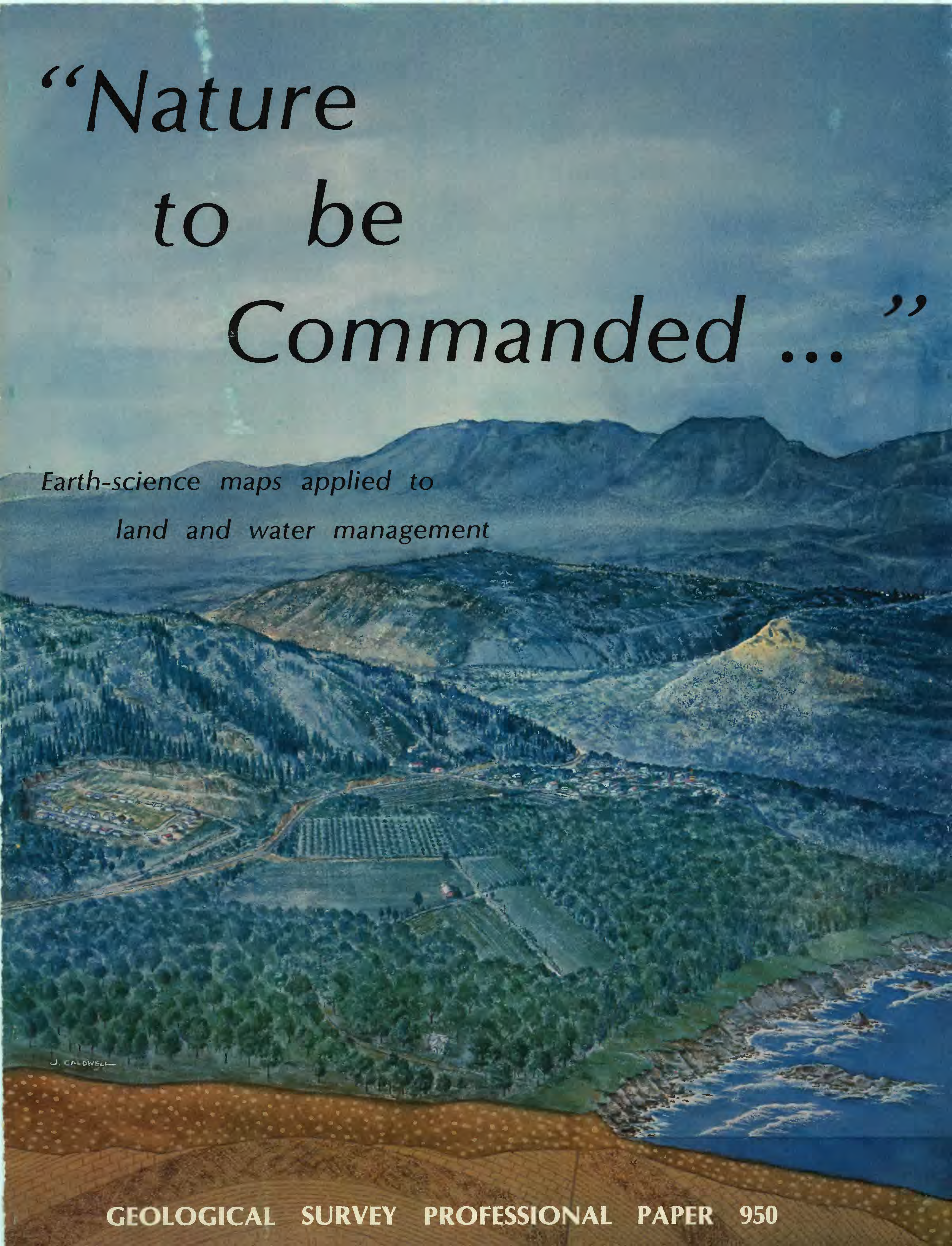
"Nature to be Commanded . . ."

Earth-science maps applied to land and water management



GEOLOGICAL SURVEY PROFESSIONAL PAPER 950

Tualatin Valley near Portland, Oregon

All over the country, orchards, farms, and undeveloped lands near cities are being rapidly turned into freeways, industrial parks, shopping centers, and housing projects. Use of earth-science maps can help insure that the coming developments make the fullest use of natural resources and are exposed to the minimum risk from natural hazards. (Photograph by Oregon Highway Department)

Cover: An artist's rendition of the concept evoked by the photograph above. The city reaches out to take over the countryside. The process has not gone very far, symbolizing the idea that the earth sciences can make their best contribution at an early stage. The geologic detail revealed at the bottom is a reminder that the rocks and waters beneath the surface are critically important to intelligent land and water management.

UNITED STATES DEPARTMENT OF THE INTERIOR—Cecil D. Andrus, Secretary

GEOLOGICAL SURVEY—W. A. Radlinski, Acting Director

"Nature to be Commanded ..."

> *"Nature to be commanded must be obeyed"*
>
> Francis Bacon, "Novum Organum," 1620

Earth-science maps applied to land and water management

GEOLOGICAL SURVEY PROFESSIONAL PAPER 950

G. D. Robinson and Andrew M. Spieker, editors

Demonstrates the value of earth-science information in land and water management by showing how earth-science maps have been used in making plans and decisions in a variety of urban settings

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON

1978

Foreword

Anyone familiar with Professional Papers of the Geological Survey will find this one very different. Professional Paper 950 is different not only in appearance but also in style and content, because it is designed for a different audience: namely, anyone interested in the well-being of cities, and especially those involved in urban planning, design, management, and development. Its publication signals an expanding commitment by the Survey to study and understand the earth-science aspects of the urban environment.

This activity is a natural consequence of history. When the Survey was founded in 1879, the population of the United States was about 50 million, of whom three-fourths were farmers. Today the population exceeds 215 million, of whom three-fourths are city dwellers. The early Survey concentrated on providing earth-science services to aid agriculture and to find and develop the resources of the hinterland; the Survey today must increasingly provide earth-science services to help make our cities safer, healthier, and happier.

One problem the Survey faces in trying to discharge its growing urban responsibility is that most of its potential urban users are unaware of what earth science has to offer. With this book we hope to help solve the problem by demonstrating with actual examples some of the many ways that earth-science information can be effectively applied to urban planning and decisionmaking.

Much of the essential earth-science information for urban environments is not yet available. However, increasing awareness of the need for an application of such information can accelerate its development by both private and public agencies.

W. A. Radlinski

William A. Radlinski
Acting Director

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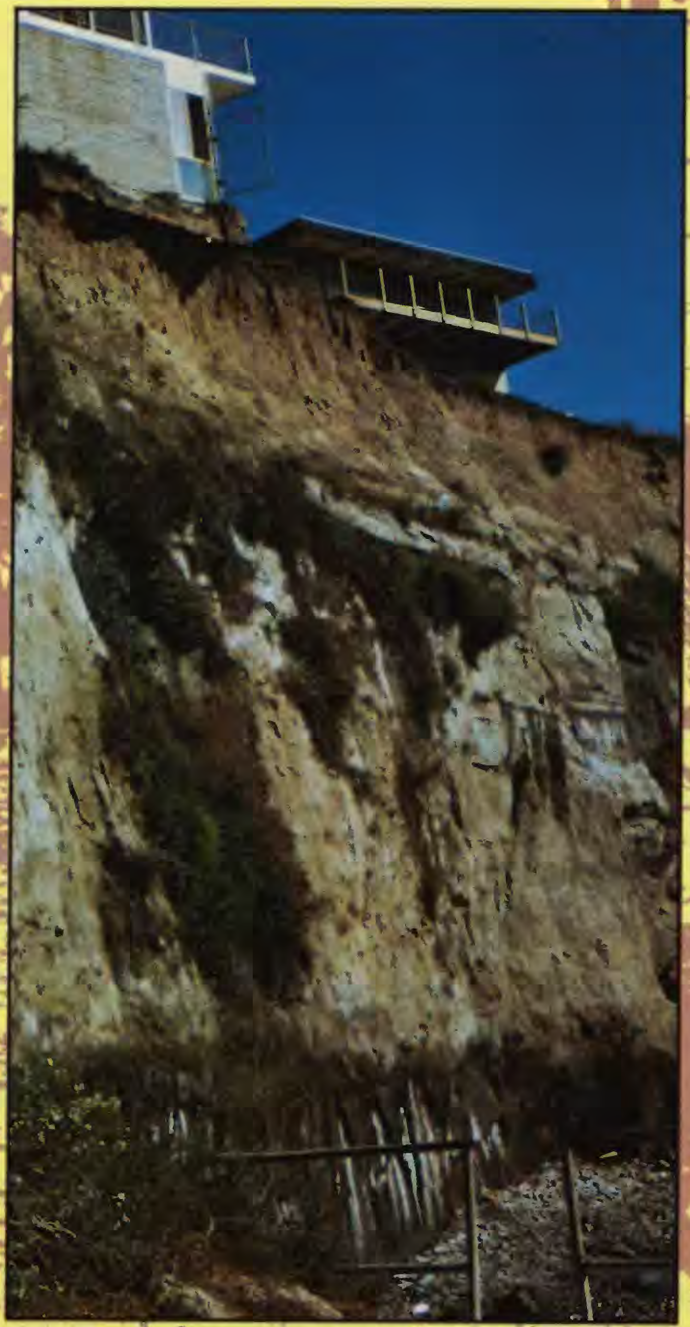


SEACLIFF EROSION

EARTHQUAKE

LANDSLIDE

EARTHQUAKE

Introduction

LAVA FLOW

By G. D. Robinson and Andrew M. Spieker

Nature's forces and processes continue virtually unimpeded by even the largest works of man. Moreover, when man builds and lives in concert with nature, his works may persist for generations; when he does not, the products of his labors, and sometimes man himself, are soon obliterated. As Francis Bacon observed, "Nature to be commanded must be obeyed!" To be obeyed, nature must be understood.

The earth sciences have developed many tools for observing nature's forces and processes and for documenting the changes in our environment that result from them. These tools help to understand nature better, including the opportunities presented by resources and the deterrents posed by hazards. If used properly, these tools can help us live in concert with nature. Some of the most valuable tools—and the most readily understood—are earth-science maps.

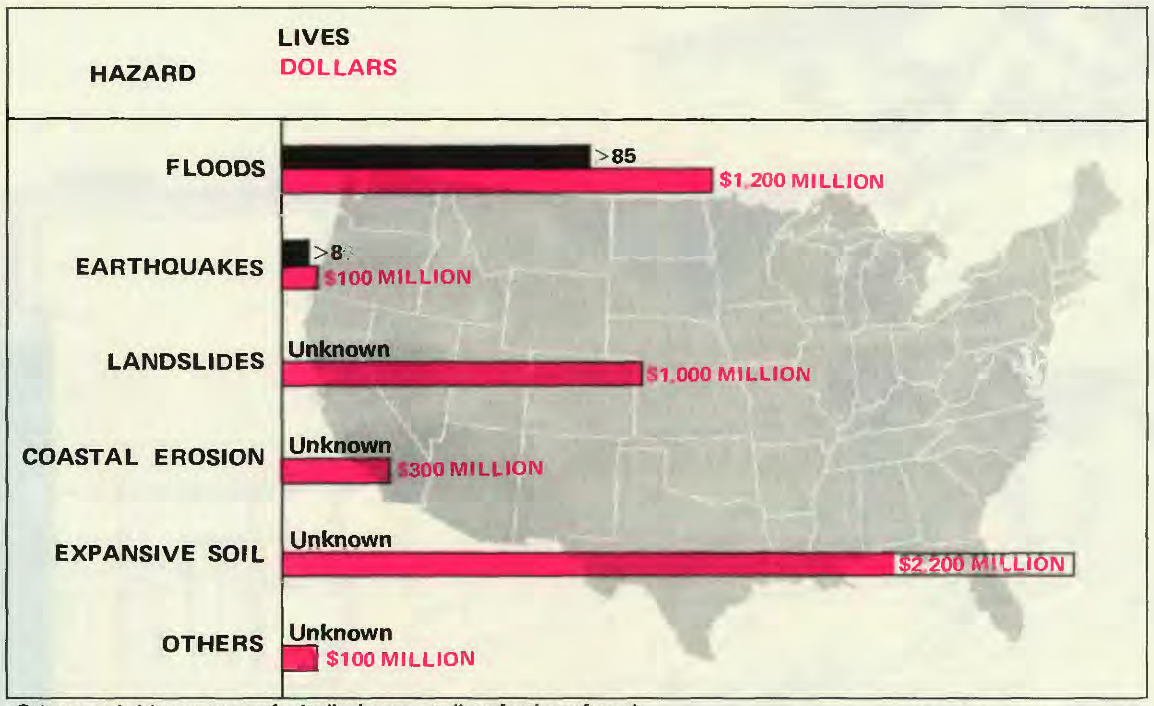
FLOOD

Why earth-science maps

Earth-science maps portray the Earth's surface; the rocks, unconsolidated materials, and waters on and beneath the surface; and the processes that make and change them. This book shows how such maps have been used in making plans and decisions in a variety of urban and suburban settings. Its purpose is to demonstrate, by examples from across the country, that the use of earth-science information in map form can lead to large returns in both public and private benefits, measurable nearly always in dollars and usually in social and cultural values.

In a very real sense, the book is a form of institutional advertising. The "institution" being advertised is earth science, or, as it used to be called, geology. For its value to mineral, water, and energy development, earth science needs no advertising. When copper or oil is being looked for or developed, geologists and geophysicists are customarily consulted; when a city needs more water, hydrologists and hydraulic engineers are regularly brought in. But earth science has not been, and is not being, used to anything like its full potential in the planning, development, and management of urban and urbanizing areas.

Mean annual losses in the United States from geological hazards



Others: *subsidence, creep, fault displacement, liquefaction of sand and clay, dust, waves caused by earthquakes, volcanoes*

For sources, see page 93.

Neglect of earth science

Evidence of this neglect abounds. It is most obvious in the urban damage wrought by catastrophic geological hazards—floods and earthquakes; less spectacular but far more costly, in terms of property if not lives, is damage due to such geological hazards as coastal erosion, landslides, expansive soil, and subsidence by compaction or into caves and mines. Annual losses from geological hazards are estimated in the table above; except for floods, these losses, aggregating billions of dollars, are concentrated in urban areas. The figures cited, coming from varied sources using different assumptions, are crude and hard to compare, but their import is plain: The price of ignoring nature is high.

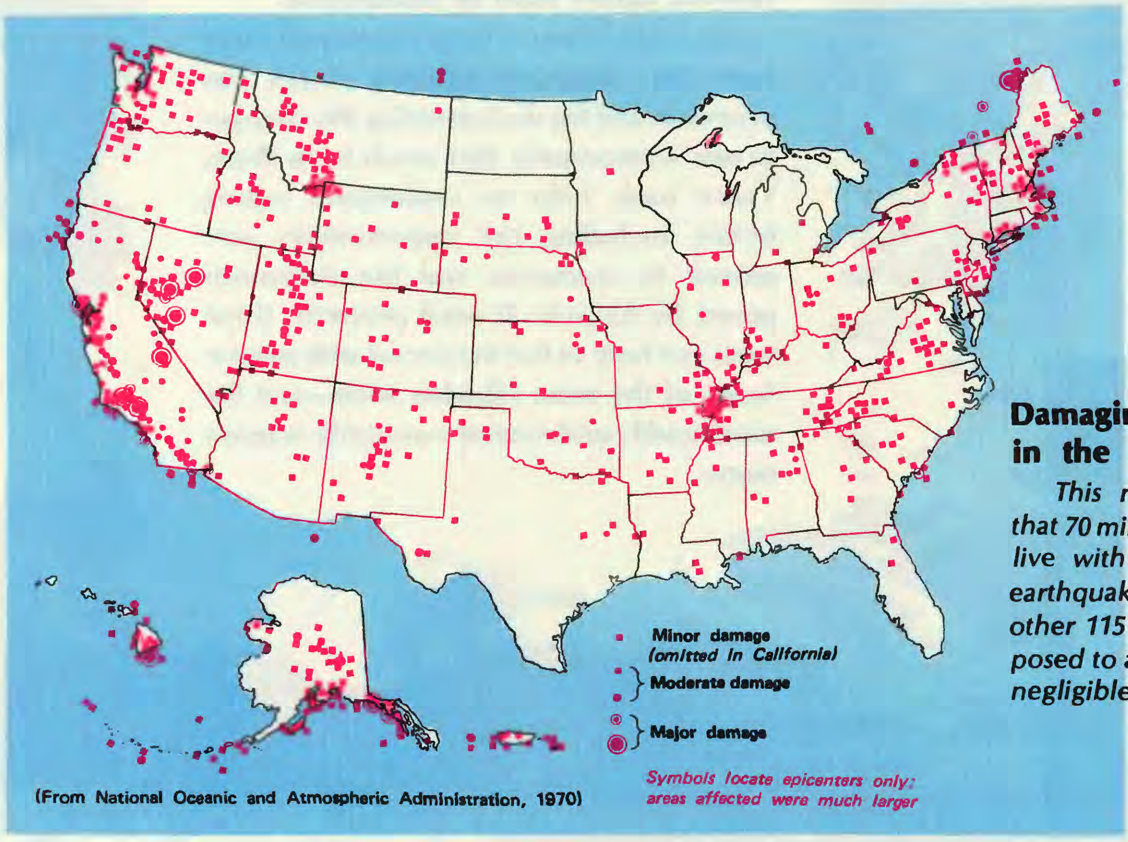
What can be done about losses from these acts of nature? Nothing, of course, about those that have already happened, but much can be done to stop or reduce losses from events yet to come. Armed with information that indicates the kind, degree, and location of potential hazards, planners and decision-makers can forestall or relocate new developments in areas where lives and property would be imperilled, they can propose appropriate design precautions in developments that cannot be placed elsewhere, and they can alert inhabitants of imperilled developments to seek protection through engineering or insurance. Houses that are not built on floodplains or floodways will not be damaged or swept away by floods; buildings in high-risk earthquake areas that do not have unsecured facades will not shower those ornaments on passersby when the earthquake comes; structures that are not built on unstable ground will not be damaged by sinking, swelling, or sliding.

Neglect of earth-science information is evident also in the mounting losses of mineral, water, and agricultural resources due to inadequately controlled urbanization: When sand and gravel or coal deposits, ground-water recharge areas, or prime agricultural lands are built over, the inevitable result is rising cost of basic construction materials, of fuel, of potable water, of food. National estimates for these costs have not been made, but are surely in the billions of dollars annually. For example, estimates made for California indicate that the annual loss due to building-over construction materials alone, or otherwise rendering them inaccessible, is greater than $500 million.[1] And the social costs, in diminished well-being, health, and safety are incalculably high. Little can be done about loss of resources that has already occurred, but with the aid of maps that show the developed and potential resources of an area, planners and decision-makers can evaluate the costs of foregone resources due to proposed developments, and respond appropriately.

Finally, failure to use earth-science information is apparent in the rapid growth of man-made and man-aided geological hazards: Collapse of slopes due to excavation for structures or roads; subsidence of land due to mining or to the withdrawal of water or gas or oil; contamination of ground water and surface water due to improper waste disposal.

Geological hazards and wasted or withdrawn natural resources are not restricted to a few unlucky places but occur throughout the country. Floods, water shortages, and conversion of good farmland to other uses (2 million acres per year) occur in all parts of the Nation; it is not so widely realized that earthquakes, landslides, and expansive soil are national problems too, as the maps on these pages testify. Few cities have reached satisfactory long-term solutions to waste disposal, which usually involves selecting suitable geologic and hydrologic settings. Yet only a handful of communities are using earth-science information systematically in reaching land and water management decisions.

[1]References are omitted throughout the text but are listed, by chapter, on pages 93-95.



Damaging earthquakes in the United States

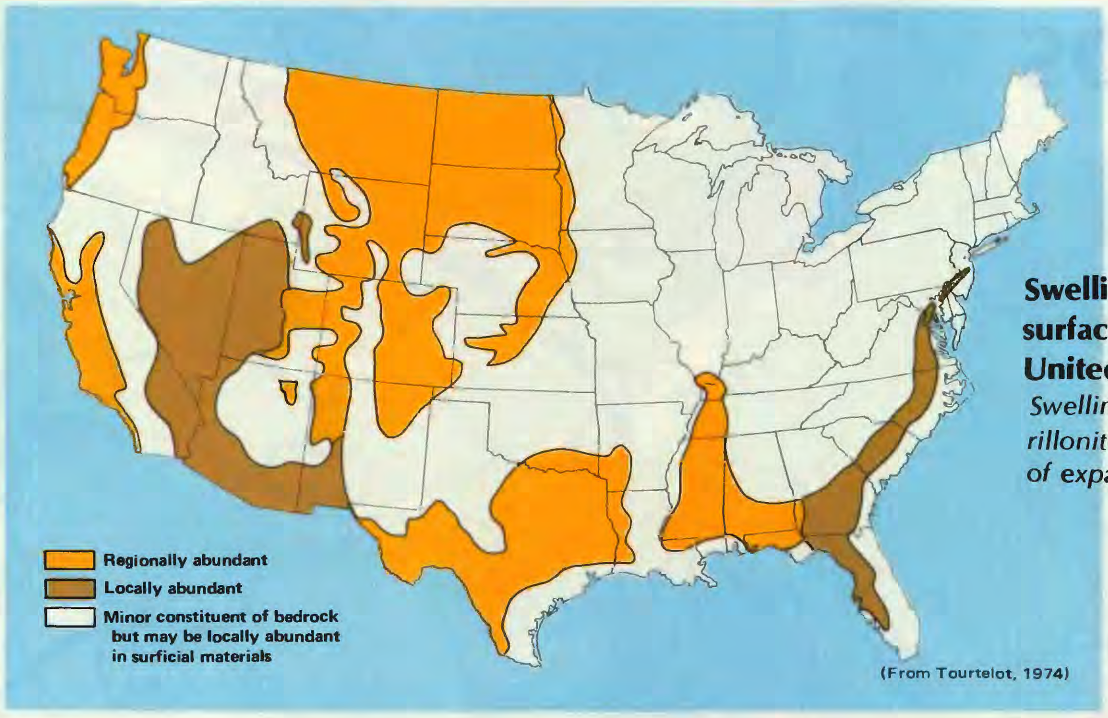
This record indicates that 70 million Americans live with a significant earthquake risk, and another 115 million are exposed to a lesser, but not negligible, risk

Overcoming this neglect

The widespread failure to use earth-science information results mainly from lack of awareness of what the earth sciences have to offer. For its part, the earth-science profession is just beginning to develop its usefulness in the urban sphere. This book publicizes that usefulness. It is addressed to everyone interested in the health, safety, and prosperity of urban areas and specifically to the "planning community," those who directly influence land-use decisions in urban areas, such as planners, architects, engineers, government officials, legislators, judges, developers, and officers of financial institutions. (In trying to reach so broad an audience we have simplified and condensed our material to the point where many professional planners, engineers, and architects may find it too elementary.)

Earth scientists can help the urban planner and decisionmaker by providing information on the resources to be developed, conserved, or protected until needed and on the hazards to be avoided or mitigated. To do so in words, tables, or numbers rarely suffices, for the user needs to know not only WHAT, HOW, HOW MUCH, and WHEN, but also WHERE. Telling WHERE requires maps. Information on maps can also help to answer the other questions.

Few earth-science maps, however, are made specifically for working with urban problems, and therefore few can be put to urban use exactly as they come from the mapmaker. Topographic maps and slope maps can be used directly for preliminary planning of such engineering works as highways, pipelines, power-lines, airports, and drainage facilities, and for planning housing location and density. But most geologic and hydrologic maps must be translated from technical to operational or practical terms and interpreted in various ways for various uses. For many uses, information must be brought together from several maps, requiring synthesis as well as translation and interpretation; often, map data must be supple-



Swelling clay in near-surface rocks in the United States

Swelling clay (montmorillonite) is the main cause of expansive soil

mented by data from laboratory or field tests. Earth-science maps and related data can thus be used to generate many kinds of derivative or interpretive maps valuable to the planning community, such as ease of excavation, landslide susceptibility, slope stability, seismic susceptibility, capability for solid waste disposal, percolation rates, subsidence potential, mineral potential, availability of construction materials, recreation potential, and scores more.

The number of earth-science maps needed depends on the use. Sometimes, as noted above, a single map will suffice. To determine the rate of seacliff erosion as a basis for regulating building setbacks, three maps are needed: one of the height of the seacliffs, one of their slope, and one of the kind of underlying rock or unconsolidated material. For an extreme example, planning a new town may require 15 to 20 or more earth-science maps. Earth-science maps, therefore, may be needed singly, in squads, or in platoons.

