assigned.
3. A set of maps, one for each land use, is produced to show these regions in terms of their suitability. Value judgment is implicit and can be expressed graphically for each land unit delineated on the map.

The Gestalt technique yields valid or invalid analytic results depending on the skills of the analyst and the circumstances surrounding the project. Several problematic issues concerning this approach to suitability assessment have been noted. First is the realization that the process is based on implicit judgment rather than explicit rules. As a consequence, the results can be difficult to evaluate since the methodology is not well documented. Therefore, the procedure relies on one's mental ability to assimilate many interactive factors, which creates results that can be difficult to communicate to decision-makers.

Combinatorial methods

Generating an expression of suitability using combinatorial methods describes the general procedure of applying a mathematical operation directly or implicitly on a set of factor maps that depict important landscape qualities. Three principal methods dominate this approach: (1) ordinal combination, (2) linear combination, and (3) nonlinear combination.

Ordinal combination – The ordination combination method explains a three-step procedure that creates a composite map detailing the developmental suitability of the planning region. The procedure begins by mapping a set of selected environmental variables according to specific categorical representations (i.e. soil types, slope classes, vegetation types). These mapped characteristics reflect distinct dimensions along which variations between land parcels can be described. Types mapped for each factor define nominal labels used to place variables along a measurement dimension. For example, land use might be typed according to well-recognized categories such as residential or industrial, while slope may be typed as low, moderate, high. The next step in the process requires creating a cross-tabulation table comparing factors to proposed or potential land uses. The elements of this simple two-dimensional matrix are filled by entries defining the relative suitability rating for each land use of each type across all the factors. The ratings explain an ordinal scaling of all the characteristics of the type. For instance soil type might include consideration of its permeability, depth to water table, organic content, and pH, together with the comparative "costs" of the land use it placed on the type. These ratings, expressed according to an ordinal measurement scale, can be derived from a number of sources such as maps, reports, or expert judgment. From here, a series of factor maps can be produced showing the suitability of the landscape for each land use under review. The final step in this process consists of physically overlaying the suitability maps of each individual factor for each land use to create a composite characterization of suitability over the region. If the number of factors is few, the visual interpretation of the composite map is relatively straightforward. However, as the number of factors increases, the associative logic needed to draw effective interpretations and recognize patterns in the data can confound meaningful interpretations. The greatest limitation of this approach, however, surrounds the implied addition of ordinal scale numbers and the assumed independence of factors. These flaws notwithstanding, the need to express suitability as a composite quality or score that will evidence spatial variation and can be displayed geographically over the planning region is clearly demonstrated by this approach.

Linear combination – The logical flaws inherent in the ordinal combination method are avoided when the types with each factor are rated on separate interval scales. The ratings for each type produced in this manner are typically multiplied by a weight to reflect the relative importance of that factor. The new "weighted" rating for a given area is then added to produce a suitability score. According to this approach, suitability becomes the product of the linear combination of factors. As demonstrated by Hopkins (1977), multiplication by weights can also be used to change the unit of measure of the ratings by the ratio of the multiplier, so that all ratings fall along the same interval scale.

Perhaps the most critical aspect of the linear combination method considers the procedures used to rate factors. Although there are no formal rules to guide the process, a logic is assumed that aims to produce a rating that can be interpreted meaningfully. Several schemes for deriving ratings are described by Largo (2001) and Hopkins (1977). A familiar rating scheme follows the analogy of assigning grades to a set of examinations. The first step in this process requires establishing a total possible suitability score. This value is divided among various factors and each assumes a given proportion of the total. Each type (class) of each factor is then rated as to its suitability in relation to the proportion of the total score assigned to the factor. Although the linear combination method corrects the measurement problems associated with ordinal approaches, the problem of factor independence remains. Linear combination methods are unable to address the situation where the relative suitability for a specific land use of a type on one factor depends on the type on any of the other factors. Despite this drawback, applying the linear combination method can be justified on the grounds that:

- Factors might be known *a priori* to be independent.
- The method is cost effective and easy to implement.
- Factors typically used in the model can be deductively determined to be independent.

