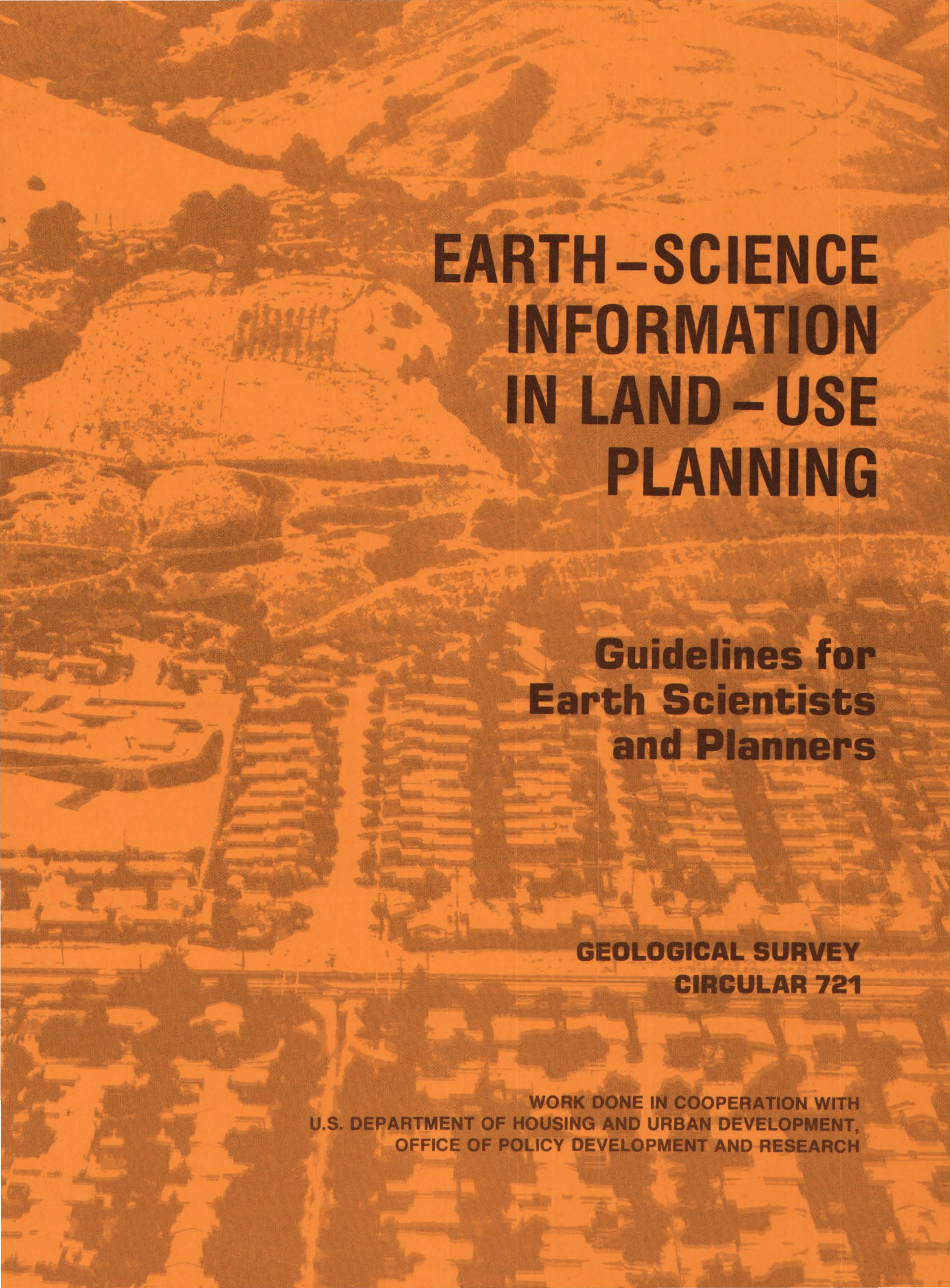

EARTH-SCIENCE INFORMATION IN LAND-USE PLANNING

Guidelines for Earth Scientists and Planners

GEOLOGICAL SURVEY
CIRCULAR 721

WORK DONE IN COOPERATION WITH
U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT,
OFFICE OF POLICY DEVELOPMENT AND RESEARCH

Earth-Science Information in Land-Use Planning—Guidelines for Earth Scientists and Planners

By William Spangle and Associates; F. Beach Leighton and Associates; and Baxter, McDonald and Company

GEOLOGICAL SURVEY CIRCULAR 721

Jointly supported by the U.S. Geological Survey
and the Department of Housing and Urban Development,
Office of Policy Development and Research,
as a part of a program to develop and apply earth-science
information in support of land-use planning and decisionmaking

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FOREWORD

This report is a product of the San Francisco Bay Region Environment and Resources Planning Study, an experimental program that is designed to facilitate the use of earth-science information in regional planning and decisionmaking. The study is jointly supported by the U.S. Geological Survey, Department of the Interior, and the Office of Policy Development and Research, Department of Housing and Urban Development. The Association of Bay Area Governments participates in the study and provides a liaison and communication link with other regional planning agencies and with county and local governments.

Although the study focuses on the nine-county 7,400-square-mile San Francisco Bay region, it bears on an issue that is of national concern. This issue—how best to accommodate orderly development and growth while conserving our natural resource base, insuring public health and safety, and minimizing degradation of our natural and manmade environment—is difficult and complex. The complexity, however, can be greatly reduced if we understand the natural characteristics of the land, the processes that shape it, its resource potential, and its natural hazards. These subjects are chiefly within the domain of the earth sciences: geology, geophysics, hydrology, and the soil sciences. Appropriate earth-science information, if available, can be rationally applied in guiding growth and development, but the existence of the information does not assure its effective use in the day-to-day decisions that shape development. Planners, elected officials, and the public rarely have the training or experience needed to recognize the significance of basic earth-science information, and many of the conventional methods of communicating earth-science information are ill suited to their needs.

The study is intended to aid the planning and decisionmaking community by (1) identifying important earth-science problems related to growth and development in the bay region, (2) providing the earth-science information that is needed to solve these problems, (3) interpreting and publishing findings in forms understandable to and usable by nonscientists, (4) establishing new avenues of communication between scientists and users, and (5) exploring alternate ways of applying earth-science information in planning and decisionmaking.

Since the study was started in 1970, it has produced more than 70 reports and maps. These cover a wide range of topics: reduction of flood and earthquake hazards, unstable slopes, engineering characteristics of hillside and lowland areas, mineral and water resources management, solid and liquid waste disposal, erosion and sedimentation problems, bay water circulation patterns, and others. The methods used in the study and the results it has produced have elicited broad interest and a wide range of applications from planners, government officials, industry, universities, and from the general public.

This report, "Earth-Science Information in Land-Use Planning," results from a nationwide sampling of applications of earth-science information to urban land-use planning. It is intended to acquaint planners and earth scientists with the needs and problems each faces in working with the other. To identify and evaluate these, the authors of the report examined earth-science applications in several urbanizing regions in different parts of the United States. Although the problems, methods, and political structure differ in each of these regions, many needs and problems that were found frequently appeared to be general in nature and of fundamental importance to communication between planners and scientists.

The report is a summary and is structured as a series of recommendations that are based on current methods and practices in those parts of the United States where earth-science information has been used successfully in planning. These recommendations are offered not as a set of directives, but as guidelines that provide a starting point for planners and earth scientists who wish to work together more effectively.

Because the use of the earth-science information in planning is evolving rapidly and because needs and practices differ from one planning jurisdiction to the next, no single set of guidelines can be final and definitive. Both planners and scientists may wish to view the guidelines given here as a set of postulates to be tested and refined against the background of their own experience.

Robert D. Brown Jr.
Project Director
San Francisco Bay Region Study

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Earth-Science Information in Land-Use Planning—Guidelines for Earth Scientists and Planners

By William Spangle and Associates; F. Beach Leighton and Associates; and Baxter, McDonald and Company

INTRODUCTION

The principal question facing those responsible for land-use decisions is clearly expressed in the recently published report of the Task Force on Land Use and Urban Growth created by the President's Citizens' Advisory Committee on Environmental Quality (1973, p. 14) and funded by the Rockefeller Brothers Fund:

> How shall we organize, control, and coordinate the process of urban development so as to protect what we most value in the environmental, cultural, and aesthetic characteristics of the land while meeting the essential needs of the changing U.S. population for new housing, roads, power plants, shopping centers, parks, businesses, and industrial facilities?

The land itself is a resource that must be used with wisdom. The needs of our growing population require that we conscientiously plan for the use of land, not only to protect its resources and esthetic values but also to reduce the exposure of urban development to natural hazards by giving explicit consideration to natural conditions and processes in land-use decisions. In this task, the work of the planner and the earth scientist can be mutually reinforcing.

From the earliest times the natural environment has influenced the location and form of human settlement (fig. 1). The land and its features present, in varying degrees, opportunities and constraints for various human activities. As expressed by Robert F. Legget (Legget, 1973, p. 70–71),

> When planning starts, for urban community or region, 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 it is rather an environment that has been exposed for a very long period to the effects of many natural modifying factors***. Development of new communities and the charting of regional development must, therefore, take account of this fundamental organic and dynamic character of Nature so that the works of man may fit as harmoniously as possible into the environment***

To achieve harmonious blending of man's works and nature requires knowledge of resources to be developed and conserved and awareness of hazards to to be avoided or mitigated. Information from the earth sciences is thus essential. Earth-science information (ESI) pertains to the natural materials, features, and processes of the land. It includes basic information from geology, soils, hydrology, and a large number of related scientific and engineering fields, together with interpretations of that basic information. ESI thus encompasses much of the information concerning the physical nature and interactions of land and water. Because of the focus of the study, and these guidelines, information from chemical and biological sciences, meteorology, and climatology is not considered, although it, too, is highly relevant to land-use planning.

This circular presents and discusses a set of general guidelines for utilizing ESI in land-use planning (table 1). The guidelines concern subject areas of interest to both planners and earth scientists. Planners should find the report useful as a brief introduction to the kinds and sources of ESI available and to techniques for applying ESI to planning. For earth scientists, the report defines in broad terms the needs of planners and how ESI can be made more useful to planners. The report is intended to stimulate the development of effective communication between planners and earth scientists.

The main purpose of this report, however, is to introduce decisionmakers and interested citizens to the potential uses of ESI in a planning program. The desires of the community as perceived by decisionmakers are frequently reflected in land-use decisions. Both planners and earth scientists

FIGURE 1.—Suburban development extending into the hills in Hayward, Calif. The natural constraints and opportunities should be evaluated before further development of these hillsides.

TABLE 1.—*General guidelines for utilizing earth-science information in land-use planning*

ESI in the planning process
- ESI should be integrated into all phases of the land-use planning process (see section "ESI in the Planning Process").

Sources, types, and interpretation of ESI for planning
- Planning agencies can obtain ESI from a variety of sources (see section "Sources of ESI").
- Scale, accuracy, and detail of the ESI required for planning vary according to jurisdictional level, environmental diversity, and rate of development of the area (see section "Scale, Accuracy, and Detail of ESI").
- Planners should be aware of the limitations of data and any qualifications placed on its use and accuracy (see section "Limitations and Qualifications on ESI").
- Basic ESI concerning topography, geology, soils, and hydrology is fundamental to any land-use planning effort (see section "Types of ESI for Planners").