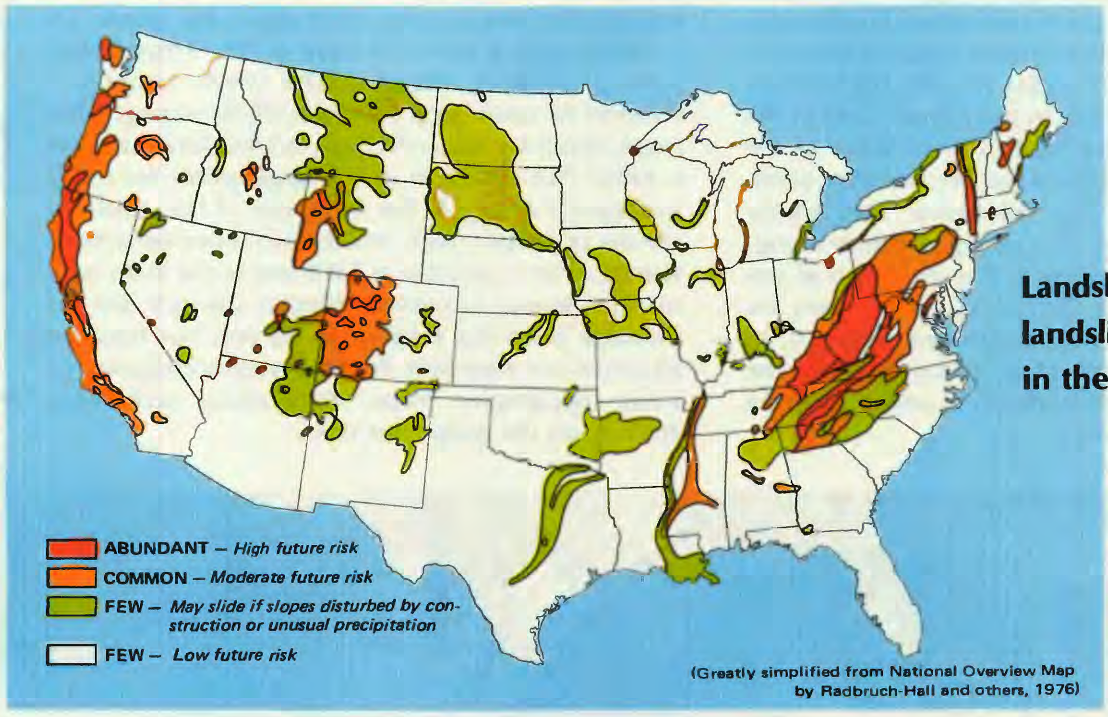
Scope of this book

This book seeks to illustrate and illuminate the preceding discussion by samples of practical applications from six areas: central San Mateo County, California; Tucson, Arizona; the Front Range Urban Corridor, Colorado; the Connecticut River Valley, Connecticut; Nassau County, Long Island, New York; and Fairfax County, Virginia. In these six areas a variety of climatic, geographic, geologic, hydrologic and cultural settings are represented: coastal and inland, mountains and plains, wet and dry, town and city, soft sediment and hard rock. But this book still provides only a meager sample of both applications and settings. To cover all known or potential applications, in every part of the country, would result in a thick and costly encyclopedia.

The samples chosen all result from recent or current work of the U.S. Geological Survey; no new mapping was done for this volume, and no use has been made of the excellent work that has been and is being done elsewhere by other Federal agencies, for example the Soil Conservation Service; by State geological surveys; by academic institutions; by some regional and local planning agencies; and by private consultants. A few of the samples in this book illustrate planning applications. But plans are not actions, and all too many plans never result in actions. Consequently, most of the samples chosen are examples of earth-science information that has contributed to actions—in the form of regulations, ordinances, rulings, or laws—by local, county, or State jurisdictions. A few examples are hypothetical, but they too are based on real cases.

For earth-science maps to be useful, they must be both relevant and understandable to potential users. These users are generally planners, whether professionally trained or not, for no matter who makes the final decision, planning is likely to be involved in the process. Therefore, professional planners have participated throughout the preparation of this book. Two chapters are coauthored by planners, and other planners reviewed the entire manuscript.

Though earth-science information is basic to the selected examples, the plans or decisions made were heavily influenced by social, economic, cultural, and political factors; consideration of these is omitted here. The treatment consists of describing a problem or situation, presenting the principal earth-science maps that bear on it, and then citing, either by quotation or paraphrase, the plan or decision that resulted. The Geological Survey's earth-scientists did not propose or advocate any particular course. Nor does citing the plans or decisions here imply judgment, favorable or unfavorable, by the earth-scientist authors or by the Geological Survey.



Landslides and landslide potential in the United States

Earth-science maps pay

What we do advocate is that land-use plans and decisions be made with the fullest possible knowledge of the natural materials and processes that are involved. As Peter Flawn, former State Geologist of Texas, wrote recently, "Land-use planning that does not consider geologic data has diminished chances of success because not all of the pertinent data have been analyzed." Or, to repeat Francis Bacon's somewhat more poetic statement made 350 years ago: "Nature to be commanded must be obeyed."

This book is not a manual or a handbook or a textbook. It barely begins to tell how or when to use earth-science maps. There are already several such works, some of them available for years, but they seem to have had little impact on the world of urban action. (Some are cited in the reference list.) They have no doubt been used by earth scientists, but not often by those who plan or make decisions.

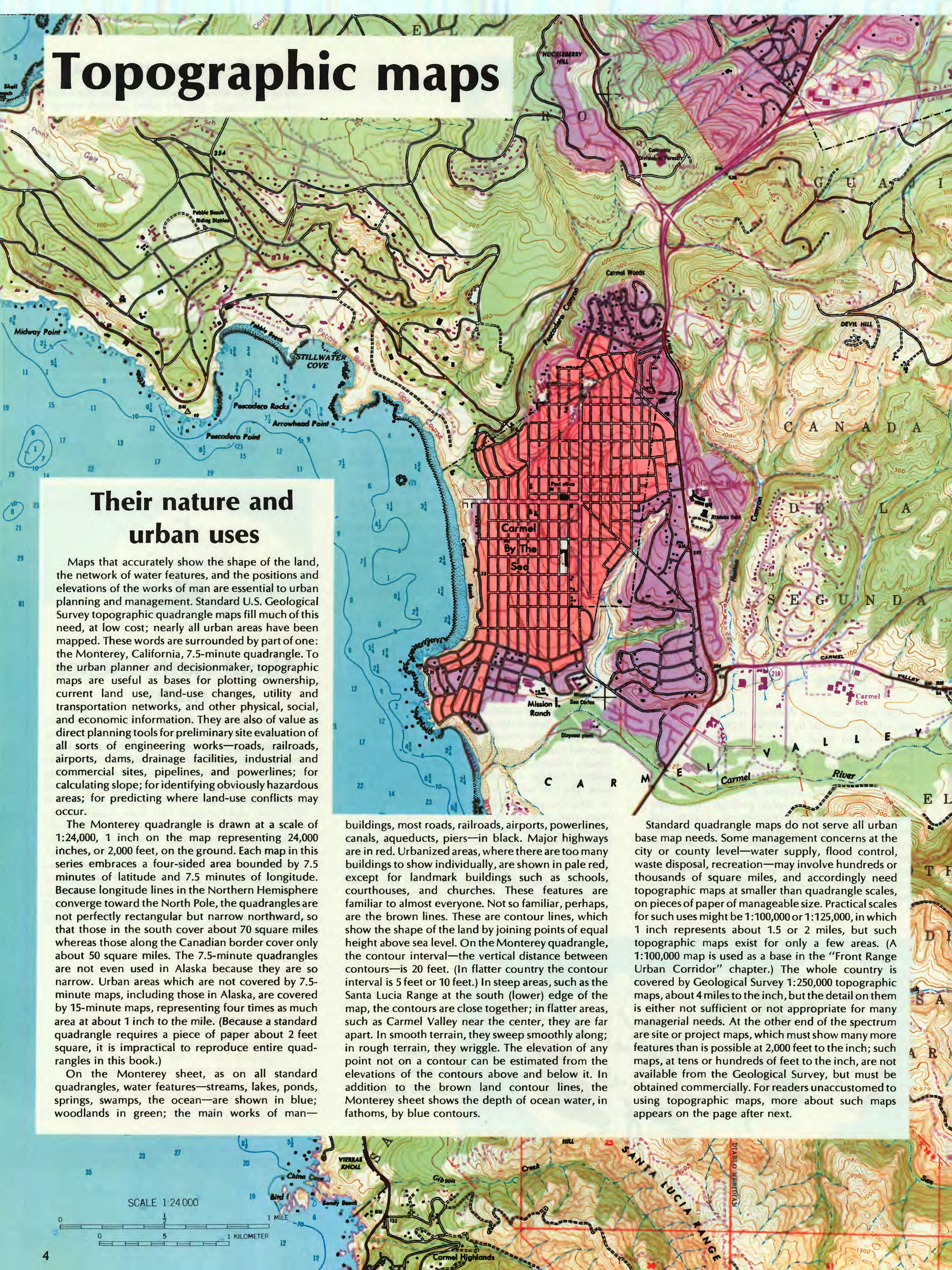
As all successful evangelists know, before you can save sinners, you must get them into the revival tent. That is what we hope to do: to place this book in the hands of a large proportion of the urban planning and decision-making community and inform those who have not yet received the message that earth-science information in map form, applied early and consistently, has been of economic benefit, has aided conservation and human values in many communities, and can probably do as much for theirs.

About earth-science maps

Earth-science maps exist in an abundance of kinds and scales, for earth science involves the forms, materials, and active processes of the whole Earth. The materials of the earth have almost innumerable properties, bear almost innumerable relationships to each other, and are acted upon by myriad forces and processes—most of these can be portrayed in map form, and hundreds have been. Covering anywhere from a city lot to the entire planet, the scales of earth-science maps may range from very large, in which 1 inch on the map may represent a few feet, to very small, in which 1 inch may represent hundreds of miles. Only a small fraction of earth-science maps, however, is directly useful for urban application. In this book, we offer a modest sample of that fraction, beginning with a general look at some basic earth-science maps.

To use earth-science information effectively, it is necessary to have the help of earth scientists. To help find them we have listed on pages 91–92 some offices of the U.S. Geological Survey and of State geological surveys or their equivalents. Most colleges and all universities have earth-science departments, and earth scientists are listed in the yellow pages of the telephone directory under such headings as Geologists, Engineers-Civil, Engineers-Consulting, Engineers-Foundation, Hydrologists, Geophysicists (but not, as yet, Earth Scientists).

Topographic maps



Their nature and urban uses

Maps that accurately show the shape of the land, the network of water features, and the positions and elevations of the works of man are essential to urban planning and management. Standard U.S. Geological Survey topographic quadrangle maps fill much of this need, at low cost; nearly all urban areas have been mapped. These words are surrounded by part of one: the Monterey, California, 7.5-minute quadrangle. To the urban planner and decisionmaker, topographic maps are useful as bases for plotting ownership, current land use, land-use changes, utility and transportation networks, and other physical, social, and economic information. They are also of value as direct planning tools for preliminary site evaluation of all sorts of engineering works—roads, railroads, airports, dams, drainage facilities, industrial and commercial sites, pipelines, and powerlines; for calculating slope; for identifying obviously hazardous areas; for predicting where land-use conflicts may occur.

The Monterey quadrangle is drawn at a scale of 1:24,000, 1 inch on the map representing 24,000 inches, or 2,000 feet, on the ground. Each map in this series embraces a four-sided area bounded by 7.5 minutes of latitude and 7.5 minutes of longitude. Because longitude lines in the Northern Hemisphere converge toward the North Pole, the quadrangles are not perfectly rectangular but narrow northward, so that those in the south cover about 70 square miles whereas those along the Canadian border cover only about 50 square miles. The 7.5-minute quadrangles are not even used in Alaska because they are so narrow. Urban areas which are not covered by 7.5-minute maps, including those in Alaska, are covered by 15-minute maps, representing four times as much area at about 1 inch to the mile. (Because a standard quadrangle requires a piece of paper about 2 feet square, it is impractical to reproduce entire quadrangles in this book.)

On the Monterey sheet, as on all standard quadrangles, water features—streams, lakes, ponds, springs, swamps, the ocean—are shown in blue; woodlands in green; the main works of man—buildings, most roads, railroads, airports, powerlines, canals, aqueducts, piers—in black. Major highways are in red. Urbanized areas, where there are too many buildings to show individually, are shown in pale red, except for landmark buildings such as schools, courthouses, and churches. These features are familiar to almost everyone. Not so familiar, perhaps, are the brown lines. These are contour lines, which show the shape of the land by joining points of equal height above sea level. On the Monterey quadrangle, the contour interval—the vertical distance between contours—is 20 feet. (In flatter country the contour interval is 5 feet or 10 feet.) In steep areas, such as the Santa Lucia Range at the south (lower) edge of the map, the contours are close together; in flatter areas, such as Carmel Valley near the center, they are far apart. In smooth terrain, they sweep smoothly along; in rough terrain, they wriggle. The elevation of any point not on a contour can be estimated from the elevations of the contours above and below it. In addition to the brown land contour lines, the Monterey sheet shows the depth of ocean water, in fathoms, by blue contours.

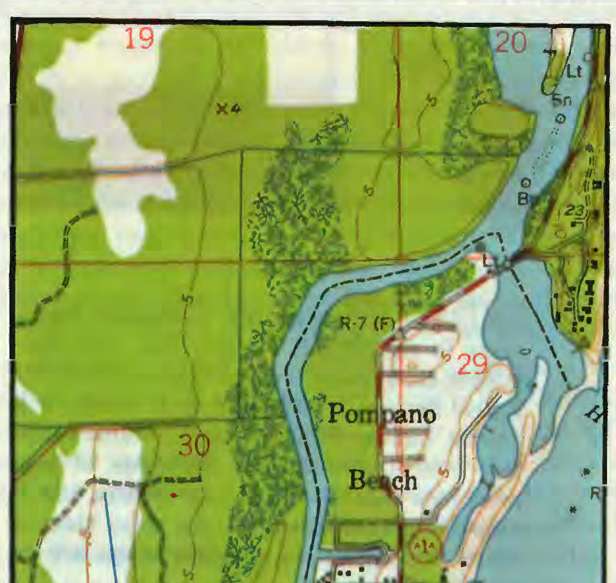
Standard quadrangle maps do not serve all urban base map needs. Some management concerns at the city or county level—water supply, flood control, waste disposal, recreation—may involve hundreds or thousands of square miles, and accordingly need topographic maps at smaller than quadrangle scales, on pieces of paper of manageable size. Practical scales for such uses might be 1:100,000 or 1:125,000, in which 1 inch represents about 1.5 or 2 miles, but such topographic maps exist for only a few areas. (A 1:100,000 map is used as a base in the "Front Range Urban Corridor" chapter.) The whole country is covered by Geological Survey 1:250,000 topographic maps, about 4 miles to the inch, but the detail on them is either not sufficient or not appropriate for many managerial needs. At the other end of the spectrum are site or project maps, which must show many more features than is possible at 2,000 feet to the inch; such maps, at tens or hundreds of feet to the inch, are not available from the Geological Survey, but must be obtained commercially. For readers unaccustomed to using topographic maps, more about such maps appears on the page after next.

Updating topographic maps

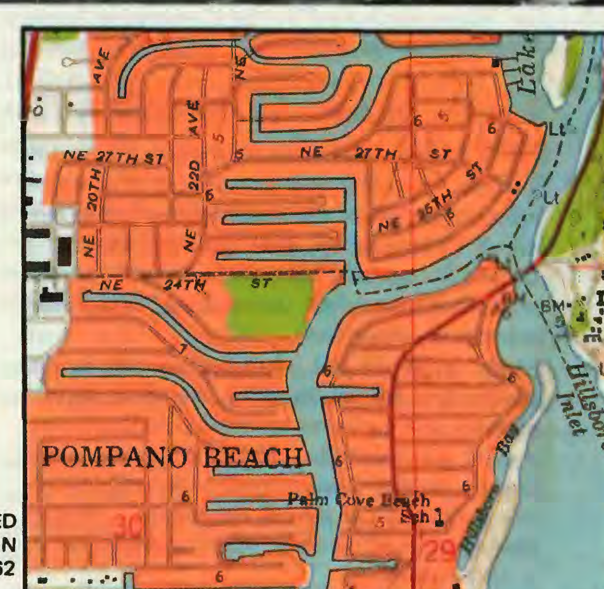
Because everything on Earth changes, no topographic map is useful forever. In unsettled interior parts of the country, the useful life of a topographic map may be 50 years or more, but it is much shorter where natural process are very active, as along rivers and coasts or where man is changing the landscape by excavating and building. The Florida example below is spectacular but far from unique. In hundreds of urban areas, growth is so rapid that topographic maps become out of date within a few years. The Geological Survey attempts to update urban maps on a 5-year basis (more than 900 were revised in 1975), usually by overprinting revisions in purple on the original map, but cannot keep up with the demand. For example, the Monterey quadrangle on the opposite page was originally printed in 1947; the area became urbanized in the 1960's and the map was revised in 1968, requiring plenty of purple ink. And now (1977) another revision is overdue.

For planning purposes, topographic maps can be updated by supplementing them with recent aerial photographs at the same scale, the procedure used in Survey revision. But it is not easy to do this with the raw photographs, because everything on them, except at the very center, is displaced optically. A photomechanical way has been found to correct this distortion, and the Geological Survey recently began producing standard 1:24,000 orthophotoquads, which consist of a black-and-white photograph that is nearly free of distortion, in 7.5-minute format. These words are printed on part of one, which matches the Monterey quadrangle and serves as an interim revision map.

Unfortunately, orthophotoquads are not yet available for many urban areas. Because they are quickly made and accurate, orthophotoquads are in great demand as interim maps for those areas that have never been mapped at the 1:24,000 scale. These include about 30 percent of the conterminous United States, mainly rural. At the present time (1977), the production capacity for orthophotoquads is monopolized by interim maps. Soon, however, it is expected that national interim coverage will be completed and that urban orthophotoquads will come into volume production.



MAPPED IN 1946



REVISED IN 1962

Reading and obtaining topographic maps

On the upper right corner of this page is a bird's-eye view of a river valley flanked by hills; beneath it is a topographic map of the same scene. Study of the view and the map may be helpful to readers who are not accustomed to using topographic maps. The river flows into a bay which is partly enclosed by a sandspit. On both sides of the valley are flatlands into which small streams have cut gullies. The hill on the right, more than 280 feet above the water, rises smoothly and gradually above a wave-cut cliff. The hill on the left, not quite so high, rises to a steep slope from which it falls off gently to form a smooth sloping surface cut into by a few small gullies. At the foot of the right-hand hill, 15 feet higher than the bay, are a school and two houses. An unimproved dirt road and a bridge connect the small settlement with an improved light-duty road, across the river, which follows the seacoast and curves up the river valley.

The map shows these features by standard symbols and colors. The works of man—school, houses, roads—are in black; the unimproved road is shown by double broken lines, the improved road by solid ones. Water features—the river and its tributaries, the bay and ocean—are in blue. And the shape and elevation of the land surface are shown by contour lines—lines of equal elevation above the sea—in brown. The vertical difference, or interval, between the contour lines is 20 feet. For easier reading, some contour lines are numbered and the 100-foot contours are drawn with heavier lines. The elevation of any point not on a contour can be estimated from the contours above and below it; the school, for example, is between the zero contour (sea level) and the 20-foot contour but is much closer to the 20-foot contour; so, its elevation must not be far from 15 feet.

The contour lines are artificial, of course, but they are an effective way to represent the third dimension on flat paper. The shoreline is a contour representing zero elevation, based on mean sea level. If the sea should rise 20 feet, the new shoreline would trace out the 20-foot contour; 20 feet more of rise would produce the 40-foot contour, and so on. With practice and imagination, planners and decision-makers can visualize clearly the land and water forms shown on topographic maps and apply these insights to their work.

Contour lines are useful for showing many things besides the shape of the land. Almost any kind of earth-science information can be portrayed as a contour map; the method is especially suited to generalizing data from specific points on the ground such as that from boreholes for water, oil, or minerals. Buried surfaces can be shown either by contouring their elevations above or below sea level, or any other level, or by contouring the depth of burial. Variations in the thickness of exposed or buried features can be well shown by contours. Such information can in turn be used to help make many kinds of planning decisions. Many examples of contour maps and their uses appear later in this book.

Topographic maps may be obtained directly from the Geological Survey or from commercial dealers, of which there are more than 1,550 throughout the United States. Indexes showing published maps for each State (and for Puerto Rico, the Virgin Islands, Guam, American Samoa, and Antarctica as well) are available free on request, by mail or over-the-counter. For areas east of the Mississippi River, including Minnesota, Puerto Rico, and the Virgin Islands:

Branch of Distribution
U.S. Geological Survey
1200 South Eads St.
Arlington, VA 22202

For areas west of the Mississippi River, including Alaska, Hawaii, Louisiana, Guam, and American Samoa:

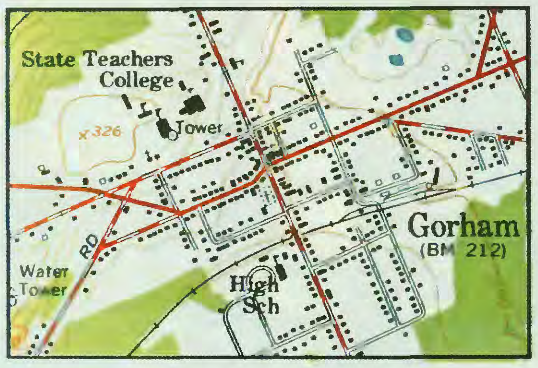
Branch of Distribution
U.S. Geological Survey
Box 25286
Federal Center
Denver, CO 80225

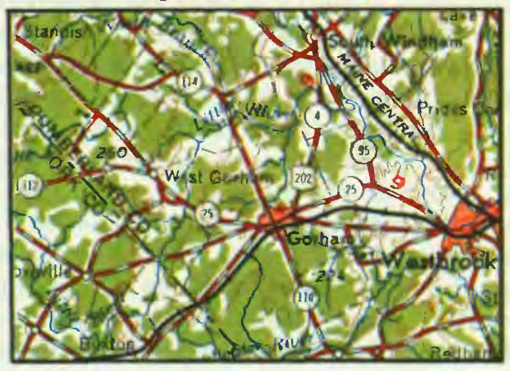
Or for residents of Alaska:

Distribution Section
U.S. Geological Survey
310 First Avenue
Fairbanks, AK 99701

The indexes list all published maps and include order blanks showing prices and detailed instructions for ordering from the Survey. They also list addresses of local map reference libraries, local map dealers, and Federal map distribution centers.

Orientation, scale, detail, and accuracy of maps





To use maps well, one must always be conscious of their orientation, scale, detail, and accuracy. To read any map it must be oriented, placed in its correct relation to the Earth. This is a simple matter for all topographic maps, orthophotoquads, land-use and land-cover maps published by the Geological Survey, and for nearly all of its other maps as well: North is at the top of the sheet, south at the bottom, east at right, west at left. All the maps in this book are oriented with north at the top. Rarely, Survey maps of irregular shape are printed with some other orientation, as are maps from other sources. The orientation of virtually every map is shown by an arrow, or similar symbol, pointing north or, rarely, in another cardinal direction (south, east, or west). The first step in reading any map, then, is to check its orientation.

To illustrate scale, detail and accuracy, we will use topographic maps, but what we have to say applies to all types of maps.

Above are segments, each the same size, from three different topographic maps around a town called Gorham. The left-hand map is almost filled by the town, which it shows in considerable detail, including streets, public buildings, and even individual houses. This map is at 1:24,000 scale, in which 1 inch on the map represents 24,000 inches, or 2,000 feet on the ground, the same scale as the Monterey quadrangle and orthophotoquad. The entire map portrays 1 square mile.

In the middle map Gorham occupies the center only, and there is space to show the surrounding country, access roads, outlying houses, a cemetery, and so on. There is also space to show the streets and landmark buildings of the town, but not individual houses, which are indicated collectively by the red overprint. This map is at 1:62,500 scale, in which 1 inch on the map represents 62,500 inches, or about 1 mile on the ground. Covering 6¾ square miles, it shows a much larger area than the left-hand map, but in much less detail. This map could be enlarged photographically until 1 inch equalled 2,000 feet, as in the left-hand map, but the amount of detail on it would be no greater than before; moreover, its accuracy would be even less than before because of distortion during the enlargement process and because all the lines on it would be 2½ times thicker and therefore take up 2½ times as much space. Enlarging a map may make it easier to work with but does not improve either its detail or its accuracy.