Grouping techniques

An alternative strategy to suitability classification that avoids issues surrounding factor independence and mathematical invalidity involves the use of the methods that define homogeneous regions explicitly. These techniques apply multivariate statistical procedures to group or cluster land units into regions based on measures of similarity (Betters & Rubingh, 1978; Omi et al., 1979; Cifuentes et al., 1995). Three multivariate techniques have been shown to be particularly useful: (1) cluster analysis, (2) discriminant analysis, and (3) factor analysis/principal components analysis. When compared to judgment-based methods of suitability analysis, multivariate techniques provide a rational framework for analyzing the similarity of units that vary with respect to numerous environmental conditions. In addition, these techniques rely on a numerical treatment of data that implies direct measurement across several dimensions. This type of approach lends itself to more robust ordination and produces results that can be easily represented in map form.

As a procedure for determining developmental suitability, multivariate methods require certain information to guide the interpretation of results:

1. Criteria to assess suitability – given a set of possible uses, the criteria needed to adequately express suitability must be specified. These criteria may involve selected environmental characteristics as well as other factors considered relevant to the problem.
2. Criteria to determine importance – the criteria developed to assess suitability will vary in importance depending on the land use under consideration. These contrasts and variations in importance should be examined across all land uses.
3. Conditions that determine favorability for a given use – given different land uses, the conditions of favorability may vary for each criterion, therefore each criterion may have a somewhat different set of conditions considered advantageous or adverse to each use.

4 Suitability classification scheme – a classification system should be developed in accordance with the specified criteria. Above all, the method of classification should be objective and provide for a hierarchical characterization of suitability.

It is with this final point, classification, that multivariate techniques make their contribution.

Suitability by clustering Cluster analysis defines a set of techniques for accomplishing the task of partitioning a set of objects into relatively homogeneous subsets based on inter-object similarities. There are four strategies employed in a clustering procedure:

1 Partitioning methods
2 Arbitrary origin methods
3 Mutual similarity procedures
4 Hierarchical clustering methods.

Although a discussion of each is beyond the scope of this section, a detailed explanation of cluster analysis can be found in Davis (1986) and Kachigan (1986).

Typically, clustering begins by measuring each of a set of n-objects on a set of variables (k). Next, a measure of similarity, distance, or difference is calculated and used to compare objects in the set. Using these calculated similarity measures, an algorithm expressing a specific sequence of rules is employed to cluster the objects into groups based on the inter-object similarities. The logic underlying a given clustering algorithm is based on the assumption that objects that are similar belong to the same group. The ultimate goal of any clustering method is to arrive at a cluster pattern of objects that displays small within-cluster variation, but large between-cluster variation (Kachigan, 1986). The differences between the resultant clusters (groups) can be interpreted by comparing each to their mean values on the input variables. The two main considerations that influence the application of this technique and the selection of a specific clustering procedure relate to: (1) obtaining a measure of inter-object similarity, and (2) specifying a procedure for forming the clusters based on the similarity measures.

An expression of suitability develops out of the formation of the clusters as land units are grouped into similarity classes. This pattern is refined as the clusters are examined and the statistical groups are assigned to informational categories. The interpretation of the cluster pattern and the naming of the resulting groups is a critical phase in this application. In general, interpretation relies on the use of judgment supported by the careful examination of the means and variances on the environmental variables used as input. For example, at the conclusion of an analysis it might be observed that Cluster 1 displays a high mean on variables x_2, x_3, and x_7, while Cluster 2 shows high mean values on variables x_1, x_5, x_6. If variables x_2, x_3, and x_7 explain soil characteristics, then Cluster 1 may reflect soil qualities or conditions. Therefore, from these comparative profiles of the input variables the distinguishing qualities of the clusters can be identified.

Suitability by discriminant analysis Discriminant analysis is a procedure for identifying relationships between qualitative criterion variables and quantitative predictor variables. The technique is particularly useful for identifying the boundaries between groups of objects, where the boundary is defined in terms of the characteristics of the criterion variables that distinguish (discriminate) the object in the respective criterion groups.

Discriminant analysis is an adaptation of regression analysis and is designed for situations where the criterion variable is qualitative. In regression analysis an equation is solved that describes a weighted combination of values on various predictor variables. This equation enables prediction of an object's value on a quantitative criterion variable given its measure on each of the predictor variables. A similar concept is employed in discriminant analysis, only here the equation is called a discriminant function. The discriminant function uses a weighted combination of predictor variables to classify an object into one of the criterion variable groups. This function is therefore a derived variable defined as the weighted sum of values on the individual predictor measurement. This derived variable is termed a discriminant score.