- Planners need ESI relevant to, and in a form suitable for, application in land-use planning (see section "ESI in a Form Usable by Planners").

Planning for natural resources
- Ideally, planning for the wise use of natural resources at the state, regional, and local levels should be consistent with national policies on resource conservation and development (see section "Need for National Policies").
- Natural-resource planning is a necessary function of agencies at all jurisdictional levels with land-use planning responsibilities (see section "Natural-Resource Plans").
- Proposals involving resource conservation and development should be subjected to both environmental and economic impact analyses (see section "Environmental and Economic Impact").

TABLE 1.—*General guidelines for utilizing earth-science information in land-use planning*—Continued

Planning for reduction of natural hazards
- Hazardous areas should be identified and evaluated for level of risk (see section "Identification of Hazardous Areas").
- Alternative measures to mitigate hazards should be evaluated for both environmental and economic impacts (see section "Impacts of Hazard-Mitigation Methods").
- Selection of measures to mitigate hazards should be consistent with acceptable levels of risk (see section "Mitigation Methods and Acceptable Risks").

Integration of ESI in planning process
- Land-capability studies to evaluate natural opportunities and constraints are basic to the integration of ESI in land-use planning (see section "Land-Capability Studies Basic to Land-Use Planning").
- Successful integration of ESI in land-use planning requires the establishment of a close working relationship between planners and earth scientists (see section "Interdisciplinary Relationships").
- Public participation in decisionmaking should be encouraged throughout the planning process to insure effective results (see section "Public Participation").

can be expected to respond to public pressures for land-use planning that recognizes natural opportunities and constraints.

This circular is a condensation of a technical report prepared after a 14-month study funded by the U.S. Department of the Interior, Geological Survey, and the Department of Housing and Urban Development, Office of Policy Development and Research. The study, called "Application of Earth-Science Information in Urban Land-Use Planning—State-of-the-Art Review and Analysis," investigated the experience of selected city, county, and regional agencies in the application of earth-science information to land-use planning.

The study was undertaken by a multidisciplinary team composed of professionals in urban and regional planning, the earth sciences, and public administration. The team members interviewed planners and earth scientists across the country in agencies identified as making effective use of ESI in their planning programs. From this investigation, an understanding of conditions favoring the use of ESI in land-use planning was developed. The reader is referred to the full technical report for more detailed discussion of the material presented in this summary (Spangle and others, 1973).

GUIDELINES FOR UTILIZING EARTH-SCIENCE INFORMATION IN LAND-USE PLANNING

ESI IN THE PLANNING PROCESS

Land-use planning is an integral part of a broader planning process variously termed comprehensive, general, or master planning. Whereas comprehensive planning treats the future development of an area in terms of all major determinants of growth and change—economic, political, social, and physical—land-use planning highlights the physical expression of the plan on the land. As such, it is primarily concerned with the arrangement and types of land uses, their impact on the landscape, and relation to transportation and community facilities and utilities.

The land-use planning process consists of five conceptually distinct phases: (1) identification of problems and definition of goals and objectives; (2) data collection and interpretation; (3) plan formulation; (4) review and adoption of plans; and (5) plan implementation. Figure 2 depicts the land-use planning process and lists typical studies and documents associated with three phases. As shown by the arrows, each phase is interrelated with all others, and the sequence, while logical, is often varied especially in response to crises, political opportunities, or legal requirements. Interaction among the phases, however, should be virtually continuous. Plan formulation often indicates the need for additional information, and additional information may alter the concept of the objectives and problems; moreover, plan implementation may reveal the need for additional information or modification of the plan.

Public initiative and response is a key part of every phase of land-use planning. "Public" may refer to elective political bodies, special-interest groups, or interested individuals. Elected public officials have final responsibility for most key policy decisions, although persons in nonelective positions actually make many important day-to-day decisions. Decisions occur throughout the process, ranging from the decision to engage in a planning effort to the final approval of a plan and adoption of implementing regulations, programs, and procedures.

ESI is necessary in each phase of the land-use planning process. The following outline lists the basic steps for integrating ESI in each phase of

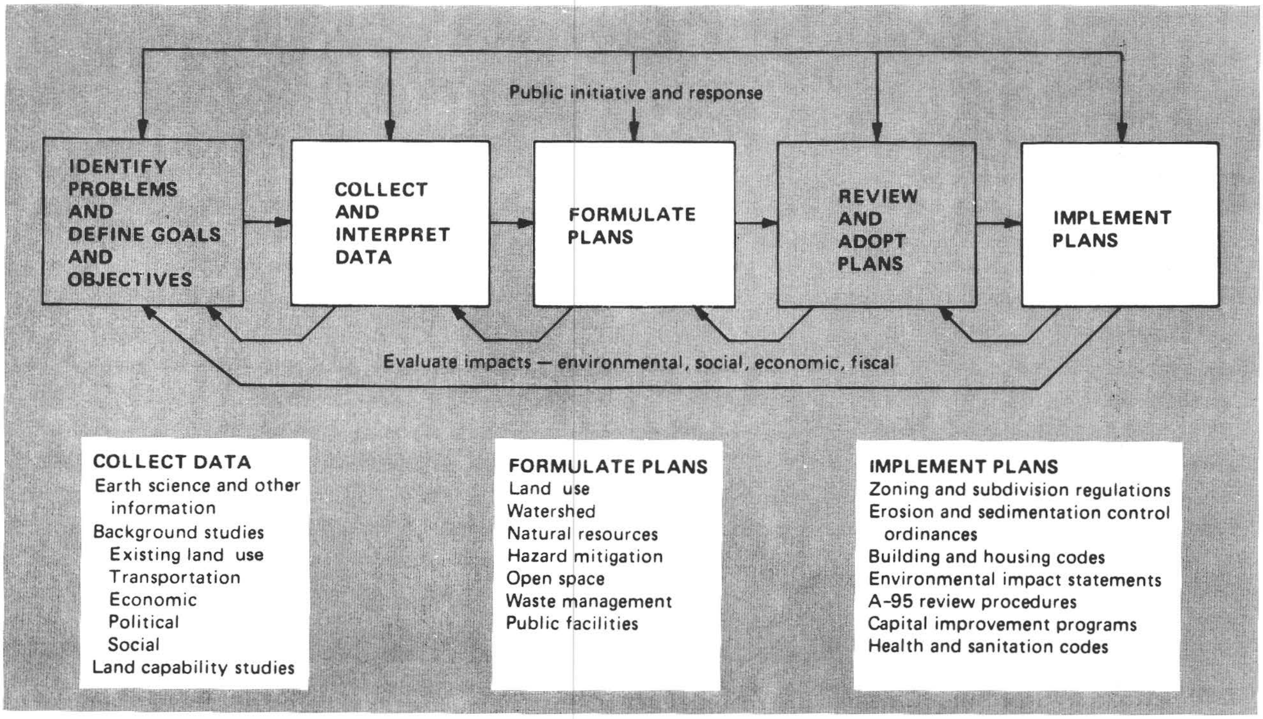


FIGURE 2.—Diagram of the land-use planning process.

land-use planning; planners and earth scientists should work together in carrying out each step:

1. Identify problems and define goals and objectives.
   a. Obtain readily available ESI for preliminary identification of natural hazards and resources.
   b. Review this ESI in relation to existing land-use plans and policies, projected growth trends, and anticipated changes to develop a tentative set of objectives and priorities, giving special consideration to hazards and resources.
2. Collect and interpret data.
   a. Develop a program for utilizing available ESI and compiling new data.
   b. Arrange with earth scientists to prepare basic and interpretive maps and texts. Map information should relate in scale and detail to other basic planning information.
   c. Estimate the probable future demand for land considering projections of population growth and distribution, economic activity, social and cultural needs, and transportation requirements.
   d. Prepare land-capability maps showing the natural capability of each land unit to accommodate each potential use.
3. Formulate plans.
   a. On the basis of land-capability maps, appropriate projections, and economic, social, and political analyses, consider feasible alternative arrangements of land uses.
   b. Evaluate alternative land-use possibilities, selecting the most desirable.
   c. Prepare a land-use plan incorporating as much detail as necessary to serve as a basis for decisionmaking.
   d. Evaluate land-use proposals for environmental, economic, and social impacts. Make any indicated revisions in the plan.
4. Review and adopt a plan. Obtain official approval of plan from public decisionmaking bodies.
5. Implement the plan.
   a. Prepare and seek adoption of land-use regulations and any land-acquisition and capital-improvement programs needed to carry out the plan.
   b. Establish guidelines and a procedure for

conducting the earth-science investigations needed to evaluate each development proposal.

c. Develop procedures and staff capability for reviewing soils and geology reports, environmental impact assessments, and project proposals.

d. Arrange for modification of previous steps as new or more detailed ESI becomes available.

SOURCES, TYPES, AND INTERPRETATION OF ESI FOR PLANNING

SOURCES OF ESI

A variety of agencies at all jurisdictional levels in the United States produce ESI (table 2). Two Federal agencies—the United States Geological Survey (USGS), Department of the Interior, and the Soil Conservation Service (SCS), Department of Agriculture —are prime sources of information, and their publications are widely available throughout the country.

The USGS has a broad research base in the earth sciences covering work in topography, geology, and mineral and water resources. Major offices in Reston, Va., Denver, Colo., and Menlo Park, Calif., have professional staffs and extensive facilities for basic earth-science research. The USGS is specifically charged with the preparation of topographic and geologic quadrangle maps of the United States. The Water Resources Division of USGS (with district offices throughout the United States) produces basic hydrologic data, inventories the nation's water supply, monitors its quality, and engages in other hydrologic research.

The USGS recently has placed an increased emphasis on production of ESI specifically applicable to planning and decisionmaking. Through a series of pilot projects, studies have been undertaken to interpret basic ESI in terms of its implications for various land uses. These products are particularly useful to planners.

The SCS is responsible for many soil and water conservation programs throughout the United States. Over 3,000 soil conservation districts established under enabling legislation in all 50 states are served by SCS field offices, each headed by a "district conservationist." District boundaries in most cases conform to county lines.

The SCS field offices are staffed largely by soil scientists involved primarily in classifying soils and evaluating their suitability for agricultural purposes. Because soil classifications have some engineering significance and because much agricultural land has been converted to urban and suburban uses, SCS products are often used in land-use planning. For this reason, and as agricultural applications of SCS products have been satisfied, SCS soil scientists are increasingly orienting their work to the needs of urban and regional planners.

The decentralization of work by the SCS brings its soil conservationists into close personal contact

TABLE 2.—*Some sources of earth-science information*

- Federal agencies
  - U.S. Department of the Interior
    - Geological Survey
    - Bureau of Mines
    - Bureau of Reclamation
    - Bureau of Land Management
  - U.S. Department of Agriculture
    - Extension Service
    - Soil Conservation Service
    - Forest Service
  - U.S. Department of Commerce
    - National Oceanic and Atmospheric Administration
  - U.S. Department of Army
    - Army Corps of Engineers
  - Energy Research and Development Administration
  - Environmental Protection Agency
  - National Aeronautics and Space Administration
  - Tennessee Valley Authority
- State divisions or departments
  - Agriculture
  - Conservation
  - Forestry
  - Geological Surveys
  - Oil and Gas
  - Soil Conservation
  - Fish and Game
  - Water Resources
  - Water Quality
  - Mineral Resources
  - Colleges and universities
- County or city departments or special districts
  - Planning
  - Water
  - Flood Control
  - Agriculture
  - Parks and Recreation
  - Engineering
  - Building and Safety
  - Public Works
- Private producers
  - Consulting firms
  - Private colleges and universities
  - Professional societies
  - Industries with in-house capabilities

with local persons and agencies requiring technical assistance. Each SCS district responds to local needs and circumstances, leading to considerable innovation and flexibility in presenting and interpreting soil data. Such data are of particular value in assessing foundation conditions and supporting systems near the surface for light structures such as single-family residences, utilities, and streets. Where foundation conditions at greater depths are of concern and natural processes such as landslides may be active, soil data can be a helpful supplement to the geologic and hydrologic information needed to characterize problem areas.