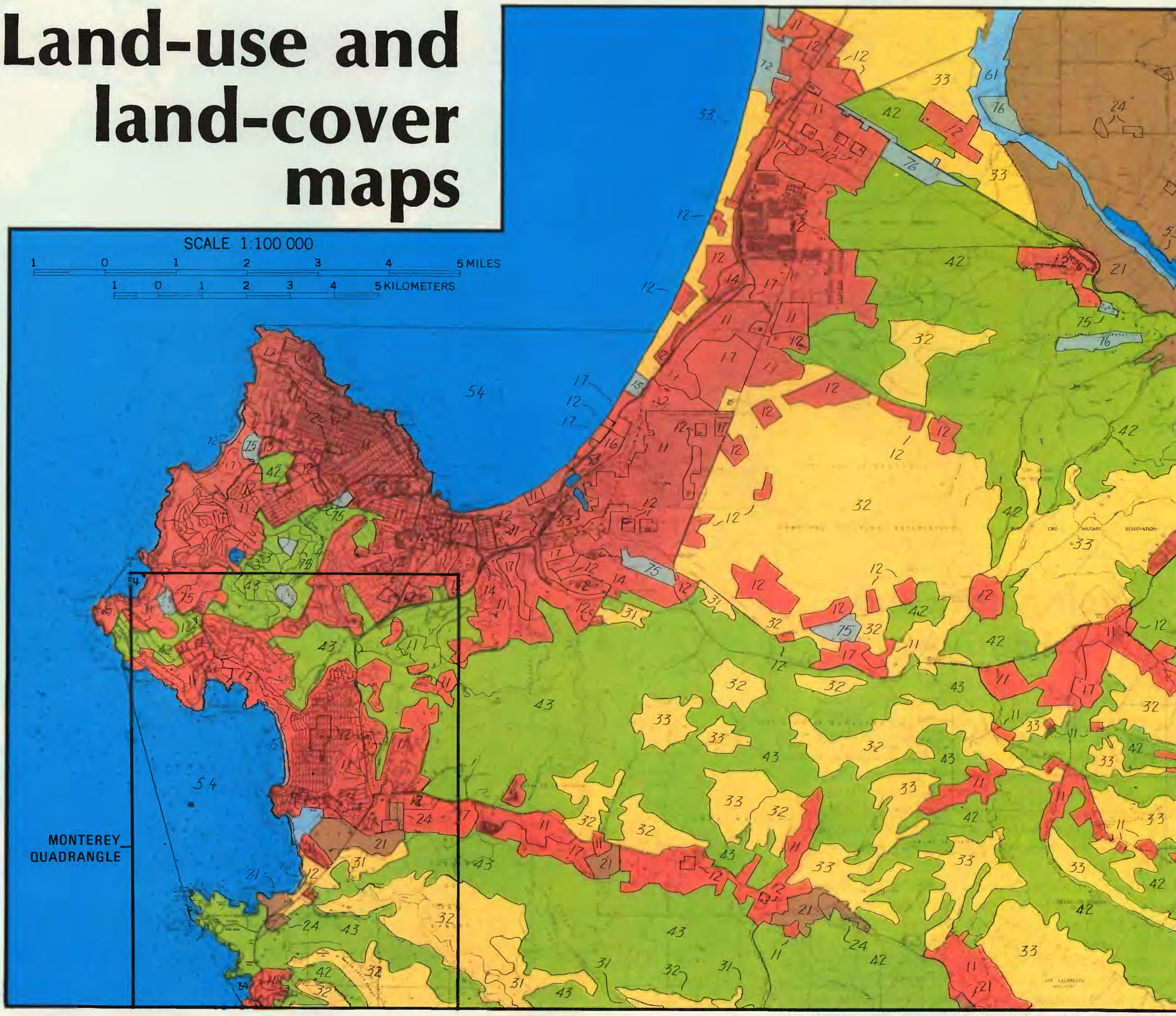
The right-hand map shows Gorham at a scale of 1:250,000, in which 1 inch represents nearly 4 miles. This map shows 107 square miles, and on it Gorham is a red-tinted blob criss-crossed by roads; enlarged from this map photographically to 1:62,500 or 1:24,000 the town would still be only a blob.

What can be said about the accuracy of these maps? It is natural to equate detail with accuracy, to assume that the more detail a map has, the more accurate it is. Put this way, the 1:24,000 left-hand map is the most accurate, the 1:250,000 right-hand map the least. But this is true only if the maps are made with equal care and from equally good information. For example, a careless mapmaker working on the 1:24,000 map might have placed a school symbol on the wrong building, with the result that the 1:62,500 map would be more accurate, more nearly correct.

But maps after all are only miniature and symbolic representations of reality, even at much larger scales than 1:24,000, and their accuracy might better be thought of as a measure of the care or precision of the entire mapmaking process, including obtaining, measuring, recording, and printing the information displayed. In this sense, all three of the Gorham maps are equally accurate, for all three comply with national accuracy standards, which require that the horizontal position of 90 percent of well-defined features must be plotted on the map within one-fiftieth of an inch of their true position. But one-fiftieth of an inch on paper represents different distances on the ground, depending on scale: it is 40 feet at 1:24,000 scale, about 100 feet at 1:62,500, and about 400 feet at 1:250,000. Similarly for elevations, 90 percent of which, to comply with national standards, must be correct within one-half the contour interval, which is ordinarily 10 or 20 feet for 1:24,000-scale maps, 40 or 80 feet for 1:62,500 maps, and 200 or 500 feet for 1:250,000 maps. Looked at this way, accuracy is a relative matter. This helps explain why 1:24,000 maps, even if greatly enlarged, will not do for site or project planning: Being correct within 40 feet horizontally and 5 or 10 feet vertically is just not close enough. A more important reason, however, is that 1:24,000 maps simply do not have enough information.

Another aspect is that large-scale maps, requiring more detail to reach standard accuracy, cost much more to prepare. As a rule-of-thumb, the cost rises proportionately to the scale.

Land-use and land-cover maps



Topographic maps offer a great deal of information about the land surface, but they do not give much specific or detailed information about the way man uses the land—land use—or about the vegetation that covers the surface—land cover. Such information is needed by planning, public works, and development agencies at all levels of government, as well as by the private sector. Thus, nearly all local governments have prepared their own land-use maps, using the standard topographic quadrangle maps or larger scale low altitude aerial photographs as a base. Most agencies have independently developed their own land-use and land-cover classification systems, based on local needs, or use one of a variety of systems developed by planners.

The increasing involvement of State and Federal agencies in managing land, water, and resources has made systematic land-use and land-cover mapping of the United States necessary and a uniform classification system for such mapping desirable. Such a system has been developed by the U.S. Geological Survey in consultation with many other Federal and State agencies. It is described in U.S. Geological Survey Professional Paper 964, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data," by James R. Anderson and others (1976). In 1975, the Survey began systematic coverage of the United States at scales of 1:100,000 (about 1½ miles to the inch) and 1:250,000 (4 miles to the inch).

The classification system recognizes the possible use of four or more levels of detail. Level 1 consists of highly generalized coverage at a small scale, which can be based on interpretation of Landsat satellite imagery. Level II mapping, which can be based on high-altitude aerial photographs, is usually presented at intermediate scales (1:100,000 or 1:250,000) and allows more detailed coverage. Levels III and IV mapping, which use lower altitude photographs at large scales, are usually done only by local governments and include much detail acquired on the ground. The accompanying table shows the categories used for Level I and II coverage.

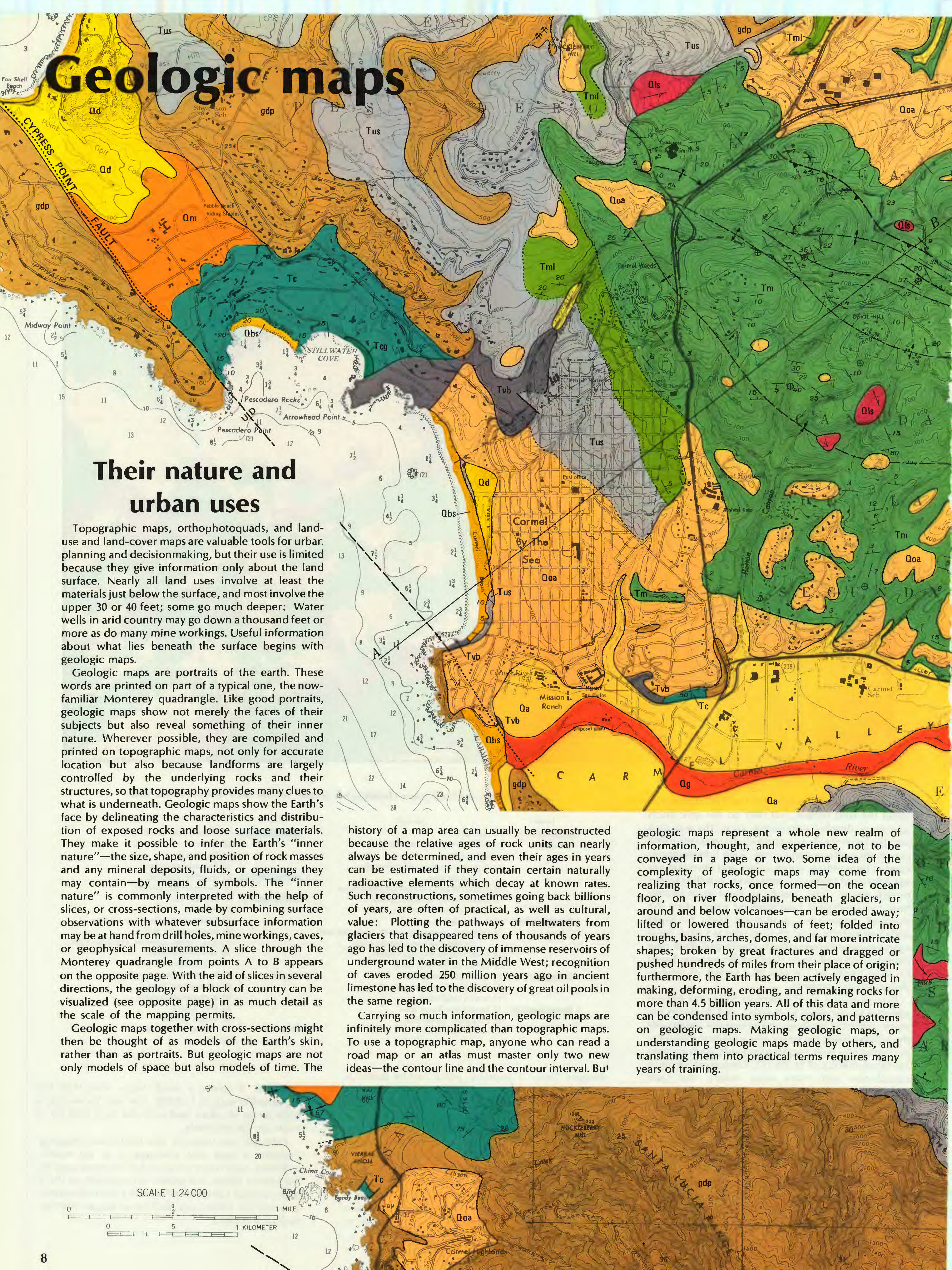
Land use and land cover classification system for use with remote sensor data

Level I	*Level II*
1 Urban or built-up land	11 Residential.
	12 Commercial and services.
	13 Industrial.
	14 Transportation, communications, and utilities.
	15 Industrial and commercial complexes.
	16 Mixed urban or built-up land.
	17 Other urban or built-up land.
2 Agricultural land	21 Cropland and pasture.
	22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas.
	23 Confined feeding operations.
	24 Other agricultural land.
3 Rangeland	31 Herbaceous rangeland.
	32 Shrub and brush rangeland.
	33 Mixed rangeland.
4 Forest land	41 Deciduous forest land.
	42 Evergreen forest land.
	43 Mixed forest land.
5 Water	51 Streams and canals.
	52 Lakes.
	53 Reservoirs.
	54 Bays and estuaries.
6 Wetland	61 Forested wetland.
	62 Nonforested wetland.
7 Barren land	71 Dry salt flats.
	72 Beaches.
	73 Sandy areas other than beaches.
	74 Bare exposed rock.
	75 Strip mines, quarries, and gravel pits.
	76 Transitional areas.
	77 Mixed barren land.
8 Tundra	81 Shrub and brush tundra.
	82 Herbaceous tundra.
	83 Bare ground tundra.
	84 Wet tundra.
	85 Mixed tundra.
9 Perennial snow or ice	91 Perennial snowfields.
	92 Glaciers.

The map on this page is an example of Level II coverage for the Monterey Peninsula, the same area used in the preceding examples. At a scale of 1:100,000, it covers a much larger area than the topographic map at 1:24,000. The map shows that a wide range of urban land uses and rural land cover exists on the peninsula.

Although the land-use and land-cover mapping program is new and coverage is as yet widely scattered, such maps are available for many parts of the United States. For further information on these maps, contact Geography Program, Land Information and Analysis Office, U.S. Geological Survey, MS 710, Reston, VA 22092.

Geologic maps



Their nature and urban uses

Topographic maps, orthophotoquads, and land-use and land-cover maps are valuable tools for urban planning and decisionmaking, but their use is limited because they give information only about the land surface. Nearly all land uses involve at least the materials just below the surface, and most involve the upper 30 or 40 feet; some go much deeper: Water wells in arid country may go down a thousand feet or more as do many mine workings. Useful information about what lies beneath the surface begins with geologic maps.

Geologic maps are portraits of the earth. These words are printed on part of a typical one, the now-familiar Monterey quadrangle. Like good portraits, geologic maps show not merely the faces of their subjects but also reveal something of their inner nature. Wherever possible, they are compiled and printed on topographic maps, not only for accurate location but also because landforms are largely controlled by the underlying rocks and their structures, so that topography provides many clues to what is underneath. Geologic maps show the Earth's face by delineating the characteristics and distribution of exposed rocks and loose surface materials. They make it possible to infer the Earth's "inner nature"—the size, shape, and position of rock masses and any mineral deposits, fluids, or openings they may contain—by means of symbols. The "inner nature" is commonly interpreted with the help of slices, or cross-sections, made by combining surface observations with whatever subsurface information may be at hand from drill holes, mine workings, caves, or geophysical measurements. A slice through the Monterey quadrangle from points A to B appears on the opposite page. With the aid of slices in several directions, the geology of a block of country can be visualized (see opposite page) in as much detail as the scale of the mapping permits.

Geologic maps together with cross-sections might then be thought of as models of the Earth's skin, rather than as portraits. But geologic maps are not only models of space but also models of time. The history of a map area can usually be reconstructed because the relative ages of rock units can nearly always be determined, and even their ages in years can be estimated if they contain certain naturally radioactive elements which decay at known rates. Such reconstructions, sometimes going back billions of years, are often of practical, as well as cultural, value: Plotting the pathways of meltwaters from glaciers that disappeared tens of thousands of years ago has led to the discovery of immense reservoirs of underground water in the Middle West; recognition of caves eroded 250 million years ago in ancient limestone has led to the discovery of great oil pools in the same region.

Carrying so much information, geologic maps are infinitely more complicated than topographic maps. To use a topographic map, anyone who can read a road map or an atlas must master only two new ideas—the contour line and the contour interval. But geologic maps represent a whole new realm of information, thought, and experience, not to be conveyed in a page or two. Some idea of the complexity of geologic maps may come from realizing that rocks, once formed—on the ocean floor, on river floodplains, beneath glaciers, or around and below volcanoes—can be eroded away; lifted or lowered thousands of feet; folded into troughs, basins, arches, domes, and far more intricate shapes; broken by great fractures and dragged or pushed hundreds of miles from their place of origin; furthermore, the Earth has been actively engaged in making, deforming, eroding, and remaking rocks for more than 4.5 billion years. All of this data and more can be condensed into symbols, colors, and patterns on geologic maps. Making geologic maps, or understanding geologic maps made by others, and translating them into practical terms requires many years of training.

We cannot make instant geologists of our readers, and we will not try. Nowhere in this book do we tell how to read geologic maps, though we list a few references that do tell. But it is important for urban planners and decisionmakers to be aware of the basic maps and sections needed for successful application. Once a geologic map exists, information relevant to some urban situation can be extracted from it, translated into relevant terms, and put to use, sometimes alone but more often in conjunction with other maps and information. Much of this book consists of maps that have been abstracted, translated, or derived from geologic maps. Some of the geologic maps themselves have been included, not with the thought that many readers will be prepared to use them directly, but as a constant reminder that the underlying geologic facts and inferences are an essential base for sound land-use and resource-management decisions.

DESCRIPTION OF MAP UNITS

SURFICIAL SEDIMENTS
- Qbs — Beach sand
- Qg — River sand and gravel
- Qd — Dune sand
- Qa — Alluvium
- Qls — LANDSLIDE DEBRIS—may be actively moving

OLDER SURFICIAL SEDIMENTS
- Qoa — Older alluvium and terrace gravel and sand
- Qm — Marine terrace sand and gravel

MONTEREY SHALE Siliceous marine deposit
- Tm — Siliceous shale, light-brown to white
- Tml — Semi-siliceous shale, yellowish-brown

MARINE SANDSTONE
- Tus — Sandstone, buff to light-gray, upper part
- Tvb — Volcanic rocks
- Tls — Sandstone as above, lower part

CARMELO FORMATION OF BOWEN (1965)
- Tc — sandstone, siltstone, mudstone, and conglomerate
- Tcg — Cobble and boulder conglomerate, mostly granitic

GRANITIC ROCKS Light-gray crystalline rocks
- gdp — Granodiorite, porphyritic
- gd — Granodiorite

Contact
Dashed where approximately located, gradational, or concealed

U / D Fault
Dashed where inferred; dotted where concealed. U, relatively upthrown side; D, downthrown side.

Thrust fault
Dashed where inferred; dotted where concealed. Sawteeth on upper plate

Horizontal — Inclined (20) — Vertical — Overturned (60) — Direction of dip from distant view

Strike and dip of beds

Anticline — Syncline

Fold axis, showing direction of dip of limbs and of plunge. Dotted where concealed

Direction of landslide movement — Abandoned exploratory well drilled for oil or gas, showing total depth in feet — Water well

Quarry — Spring

Some symbols do not appear on that part of the map shown opposite

Reading and obtaining geologic maps, cross-sections, and block diagrams

Geologic maps, slices (cross-sections) through the area they represent, and block diagrams constructed from the maps and cross-sections are basic tools for viewing the materials of the earth and their relations to each other. Concealed in their technical words and symbols is a wealth of information useful to urban planning and management. Geologic maps have many common characteristics, regardless of scale; some of these are exhibited on the map of part of the Monterey 7.5-minute quadrangle on the opposite page. Covering the same area as the Monterey topographic quadrangle and orthophotoquad on preceding pages, the geologic map is far more complicated.

The boxes in the "Description of Map Units" show the colors, patterns, and letter symbols assigned to each map unit, which is briefly described. This part of the map has 16 units, arranged in order of relative age (oldest at bottom); the whole map has 27. Some quadrangle maps have 50 to 60 units; regional or State maps may have a hundred or more.

The symbols below the boxes give additional information. Most of it is about the structures in the rocks, which may range from the alinement of grains or layers visible in a hand specimen (not noted on this map) to the direction and inclination of layers in large natural or manmade exposures ("strike and dip of beds") and to giant bends or folds ("anticline," "syncline") or long and deep breaks in the rocks ("fault," "thrust fault") measurable in miles. Other symbols convey information about landslides, minerals, fuel, construction materials, and water resources (the bottom row of symbols to the left for the Monterey map).

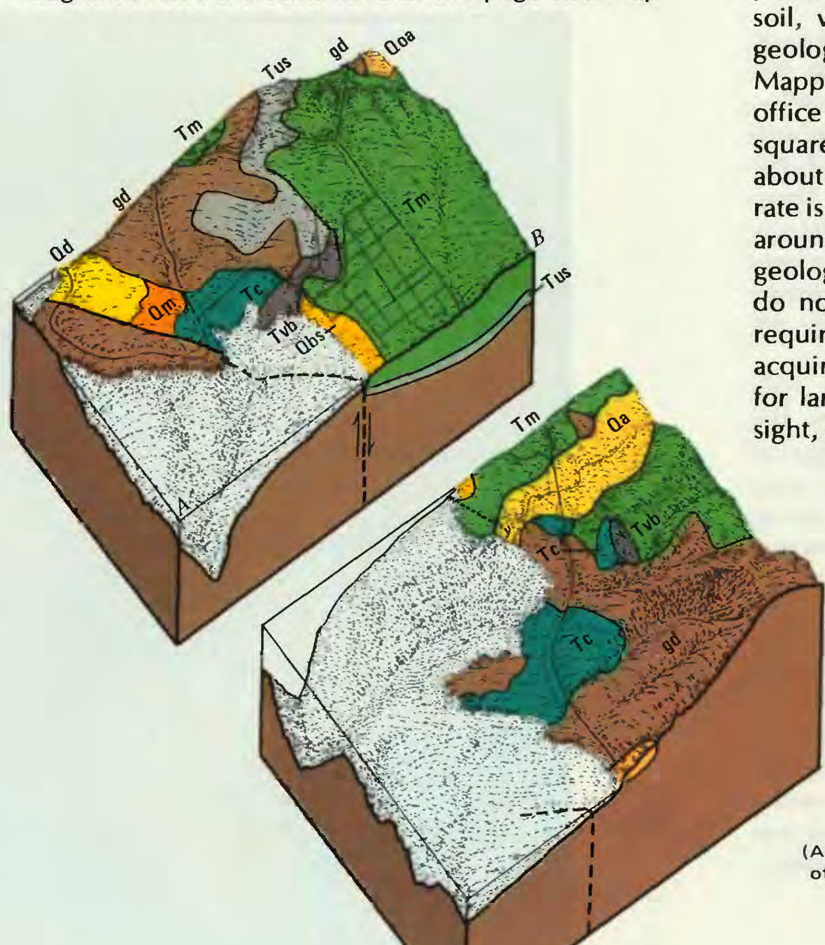
Cross-sections, or slices, through the mapped area, like the one at the bottom of this page, give an idea of the third dimension. Often, the vertical scale on cross-sections is exaggerated for easier viewing. This leads to some distortion, which should be kept in mind.

Finally, map and cross-sections can be combined into three-dimensional sketches or block diagrams, like that below, to create a sense of realism. The diagram shows the same area as the page-size map but is reduced to about one-fifth the scale, 1:125,000. So much detail must be omitted at this scale that it takes a while to realize we are viewing the same area. The omitted map units are mainly of loose surface materials. Although patchy and thin, these materials may be very significant for site planning and development—another demonstration of the importance of map scale to urban application.

Finding out what geologic maps are available is not as simple as tracking down topographic maps, because geologic maps have many sources. They are produced not only by geologists of the U.S. Geological Survey but also by geologists of State geological surveys, by teachers and graduate students at many collegiate institutions, and by private companies and consultants. Indexes to all published geologic maps in each State, updated every few years, can be obtained free on application to the Geological Survey offices listed three pages back. Many usable maps, however, are never published, and of course recently published maps are not yet listed. The best guide to unpublished or newly published local maps is the appropriate State geological survey or its equivalent, and the District and Public Inquiries offices of the U.S. Geological Survey, listed on pages 90–91. Geology or earth-science departments in nearby universities and colleges can also be helpful.

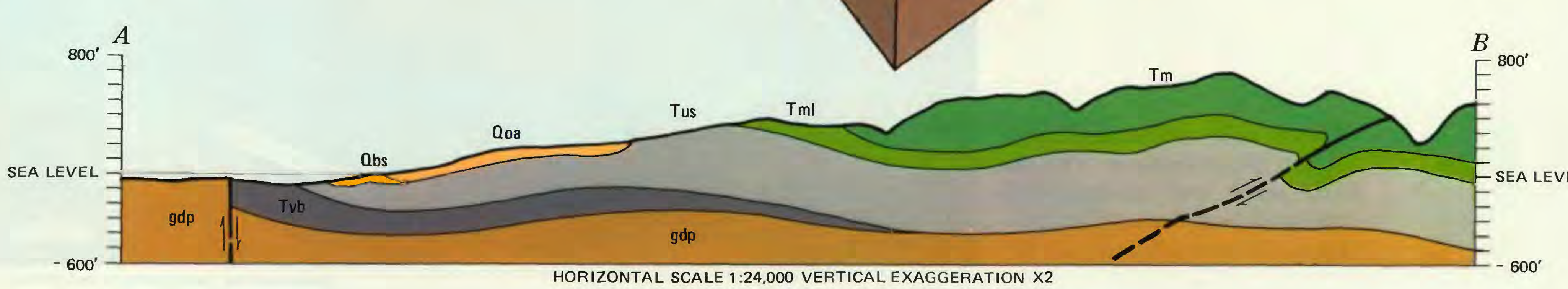
Unfortunately, basic geologic maps at large scales are not available for many urban or urbanizing areas. Most existing mapping has not been in or near cities, but rather in remote areas that have mineral or fuel potential or are of scientific interest. Nor is much new geological mapping being done: Mapping at scales of 1:100,000 or larger is now proceeding at the snail-like pace of 30,000 to 40,000 square miles per year, most of it far from cities. More than half of this mapping is by the U.S. Geological Survey, which conducts as much as its staff and funds permit. The bulk of the remainder is by State surveys.