The general form of the discriminant function can be expressed as:

$$\lambda = \beta_1 X_1 + \beta_2 X_2 + \dots \beta_n X_n, \tag{5.2}$$

where $X_1, X_2, \dots, X_n$ represent values on various predictor variables, while $\beta_1, \beta_2, \dots \beta_n$ explain weights associated with each variable. The value λ defines an object's discriminant score. Central to the application of this technique are the defining characteristics or parameters that guide its use. These include: (1) the weights associated with each predictor variable, and (2) the critical cut-off score for assigning objects into their criterion groups. Typically, these parameters are determined in such a way as to minimize the number of classification errors.

Applying discriminant analysis involves the following steps:

1 Selecting from a tentative list of variables those that contain the most useful classificatory information.
2 Constructing the relevant disciminant functions or scores based on the selected variables.
3 Interpreting the discriminant functions in order to identify factors that reflect major group differences.
4 Examining the discriminant functions in order to study the effects of several variables on an individual's group identity.
5 Making the final classification and validating the results.

Suitability by factor methods Factor analysis describes a family of procedures for removing the redundancy from a set of correlated variables and representing these variables as a smaller set of "derived" variables or factors. Perhaps one of the more applicable derivations of this approach is the technique referred to as "principal components analysis."

Although it is not strictly a method of factor analysis, principal component analysis (PCA) is a multivariate statistical procedure used to determine the underlying dimensionality of a data set. The main objectives of the PCA transform are to:

1 Reduce the dimensionality of a data set.
2 Determine a linear combination of variables.
3 Direct the choice of meaningful variables in an analysis.
4 Assist visualization of multidimensional data.
5 Identify underlying or latent structures in data.

In the majority of applications, PCA is employed to reduce the dimensionality of a data set and produce a set of components that are uncorrelated and ordered in relation to the variance explained by the original data. Following this procedure, environmental data describing important landscape qualities can be represented as a matrix of the form:

$$\mathrm{F}_n = \begin{bmatrix} f_{1n} \cdots & f_{1p} \\ \vdots & \vdots \\ f_{mn} \cdots & f_{mnp} \end{bmatrix}$$

Where f_{1n} represent observations $1 \dots m$ with attributes $n \dots p$.

The matrix F_n can be linearly transformed to contain a set of eigen vector components $V1$. The resulting new variables, termed principal components, can be expressed according to the relation:

$$V_{ij} = a_{ij} X_1 + a_{ij} X_2 + \dots a_{ij} X_n. \tag{5.3}$$

When the input data explain geographic qualities or quantities, the components express composite spatial patterns that are defined in terms of component loadings. These loadings quantify the relationship each component shares with the underlying patterns found within the original data. The principal component transform has several characteristics that are of special interest when applied to the problem of suitability analysis. First, the total variance is preserved in the transformation. Second, the transform minimizes the mean square approximation of error. Lastly, this is the only transform that generates uncorrelated coefficients.

An important issue that influences the usefulness of PCA relates to the problem of component structure and interpretation. After the reduction of observation space has been accomplished, which initial variables contribute the greatest share in the variance is often difficult to determine. Equally difficult to explain is the overall meaning of the component patterns. Thus, regardless of the application area, it is generally impossible to specify beforehand the number or significance of the components that will emerge from PCA. Consequently, since PCA may be regarded more as an exercise in mathematical manipulation than a pure statistical procedure, its value is best judged by performance rather than by theoretical considerations. Therefore, interpretation of the resulting components, their structure and meaning relies on judgment, the use of supporting information, and careful validation.

Extensions based on artificial intelligence

The suitability analysis problem has attracted interest from a variety of fields beyond environmental planning. Several of the more promising methodological approaches to assessment have emerged from the field of artificial intelligence (Lein, 1997). One AI technology in particular has been shown to be a viable alternative to traditional methods of suitability analysis (Lein, 1990). This alternative identifies a branch of AI research referred to as "expert systems." An expert system is a computer program designed to mimic the reasoning process of a human expert in a narrowly defined subject area. Using this expert knowledge, the system can approach problems using symbolic forms of data and information processing and reach conclusions similar to those a human expert would reach. In a paper by Lein (1990), a rule-based expert system was developed and applied to the suitability assessment problem. The system was designed to incorporate the subjective-technical judgment common to the procedures discussed previously, and treat them explicitly in the assessment process. The prototype system functions as a consultative expert system and uses a backward chaining inferencing strategy. The demonstration program consists of 110 rules, 223 qualifiers, and 45 choices that guide the planner through an assessment of suitability.