State geological surveys can be important sources of ESI for planners. These agencies may undertake geological surveys, publish statewide earth-science maps, and serve as information bureaus for the people of the state. All states, except Rhode Island, have geological surveys, but staff size, facilities, organizational structure, and areas of emphasis vary considerably from state to state.

Many state governments also have departments or divisions that are responsible for soil and water conservation. Such a department or division may work largely through the state SCS office or may act independently in developing a separate program of its own. It may be an excellent source of ESI related to soil and water resources.

Earth-science departments at public and private universities and private consultants are other sources of ESI. If the need is for fairly detailed data related to a specialized problem or particular site, a special study will ordinarily be required.

SCALE, ACCURACY, AND DETAIL OF ESI

A major consideration in building a data base of ESI for land-use planning is the relationship of scale, detail, and accuracy to an agency's planning responsibilities and requirements. There is often misunderstanding over the fact that scale, accuracy, and detail do not refer to the same thing and may not even be related to each other in a consistent manner.

Map scale is the relationship between corresponding distances on a map and on the earth. A scale of 1:24,000 means that 1 map-inch is equivalent to 24,000 inches on the ground. Planners would normally translate this to 1 map-inch is equivalent to 2,000 feet. A map's scale is considered "small" if the second figure of this ratio is "large"; a scale of 1:62,500 is thus smaller than a scale of 1:24,000 (fig. 3). A small-scale map does not usually show as much detail as a large-scale map (fig. 4).

Accuracy has two distinct meanings. First, it refers to whether the information is right or wrong. Accurate information is correct, free from error. Second, accuracy in a relative sense refers to the degree of precision with which the information was obtained, measured, and recorded.

Although scale and accuracy are important in planning, obtaining data of an appropriate level of detail for the task at hand is usually the most significant informational concern of the planner. Confusion occurs when the common but sometimes unwarranted assumption is made that a large-scale map (say of scale 1:24,000) shows more detail and is more accurate than a small-scale map (say of scale 1:125,000). The planner who indicates a need for "larger scale" may really mean that he needs more detailed or more accurate maps. A map may easily be enlarged to a larger scale, but the enlargement process will result in a map no more detailed nor accurate than the original. Enlarging a map may, however, render detail already present in the original more legible and hence make it more useful. Data plotted on the enlarged map cannot be located any more accurately than on the small-scale map. In fact, the enlarged map does not have the accuracy of a map prepared specifically at the enlarged scale.

The term "map detail" refers to the amount of information presented in a given map area—the more information per map unit, the more detailed the map. Map production techniques and legibility requirements impose physical limits on the level of detail that can be shown on a map of a given scale. Within these limits, however, two maps of identical scale may present data with different levels of detail.

Successful application of ESI to land-use planning requires that ESI be available in sufficient detail to meet the planning needs of an agency. The level of detail required varies in a general way with the jurisdictional level and phase of the planning process. The need for detailed data in plan formulation is generally hierarchical with respect to governmental level; that is, more detailed data are needed at the local level than at the state or national level. More detailed data are ordinarily required for plan implementation regardless of jurisdictional level. Administration of

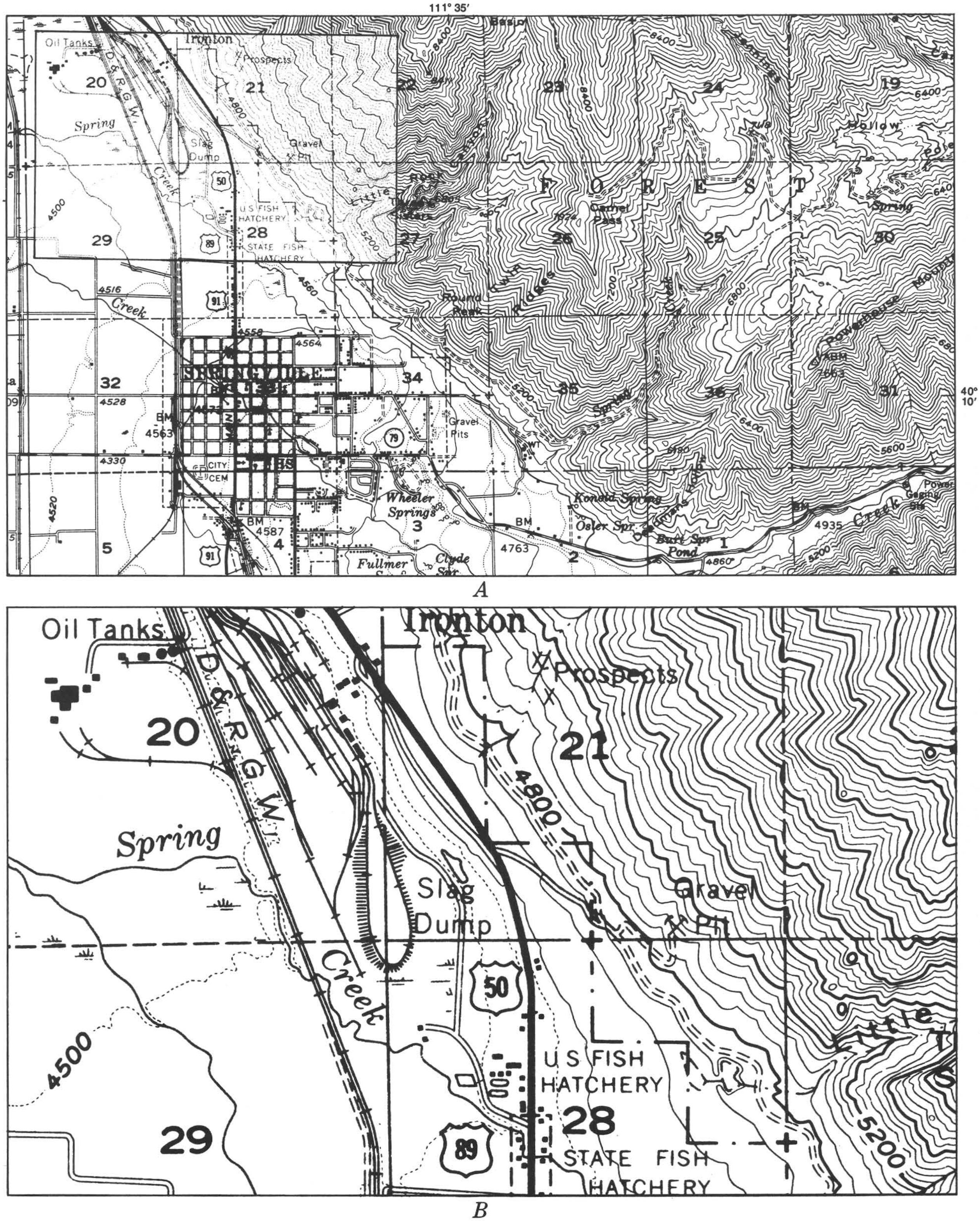


FIGURE 3.—The top map is a basic topographic map at a scale of 1:62,500 (Provo quadrangle, 1949). The bottom map is a part of the top map enlarged to a scale of 1:24,000. The enlarged map has no greater detail and is no more accurate than the smaller scale map.

FIGURE 4.—Three geologic maps that differ both in scale and amount of detail. *A*, Part of geologic map of Palo Alto 7.5-minute quadrangle, California, scale 1:24,000 (Pampeyan, 1970). *B*, The same area at a scale of 1:62,500 (Dibblee, 1966). *C*, The same area at a still smaller scale, 1:250,000 (Jennings and Burnett, 1961).

land-use regulations ultimately depends on decisions made at the site level where the need for detail is greatest.

The level of detail of ESI needed also depends on the environmental diversity of the planning area. It is generally true that the more varied the natural environment of a planning area, the more detailed its ESI requirements. Generalized data on geology, soils, and hydrology may be sufficient for land-use planning in relatively flat agricultural areas of the Midwest where similar natural conditions may prevail throughout the planning area. In parts of California, on the other hand, many single planning jurisdictions include mountains, coastsides, deserts, and valleys with a great variety of geologic conditions. The very diversity of terrain poses planning constraints and opportunities that can be identified only with detailed information.

The present and anticipated rate of development within a jurisdiction also determines its ESI requirements. Generalized ESI is usually sufficient for areas that are relatively unchanging, clearly inaccessible, or otherwise undesirable for urban development. Detailed ESI is needed in rapidly growing areas for effective, almost daily, evaluation of project proposals. In areas where growth pressures are especially strong, development may be guided primarily by the economic judgments of private landowners without regard for the natural features of the land. When an area is under growth pressure, the planner needs great persistence and accurate and detailed ESI to insure consideration of earth-science factors in land-use decisions.

LIMITATIONS AND QUALIFICATIONS ON ESI

Planners should always read the notes on an ESI document before use. They may discover, for instance, that there is considerable variation in the precision or completeness of data for different parts of the same map. Inaccessible areas may be less thoroughly mapped than accessible ones; important assumptions may have been made about the relationship of certain features; or the data may have been derived from different sources. Such information should always be included with a map or report, and a planner should always heed it. The disclaimer in figure 5 is part of the legend provided by the California Division of Mines and Geology for a recently issued map on special studies zones for the State of

WOODSIDE QUADRANGLE

IMPORTANT – PLEASE NOTE

1) *This map may not show all potentially active faults, either within the special studies zones or outside their boundaries.*

2) Faults shown are the basis for establishing the boundaries of the special studies zones.

3) The identification of these potentially active faults and the location of such fault traces are based on the best available data. Traces have been drawn as accurately as possible at this map scale, however, the quality of data used is highly varied. The faults shown have not been field checked during this map compilation.

4) Fault information on this map is not sufficient to serve as a substitute for information developed by the special studies that may be required under Chapter 7.5, Division 2, Section 2623 of the California Public Resources Code.

FIGURE 5.—Example of a qualifying note on a geologic hazard map (State of California, 1974).

California. The disclaimer makes it clear that for most planning purposes, supplementary information will be necessary.

The planner must also note the scale and detail of a map. For instance, a highly generalized landslide map at a regional level may show an entire mountainside as being in a high landslide-susceptibility category, whereas additional, more detailed information may reveal a range of conditions including stable areas within the more generalized hazardous areas.

The degree of specificity of a planning decision should be no greater than warranted by the data upon which it is based. Planners, in seeking firm data on which to base decisions, may risk placing undue reliance on ESI that is too generalized for their purpose. The planner is well advised to write plans or regulations to accommodate more specific data as they become available. For example, the Portola Valley, Calif., zoning ordinance (Article II, Section 6209.2) prohibits structures for human occupancy within 50 feet of a "known" fault trace and 100 feet of an "inferred" fault trace. The ordinance provides that "when geologic studies acceptable to the Planning Commission identify an 'inferred' segment of a trace at a level of accuracy equivalent to previously mapped 'known' traces, such fault trace segments shall be automatically reclassified as a 'known' location."