Geologic mapping, unlike modern topographic mapping, cannot be done largely indoors from aerial photographs but requires intensive field work. Only a few useful properties of rocks can be measured on photographs, and even these are often obscured by soil, vegetation, or the works of man. Producing geologic maps is therefore rather slow and expensive: Mapping at 1:24,000 scale, and related laboratory and office work, typically proceeds at a rate of about 50 square miles per mapper per year, at an overall cost of about $1,500 per square mile; at 1:100,000 scale, the rate is about five times faster and the cost decreases to around $200 per square mile. However, when geologic maps are well done at suitable scales, they do not go out of date quickly, so the investment required can be amortized over a long time. Plainly, acquiring geologic mapping as planning information for large urban areas requires understanding, foresight, and commitment.



HORIZONTAL SCALE 1:125,000
VERTICAL EXAGGERATION X2

(Adapted from California Division of Mines and Geology, 1959)

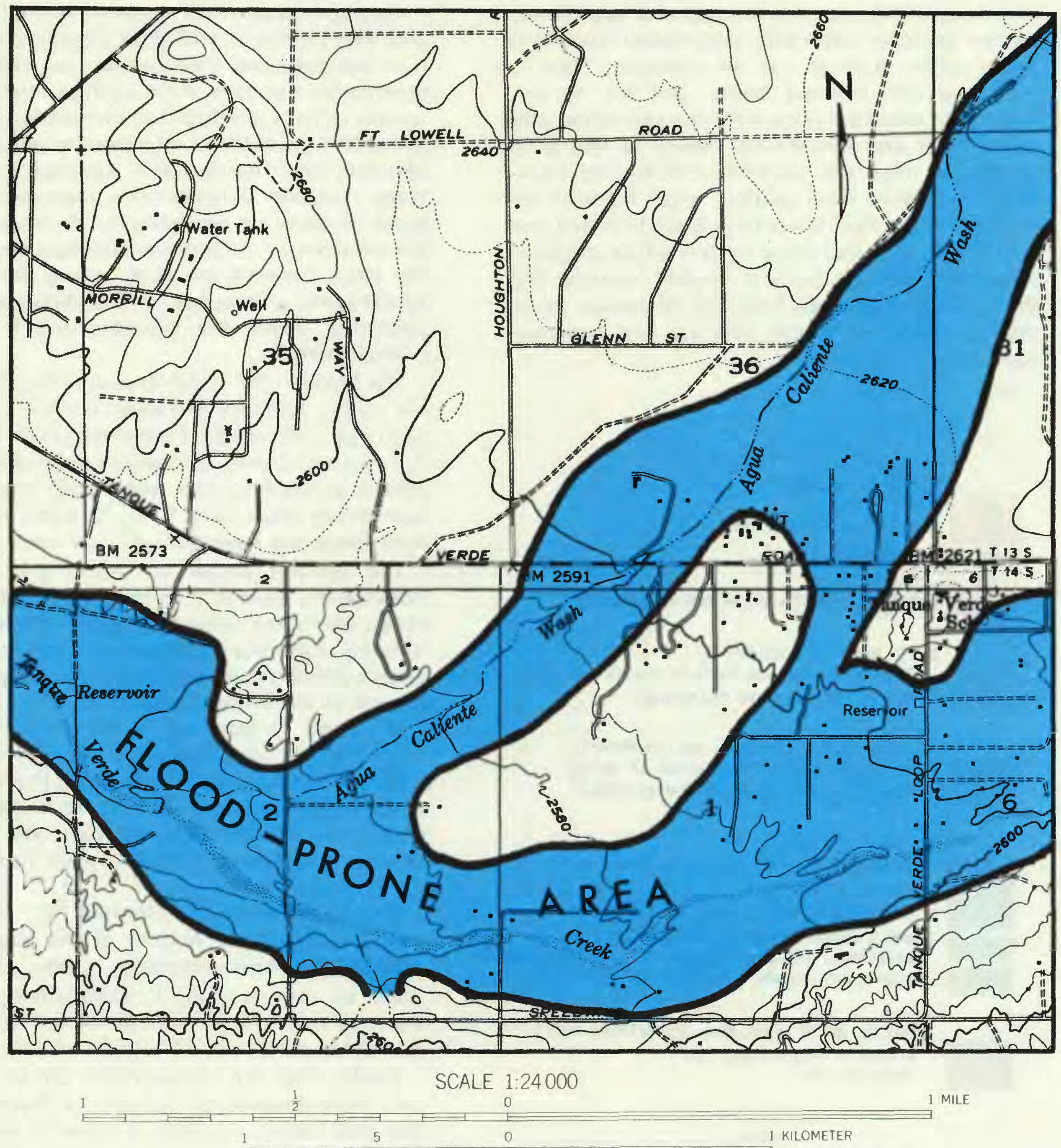


HORIZONTAL SCALE 1:24,000 VERTICAL EXAGGERATION X2

Hydrologic maps

Hydrologic maps portray the occurrence of water on and beneath the land surface. They are useful to planners and managers in evaluating water supply, water-related hazards such as flooding and high hydrologic maps exists; so great, in fact, that it is not practical to show representative examples in this practical to show representative examples in this "Introduction." Numerous examples of hydrologic maps appear throughout this book. Among them are maps showing drainage areas, maps showing the depth to ground water and the thickness of water-bearing formations, maps depicting the quality of water, and maps showing the predicted water-level declines which would result from increased pumping of ground water. The full range of hydrologic maps is seldom available for any given area.

One type of hydrologic map—the flood-prone area map—is widely available and is illustrated here. More than 12,500 of these maps have been prepared by the U.S. Geological Survey, covering virtually all the developed and developing parts of the nation. Still to be mapped, however, are many areas of potential future development, public lands for which planning and management decisions are needed, and recreational lands. Flood-prone area maps have been used in making many decisions regarding uses of land subject to flooding. Among the most widespread and important uses are in the National Flood Insurance Program.

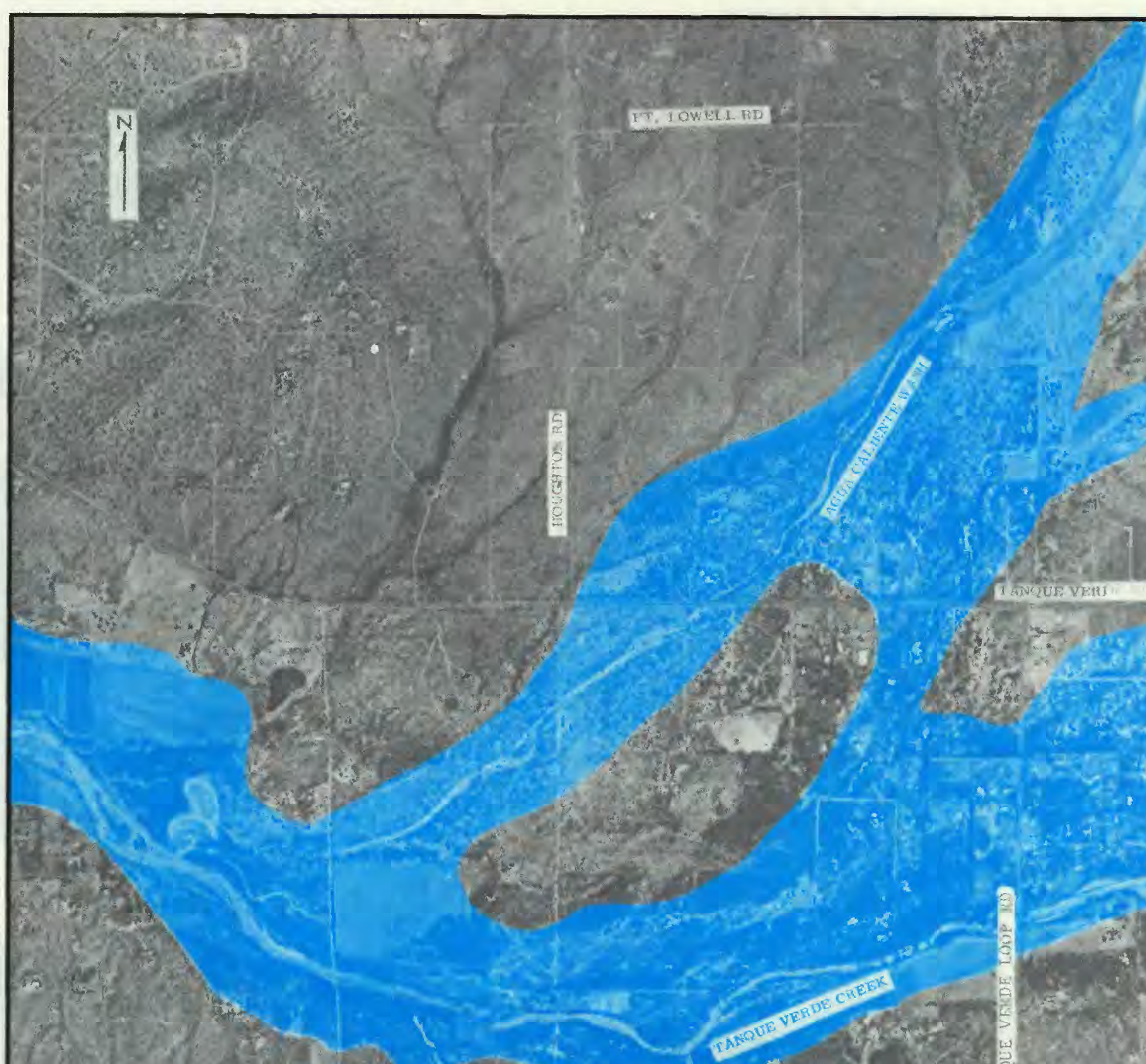


Flood-prone area of Agua Caliente Wash and Tanque Verde Creek, Arizona (1957)

Flood-prone area maps made by the Survey show on a standard 7.5-minute quadrangle base the approximate boundaries of the "100-year flood"—the area that has a 1 percent chance of being flooded in any given year. They are available free of charge from the District Offices listed on pages 90–91. These maps are generalized. More detailed flood-hazard maps, prepared by such agencies as the Army Corps of Engineers, the Soil Conservation Service, private consultants, and also the Geological Survey, are available for some areas.

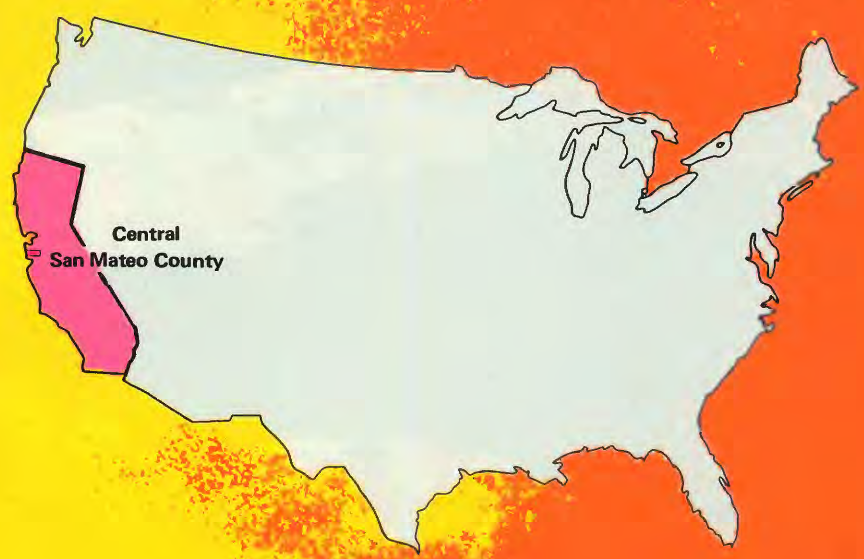
Part of a typical flood-prone area map, from suburban Tucson, Arizona, is at the upper right. The area in blue has a 1-in-100 chance, on the average, of being inundated during any given year; rarely, even larger floods than that illustrated may occur, inundating additional areas. The small areas that may be inundated by floods on minor streams are not shown.

When the topographic map was made, in 1957, the flood plains of Agua Caliente Wash and Tanque Verde Creek were only sparsely developed, with a few roads and widely separated buildings. Since then, more roads and many more houses and industrial structures have been built within the flood-prone area, as the recent aerial photograph of the same area shows (below) endangering more lives and property.



Recent and established residential development in the flood-prone area of Agua Caliente Wash and Tanque Verde Creek, Arizona (1973)

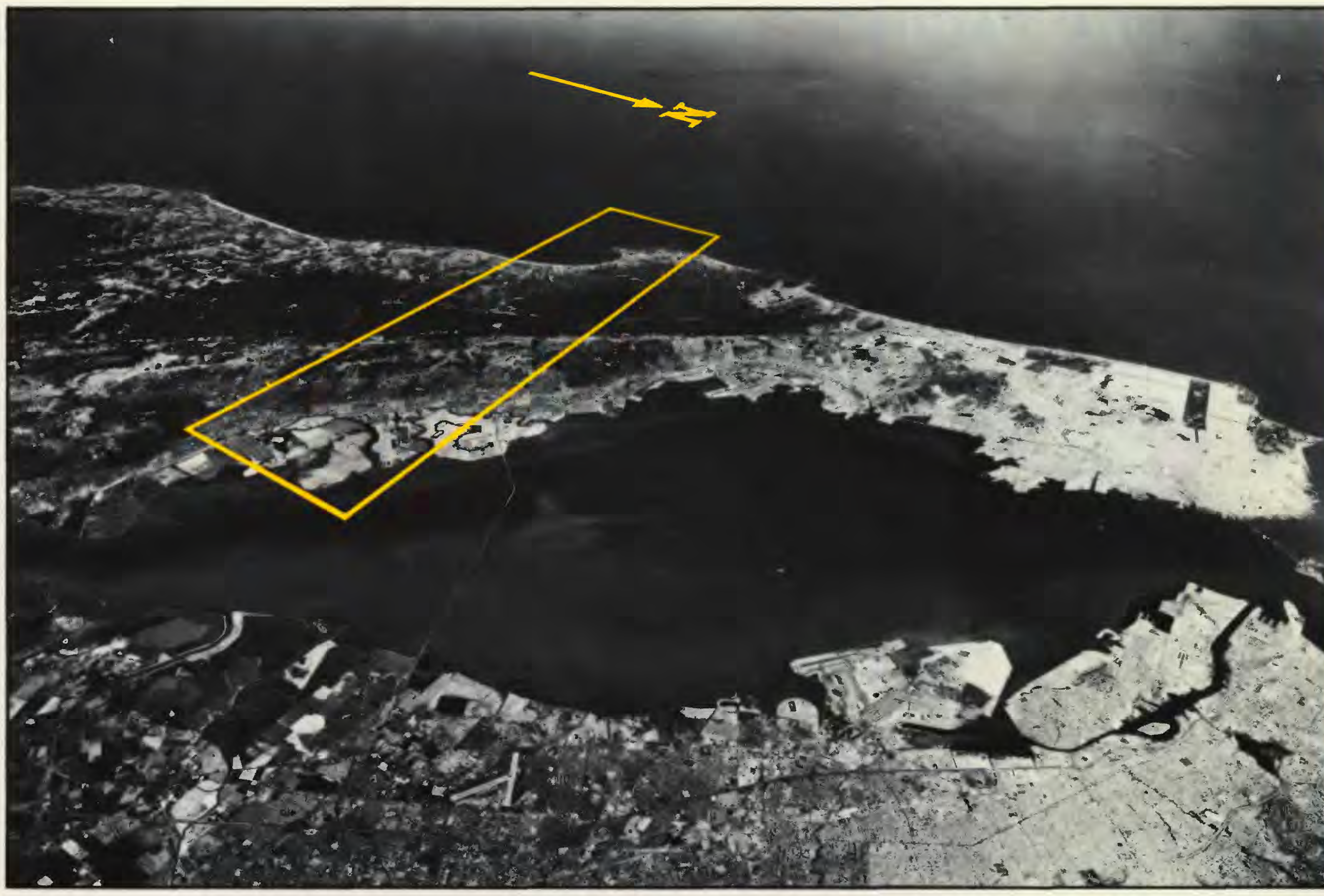
Photograph by Cooper Aerial Survey Company

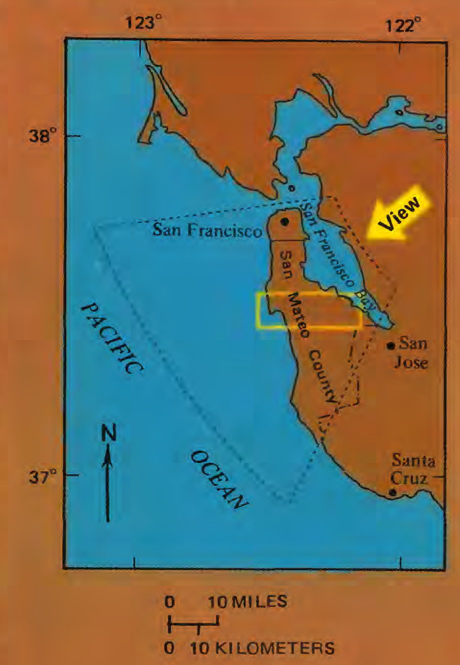


Central San Mateo County, California

Land-use controls arising from erosion of seacliffs, landsliding, and fault movement

By Brian Atwater





Central San Mateo County

The subject area is outlined in yellow on the aerial photograph (left) and on the index map (right).

Geologic processes and land-use controls

Failure to recognize and adjust to geologic processes in California has cost approximately 1,000 lives and $10 billion in property damage (1970 dollars) during the past 125 years. The threat of even greater losses in the future has caused the legislature to require local government authorities to incorporate geologic information into land-use plans and decisions. This chapter describes the geologic basis for several land-use regulations and guidelines in San Mateo County, which is just south of San Francisco (see index map above, right).

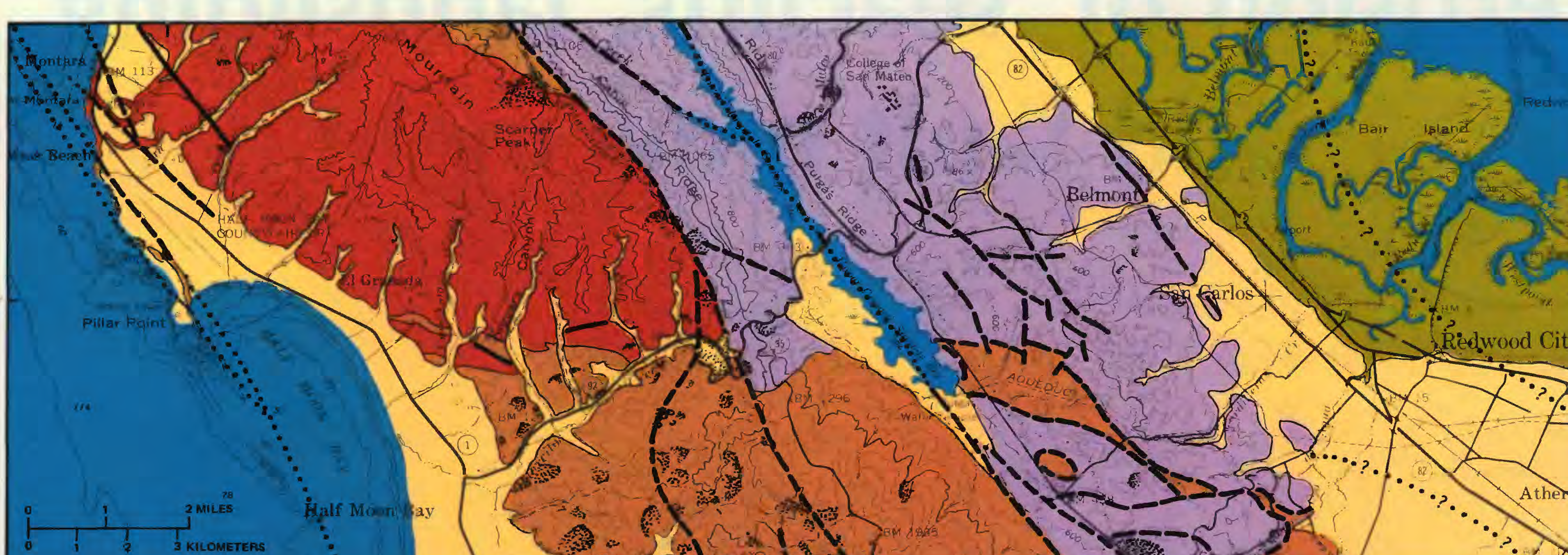
Geologic processes that have evoked governmental controls in this county include erosion of seacliffs and beaches, landsliding, movement along faults, deformation of water-saturated clay and sand, flooding of coastal areas by earthquake-induced sea waves, flooding from surface runoff, and intrusion of seawater into fresh-water aquifers. Public policies and ordinances, as of 1977, that pertain to the first three of these processes—erosion of seacliffs and beaches, landsliding, and fault movement—are summarized at the top of the facing page and discussed in greater detail in the rest of the chapter. Regulations and guidelines that incorporate new geological information will no doubt supersede these ordinances from time to time.

The critical first step toward avoiding or minimizing loss of life and property due to geologic processes is to determine the location of potential hazards such as faults and unstable slopes. Much of this information can be obtained or derived from aerial photographs and from earth-science maps, as this chapter illustrates.

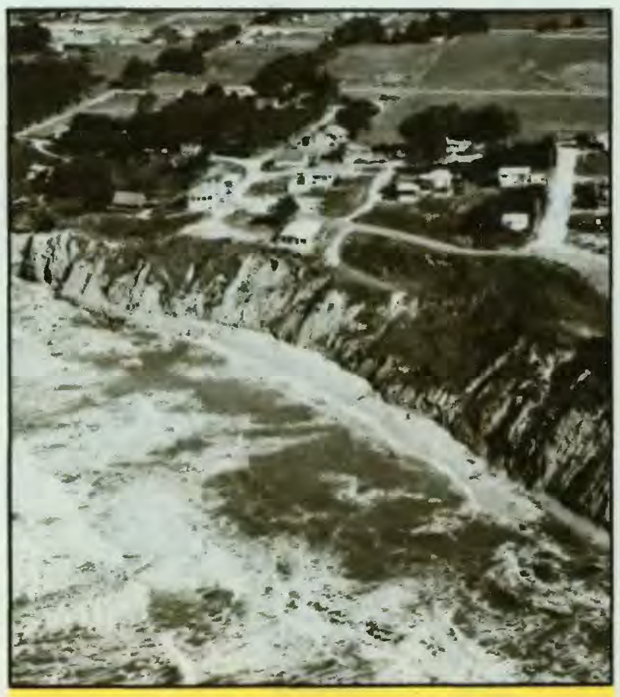
The capacity of land to support human uses depends partly on topography, the shape of land surface. Thus, most of the people in San Mateo County live on the plain and foothills bordering San Francisco Bay and on lowlands along the Pacific Ocean, but relatively few inhabit the rugged mountains in between (note distribution of urban areas on aerial photograph above). The block diagram on the facing page sketches these landforms but greatly exaggerates their vertical dimensions; the shape of the land is depicted much more accurately by contour lines on topographic maps. A small-scale (1:125,000) topographic map is the base for the various maps of central San Mateo County shown here and later in this chapter.

The capacity of the land to support human uses also depends on the physical properties and distribution of earth materials. The distribution of various kinds of rocks and sediments and the location of structural features such as faults in central San Mateo County are shown on a geologic map at the bottom of this page. The area of the map is outlined in yellow on the index map and the aerial photograph (above). In the block diagram opposite, the front and right sides are vertical slices through or cross sections of the southern and eastern margins of this area.