The primary intent of the prototype is to assist the planner in identifying relevant information and to direct the interpretation of effects. The user of this system interacts with a knowledge-base made up of rules and facts describing the suitability of selected environmental characteristics relative to a set of potential users (Table 5.8). By responding to a series of system queries, information is returned to the user listing the alternatives that best match the environmental conditions of the site (Table 5.9).

Table 5.8 Sample rule in knowledge-based suitability system.

IF:
Proposed use is single family dwelling
AND septic system is YES
AND soil_permeability is 2.0 to 0.2 inches/hour
THEN:
Soil_limitations are moderate

Table 5.9 Sample conclusion window of suitability limitations.

Values based on 0.0 to 10.0 system	**Value**
1 flood limitations are. . . . **Severe**	**10.0**
2 groundwater limitations are. . . . **Severe**	**10.0**
3 bedrock limitations are. . . . **Moderate**	**9.0**
4 slope limitations are. . . . **Moderate**	**9.0**
5 drainage limitations are. . . . **Slight**	**8.0**

When compared to traditional methods of assessment and the limitations associated with each, the expert system becomes an attractive alternative that facilitates the synthesis of facts and qualitative experience into an automated support tool that can:

- Help clarify knowledge and effective problem-solving strategies.
- Preserve knowledge and encourage its sharing.
- Integrate knowledge and experience from several different fields.
- Apply heuristic knowledge.

A related AI technology that has been applied to the suitability analysis problems is the artificial neural network (Wang, 1994). Based on an abstraction of the human brain, an artificial neural network is a mathematical model comprised of a series of highly interconnected computational elements linked together to form a specific architecture. From this structure, information is processed according to a set of external inputs (stimuli). To demonstrate the feasibility of this approach, Wang (1994) developed a back-propagation neural network that takes as input a series of environmental variables then maps the input data to one of four suitability classes. Because neural network models are powerful pattern classifiers, the are extremely useful in situations that define high-dimensional problem spaces and complex interactions between variables. As illustrated by Wang (1994), a neural network can assess land suitability and provide classification accuracies of 80% or better. Therefore, when neural networks are compared to existing methods of analysis several advantages can be noted:

1. They can be trained to make decisions based on a more complex decision rule.
2. They are simple in structure and comparatively easy to construct.
3. They can be modified to fit other applications.

Carrying-capacity analysis

Carrying capacity has been a central concept in planning and environmental management for well over three decades (Mitchell, 1989). The concept emerged from the biological sciences, but when it is applied in the context of environmental planning, carrying capacity can be defined as the degree of human activity that a region can support at an acceptable quality of life without engendering significant environmental degradation (Bishop et al., 1974). Alternatively, Hayden (1975) and Cook (1972) have defined carrying capacity as the maximum ability of an environment to continuously provide resources at the level required by the population. Both definitions are valid and suggest that the interaction between population, development, and the local resource base is governed by thresholds or levels of intensity that will influence long-term sustainability.

Arriving at an expression of carrying capacity has traditionally relied on the subjective judgment of those familiar with the region in question, coupled with the measurement of surrogate estimators that could be related in a statistical algorithm (Lein, 1993). Applying this expression, carrying capacity can be integrated with a range of social and economic indicators to define an "optimal" level of development. Based on this optimum, the environment may remain intact relative to its potential for sustained output. When one is considering the question of measurement, connecting the concept of carrying capacity back to its biological origins helps to frame an assessment methodology.

In the biological sciences, carrying capacity defines the relationship between the resource base, the assimilative and restorative capacity of the environment, and the biotic potential of a species. The biotic potential of a species, defining the maximum rate of population growth that could be achieved given the number of females that reach and survive through their reproductive years, is the controlling variable in this relationship. Biotic potential, given adequate food supplies, living area, and the absence of disease and predation, contributes to population increases that must be balanced by the environmental system. In the ecosystem, environmental resistance regulates biotic potential by imposing limits on food supply, space, and other inhibiting factors. Within this relationship, carrying capacity emerges as the limit or level a species population size attains given the environmental resistance indigenous to its location.

Whether it is explained within a biological context or from the perspective of a planner, carrying capacity is influenced by three critical assumptions:

1. There are limits to the amount of growth and development that the natural environment can absorb without threatening environmental stability through environmental degradation.
2. Critical population thresholds can be identified beyond which continued growth will trigger the deterioration of important natural resources.
3. The natural capacity of a resource to absorb growth is not fixed.