TYPES OF ESI FOR PLANNERS

The standard Geological Survey topographic map in the quadrangle series is one of the most basic and valuable sources of ESI and is of great use as a planning tool (fig. 3). It not only shows terrain features, such as the shape and elevation of the land, and cultural features, such as transportation networks and areas of urbanization, but also serves as a good base map on which to record both earth-science and planning information. Topographic maps are readily available for most areas of the United States at very modest prices. With these maps, the knowledgeable planner can, among other things, calculate slope, inventory surface water resources, identify some obviously hazardous areas, and make a good preliminary assessment of where land-use conflicts may occur.

In addition to standard topographic maps, the Geological Survey is now producing orthophotoquads and hopes to have within the next few years complete coverage of all conterminous areas of the United States that are not already mapped at 1:24,000 scale. An orthophotoquad is a vertical aerial photograph in quadrangle format, corrected for position distortion related to differences in elevation and camera angle. A planimetrically accurate and detailed photoprint is produced providing planners with geographic and topographic information (with the exception of contours and elevations) more quickly than is possible with a standard topographic map. The Survey also has orthophotoquads overprinted with contours and elevations for some areas.

Geologic maps show the kinds, distribution, and some physical characteristics of geologic units at or near the earth's surface and can be especially useful to planners when supplemented by engineering and planning interpretation. Areas susceptible to such geologic hazards as faults, landslides, and subsidence can be identified from these maps. The most commonly used basic geologic maps are 1:24,000-scale geologic quadrangle maps published by the Federal and state geological surveys (fig. 4A). These may be supplemented by more detailed information available from local sources. Other important sources of geologic maps are listed in table 2.

Soil classification maps show the distribution of different types of surface soils (fig. 6). The Soil Conservation Service soils surveys, which provide information pertaining to the upper 5–6 feet of earth materials, are widely used by planners. SCS publications may also include tabulations of basic data and interpretation of the data. Recent soil surveys provide soil ratings (limitations and capabilities) for a variety of agricultural, urban, and engineering uses. Soils information is frequently more readily available to planners than many other categories of ESI. When used in conjunction with geologic, hydrologic, and engineering data, it provides the basis for many studies on the natural limitations and potentials of the land for particular uses.

Data describing the hydrologic system of an area are always needed for land-use planning. Available from the Geological Survey, state and local water resources agencies or local flood-control and water districts, hydrologic maps depict the character of, and interrelationships between, surface and ground-water resources (fig. 7). They are useful for delineating and evaluating water supply, flood-prone areas, water quality, areas of potential subsidence, seepage areas, and areas where erosion or sedimentation is a potential problem.

FIGURE 6.—A typical soils map from southeastern Wisconsin. Map furnished by courtesy of Southeastern Wisconsin Regional Planning Commission.

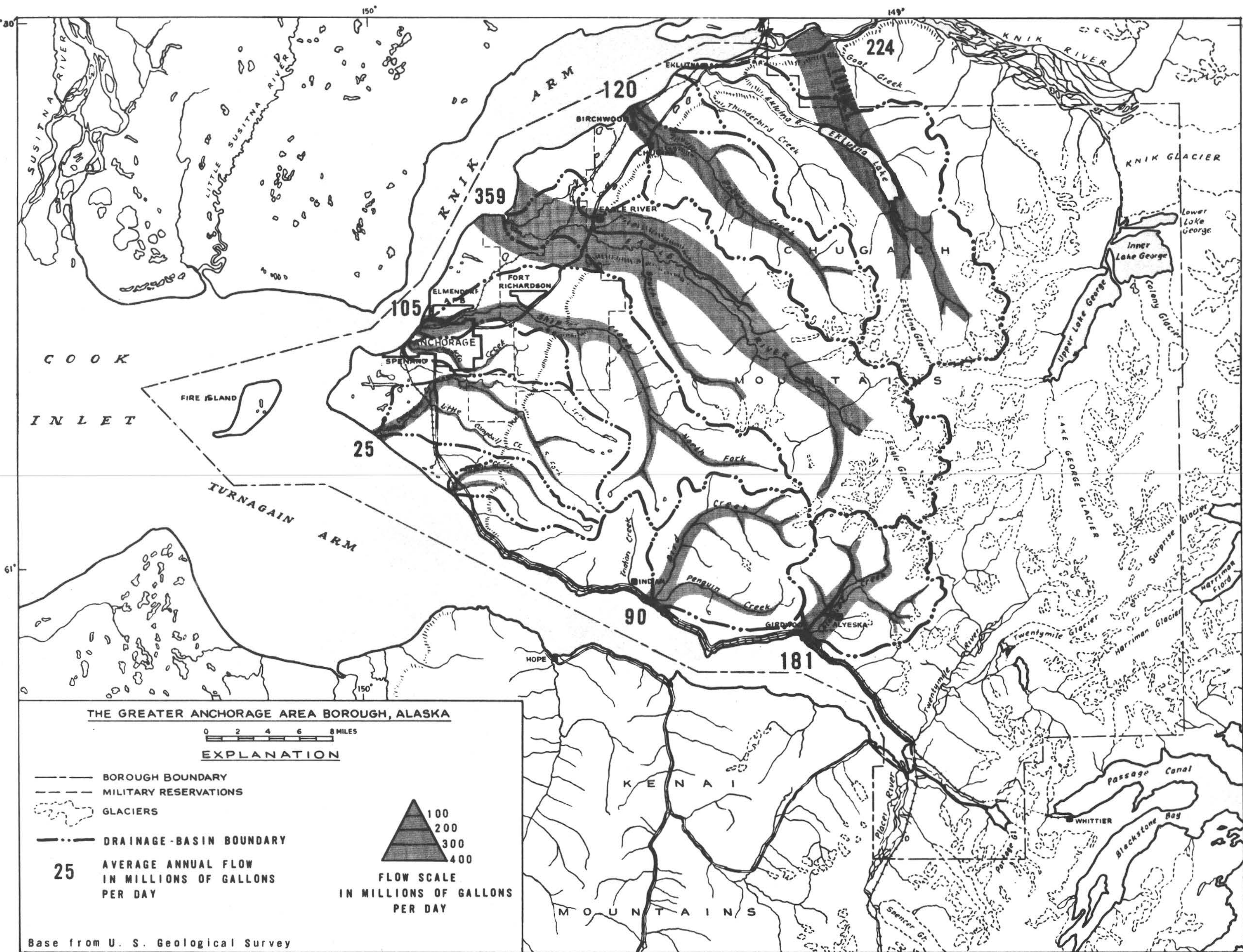


FIGURE 7—A typical hydrologic map from Greater Anchorage Area Borough, Alaska (Barnwell and others, 1972, p. 25).

ESI IN A FORM USABLE BY PLANNERS

Earth-science data applicable to land-use planning are often presented in map form. These maps may contain only basic data, or they may provide interpretive material as well. Actually, no sharp break separates basic and interpretive data. There is, instead, a continuum of information ranging from the very basic, such as bedrock material, to the highly interpretive, such as relative slope stability. When a planner says interpretive data are needed, he means, in a general sense, that a description of a natural feature or process is not very helpful to him unless accompanied by information concerning its probable behavior under certain natural and manmade conditions or by the implications regarding capability of land to accommodate particular uses.

An example from an environmental geologic study of the Santa Cruz Mountains in California illustrates this point. Basic geologic units mapped for the Santa Cruz Mountains were combined into six categories of relative geologic stability (D, H, L, P, S, W) and mapped. Each category was described in terms of its basic geologic composition and nature. For example, category "S" is described as "Unconsolidated to semi-consolidated sand and gravel, locally clay rich, interbedded with clay, Quaternary-Tertiary age. Unconsolidated alluvium, Quaternary age, ranges from P to S categories ($QT_{sc_{sc}}$, QT_{sc_s}, QT_{sc_u}, Qoal, Qal)" (Rogers and Armstrong, 1973). Such a geologic description becomes meaningful to a planner only when its implications are spelled out. The same map category ("S") is interpreted for "anticipated response to earthquakes" in the following terms: "Ground shaking—slightly more intense than L category, possible severe shaking in water-saturated Qoal and Qal; ground failure—landslides may occur as in H category and in poorly consolidated units along steep margins of stream channels. Severe lurch cracks may occur in water-saturated Qoal and Qal (as near Congress Springs in the 1906 earthquake)."

Interpretations such as this give the planner a feel for the specific nature of the problem involved on land containing these geologic units. Maps combining data on several natural conditions to provide interpretations related to complex natural processes can be particularly useful to the planner. One such example is a landslide-susceptibility map of another part of the Santa Cruz Mountains (fig. 8) that synthesizes information from geology, slope, and landslide inventory maps (Brabb and others, 1972). Such a map is a very important planning tool, useful both in developing land-use policy and plans and in identifying areas that require detailed site investigation.

PLANNING FOR NATURAL RESOURCES

NEED FOR NATIONAL POLICIES

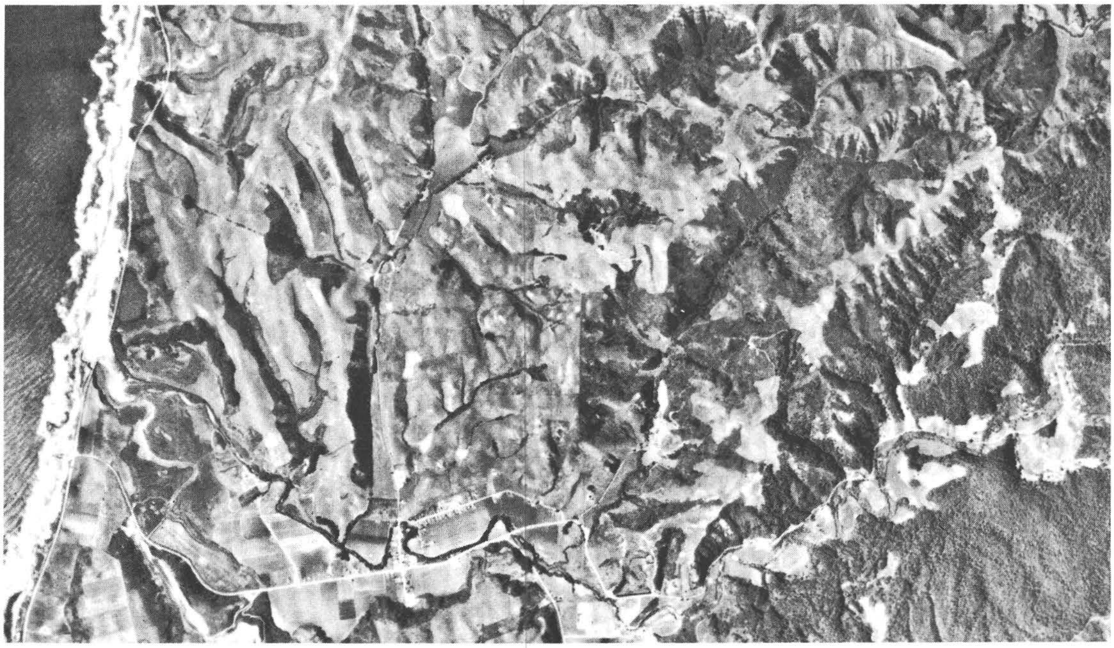
Natural resources include earth materials such as minerals, soil, and water that are either consumed or altered by man. The combination of growing population and rising per capita consumption is leading to the real possibility of serious shortages of essential nonrenewable natural resources in the not-too-distant future. As a nation, we have not developed a systematic, comprehensive approach to resource planning. Planning and regulatory authority are dispersed; costs and benefits—both environmental and economic—fall unevenly on different jurisdictions and communities; and mechanisms for resolving basic conflicts over whether or not to develop a particular resource are lacking.