Geologic map of central San Mateo County

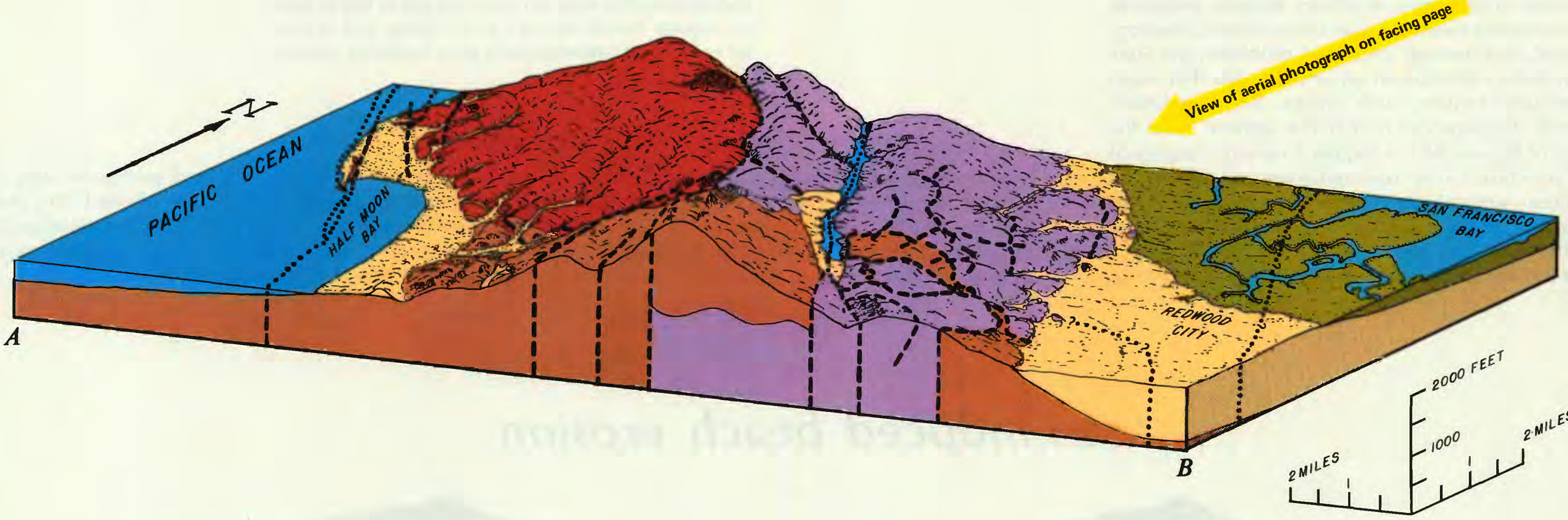


A *B*



GEOLOGIC PROCESS	Erosion of cliffs and beaches along the Pacific Ocean	Landsliding in hillside areas	Displacement of the ground surface along active faults
PUBLIC POLICY	Discourage development of unstable shoreline areas	Discourage development of unstable slopes	Discourage development in active fault zones
PUBLIC ORDINANCE	Prohibit or restrict construction of buildings within certain setbacks from unstable seacliffs	Restrict density and type of development where slopes are unstable or steep	Prohibit or restrict construction of buildings for human occupancy in active fault zones

Some land-use controls in San Mateo County arising from geologic processes



Geology of central San Mateo County in three dimensions

SAN FRANCISCO BAY SEDIMENTS
Soft mud with shells, peat, and sand. Covered with manmade fill in many areas

LANDSLIDE DEBRIS
Masses of rock and soil moved downhill by gravity

STREAM AND BEACH SEDIMENTS
Gravel, sand, silt, and clay. Locally interlayered with San Francisco Bay sediments

YOUNGER SEDIMENTARY ROCKS
Sandstone and mudstone. Locally includes volcanic rocks

GRANITE
Locally includes metamorphic rocks

OLDER SEDIMENTARY AND IGNEOUS ROCKS
Sandstone, mudstone, altered igneous rocks, and scarce limestone

FAULT
Solid line where location is well-known, dashed line where location is approximate, and dotted line where location is concealed. Query indicates uncertainty about existence of fault

BOUNDARY BETWEEN DIFFERENT KINDS OF EARTH MATERIALS

Erosion of seacliffs and beaches

The coastal areas of the United States are narrow in extent but broad in human significance. Most Americans depend directly or indirectly on coastal lands and waters for recreation, industrial and commercial activities, waste disposal, food production, and natural preserves. In addition, more than half the Nation's people live within 50 miles of the ocean or the Great Lakes, and the percentage is increasing.

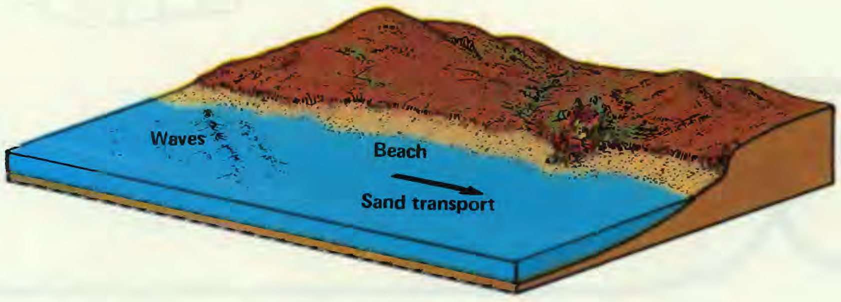
Recognition that coastal resources are finite, that claims on them are often competitive, and that some claims are broader than local has led several States to assume legislative authority over development of their coastal areas. These problems have also prompted the Federal Government to fund coastal-zone planning by State governments under the Coastal Zone Management Act of 1972. As a result California has adopted a comprehensive plan for resource use in the coastal zone. Mandated by a Statewide referendum in 1972, this plan was ratified by the State legislature in 1976. The principal policies of the plan are to guarantee public access to the shore, to insure that coastal developments serve the public as a whole, to protect and restore coastal marshes, to preserve coastal farmlands, and to provide stringent environmental safeguards for coastal developments, particularly energy facilities. These policies are to be implemented by local governments, which are required to adopt them as part of their own general plans.

California's coastal zone plan recognizes erosion of seacliffs as one of several geological processes that can endanger human life and property in coastal areas. Battered by waves and rain, many seacliffs in California have retreated during historic time, as shown in the photograph (right). Rapid erosion of developed cliffs has led to loss of property and to the building of protective structures. Because protective structures are costly and may cause esthetic, environmental, engineering, and legal problems, the State plan limits construction on or near cliffs that might eventually require such works. The regulations permit development only if the setback from the edge of the seacliff is adequate to assure integrity of the structure for its expected economic lifespan. In addition, site stability must be demonstrated for an area that includes the base, face, and top of all cliffs or bluffs more than 10 feet high.

In San Mateo County, State guidelines for bluff-top development have been adapted and refined to include information on historical bluff erosion (middle map on opposite page), resistance of bluff materials to erosion (bottom map opposite), and degree of natural protection from waves. This combination of historical and geological data has permitted coastal bluffs to be divided into three stability categories with corresponding development regulations that reflect the relative instability of the seacliff (top map opposite).

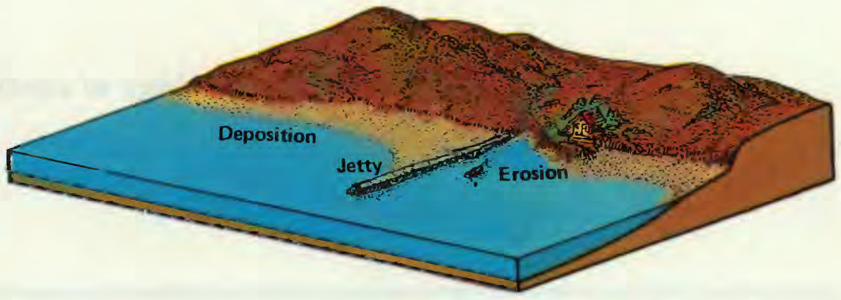
Unsightly boulders temporarily guard this structure, built near El Granada in 1973, from further battering of storm waves. Continued bluff retreat at historic rates (see middle map on opposite page) will require additional protective measures or lead to demolition of the building within the next few decades. County regulations (top map on opposite page) will prevent or reduce future damage to property and scenery by controlling development near unstable seacliffs.

Man-induced beach erosion



Natural sand transport

Waves striking the shore obliquely cause beach sand to move parallel to the shore.



Jetty-obstructed sand transport

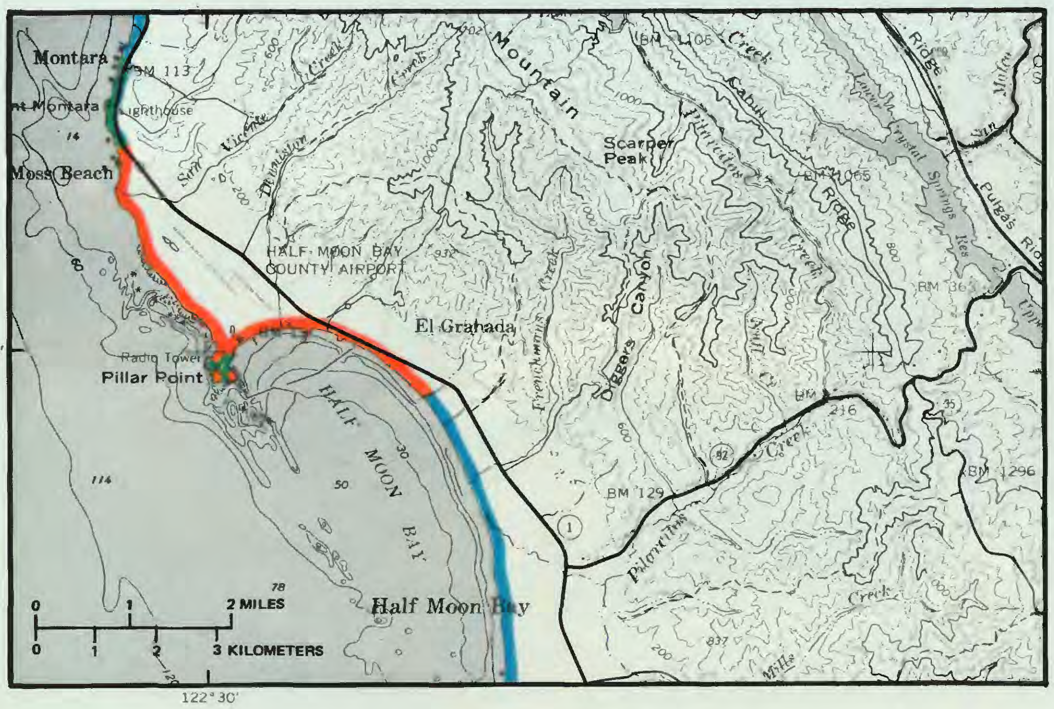
Sand accumulates on one side of the jetty, starving the beach on the other side, and resulting erosion threatens the house.

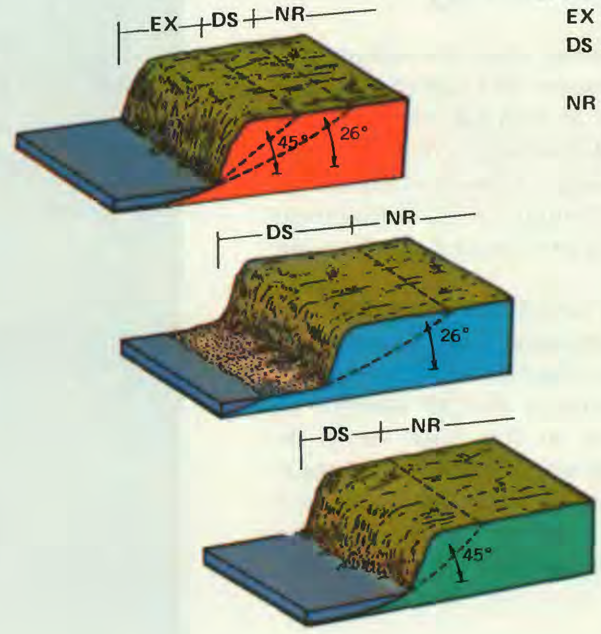
Seacliffs dominate the coast of northern California, but beaches line other parts of the Pacific coast and much of the Atlantic and Gulf coasts. Consequently, movement of beach sand is more important than retreat of bluffs in shoreline-erosion problems of many coastal areas.

Man contributes to beach erosion by reducing the supply of beach sand and obstructing its movement along shore. Supply is reduced by seawalls and dams; seawalls prevent production of sand from erosion of seacliffs, and inland dams prevent transport of sand to the ocean by rivers. Sand movement along beaches is commonly obstructed by jetties and breakwaters (see diagrams above). Jetties and breakwaters also can generate erosion by redirecting wave energy. For example, a breakwater at Half Moon Bay has accelerated retreat of nearby bluffs as much as fourfold since its construction in 1959 (see middle map on opposite page). Efforts to halt this erosion, such as emplacement of riprap barriers, have failed in the areas of most rapid retreat (see photograph of undermined road on opposite page).

The State and county regulations for bluff tops discussed above may prevent some man-induced erosion of beaches. By preventing construction of barriers between coastal bluffs and attacking waves, these regulations insure continued production of sand from seacliffs.

County regulations for bluff-top development





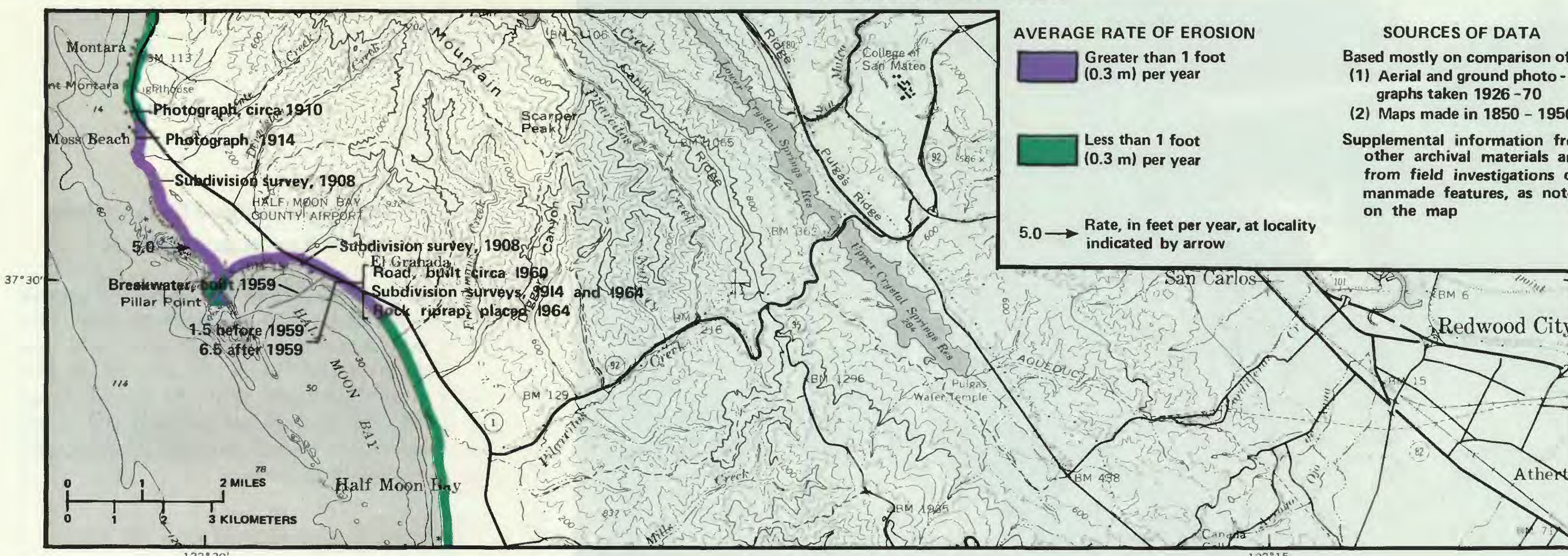
EXPLANATION OF SETBACKS

EX - *structures excluded*

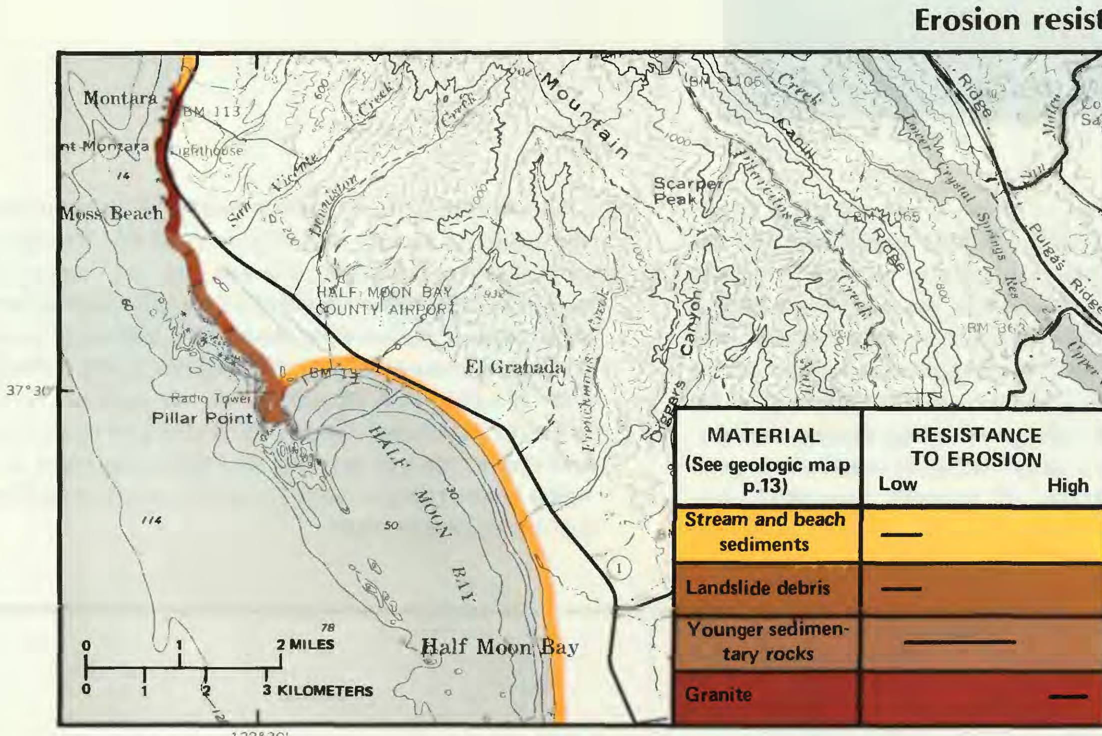
DS - *demonstrate stability in geotechnical reports*

NR - *normal geotechnical reports for proposed land use*

Historic bluff erosion



Erosion resistance of bluff materials



MATERIAL (See geologic map p.13)	RESISTANCE TO EROSION (Low — High)
Stream and beach sediments	— (low)
Landslide debris	— (low)
Younger sedimentary rocks	—— (low to moderate)
Granite	— (high)

Very soft stream and beach sediments

Hard granite

Soft marine sedimentary rocks

Landsliding

Landslides, like those shown here, are widespread in the San Francisco Bay region. The cost of landslide damage in the region was at least $25 million in the rainy season of 1968–69. According to the California Division of Mines and Geology, as much as $10 billion may be lost to landslides throughout California from 1970 to 2000 unless existing policies and practices are improved.

Damage resulting from landslides can be reduced by avoiding landslide-prone areas or by removing or stabilizing landslide masses. The California Division of Mines and Geology estimates that 90 percent of projected landslide losses in the State could be avoided by applying preventive and remedial measures. The estimated cost of these loss-reduction measures would equal only 10 percent of the projected landslide losses—a highly favorable cost-benefit ratio.

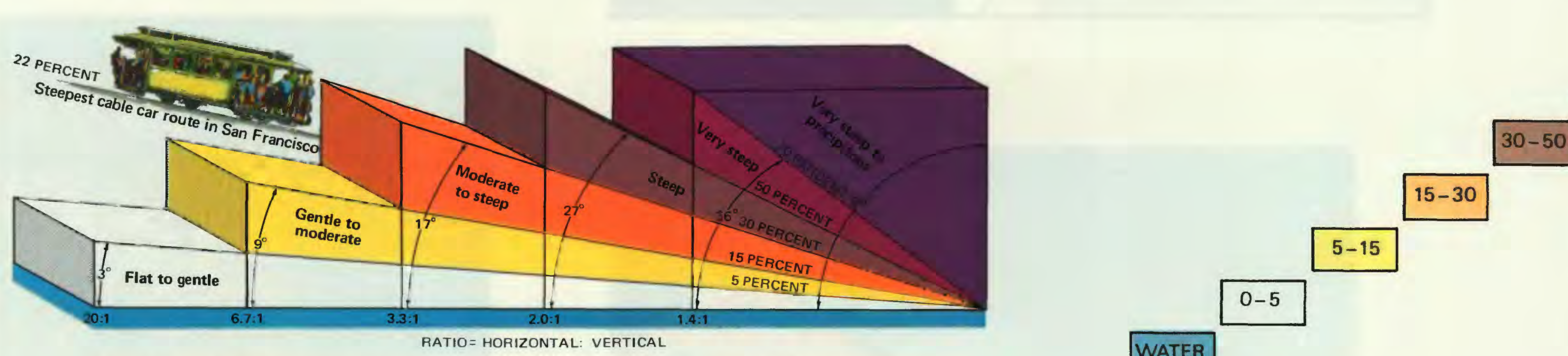
Houses damaged by landslides in San Mateo County

In the upper scene, the house and several neighboring houses have been made uninhabitable by relatively small and undramatic downslope movements of the ground beneath them. In the scene at left, the ground has suddenly slid away, leaving the houses dangling. (Photographs by Earl Pampeyan.)

San Mateo County began to apply preventive measures in 1973 by regulating the density and nature of development in landslide-prone parts of remote, mountainous, unincorporated areas. The maximum residential densities allowed by San Mateo County are shown on the map at the top of the opposite page. This map is based on two maps, one of landslide susceptibility (simplified in the map below it showing identified landslides), and one of land slopes (bottom of page). It reflects the fact that landslides are more likely to occur in areas that have steep slopes or are underlain by preexisting landslides.

Zoning ordinances in these areas permit a maximum average density of 1 dwelling unit per 5 acres, but a slope-stability ordinance further restricts development to 1 unit per 40 acres where the land is underlain by landslide deposits more than 500 feet long. In addition, no residential structures can be built on landslides without detailed geologic site investigations and adequate engineering design. Finally, the county's slope-stability regulations prohibit the construction of schools, hospitals, fire stations, dams, and powerplants in areas underlain by landslide deposits.

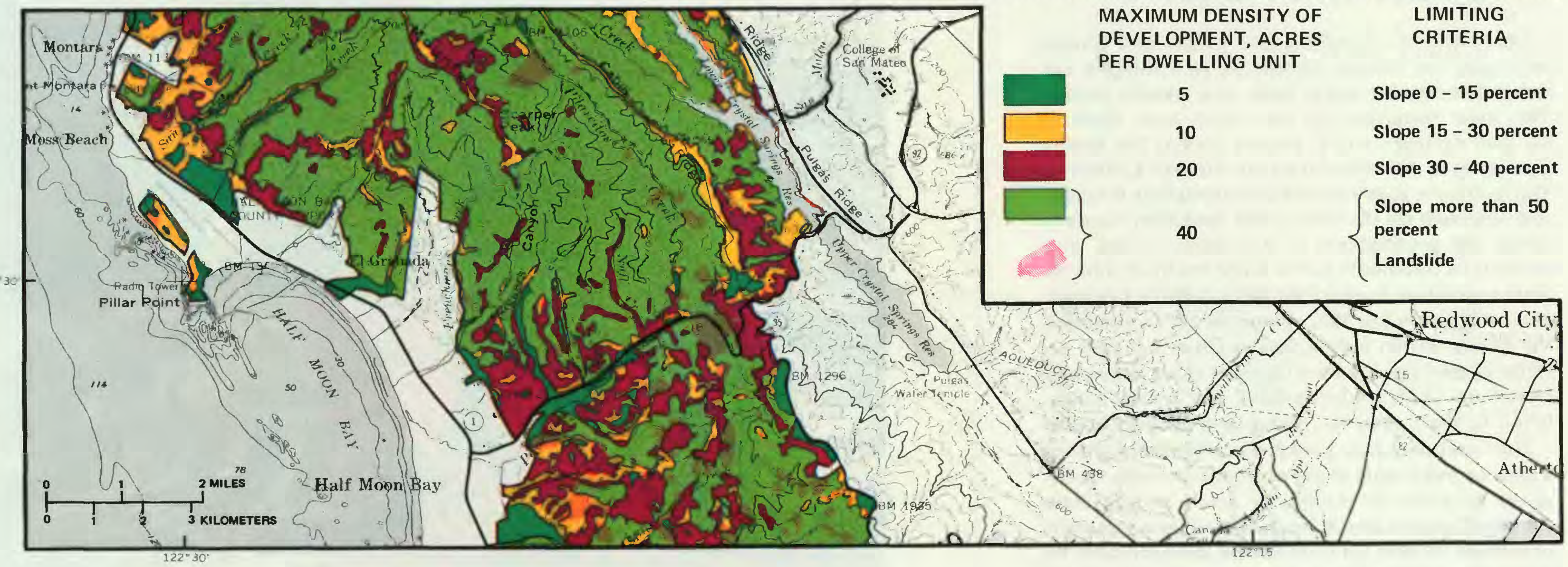
San Mateo County's residential density regulations also apply to steeply sloping areas which, though not underlain by landslide deposits, are very susceptible to landsliding. Development of steeply sloping land is discouraged not only because of the landslide hazard, but also because it commonly necessitates considerable grading and alteration of the natural terrain, requires pumping stations for water and sewer lines, and contributes to erosion and flooding. Most of the steep lands in the county are south of the area shown on the opposite page.