These assumptions have led to numerous attacks on the concept and the methodologies used to derive estimates of carrying capacity. Criticism tends to focus on questions concerning the definition of threshold levels, the representation of environmental equilibrium, and the manner by which carrying capacity estimates are interpreted (Lein, 1993a). These concerns have been summarized by Hassan (1982), and recognize the fact that (1) it is difficult to calculate environmental thresholds, (2) external influences can frustrate the "closed-system" perspective and introduce uncertainty, (3) strict concern for environmental potential limits the scope of analysis when applied to human systems, and (4) assessment relies heavily on subjective-professional judgment.

While the practical problems listed above conspire to frustrate the simple estimation of carrying capacity, the concept remains a useful applied methodology largely for its facility for:

- Raising questions about development strategies.
- Providing insight regarding the relationship between environmental degradation and human activities.
- Assisting in setting priorities in response to growth pressures.

Therefore, as Lein (1993a) maintains, the philosophical appeal and heuristic value of the carrying-capacity concept compensates for the pragmatic difficulties encountered with its application.

The majority of methods designed to assess carrying capacity (C) employ a deterministic solution to the general relation:

$$C = f(\text{potential resources, technology}).$$

Two central conditions are implied by this relation and influence the manner by which carrying capacity estimates are derived: (1) identification of a growth variable, and (2) identification of a limiting factor. A growth variable can represent either population or a measure of human activity such as the number of new dwelling units per year or the number of park visits per day (Ortolano, 1984). Limiting factors may include natural resources, physical infrastructure, or other finite elements that may restrain growth as a function of available technology. Limiting factors applied in carrying-capacity assessments help define three general expressions of the concept and direct its application to problems where such measures can provide meaningful information. Three useful expressions of carrying capacity are:

1 **Environmental carrying capacity** – defined by biophysical characteristics (variables) including measures of air and water quality, ecosystem stability, and soil erosion. These variables define thresholds such as emission standards, BOD, and net primary productivity, that can be measured and linked by theory or empirical evidence to specific consequences. Employing these measures allows careful examination of the assimilative capacity of the environment and the ability of environmental "sinks" to accommodate change.

2 **Physical carrying capacity** – describing the capacity of infrastructure such as roads, highways, water supply systems, landfills, etc., to maintain an acceptable level of performance under population growth and development pressures. Because physical infrastructure is designed with specific capacity levels in mind, growth forces can exceed the predetermined optima and result in a degradation of performance and environmental quality.

3 **Psychological carrying capacity** – directs focus to the social environment and explains the role perception, attitude, behavior, and culture play in the way people react to their surroundings. Embedded in this expression are cultural and psychological factors that influence individual behavior and responses to the quality and condition of amenity resources, recreational area, institutional settings, and the aesthetic aspects of the environment.

Making carrying capacity work

Admittedly, carrying capacity, while it is intuitively appealing, is difficult to implement. However, it can be used to help formulate plausible alternative scenarios for how a region may develop or to refine a basic understanding of possible environmental constraints. To operationalize an exercise in carrying capacity analysis it is necessary to:

1. Identify the relevant growth variables and limiting factors.
2. Establish minimum and maximum values for each limiting factor.
3. Derive a quantitative link between limiting factors and growth variables based on either mathematical models, empirical relationships, or expert judgment.
4. Develop growth scenarios to explain (characterize) the dynamics of the processes involved.
5. Estimate the restrictions imposed by each limiting factor on the growth variable(s).
6. Review carrying-capacity estimates and refine methods as needed until results communicate constraint effectively.

Although the procedures for applying the concept to environmental planning are still evolving, Ortolano (1984), Mitchell (1989), and Westman (1985) have reviewed several useful examples.

Summary

Before decisions can be made regarding the future state of the planning area, information pertaining to the region must be collected, assembled, and analyzed. Because planning is an information-driven activity, methods to manage information and direct its use are critical to successful plans. In this chapter the collection and analysis of landscape information was examined. Drawing on the basic principles of regional landscape analysis and the formulation of a natural resource inventory, this chapter described how land evaluation methods can be applied by the environmental planner and how this information can be used to balance human development with the large goal of maintaining environmental functioning. The principal methods examined were land capability, developmental suitability, and carrying-capacity analysis; and the ability of each to provide an expression of landscape opportunity or constraint was evaluated.

Focusing questions

What does it mean to inventory a site and what does an inventory communicate?

Define the process of land evaluation and discuss the two basic types of land evaluation method.

What is the ultimate goal of developmental suitability assessment methods and what are the limitations associated with rating and weighting techniques?

How do the terms suitability and capability differ, and what does this difference mean?