There is need for broad, national policies to guide state and local jurisdictions in making land-use decisions related to resources. Except for the most widespread resources, the questions of adequacy and quality of resource supply are national, even global, concerns, while the direct environmental impacts from extraction are often localized. For instance, a decision to strip mine for coal may be a logical response to the growing national demand for energy, but the attending destruction of the land and loss of air quality may have a devastating local impact. Resource planning must address both the broad question of need and the more localized question of environmental impact.

The adequacy of known resources to meet present and projected needs is difficult to determine. There may be significant undiscovered sources for some materials, and moreover, technological advances may render the need for certain resources obsolete or make possible the utilization of presently inaccessible or unusable resources. Also, the location of a resource with respect to national or even regional boundaries influences the judgment of its adequacy.

National and state policy is needed to prevent the loss of resources through local decisions that, while individually rather insignificant, have a great combined impact. For example, one com-

A



B

FIGURE 8—Landslide susceptibility in San Mateo County, California. *A*, Map specifically prepared for application in land-use planning studies. It was derived from a basic geologic map, an inventory of landslides, and a slope map (Brabb and others, 1972). Explanation on facing page. *B*, Aerial photograph showing the area outlined in the landslide-susceptibility map.

munity's decision to permit the subdivision of agricultural land may yield local benefits and have little negative impact on the nation's food supply. If, however, many communities make this same decision, the impact on food supply may become critical. Such choices regarding alternative uses of land need to be made on the basis of established national, state, and regional priorities that consider the long-term as well as short-term consequences.

Explanation of Map Units

I Areas least susceptible to landsliding. Very few small landslides have formed in these areas. Formation of large landslides is possible but unlikely, except during earthquakes. Slopes generally less than 15 percent, but may include small areas of steep slopes that could have higher susceptibility. Includes some areas with 30 percent to more than 70 percent slopes that seem to be underlain by stable rock units. Additional slope stability problems; some of the areas may be more susceptibile to landsliding if they are overlain by thick deposits of soil, slopewash, or ravine fill. Rockfalls may also occur on steep slopes. Also includes areas along creeks, rivers, sloughs, and lakes that may fail by landsliding during earthquakes. If area is adjacent to area with higher susceptibility, a landslide may encroach into the area, or the area may fail if a landslide undercuts it, such as the flat area adjacent to sea cliffs.

II Low susceptibility to landsliding. Several small landslides have formed in these areas and some of these have caused extensive damage to homes and roads. A few large landslides may occur. Slopes vary from 5–15 percent for unstable rock units to more than 70 percent for rock units that seem to be stable. The statements about additional slope stability problems mentioned in I above also apply in this category.

III Moderate susceptibility to landsliding. Many small landslides have formed in these areas and several of these have caused extensive damage to homes and roads. Some large landslides likely. Slopes generally greater than 30 percent but includes some slopes 15–30 percent in areas underlain by unstable rock units. See I for additional slope stability problems.

IV Moderately high susceptibility to landsliding. Slopes all greater than 30 percent. These areas are mostly in undeveloped parts of the County. Several large landslides likely. See I for additional slope stability problems.

V High susceptibility to landsliding. Slopes all greater than 30 percent. Many large and small landslides may form. These areas are mostly in undeveloped parts of the County. See I for additional slope stability problems.

VI Very high susceptibility to landsliding. Slopes all greater than 30 percent. Development of many large and small landslides is likely. The areas are mainly in undeveloped parts of the County. See I for additional slope stability problems.

L Highest susceptibility to landsliding. Consists of landslide and possible landslide deposits. No small landslide deposits are shown. Some of these areas may be relatively stable and suitable for development, whereas others are active and causing damage to roads, houses and other cultural features.

Definitions: Large landslide — more than 500 feet in maximum dimension
Small landslide — 50 to 500 feet in maximum dimension

FIGURE 8.—Continued.

NATURAL-RESOURCE PLANS

Decisions regarding the use of land are decisions concerning the allocation of a very important resource. This statement is true whether or not explicit policies and priorities regarding natural-resource conservation or development are adopted and adhered to. Obviously, however, it is desirable for decisions to be made in the context of full information and clearly stated policies.

Natural-resource planning is presently carried out to some degree by all levels of government. Federal and state agencies become most directly involved in resource planning in the management of government-owned land. For example, the U.S. Forest Service and Bureau of Land Management each plan for the use of significant parts of the nation's important natural resources. At the regional and local level, resource planning is more likely to be an integral part of general land-use planning. However, the nature of the planning process and requirements for ESI differ less with jurisdictional level than with the particular resource involved.

Natural-resource planning is a prerequisite to development and administration of a resource management program. A natural-resource plan provides policies covering the basic question of whether or not particular resources should be developed or utilized. Such plans usually have three broad objectives: (1) Conservation of natural resources such as timber, water, agricultural land, and sand and gravel to provide a sustained yield for man's use, (2) preservation of areas with special scenic, scientific, ecological, and historical value, and (3) utilization of resources for the benefit of man.

Natural-resource management programs deal more specifically with the rate of resource utilization, the impacts of resource development or extraction, and the means of conserving or preserving certain natural resources. Management programs provide the basis for review of specific proposals for resource extraction and for administration of regulations pertaining to resource utilization.

Natural-resource planning requires an inventory of the resources of a planning area. Typically, resource areas are described, mapped, and classified according to resource potential. Special attention is given to areas with extractive resource potential or areas of special scenic, scientific, or cultural value. Policy recommendations are then developed to resolve possible conflicts between resource conservation and development.

The Natural Resources Plan produced by Bucks County, Pa., is an example of natural-resources planning appropriate to regional and local planning agencies. Phase I (1971) presented an inventory of natural resources, including prime agricultural soils, forests, wetlands, steep slopes, lakes and ponds, flood plains, extractive resources, scenic areas, and aquifers. In this phase, each natural feature was defined, weighted, and computer mapped on a grid. Phase II (1972) of the plan set forth specific policies for the protection of each natural resource in terms of the percentage of each grid cell containing a particular natural resource that should remain in open-space use. The land-use consequences of carrying out the policies are depicted on the Natural Resource Protection Map, which shows prime agricultural lands, existing parks, scenic areas, and open space required for resource protection.

The Bucks County planning effort was an integral part of a comprehensive land-use planning program. It is a particularly relevant example because the natural resources considered are those that occur to some extent in most local areas. The study and resulting plan respond primarily to concerns regarding resource preservation. As such, the Natural Resources Plan is an important contribution to open-space planning in Bucks County.

Usually the economics of resource development is calculated on a fairly short-term basis. This tends to militate against the conservation of resources for the use of future generations and, in addition, creates conflicts when resource potentials overlap. For example, fine agricultural land in some areas overlies rich coal deposits. In the short term, the gain from development of the coal may exceed that from the productive use of the agricultural land. It is possible that the reverse would be true in the long term. Each use of land has its economic effects. Careful assessment of both long- and short-term economic costs and benefits are needed to develop sound resource policy. In addition, any effort to balance economic costs and benefits must consider both costs and benefits as they relate to different economic and social groups and jurisdictions. Only recently have operators been required to assume the external costs of extracting and processing natural resources. In the past, it was legally and politically acceptable for the costs of air, water, and noise pollution to be passed on to the owners and occupants of adjoining lands and downstream, downwind areas.

Planning for the conservation and utilization of commonly occurring natural resources such as agricultural land, sand and gravel, timber, water resources, and scenic areas has been left primarily to regional and local agencies. Regional agencies can be particularly effective in carrying out regionwide inventories of natural resources, for areas of significant resource potential often transcend local political boundaries. In addition, the production of resource inventories is often beyond the financial and technical capabilities of local government. The inventories form a foundation for preparation of regional policies concerning resource conservation and development that provide a useful context for local planning efforts. The implementation of natural-resources plans, whether formulated by regional or local agencies, depends primarily on local government under the present allocation of governmental powers. The key implementation mechanisms are land use, land division, land-development regulations, and land acquisition.

To assure that natural resources are utilized in a way that minimizes environmental damage requires a detailed resource management program. The National Environmental Policy Act of 1969 and various state requirements provide a framework for regional and local consideration of the environmental impacts accompanying resource development and use. The regulation of the utilization process is a part of the administrative process of project review. It is possible, for example, to plan for sequential multiple use of an excavation site. Issuance of a permit to extract the resource can be conditioned on the developer's commitment to leave the site usable for another purpose once the resource has been exhausted (fig. 9). For example, some exhausted sand and gravel pits can be used for sanitary landfills and later converted to open space and recreational uses with adequate planning and controls at the outset. Many states have passed legislation requiring the mine operator, after mining, to restore the land to a semblance of its original state. However, the responsibility for regulating resource development operations to prevent environmental degradation historically has rested primarily with local government. The effort frequently requires extensive and detailed ESI and agency capacity to review earth-science reports that may be highly technical.

ENVIRONMENTAL AND ECONOMIC IMPACT

Most decisions to develop natural resources are based on economic judgments made by private

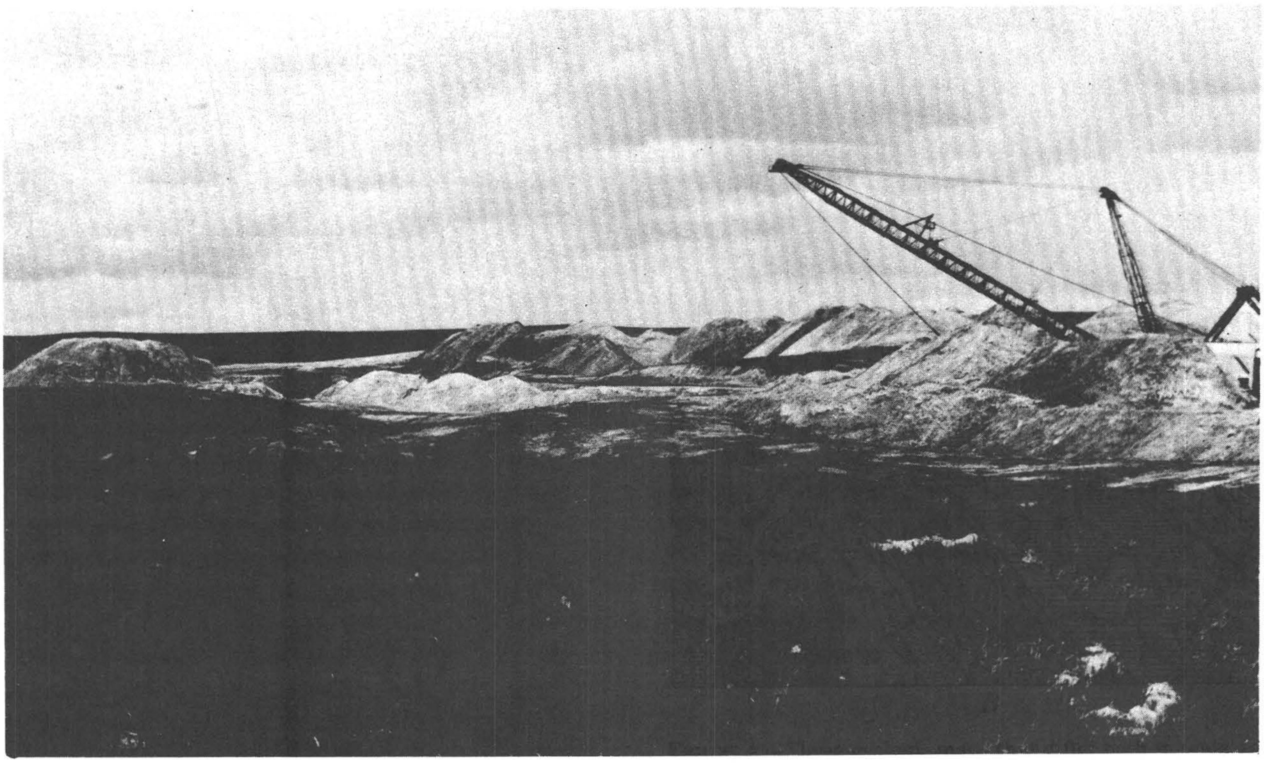


FIGURE 9.—Strip-mined area in Washington after land reclamation. The area in the foreground has been mined, refilled, and recontoured. New topsoil was added and fertilized, and grass was planted. With proper planning, the long-term environmental effects of such operations can be minimized. (Source: Bureau of Outdoor Recreation, 1974.)

and, in some cases, public entities. This fact affects the degree and sequence of development. Those resources that can be obtained with the least cost, closest to the user, are usually developed first. For example, a community usually looks first to the most immediately available water source of adequate quality—ground or surface. If the initial source proves to be inadequate, cost considerations will be dominant in choosing among alternative means of assuring a firm supply—to impound, import, increase the level of treatment of the local source, or recycle.