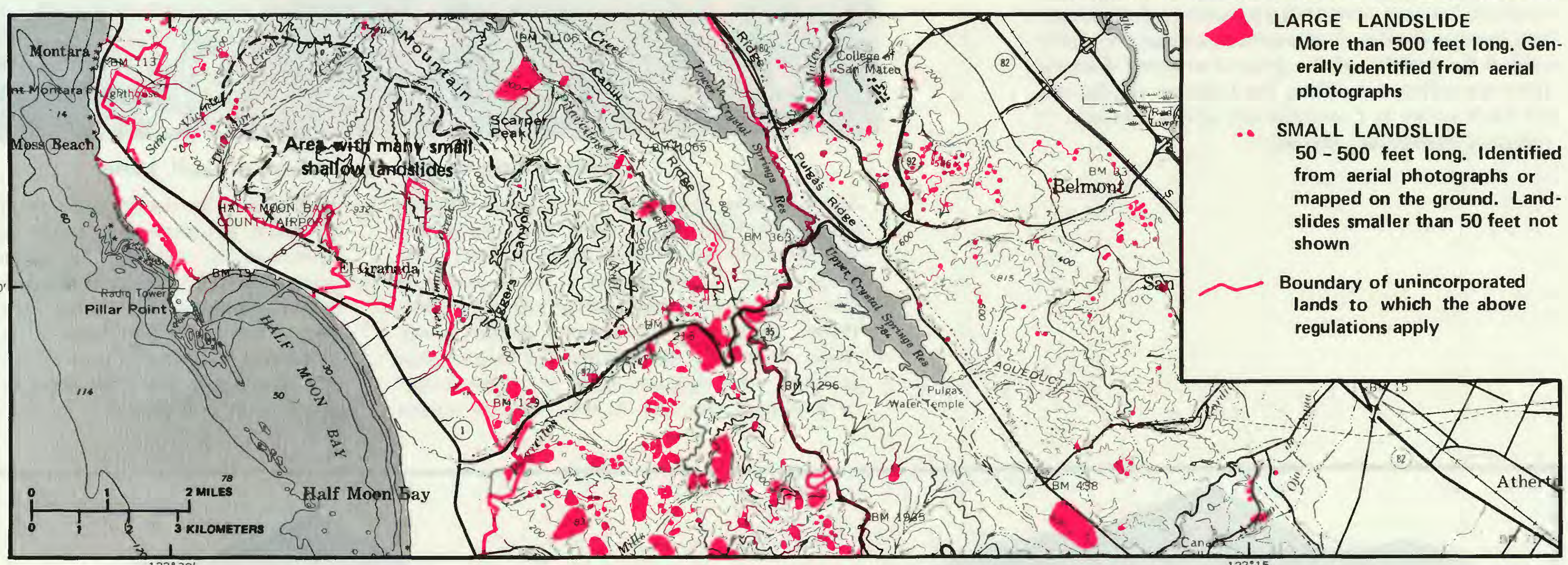
Categories of land slope expressed as percentages, degrees, and ratios (based on Nichols and Edmundson, 1975).

PERCENT OF SLOPE

Maximum residential density allowed by San Mateo County

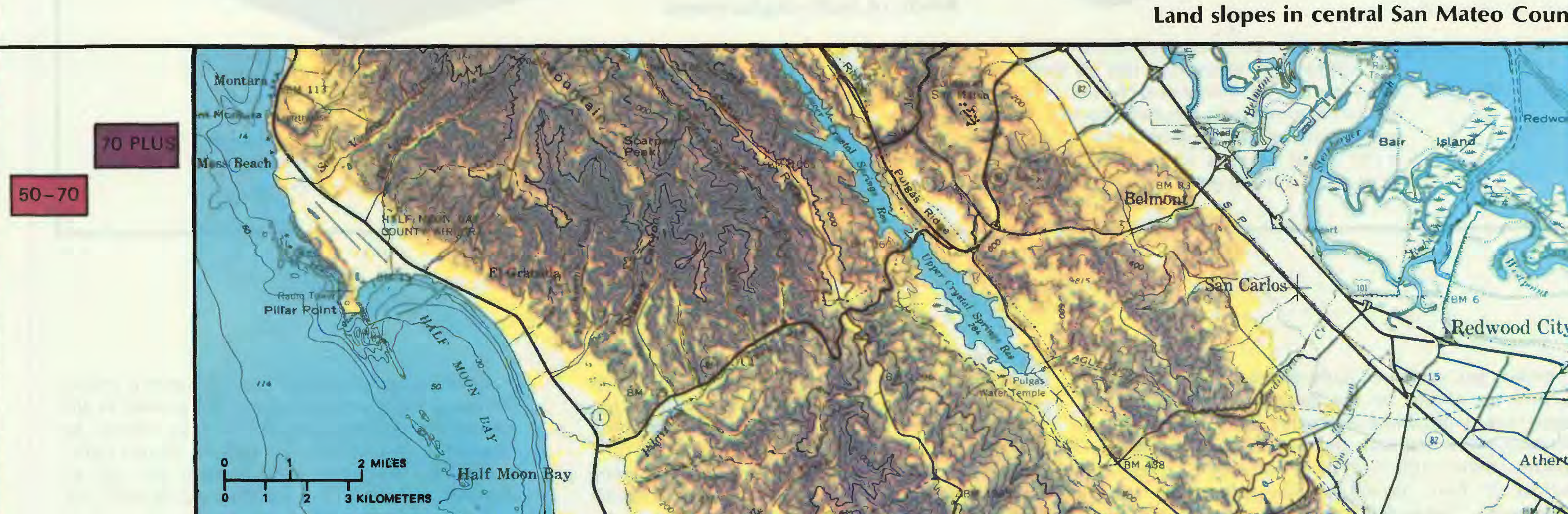


Landslides in central San Mateo County



(Modified from Brabb and Pampeyan,1972b)

Land slopes in central San Mateo County



Fault movement

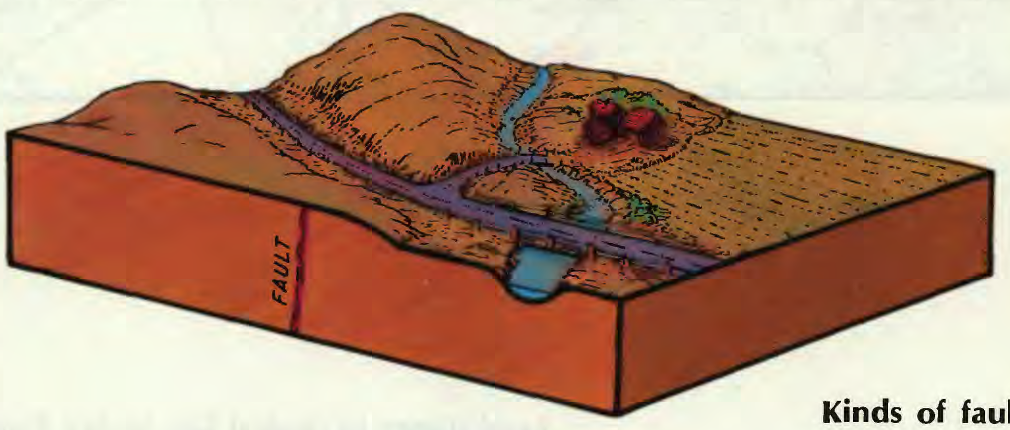
Many schools, hospitals, and public and private structures for human occupancy in California are located on or near active faults (see sketch below). The most notorious of the many such faults is the San Andreas, which crosses central San Mateo County in its 600-mile-long path through California. The fault zone appears in the photograph on this page and is shown on the three maps opposite. Concern about the proliferation of structures on and near recently or potentially active faults led the California State Legislature to enact the Alquist-Priolo Geologic Hazard Zones Act of 1972, revised in 1975 and retitled the Alquist-Priolo Special Studies Zone Act. This act requires geologic site investigations along potentially hazardous faults under policies and criteria established by the California Mining and Geology Board.

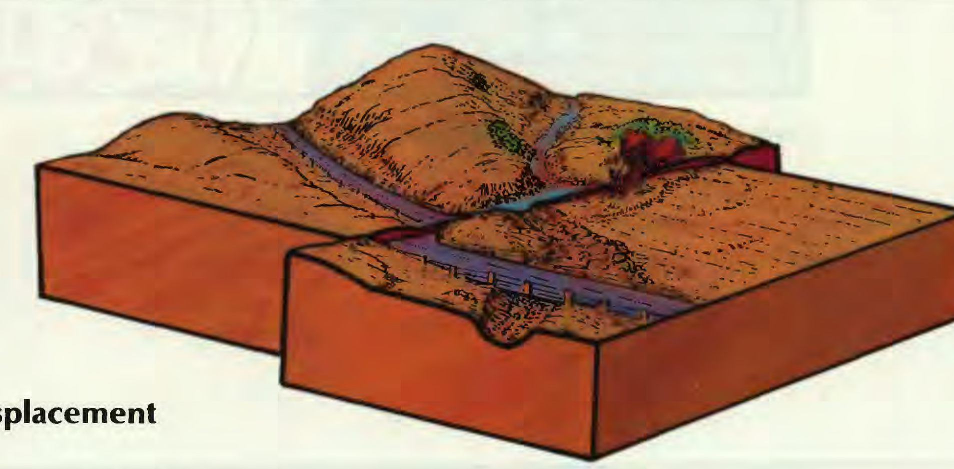
The "special studies zones" are strips one-eighth of a mile or more wide along each side of faults recognized as active or potentially active by the State Geologist, within which the danger of fault rupture is presumed to exist until otherwise demonstrated by direct investigation (see top map opposite). Geologic reports directed at the problem of potential surface faulting are required by State law for all public structures within the "special studies zones" if faults have moved within the past 11,000 years and prohibits such construction within 50 feet of a fault which has displaced the ground surface. Site investigations may also be required by local governments for single-family residences, which may similarly be prohibited within 50 feet of an active fault.

Displacement of the ground surface along faults accounts for only a small part of earthquake damage. The most intense and widespread damage is typically caused by shaking of the ground at some distance from the active fault. Thus, the land-use regulations for fault zones in California are only a first step in reducing earthquake damage.

Construction in the San Andreas fault zone

Some of the suburbs in this view, looking southeast from above Daly City, lie across strands of the San Andreas fault (red lines). The earthquake of 1906 caused as much as 8 ft of horizontal displacement along fault strands like these; much less movement would wreak havoc here. State laws enacted in 1972 require geologic investigations prior to construction of a public structure in the "special studies zone" (area in orange) and prohibit building of public structures across the red lines. Site investigations may also be required by local governments before construction of new single-family dwellings. The maps on the opposite page show faults and "special studies zones" in central San Mateo County, which is outlined in yellow at the top of the photograph. (Photograph by R. E. Wallace.)





Kinds of fault displacement

Much of California is laced with faults—surfaces in the Earth along which failure has occurred, so that the earth materials on opposite sides have moved relative to each other. The diagrams above show horizontal movement, the main kind of displacement along the well-known San Andreas fault, a small segment of which is pictured at the top of the page. Other faults may produce vertical movement or a combination of horizontal and vertical movement.

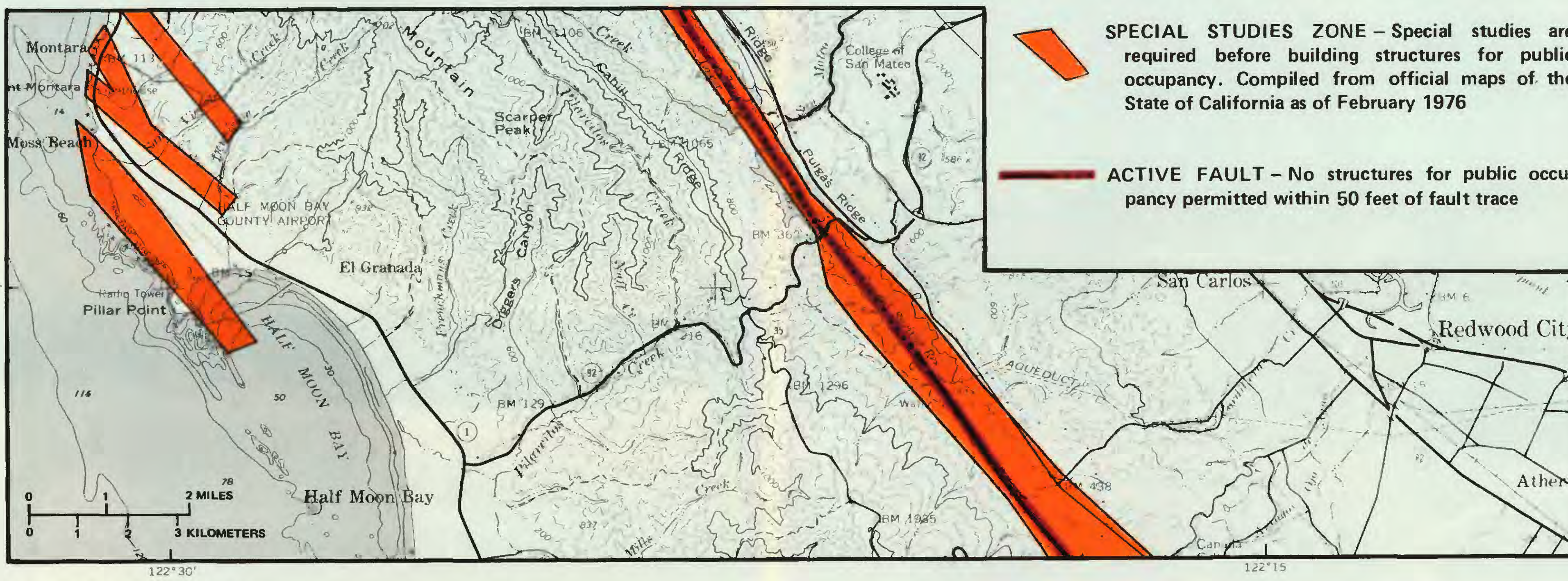
Although the diagrams above and the maps on the opposite page represent faults as simple, single breaks, most faults actually occupy zones which are tens to thousands of feet wide and which include many individual surfaces, called strands, along which movement has occurred. Multiple strands of the San Andreas fault zone are shown as red lines on the photograph above.

Dating fault movements

Known and suspected faults in central San Mateo County are shown on the bottom map opposite. Some of the faults shown on that map have not moved for many millions of years and thus can be considered inactive. Others, however, show evidence of current activity or have moved recently enough to be considered "potentially active" by the State of California for the purposes of the Alquist-Priolo Act; such faults are singled out on the middle map opposite. They have been used as the basis for "special studies zones," shown on the top map opposite.

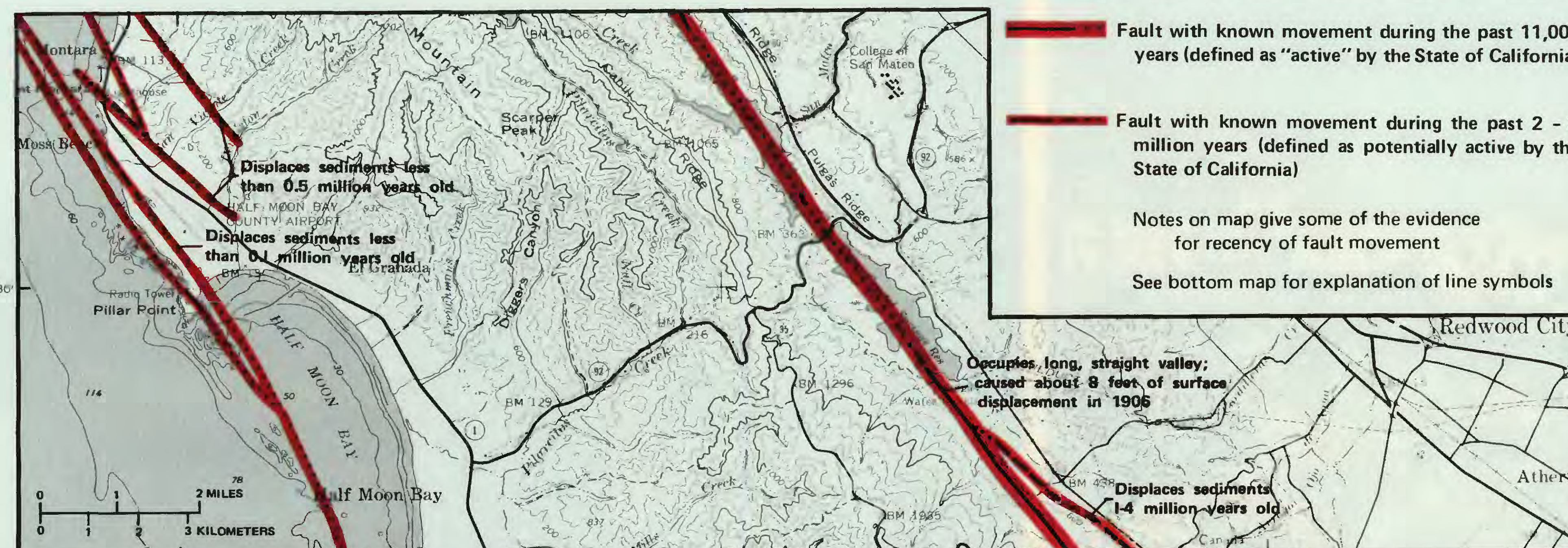
Faults are easy to date if they are caught in the act of moving. If not, only rather rough limits can be set on time of movement. The maximum age of an unwitnessed or prehistoric fault movement can be learned if the youngest rock or soil broken by the movement can be dated. This rock or soil can be dated if it contains certain fossils or certain radioactive elements. And the minimum age can be determined if the fault is covered by unbroken rock or soil that can be similarly dated.

Fault hazard zones mandated by State law



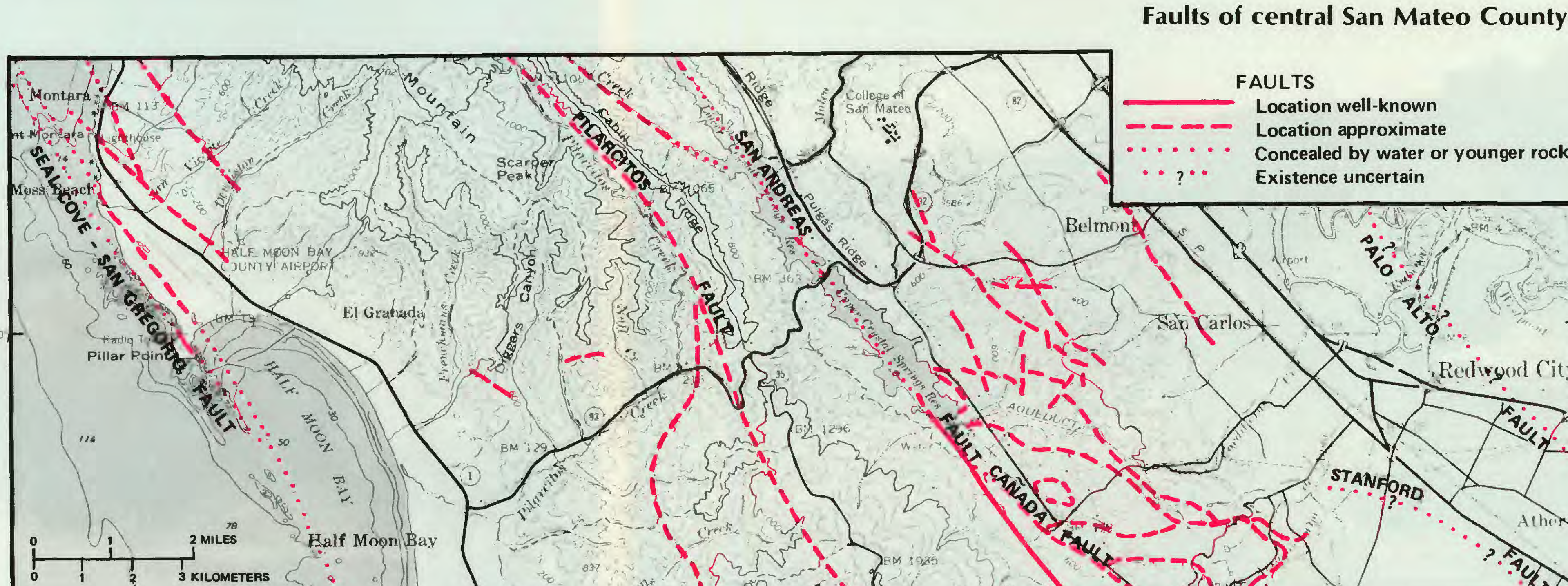
(Compiled from California Division of Mines and Geology, 1974, 1975)

Faults that may cause displacement of the ground surface

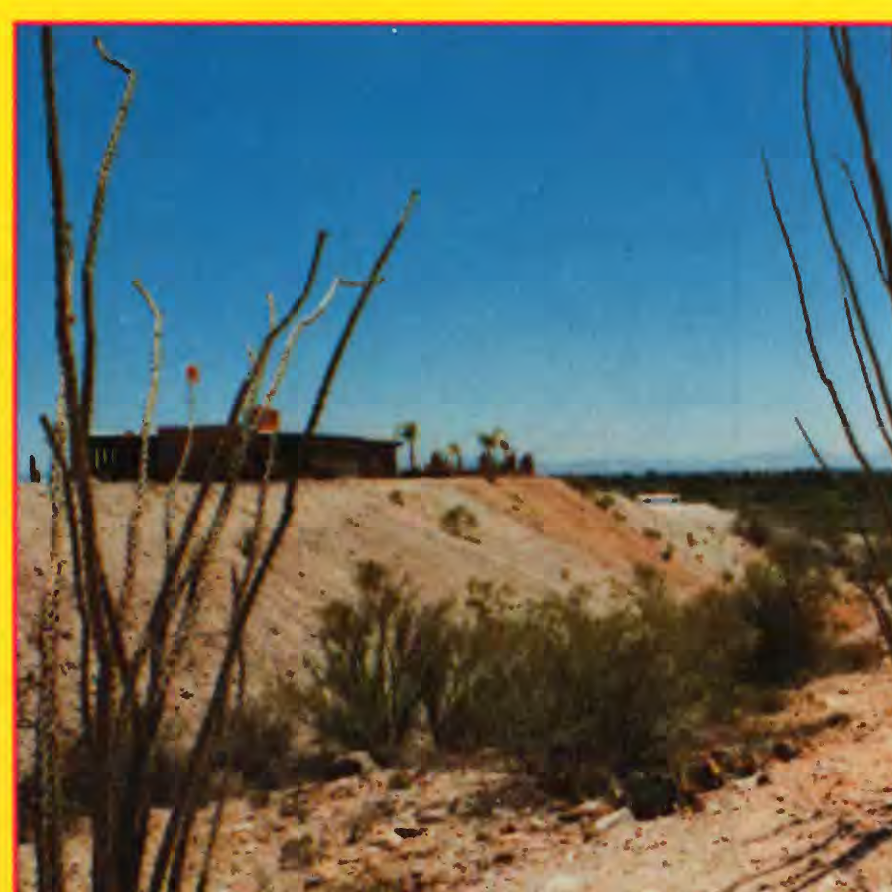


(From Lawson and others, 1908, and K. R. Lajoie)

Faults of central San Mateo County



(Generalized from Brabb and Pampeyan,1972a)



Tucson, Arizona

Controlling hillside development; protecting and conserving mineral and water resources

By E. S. Davidson, J. H. Feth, and Andrew M. Spieker

Hillside development ordinance based on slope

We have just read about the instability of steep slopes in the seasonally wet environment of the San Francisco peninsula, but even in the semiarid desert environment of Tucson, Arizona, slope of land is an important consideration in preparing sites for urban development. For example, some sites require cut-and-fill for building pads and access roads. The amount of cut-and-fill needed depends on the design of the structures and the slope of the construction site. Slope is also an important consideration for utilities such as sewer lines.

Constructing building pads, roads, and utility trenches on excessively steep slopes is not only costly to developers and local governments but may be esthetically and environmentally damaging. For example, the soils in many steep areas, although shallow, absorb precipitation, retard runoff, and provide a growth medium for hardy desert vegetation which in turn serves as both food and protective cover for a variety of wildlife.

To provide building pads, utility systems, and roads, the thin soil veneer must be scraped away, and extensive blasting in hard bedrock may be necessary. Loss of the soil veneer and vegetative cover can lead to an increase in runoff by a factor of three or more. And in the desert, rainfall, though infrequent, commonly is torrential. Fill and unprotected soils are highly susceptible to erosion, particularly on steep slopes. Storm runoff with its larger loads of silt and other debris thus results in deposition of silt which can increase flood hazards downstream.

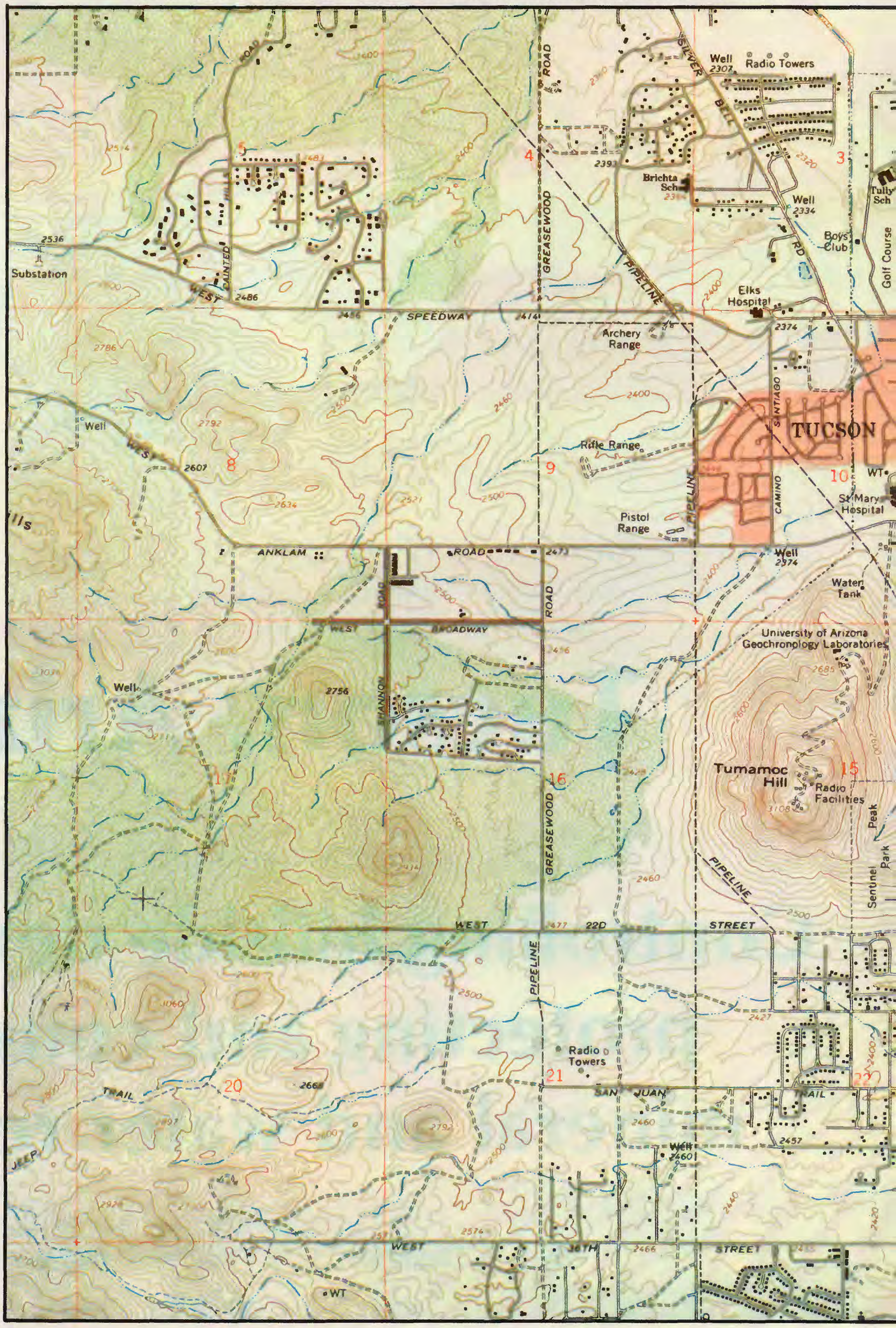
Cut-and-fill techniques also tend to leave large visual scars. In the desert, these bare rock scars may exist for many decades, because revegetation is usually slow.

Slope maps are a valuable tool in developing and administering slope regulations. Slope can be calculated from a standard topographic map, but this is laborious in any case and is done easily only by a person trained in using maps. Therefore, making slope maps from topographic maps by a photomechanical process greatly simplifies their preparation. The map on the facing page is such a slope map of an area on the west side of Tucson which is undergoing considerable new residential and other urban development. A wide range of slope can be seen, illustrated by a few representative photographs. The matching part of the topographic map from which the slope map was made is shown on this page.

Many communities in semi-arid country have enacted building regulations and zoning ordinances based on slope in an attempt to control excessive runoff, siltation, and erosion; to maintain vegetative cover; to protect wildlife habitat; and to preserve the esthetic character of mountain areas. Pima County, which includes Tucson, has enacted such an ordinance, establishing a Hillside Development Zone.

Slope is not the only consideration which should be used in regulating development in hillside terrain. The relative stability of rock units is equally important, as illustrated in the preceding example from San Mateo County, California, and in the last example, from Fairfax County, Virginia. Relative slope stability was not considered in Pima County's Hillside Development Ordinance only because the County's building code requires fill stabilization in conformance with the National Uniform Building Code. The following excerpt from the Pima County Hillside Development Zone Ordinance is cited as an example of how one community is approaching the problem and not necessarily as a model for other communities to follow.

Topographic map of part of the Cat Mountain quadrangle (scale 1:24,000)



ARTICLE 44 HILLSIDE

SEC. 4401 GENERAL PURPOSE OF THE HILLSIDE DEVELOPMENT ORDINANCE

Whereas the hillsides of Pima County differ from the county's flat lands, hillsides necessitate different provisions for their development and their protection. The purpose of the Hillside Development Ordinance is to permit development on hillside areas while conserving and promoting the public health, safety, convenience and general welfare by minimizing water-runoff and soil erosion problems incurred in adjustment of the terrain to meet development needs; providing safe and convenient access to hillside development; conserving the unique natural resources of hillside areas; and maintaining the character, identity, and image of Pima County.

SEC. 4402 SCOPE

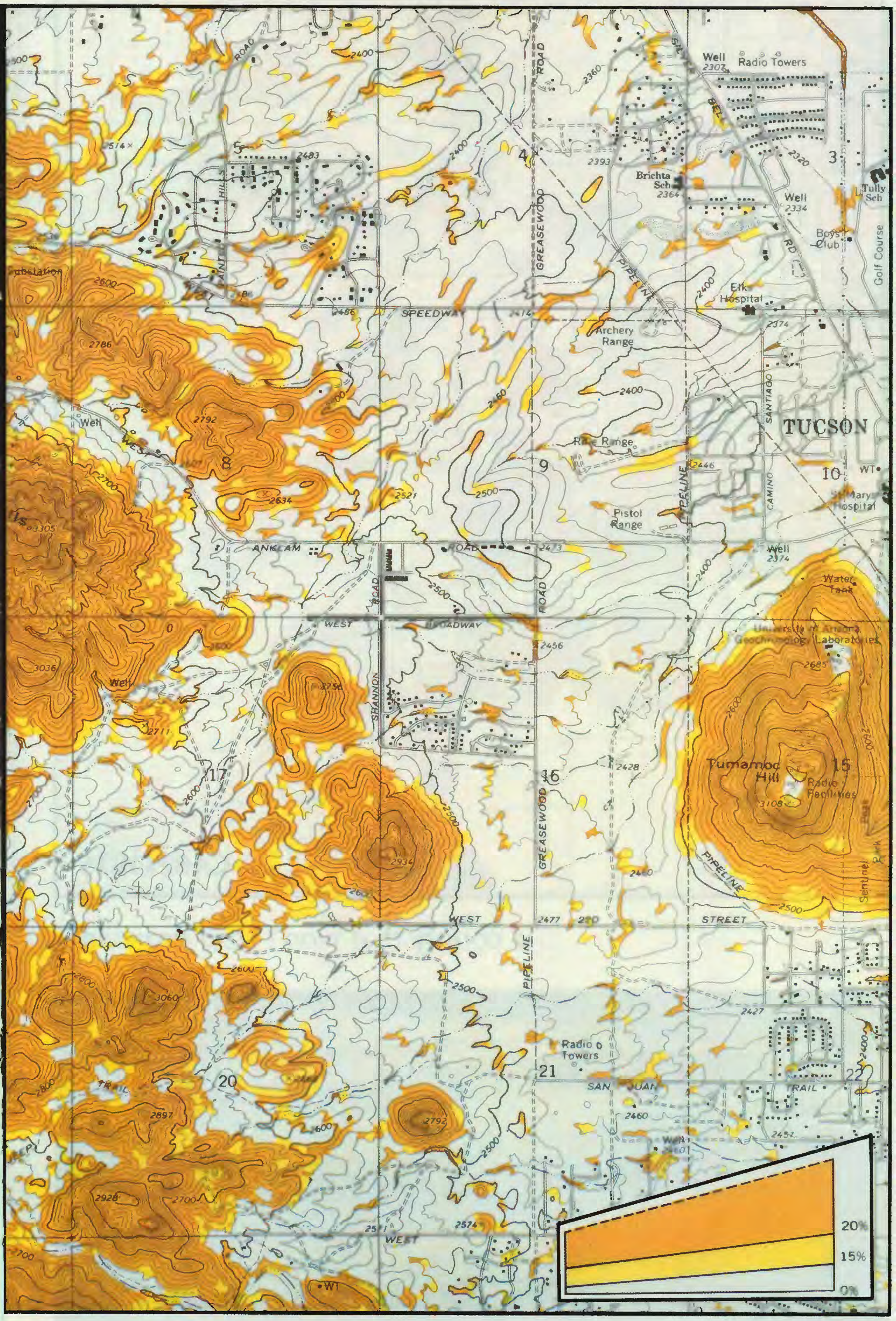
The Pima County Hillside Development Zone shall apply to the following areas:
4402.1 All lots or parcels or any portion thereof containing slope zones of fifteen percent (15%) or greater as identified on the United States Geological Survey (USGS) 7.5 Minute Series Slope Maps, identified in Exhibit A of this Ordinance.

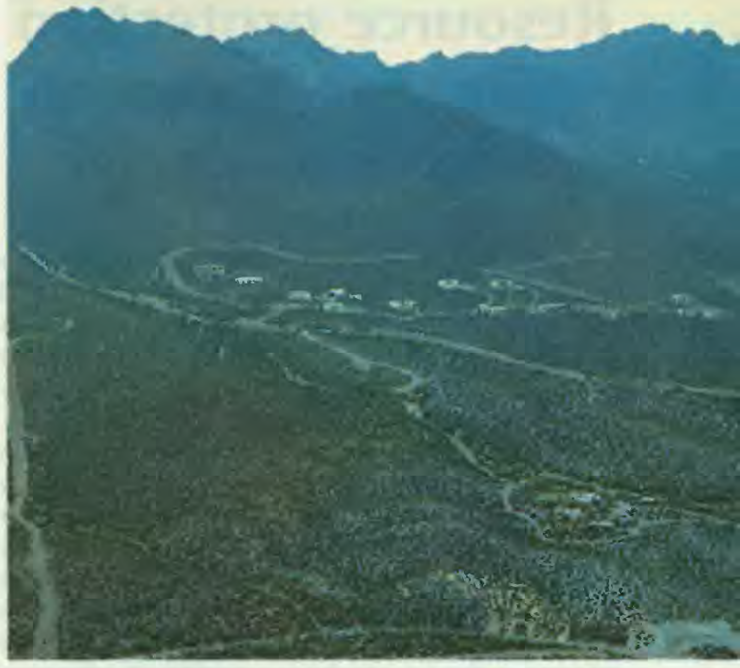
* * *

SEC. 4407 SLOPE DENSITY REQUIREMENTS

4407.1 For land areas within the jurisdiction of the HDZ, average dwelling unit density shall not exceed that allowed by the following table or existing zoning whichever is more restrictive:

Slope map of part of the Cat Mountain quadrangle (scale 1:24,000)





Housing on slopes above 20 percent
Mountains: Building and construction problems likely to be severe; danger from foundation erosion, rockfalls, and landslides may be great.

Housing on slopes between 15 and 20 percent
Foothills of mountains and banks of deeply incised streams: Building and construction problems moderate to severe; special engineering practices may be necessary.

Housing on slopes below 15 percent (lot size based on existing zoning)
River floodplains to lower foothills of mountains: Few or no construction problems due solely to slope.

DEVELOPMENT ZONE (HDZ)

Average cross slope* (%) (round off to nearest whole number)	Average lot size (acre)
15	1.0
16	1.0
17	1.25
18	1.37
19	1.5
20	2.0
21	2.25
22	2.5
23	3.5
24	4.5
25	6.0
26	7.0
27	8.6
28	10.4
29	12.8
30	16.0
31	23.5
32	31.0
33 and greater	36.0

*As defined in "User's Guide to the Hillside Development Zone for Pima County, Arizona," Pima County Planning Department, September 1976, p. 2.

* * *

SEC. 4412 SITE CUT AND FILL REQUIREMENTS

4412.1 The uppermost point of a cut slope shall not be higher than the top of a structure on the same site.
4412.2 The vertical distance of exposed fills shall not be greater than fifteen (15) feet from the natural ground or top of the retaining wall.
4412.3 Vegetation shall be re-established on all exposed fill slopes by the developer. Exposed graded areas shall be mulched and seeded with a mixture of desert grasses and desert shrubs, trees, or cacti to provide a basic ground cover which will prevent erosion and permit natural revegetation.
4412.4 In lieu of re-establishing vegetation on cut and fill slopes, exposed slopes may be rip-rapped with stone which blends in with the natural setting.

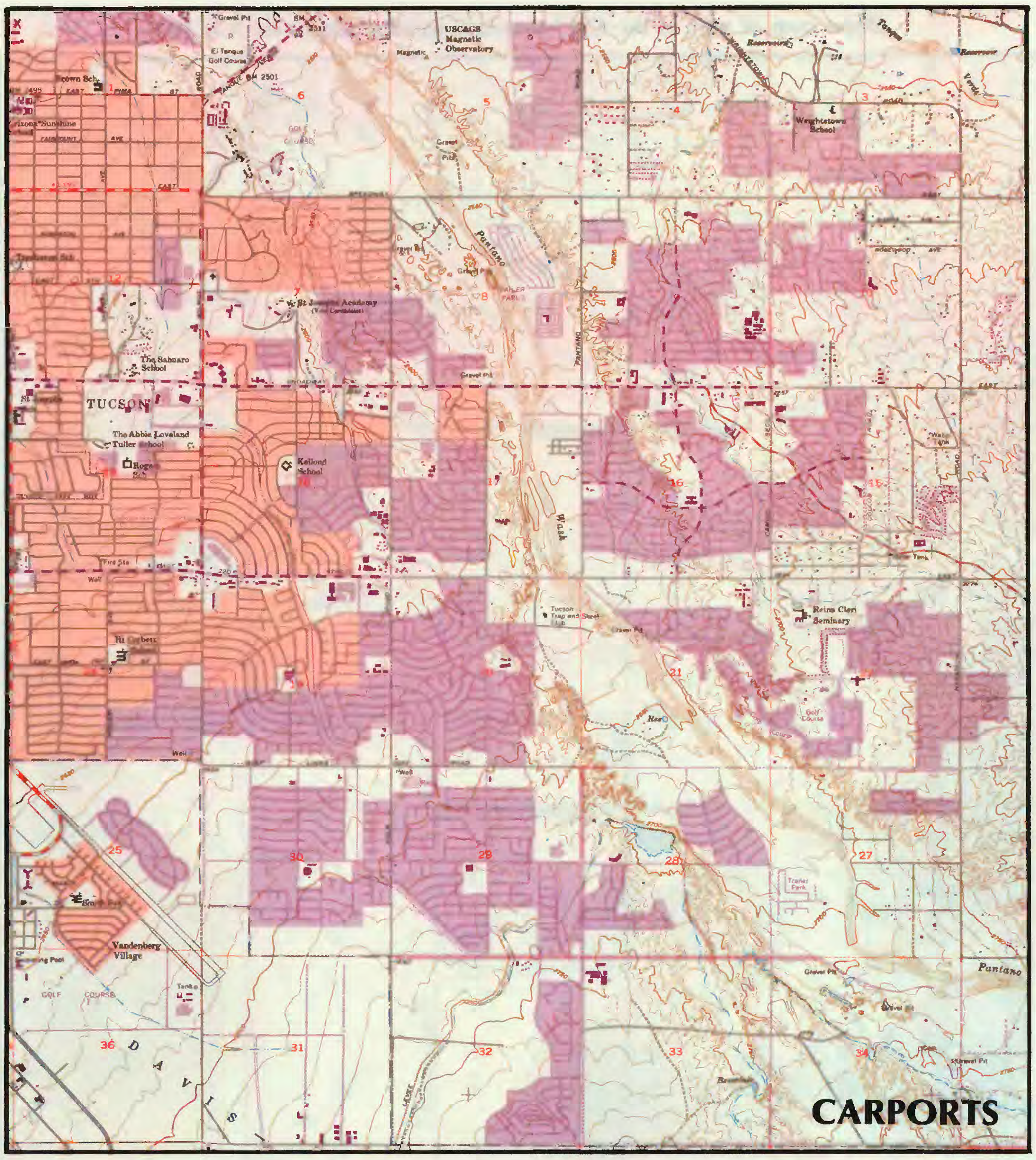
* * *

Resource protection ordinance based on copper potential

Eastern Pima County has yielded millions of tons of copper metal since commercial mining began in 1858, and copper mining is and will continue to be a major contributor to the regional economy. Past production and potential for other copper deposits are suggested by the map on the facing page.

Eastern Pima County, which includes Tucson, is also one of the fastest growing urban areas in the country. From a population of 130,000 in 1950, the greater Tucson area ballooned to 415,000 in 1976, and this rapid growth, illustrated by the map on the right, continues unabated. The huge embankments and dried ponds that are the waste products of copper recovery are encroaching on a satellite development built before large-scale mining began (see photograph); as houses spread up the hills that flank the basin and into the valley to the west of Tucson, they begin to impinge on land that may be ore bearing, and on the copper mines themselves.

Open-pit mining and quality housing are not compatible. On the one hand, housing development may prematurely or inadvertently occupy ore-bearing ground, hampering its development and its eventual economic contribution. As mineral rights are reserved to the Federal Government, and mineral lands, even if the surface is privately owned, are open to mining claims, the potential for conflict is great and inevitable.



Growth near Tucson, 1957–71, illustrated by part of the Tucson East quadrangle (at scale of 1:48,000)

The map, prepared in 1957, was photo-revised in 1971. Areas shaded purple became urbanized between 1957 and 1971. Updating to the present would show much more urbanization.

... a county that won't stop growing

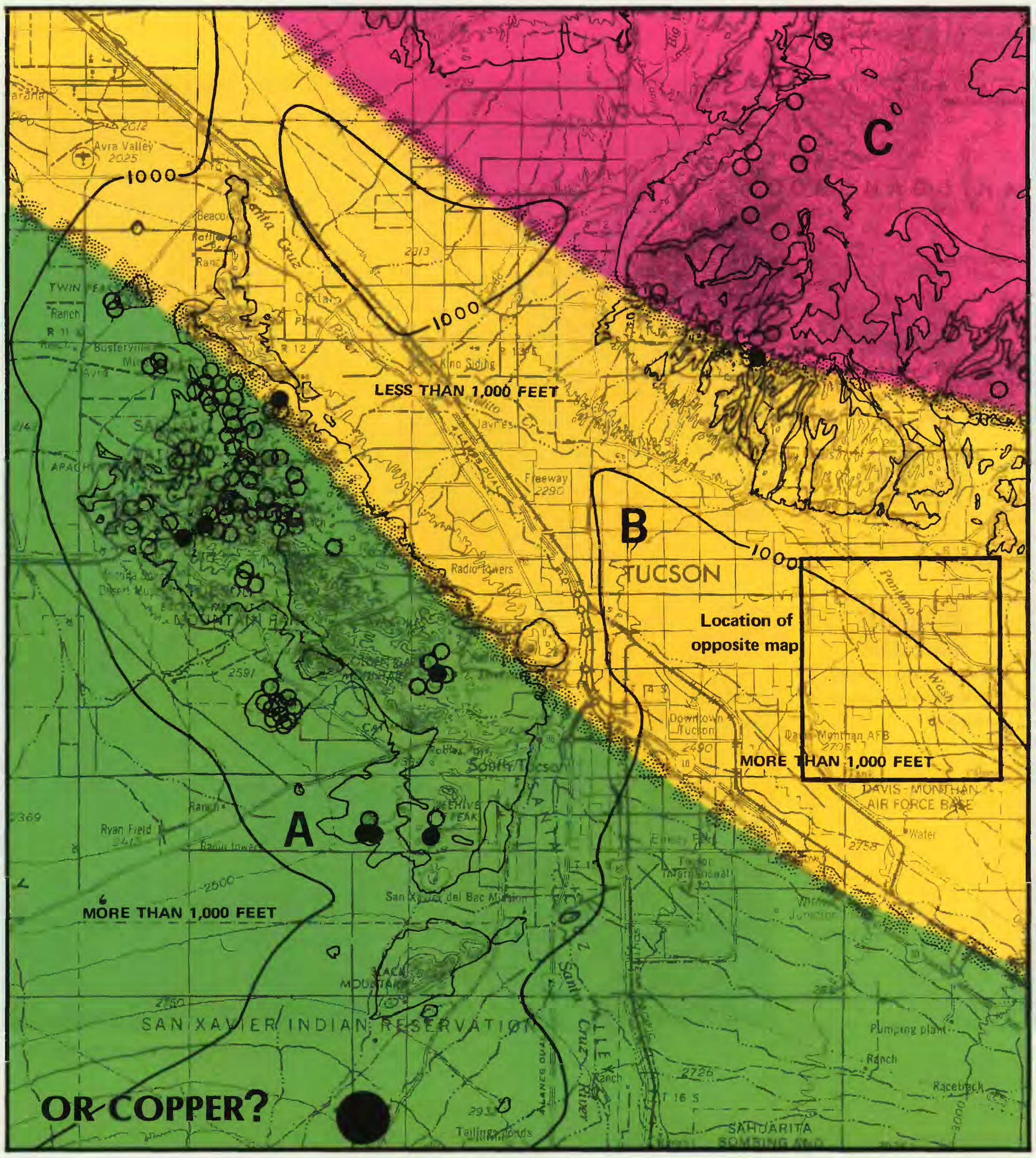
On the other hand, the waste products of large-scale mining are often a nuisance and sometimes a safety or health hazard. The pits and appurtenant waste-rock dumps may occupy several square miles. Concealing the dumps is difficult because of the time and cost needed to reestablish vegetation on them. In addition to the visual intrusion, the dumps are a source of windblown sediment; and the highly mineralized water used to transport the fine-grained waste rock may degrade ground water, the only source of public supply for Tucson. Use of the adjacent land for farming or industrial purposes, rather than for housing, is less troublesome but results in competition for the limited ground-water supply.

Abandoned open-pit workings or underground workings with surface openings may become serious hazards if urbanized. The openings may be too large to fill with waste rock, or to render less hazardous in other ways at justifiable cost.

The Board of Supervisors of Pima County, after considering the problem at length, decided that the first step should be to protect the resource. Fortunately, the U.S. Geological Survey, building on many decades of regional and detailed mineral resource examination and mapping, had released two maps showing, in a preliminary form, the potential for copper deposits in the Tucson region (the map on the facing page is part of one, reduced and simplified). Using these maps as basic data, the Board authorized its staff to propose an amendment to a long-standing county zoning ordinance to create "mineral extraction zones." The proposed ordinance provides for review every 5 years, so that zoning classifications can be changed where classification of mineral potential has changed. The preamble and selected excerpts from the proposed ordinance are quoted on the opposite page.

Tailings (mining waste) ponds at edge of the town of Green Valley (near Tucson)
The copper mines, equally extensive and far deeper, are out of view to the left.

This proposed ordinance may not be the final solution, but it is a start. Experience will reveal how effective it is in protecting the resource from the expanding city. Still to be enacted (as of 1977) are comparable measures to protect the city from development of the resource. (Article C of the proposed ordinance does forbid residential, commercial, and industrial development in "metallic mining residual hazardous areas" until such areas have been certified nonhazardous by a registered geologist or soils engineer.)



Potential for copper deposits near Tucson (at scale of 1:250,000)

A — more potential
B — intermediate potential
C — less potential

Gradational boundary between map units

The Tucson region contains many large deposits of copper minerals that have been commercially mined, and more are still to be discovered. The relative copper-bearing potential of the rocks has been appraised, based on the location and characteristics of known ore bodies and prospects; on the age, type, and alteration of rocks; on the intensity of rock fracturing; and on geophysical measurements. The relative potential for silver, gold, uranium, lead, and zinc is similar to that for copper.

Because depth of cover may significantly deter ore discovery and mining, the map shows where the blanketing deposits are more or less than 1,000 feet thick. The boundaries will surely change as knowledge and experience accumulate. Reduced and simplified excerpt from Preliminary Map Showing Potential for Copper Deposits in the Tucson 2° quadrangle, Arizona OF 76–458.