Judgments concerning the economics of resource development cannot be adequately made without thorough and accurate earth-science information. The cost of utilizing a given resource directly reflects natural conditions that must be understood. For example, information concerning geologic structure, ground-water level, and soil depth is needed to estimate the cost of extracting coal from a given location.

Adverse environmental effects often accompany the extraction and utilization of resources. The withdrawal of ground water may result in the subsidence of land; the overcultivation of soil may destroy its fertility or contribute to its loss through erosion; strip mining sharply alters the surface of the land; leaks from offshore oil wells may destroy beaches, pollute the water, and kill marine life. There is some environmental cost to be borne with almost any resource use. Assessment of the environmental impacts associated with the utilization of a resource should be made prior to its extraction and balanced against the net economic gains. Where utilization is clearly desirable, a thorough assessment of environmental impacts can lead to proper actions to reduce environmental degradation to an acceptable level.

PLANNING FOR REDUCTION OF NATURAL HAZARDS

IDENTIFICATION OF HAZARDOUS AREAS

The natural features of the earth are created by, and constantly altered by, natural processes. Some of these processes are potentially hazardous to man and his works. Man himself is an important hazard-creating agent. In fact, almost every natural hazard is aggravated by man's actions. Disturbance of the ground may increase storm run off and erosion and decrease slope stability. Subsidence of land is often directly attributable to acts of man. There is even evidence that the injection of waste materials below the earth's surface near Denver, Colo., increased seismic activity in that area (Raleigh and others, 1972). Thus, not only is man acted upon by natural processes, he is also a prime agent in determining the course, speed, and nature of some processes. In this complex relationship, man and his activities must be viewed as part of the natural environment.

Table 3 lists widespread natural processes that are hazardous to man and his works. In areas where these processes occur, the identification of the hazards and evaluation of the potential for risk from natural hazards is an important part of land-use planning. Once an area has been identified as hazardous, appropriate land-use designations can be made. Intensive land uses; high-rise buildings, hospitals, schools, or other institutions with involuntary occupancy; critical public facilities such as dams or highway overpasses; and major utility installations should be prohibited or located and designed so as to withstand the hazard in areas determined to have high risk. Such areas should be considered for open-space uses, such as as agriculture or recreation.

IMPACTS OF HAZARD-MITIGATION METHODS

There are four basic ways to reduce the risks associated with natural hazards. First, land use may be regulated to restrict man's use and occupancy of potentially hazardous areas. Flood plains and unstable slopes, for example, can be recommended for open space or very low intensity uses. Second, efforts can be made to control the hazardous processes. For example, channel improvements or holding ponds may be constructed to control floodwaters. And, since man is an agent in aggravating natural occurrences, regulation of how he treats the land can reduce risks. Third, measures can be taken not toward controlling the processes, but toward reducing their impact. Such measures include special foundation requirements and construction techniques for landslide-prone slopes, artificial recharge of ground water to prevent subsidence, or special structural safety standards for seismically active areas. Fourth, monitoring of natural processes may permit the development of warning systems to allow evacuation of hazardous areas when disaster appears imminent. This method is especially effective in reducing loss of life and property damage from flooding.

TABLE 3.—*Natural processes important to land-use planning*

Process	Description of hazard
Flooding	Overtopping of river and stream banks by water produced by sudden cloudbursts, prolonged rains, tropical storms or seasonal thaws; breakage or overtopping of dams; ponding or backing up of water because of inadequate drainage.
Erosion and sedimentation.	Removal of soil and rock materials by surface water and depositing of these materials on flood plains and deltas.
Landsliding	Perceptible downslope movement of earth masses.
Faulting	Relative displacement of adjacent rock masses along a major fracture in the earth's crust.
Ground motion	Shaking of the ground caused by an earthquake.
Subsidence	Sinking of the ground surface caused by compression or collapse of earth materials; common in areas with poorly compacted, organic, or collapsible soils and commonly caused by withdrawal of ground water, oil, or gas; or collapse over underground openings, such as mine workings or natural caverns.
Expansive soils	Soils that swell when they absorb water and shrink when they dry out.
High water table	Upper level of underground water close to ground surface causing submergence of underground structures, such as septic tank systems, foundations, utility lines, and storage tanks.
Seacliff retreat	Recession of seacliffs by erosion and landsliding.
Beach destruction.	Loss of beaches owing to erosion and (or) loss of sand supply.
Migration of sand dunes.	Wind-induced inland movement of sand accelerated by the disturbance of vegetative cover.
Salt-water intrusion.	Subsurface migration of seawater inland into areas from which freshwater has been withdrawn, contaminating freshwater supplies.
Liquefaction	Temporary change of certain soils to a fluid state, commonly from earthquake-induced ground motion causing the ground to flow or lose its strength.

There is often a fortuitous overlapping of hazardous areas and areas suitable for open-space uses. For example, areas subject to flooding are often ideal for water-related recreational uses, hiking trails, wildlife refuges, parking areas, or outdoor storage. Land-use planners can often achieve dual objectives of hazard mitigation and open-space preservation by recommending nonintensive uses for such areas.

Losses from some natural hazards can be reduced more readily than from others, but in most cases, the dollar savings from efforts to reduce losses are significant. Figure 10 shows the estimated total losses due to the five most costly natural hazards in California for the period 1970–2000 under current hazard-reduction practices, the amount of loss reduction possible if the

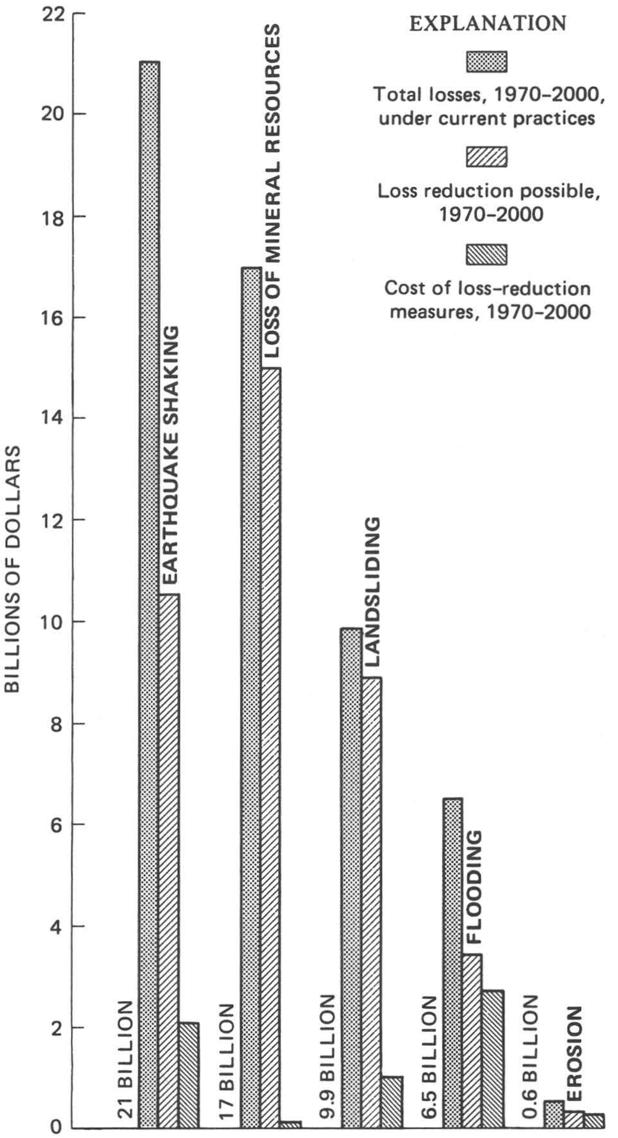


FIGURE 10.—Estimated dollar losses from environmental problems that could be alleviated by the use of earth-science information and technology. Amounts that such losses could be reduced and the estimated cost of loss-reduction measures are also shown. (Modified slightly from State of California, 1973, p. 6).

best of known practices were followed, and the cost of applying such measures.

Man's ability to predict hazardous events varies considerably. For example, earth scientists can predict quite reliably where fault activity will occur but are less able to predict frequency or severity. Flooding, on the other hand, can be more exactly predicted with respect to location, severity, and statistical frequency, but the time of a flood cannot be determined very far in advance.

The selection of approach or combination of approaches appropriate to each situation should be based on a careful weighing of environmental, social, and economic costs and benefits. Costs of controlling natural processes may be very high. All four ways of reducing risks have social, environmental, and economic effects that need to be balanced against the nature of the risk and the degree to which it can in fact be mitigated.

MITIGATION METHODS AND ACCEPTABLE RISKS

The development of public policy to deal with natural hazards and the appropriate allocation of public resources to mitigate them require an answer to the question "How safe is safe enough?" Each individual may be able to answer this question for himself in any given circumstance, but planners and earth scientists share responsibility for providing a framework on which to base a communitywide response to the question (fig. 11).

Several steps appear to be essential to the public process of judging acceptable levels of risk. First of all, the presence of a hazard must be recognized. Development frequently has proceeded without explicit recognition of the natural forces at play. Towns have been built on flood plains, on unstable hillsides, astride faults, and on subsiding ground. The results are well documented in accounts of many of our nation's worst natural disasters. Second, considerable effort may be required to characterize the hazard. It is important to know its likely severity and the frequency of its occurrence, as well as the physical and cultural characteristics of the area that may be affected. Third, the degree of risk must then be evaluated. This step should take into account what can be done to reduce the hazards and balance these possibilities against public costs and benefits.

The accumulation and interpretation of detailed information as to the nature, severity, and frequency of the risk and as to the alternative responses to the hazard are necessary. Public decisionmakers can then balance risk against the economic and environmental costs of mitigating risk to decide the level of risk acceptable to the community.

INTEGRATION OF ESI IN THE PLANNING PROCESS

LAND-CAPABILITY STUDIES BASIC TO LAND-USE PLANNING

In any area the existing natural features and processes present a range of advantages and disadvantages for different uses of land. It is well recognized that the natural characteristics of different parcels of land vary. Different uses of the land also have different physical requirements. For example, farmers seek fertile soils; manufacturers in heavy industry want level sites with good foundation conditions; golf course developers look for rolling terrain with adequate surface and subsurface soil conditions. An important part of land-use planning is matching land uses with the appropriate physical characteristics of the land.

Evaluating the physical features of an area with regard to different types of land use is termed a "land-capability study." The natural features and processes considered usually include topography, hydrology, geology, soils, vegetation, climate, and ecology. Although this report emphasizes the earth-science factors (mainly geology, hydrology, and soils), the concepts and methods discussed are applicable to land-capability studies involving a full range of natural factors.

Land-capability studies are a means of determining the relative physical merits of lands for a specified land use. However, such determination usually provides only a part of the information needed to make land-use decisions. Economic, social, and political considerations are also essential. A parcel of land may have a low physical capability for supporting intensive use, but other factors, such as location and accessibility, land cost, absence of alternative lands, and overriding public need, may well indicate that it should be intensively developed. In this report, a study that considers economic, social, and political factors in addition to land-capability factors is called a "land suitability study."[1] Thus, land-capability studies may be undertaken as part of a broader land-suitability study.

[1]The terms "capability" and "suitability" are often used without precise definition and are sometimes used interchangeably.

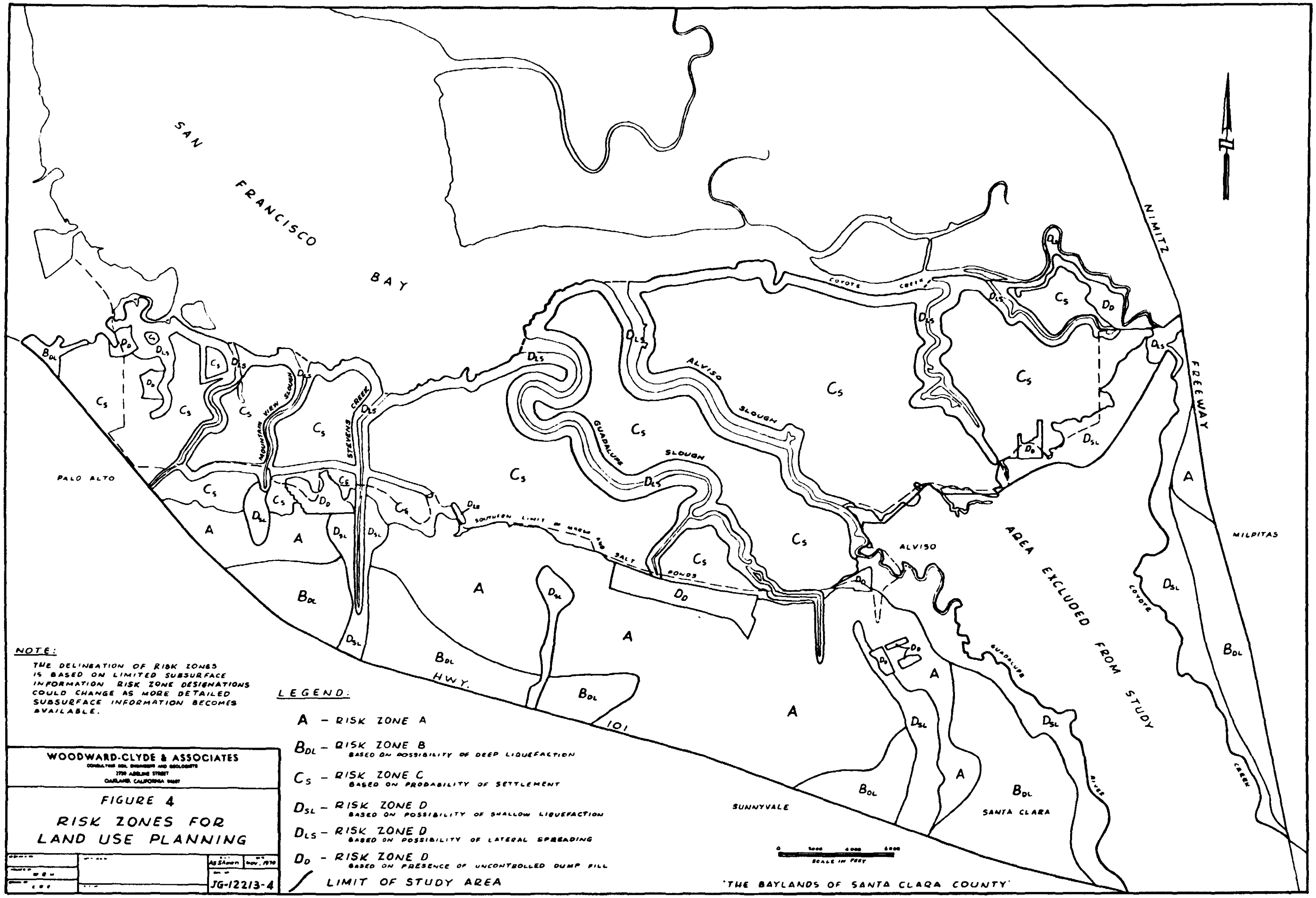


FIGURE 11.—A risk-zone map that provided important information for the preparation of the Santa Clara County (Calif.) Policy Plan for the Baylands (Planning Policy Committee of Santa Clara County, 1972). The map represents an explicit attempt to evaluate risk from natural processes as an integral part of land-use planning. The risk is lowest in zone A and highest in zone D. The subscripts indicate the nature of the risk (see legend at lower left; Woodward-Clyde and others, 1970, part II, fig. 4).

Many different methods are employed in making land-capability studies. A study may be largely descriptive, stating in narrative form information concerning the natural features and processes relevant to a particular land use. Such descriptive analyses are often used when the capability of a given site or alternative sites for a specific use are being considered. A land-capability study may also involve a fairly sophisticated effort to quantify, weight, and aggregate the earth-science information relevant to specific uses for all lands within a planning area. Regional land-use planning agencies and those with computers for data processing are most likely to undertake such studies.

An example of a land-capability study integrated within a land-suitability study is contained in the report prepared by the consulting firm Livingston and Blayney (1971) for Palo Alto, Calif. Although the study is properly termed a land-suitability study, it provides a good example of the general methods employed in land-capability studies. Material adapted from the report is used below to illustrate each of the following five basic steps usually involved in a land-capability study:

1. *Identify the types of land use for which land capability is to be determined.*—In the Palo Alto study, land uses range from low-density residential to industrial. In formulating a land-use plan, the capability of the lands within the planning area for the reasonable alternative types of land use would need to be evaluated.
2. *Determine the natural factors having a significant effect on the capability of the land to accommodate each use.*—The choice of factors depends on the physical requirements of the land use under consideration. In the Palo Alto suitability study, 23 factors were selected and categorized[2] as geologic and soils factors (10 factors), ecologic factors (4 factors), visual and recreation factors (4 factors), and planning and market factors (5 factors). Most of the capability factors involving earth-science information were included in the first category, geologic and soils factors. These 10 factors were average slope, San Andreas fault zone, other fault zones, landslides, natural slope stability, cut slope stability, excavation difficulty, soil suitability as fill, soil erosion, and soil expansion.
3. *Develop a scale of values for rating each natural factor in relation to its effect on land capability.*—Two operations are involved in this step. First, the relevant range of conditions of each factor is determined. The expression of this range may be quite precise, as for average slope (table 4), or very general, as in the poor, fair, and good ratings shown for several factors on the table. The degree of precision depends on the degree of refinement needed (or possible, given the level of detail of data available) to make judgments regarding land capability for the selected use.

   Second, a scale of values is established to quantify the different conditions within each factor. In the example from the Palo Alto study, the significant differences within each factor were rated on a scale of 1–5 (column 2 of table 4).
4. *Assign a weight to each natural factor indicating its importance relative to the other factors as a determinant of land capability.*—In the Palo Alto example, each factor was given a weight ranging from 1 to a possible 10 (column 3 of table 4). The weight represents a judgment of the relative importance of each factor for "development."
5. *Establish land units, rate each land unit for each*

TABLE 4.—*Rating system for land-capability factors*

[Source: Adapted from Livingston and Blayney and others, 1971, p. 59–65]

1 Geologic and soils factors	2 Rating	3 Weight	4 Weighted rating
Average slope:			
Over 50 percent	1	10	10
31–50 percent	2		20
16–30 percent	4		40
0–15 percent	5		50
San Andreas fault zone:			
Within zone	1	7	7
Not within zone	5		35
Landslides:			
Within slide area	1	6	6
Not within slide area	5		30
Natural slope stability:			
Poor	1	5	5
Fair	3		15
Good	5		25
Cut-slope stability:			
Poor	1	4	4
Fair	3		12
Good	5		20
Soil suitability as fill:			
Poor	1	2	2
Fair	3		6
Good	5		10
Soil erosion:			
Severe	1	6	6
Moderate	5		30
Soil expansion:			
High	1	3	3
Moderate	3		9
Low	5		15

[2] For purposes of illustration, the factor "average slope" was moved from the "planning and market" category in the original study to the "geologic and soils" category, since slope is a major determinant of land capability.

factor, calculate the weighted ratings for each factor, and aggregate the weighted ratings for each land unit.—This step involves the application of the rating system developed in the previous steps to the land under consideration. The study area is divided into land units for evaluation. The size and configuration of the land units depends on the diversity of physical conditions within the study area, the physical requirements for the land use under consideration, and the kind of land-use policy needed. The Palo Alto study area was divided by a grid into 330 cells each of 20 acres. Each cell was evaluated and rated for each factor (that is, was assigned a number from column 2 on table 4). The rating for each factor was multiplied by the weight assigned to the factor in column 3 of table 4 to yield the weighted rating as shown in column 4. The weighted ratings for all factors were then added for each cell. The total is a score reflecting the capability of the cell for the selected land use.

In the Palo Alto study, the weighted ratings for the other suitability factors were added to those for capability factors shown on the table to produce the total score for each cell. The range of possible total scores for each category of factors was planning and market factors, 19–95; ecological factors, 18–90; visual and recreational factors, 11–55; and geologic and soils factors, 48–240. It is clear that the capability factors related to earth science are very important in the determination of land suitability. The total scores for all factors ranged from 96 to 480. These scores were divided into six groups and mapped as shown in figure 12.

Land-capability studies such as the one described above are increasingly important to land-use planning at all governmental levels. They assure that physical characteristics of the land will be given systematic consideration in the development of plans and policies. The earth-science information requirements for such studies vary with the total land area and the specific use to be studied. At the regional level, for example, fairly generalized data may be appropriate for an analysis of land capability for open space. On the other hand, a study undertaken, at any governmental level, to locate a specific site with a high capability for use as a sanitary landfill will require detailed information.

In most cases, the land-capability analysis provides only part of the information needed for land-use decisions, but on occasion capability factors are, or should be, determining. The studies can be useful in eliminating areas with very low capability for a particular use from further consideration and allow the planner to focus attention on more realistic options.

INTERDISCIPLINARY RELATIONSHIPS

Integrating man's works and activities with his natural environment is an objective generally shared by planners and earth scientists. To effectively attain this objective requires the contributions of both professions, and since it is unreasonable to expect either planner or earth scientist to become proficient in the other's area of expertise, the establishment of a cooperative working relationship is a prerequisite for a successful program.

There are, however, several obstacles to the establishment of such relationships arising from three factors, the education, working environment, and terminology of each profession. First, planners are generalists by education and are taught to draw information from a wide variety of subjects including architecture, engineering, landscape design, economics, sociology, public administration, and political science. Yet planning curriculums frequently offer little or no exposure to the earth sciences. Earth scientists, although conversant with related scientific fields, typically are not required to draw on the extensive range of subject matter normally dealt with by planners.

Second, a professional career is normally pursued within an institutional framework that limits opportunities for interdisciplinary effort. In addition, professional advancement in both fields usually requires an ever-increasing degree of specialization. Since specialists may be reluctant to tread on each other's professional territory, interdisciplinary contact is even further inhibited. Perhaps more important is the fact that, until recently, the earth scientist has not regarded the planner as a "customer" for his product. In turn, the planner has not recognized the need for ESI in land-use planning. Until fairly recently, natural resources were considered inexhaustible, the effects of natural hazards were viewed as "acts of God," and governmental bodies tended to place the rights of the private property owner above those of the public at large. Under these circumstances,

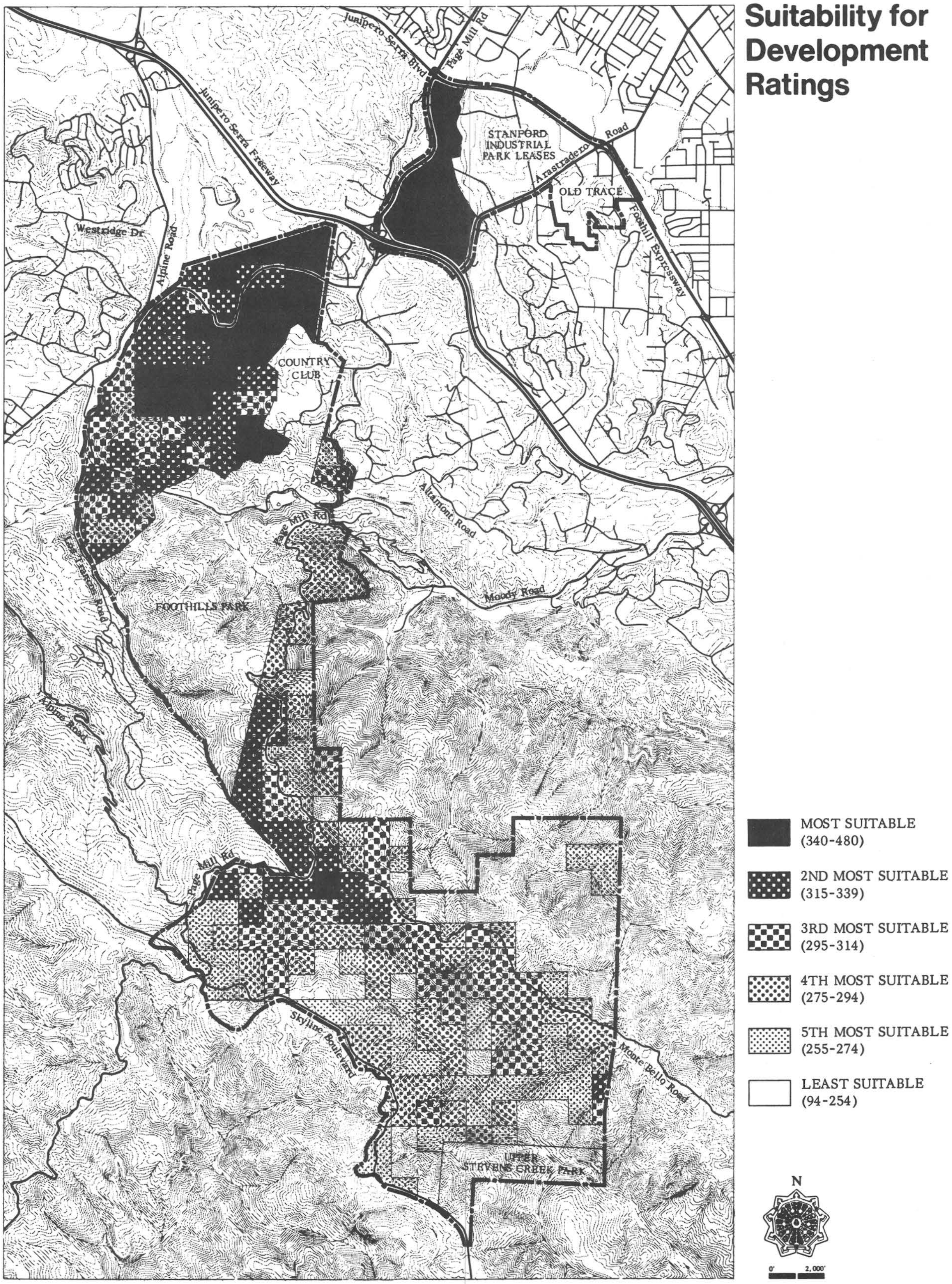


FIGURE 12.—Land-suitability map of part of Palo Alto, Calif., prepared by Livingston and Blayney and others (1971).

economic and political considerations easily become the primary determinants of land use. Only with acceptance by public agencies of some responsibility for resource conservation and mitigation of dangers and damages from natural hazards has the planner needed ESI. The need for interdisciplinary efforts is being recognized by both professions.

Another working-environment problem arises from the fact that planning is a public undertaking usually culminating in decisions made by political bodies. The planner's role in the political process requires the ability and willingness to respond to the needs of conflicting interests of different segments of a community. The earth scientist's work is usually evaluated by fellow earth scientists according to scientific standards of truth. He is often uncomfortable when faced with the reality of political compromise and dismayed when a recommendation supported by exacting earth-science analysis is rejected by decisionmakers on political, social, or economic grounds.

The third obstacle to establishing interdisciplinary relationships is that each profession has its own jargon, which, though it may facilitate exchange of ideas within the profession, tends to inhibit communication with outsiders. Earth scientists employ a technical vocabulary that includes many words not in common usage. Even with a glossary, it is difficult for a person who is not an earth scientist to read and understand a report prepared for a professional audience of earth scientists. Planners, on the other hand, lack precision and consistency in their use of terms. They frequently use everyday words in specialized senses or borrow terms from other disciplines, altering their definitions.

Planners and earth scientists will find, however, that many of these problems will diminish rapidly once they are working together. With a little effort on both sides, they will find that their effectiveness in solving common problems and achieving common objectives greatly increases. The planner who joins the earth scientist in the field gains a new perspective not only of the natural characteristics of his planning area but also the application of the earth scientist's work. The earth scientist, similarly, gains insight into the nature and perspectives of planning. The result can be a creative synthesis in which innovative interpretations and applications of ESI are much more likely to occur.

A variety of arrangements permit the earth scientist and planner to work together directly. For the most part, the responsibility for establishing such arrangements rests with the land-use planning agency. With the growing awareness of environmental problems, all land-use planning agencies have some need for earth-science expertise. Some may require a full-time staff person; others may find that part-time or consultant services will suffice. However, for large agencies involved with varied and complex environmental problems, the addition of an earth scientist to the planning staff may prove valuable.

The presence of an earth scientist on the planning staff encourages the consideration of earth science in all phases of the planning process. The staff earth scientist would typically perform the following functions: Help develop and carry out a realistic data-acquisition and interpretation program, including advising on costs and priorities; assist in the determination and evaluation of land capabilities; help formulate plans and policy regarding such topics as geologic hazards and mineral and water resources; undertake detailed studies of particular development issues, such as the impact of urbanization on water pollution or the geologic stability of hillside areas; assist in the formulation and administration of land-use regulations, such as subdivision, zoning, grading, and erosion-sediment control ordinances; make field checks in connection with particular projects and prepare and (or) review soils reports, geologic reports, and environmental impact assessments prior to development approval; assist in presenting technical information directly to decisionmakers to facilitate evaluation of alternatives, prepare slides, models, or other graphic materials for these purposes, and respond directly to questions arising from the presentation; advise when additional earth-science expertise is needed and know where and how to obtain it.

While few planning agencies interviewed during the course of this study employed a permanent earth scientist on the staff, considerable benefits were derived in those cases where planners established a close working relationship with earth scientists outside the agency. For example, in many areas, earth scientists are in frequent contact with planning agencies and perform a number of the functions discussed above. In many areas, private consultants and university scientists, on a contractual or informal basis, provide similar services.

PUBLIC PARTICIPATION

As a governmental function, planning is inextricably bound to the political process. Land-use decisions have a strong influence on the quality of life. Whether or not a freeway is constructed, a new shopping center approved, or land zoned for open space is of concern to the whole community as well as to the property owners and residents whose land is directly involved. Land-use decisions affect different segments of the community in different ways and are commonly the subject of much controversy, for it is through the political process that conflicting interests and differences of opinion are resolved. Effective resolution requires the informed participation of all segments of the community at all stages in the planning process.

The professional planner may serve solely as a technical advisor to the decisionmakers or may be a more active advocate with respect to planning proposals or particular issues. The planner, however, rarely makes the decisions; this is the function of elected public officials. Even though the planner's information may be complete and accurate and his logic impeccable, there is no guarantee that his advice will be taken.

Both the earth scientist and the planner need to be aware that providing accurate and well-interpreted ESI for use in the planning process is only a first step. To assure that ESI will influence actual decisions requires public understanding of the issues. It is encouraging that in recent years much of the impetus for the use of ESI in planning has come from citizen groups concerned about environmental quality.

CONCLUSION

It is a human tendency to assume that the land upon which we live, work, and play is one permanent aspect of an otherwise constantly changing world. Yet the land itself undergoes continuous alteration as a result of natural processes and the actions of man. This report points to the importance of reconciling man's use of the land with its natural characteristics. Implementation of land-use plans formulated with full awareness of natural features and processes is the key to achieving such reconciliation.

The state-of-the-art in applying earth-science information to land-use planning and decision-making is currently undergoing rapid evolution. In the last few years, agencies producing ESI have dramatically increased efforts to provide data specifically for land-use planning. The new information is just now becoming widely available to planners, and it is too early to evaluate in detail its impact on land-use plans and decisions. Certainly the impact will be great. In most metropolitan areas the need to preserve open space, protect natural resources, and maintain high standards of environmental quality often conflicts with the need to expand employment opportunities, the housing stock, and the tax base. Land-use planners are faced with resolving basic land-use conflicts with what is now recognized as a finite supply of land. The decisions are becoming increasingly important and subject to controversy. In this context, the planner will seek out and use all relevant information, including ESI.

Studies of land capability are becoming much more common and serve to formalize the consideration of natural factors in land-use planning. ESI is increasingly translated into quantitative terms allowing aggregation of data relevant to a particular site or area. Quantification and weighting of physical factors is becoming an important feature of capability studies, especially in agencies with computer data-processing capacity.

Although the guidelines presented here are very general, they provide a framework for the effective utilization of ESI in land-use planning. However, no single set of guidelines can possibly include the wide range of conditions and problems encompassed by the fields of planning and the earth sciences. The essential point, however, is the need to foster an institutional, legal, and political climate favorable to full and effective interplay between planners and earth scientists on the one hand and professionals and public decisionmakers on the other. Ultimately, it is the public, through its representatives, who must assume the responsibility for considering long-term as well as short-term social, economic, and political impacts from the land-use decisions made today.

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