Major copper deposit producing in 1974

Minor productive copper deposit

Copper occurrences

... a vital resource that must not be lost

ORDINANCE NUMBER ______

AMENDING THE PIMA COUNTY ZONING ORDINANCE NUMBER 1952–III BY ADDING ARTICLE 44 MINERAL EXTRACTION ZONES

BE IT ORDAINED BY THE BOARD OF SUPERVISORS of Pima County, Arizona:

Section 1. That the Pima County Zoning Ordinance Number 1952–III be amended by adding Article 44 Mineral Extraction Zones to read as follows:

ARTICLE 44

MINERAL EXTRACTION ZONES

Sec. 4401 PURPOSE

The purpose of this article is to protect economic mineral resources and to insure the orderly and systematic development of these mineral resources while protecting the public health, safety, peace, comfort, convenience, and general welfare of the people of Pima County and to secure for them the social and economic advantages of an orderly efficient use of land and also to inform potential land owners of the possibility of mining in the area in the future as authorized by the Arizona Revised Statutes (A.R.S. 11–806).

Sec. 4403 AREAS WHERE RESIDENTIAL DEVELOPMENT SHALL BE REGULATED

A. Active Metallic Mining Areas

B. Metallic Mineral Occurrence Areas

C. Metallic Mining Residual Hazardous Areas

D. Patented Claims and Active Metallic Mines within Withdrawn Areas

Sec. 4405 REVIEW

The Active Metallic Mining Area Zones and the Metallic Mineral Occurrence Zones will be reviewed no less than once every five years. Areas no longer designated Class A on U.S.G.S. Geology, Production and Mineral Occurrence Open File Maps (74–143) shall be considered for rezoning in accordance with the adopted area and neighborhood plans of Pima County.

A. Active Metallic Mining Areas

a. Major Areas

Contiguous land areas 100 acres or greater in size owned or leased by mining companies or persons which contain or are utilized for metallic mining currently in production including but not limited to open pit mining, underground mining, subsidence areas, shops, dumps, tailings ponds, shafts, mills, smelters, haul roads, and all other adjacent and ancillary structures associated with metallic mining operations.

1. **A buffer zone will extend no less than one mile from the perimeter of the Major Active Metallic Mining Area.**
2. **Residential densities shall not exceed one dwelling unit per thirty-six acres (1 D.U./36 acs.) within the Major Active Metallic Mining Buffer Zone.**
3. **All other uses permitted by Section 801 of the General Rural Zone shall be permitted within the Major Active Metallic Mining Buffer Zone.**

b. Minor Areas

Contiguous land areas less than 100 acres in size owned or leased by mining companies or persons, which contain or are utilized for metallic mining currently in production including but not limited to open pit mining, underground mining, subsidence areas, shops, dumps, tailings ponds, shafts, mills, smelters, haul roads, and all other ancillary structures associated with metallic mining operations.

1. **A buffer zone extending no less than six hundred and sixty feet (660 feet) shall extend from the perimeter of all sides of the Minor Active Metallic Mining area.**
2. **No residential or commercial uses shall be allowed within the minor active metallic mining area buffer zone.**
3. **All other uses permitted by Section 801 of the General Rural Zone shall be allowed within the Minor Active Metallic Mining Area Buffer Zone.**

B. Metallic Mineral Occurrence Areas

Metallic Mineral Occurrence Areas are defined as lands classified as "A" and underlain by less than 1,000 feet alluvium on U.S.G.S. Map I–844–G. "(Preliminary) Map showing potential for copper deposits in the eastern three-quarters of the Nogales 2° quadrangle, Tucson area, Arizona," and open-file map (76–458) "(Preliminary) Map showing (potential for) copper deposits in the Tucson 2° quadrangle, Arizona."

a. Residential development shall be restricted to one dwelling unit per 10 acres (1 D.U./10 acs) or lower densities.

b. All other uses permitted by Section 801 of the General Rural Zone shall be permitted within the Metallic Mineral Occurrence Areas.

C. Metallic Mining Residual Hazardous Areas

Metallic Mining Residual Hazardous Areas are defined herein as, but not limited to: Open pits, shafts, tunnels, tailings ponds, mining subsidence area, and dumps as a result of metallic mining activities.

1. **No residential, commercial, nor industrial development with the exception of mine uses as defined in Section 4402, paragraph 1 of this Article shall be permitted on residual hazardous areas until these lands are certified non-hazardous by a geologist or soils engineer registered in the State of Arizona. The geologic and soils reports shall be submitted to, approved and certified by the Pima County Highway Department.**
2. **If applicant has shown that the residual hazardous area is non-hazardous and non-mineral as certified by the Pima County Highway Department, these areas shall be considered for rezoning in accordance with adopted areas and neighborhood plans for Pima County.**

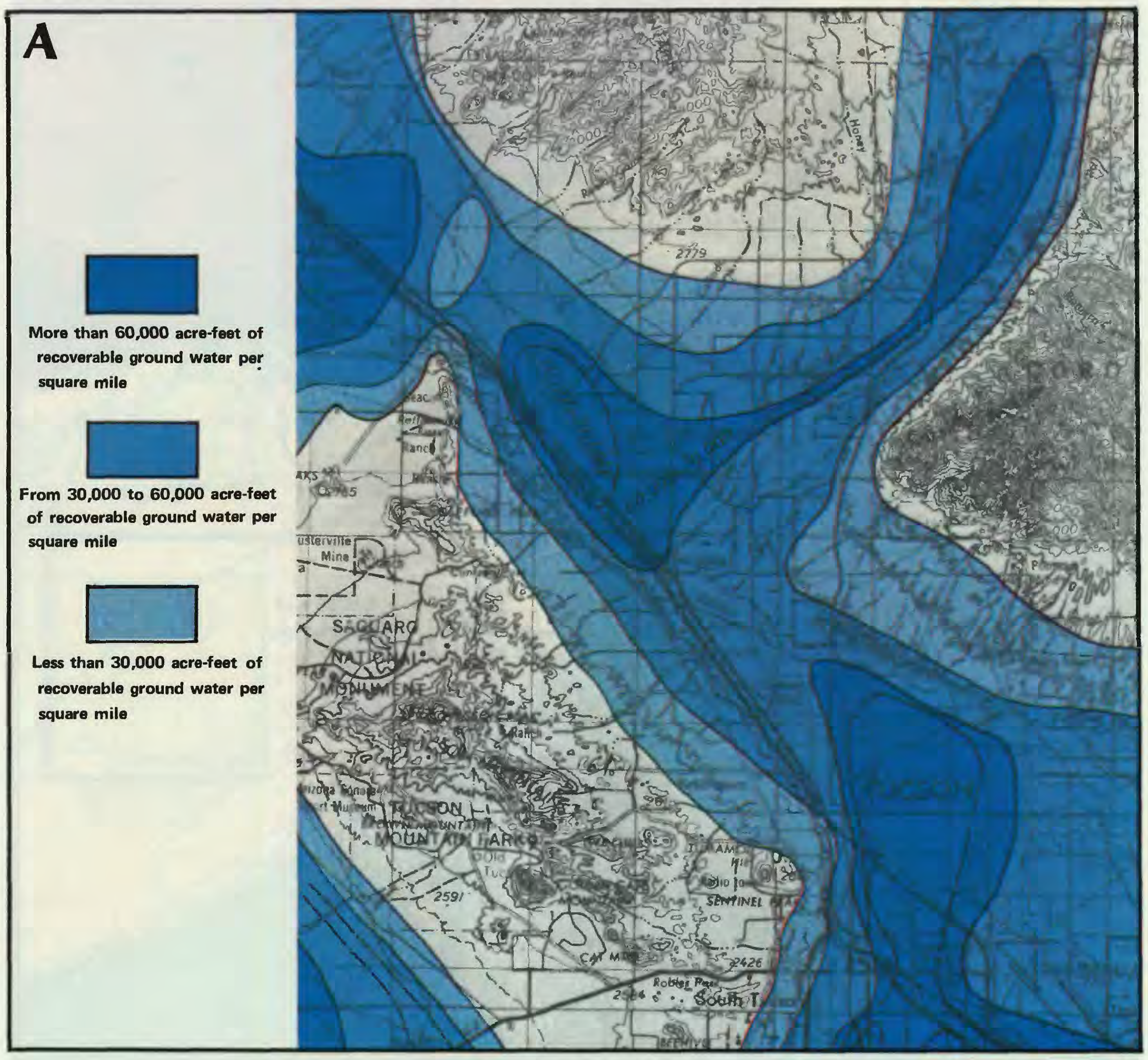
[D. omitted]

Water problems in dry country

Conserving and protecting the ground-water resource

The rapidly increasing population of Tucson requires more and more water, a commodity always in short supply in arid regions. Even the major streams here are dry more than 300 days each year, so ground water is the only dependable water source unless water is imported. Fortunately, the basin of the Santa Cruz River is underlain by thick deposits of sand and gravel in which vast volumes of water—nearly 14 cubic miles of it, equal to 1½ times the total capacity of Lake Mead—have accumulated over the centuries, as water from scanty rainfall and inflowing streams has soaked into the ground.

But the supply of ground water is not inexhaustible. During 1970–72, more than 186,000 acre-feet (1 acre-foot is enough water to cover one acre of ground to a depth of 1 foot) was withdrawn each year from the Tucson basin, but the average annual recharge from all sources was only about 126,000 acre-feet, an annual deficit of about 60,000 acre-feet, about one-seventh cubic mile, which is taken from the reserves in storage. As a result, the water level in wells is falling: In the 11-year period 1966–76, representative wells had an average total decline of 22 feet, and the rate of decline is accelerating. In some areas, the declines are as great as 10 feet per year. If this trend continues, Tucson will eventually run out of water; long before this happens, however, the cost and energy consumed in pumping water from increasingly greater depths will have become prohibitive and deteriorating water quality at greater depths will force a change in water-management practices. Further, deep dewatering of the aquifer is likely to cause differential subsidence of the land surface and development of earth cracks, which may lead to failure of some structures.



(From Osterkamp, 1973b, scale 1:250,000)

Map A. Major ground-water resources

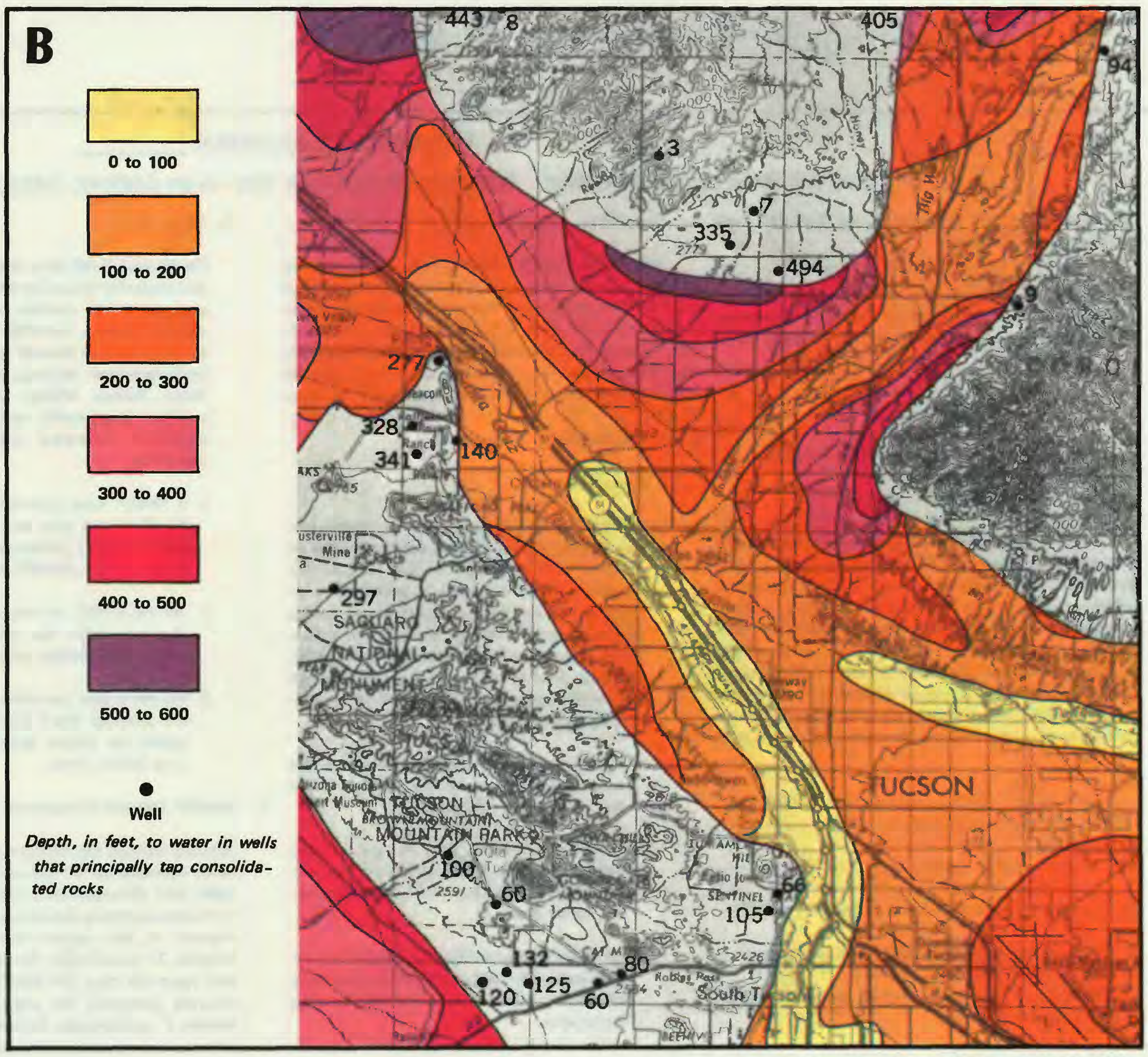
Map shows estimated recoverable water to a depth of 1,200 feet.

Map B. Depth to water in wells

Map based on measurements where depth to water is less than 400 feet; mainly inferred in areas where depth to water is greater than 400 feet.

Map C. Quality of ground water

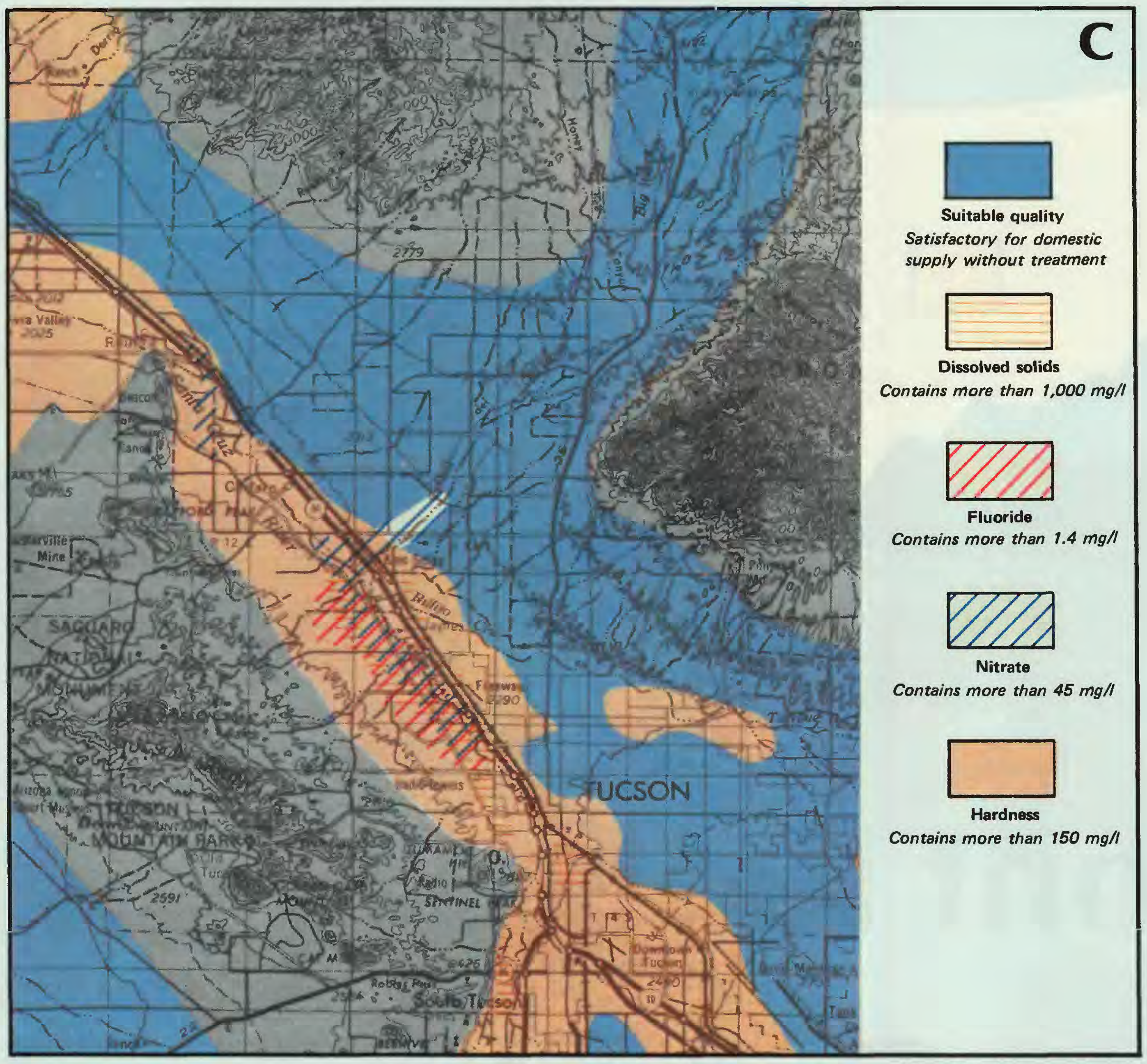
Gray areas for all three maps are underlain by rocks that contain only small amounts of recoverable ground water



(From Osterkamp, 1973a, scale 1:250,000)

Solving the water-deficit problem will require careful planning based on selection of management alternatives that are hydrologically, economically, and socially acceptable. A multitude of possible policies and actions exists. Among the possible alternatives are reducing consumptive use by conservation measures; changing land use (for example, converting irrigated land to other uses requiring less water); recycling water, including advanced treatment and reuse of waste water; importing water; reducing the population; and augmenting recharge. The ramifications of the alternatives are complicated and only some of them involve earth-science maps in significant ways. In this brief chapter it seems best, therefore, to go no further into long-range solutions, which will, of course, require continuing geologic and hydrologic studies.

Available information provides guidance for solving pressing immediate water problems, which we will illustrate for a part of the Tucson region only.



(From Osterkamp, and Laney, 1974, scale 1:250,000)

Criteria of water quality

Most ground water in the Tucson area meets both the mandatory and recommended chemical-quality limits of the drinking-water standards (Environmental Protection Agency, 1975). The most undesirable quality features are excessive amounts of dissolved solids, fluoride, nitrate, and hardness.

Dissolved solids. Salts or minerals dissolved in the water. The recommended limit is 500 mg/l (milligrams per liter), but more mineralized water of necessity is used for public supplies in many places. In this area, water containing more than 1,000 mg/l generally is mixed with water of lower concentration to improve the quality.

Fluoride. In drinking water strengthens teeth and prevents dental caries in children. Excessive concentrations of fluoride, however, can cause mottling of teeth. The optimum concentration in the Tucson area is 0.7 mg/l, and concentrations of 1.4 mg/l or more should be rejected for public use unless diluted with water of much lower concentration.

Nitrate. Excessive concentrations in drinking water can be fatal to infants. The recommended limit is 45 mg/l.

Hardness. Not a health hazard, but reduces the effectiveness of soap and causes incrustation on pipes, utensils, and appliances; water with less than 150 mg/l hardness generally is not objectionable for domestic use, and harder water can be softened or deionized before use.

Managing existing water supplies

We have seen that nearly all the water used in this region is from wells, a few feet to many hundreds of feet deep, that tap saturated sand and gravel beneath the surface of the Tucson basin. Small amounts of water, usually sufficient only for a single household, also can be obtained from the ground in mountainous areas and along the edges of the basin. Generally, the depth to water in wells developing these small supplies is not more than a few hundred feet.

Information from many hundreds of these wells makes it possible to say a great deal about the quantity and quality of water in Tucson's underground reservoir. This information, assembled and summarized in the maps on these pages, provides the hydrologic basis for indicating areas with existing or potential constraints on development.

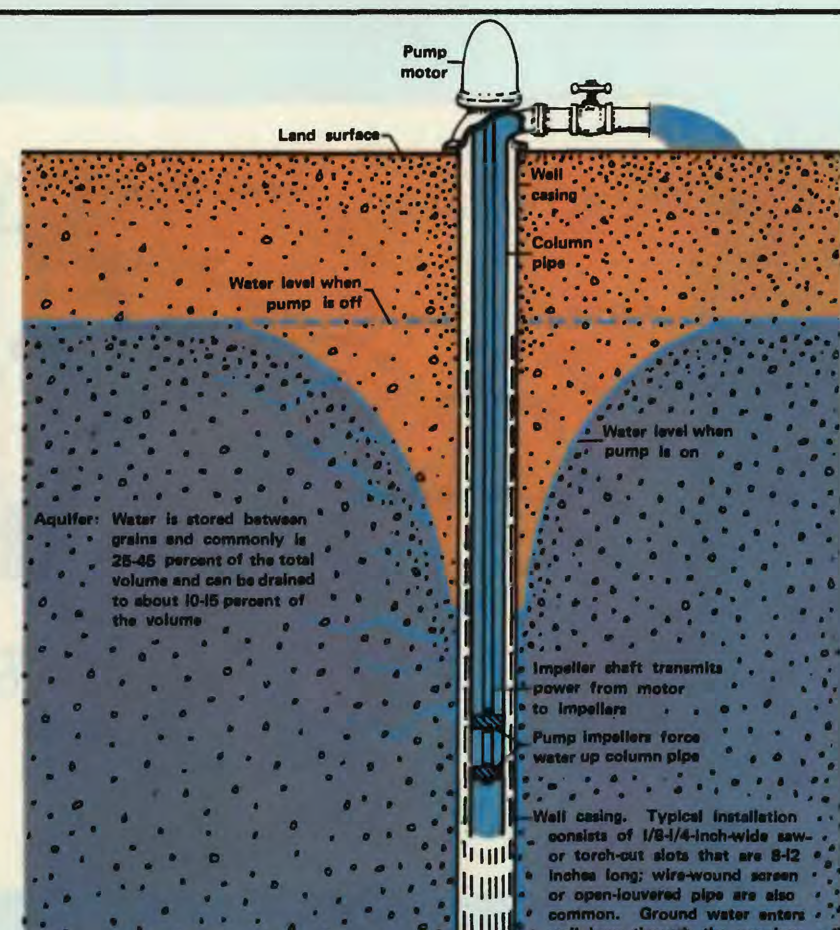
Development of the ground-water resource in the Tucson basin has now reached the point where virtually every drop of economically recoverable ground water is bound to be developed. These three maps, used together, provide part of the basis on which the water manager can make sound decisions regarding the optimum development of the ground-water resource. The most critical problems facing the water manager in the Tucson area are locating wells so as to maximize efficiency and minimize cost while maintaining a satisfactory quality of water in the supply. Thus, the optimum location of wells involves tradeoffs, and the maps are useful tools in evaluating them. For example, much water is stored directly below downtown Tucson itself, although some of it is high in dissolved solids. Excessive water-level declines in the area could cause subsidence and earth cracks, which would threaten buildings. On the other hand, considerable water is stored below the Santa Cruz River, which flows through the west side of the city, but its quality may be poor. And so on.

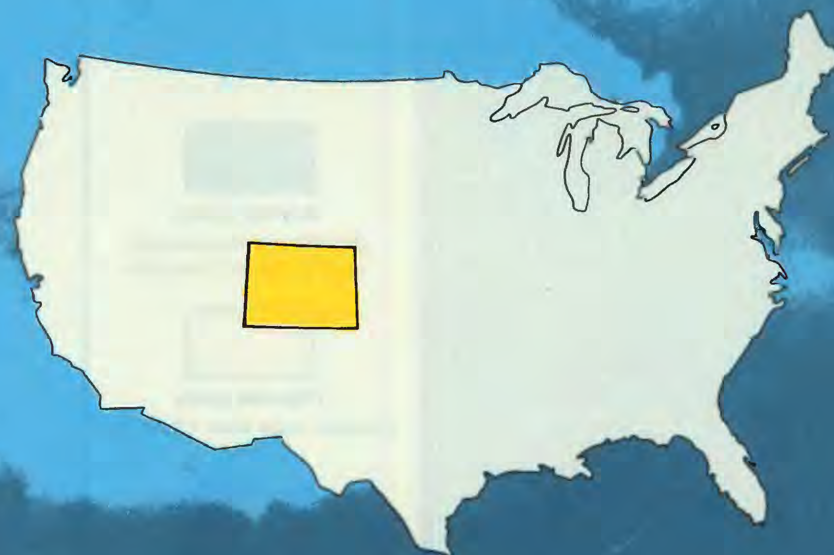
In locating and developing additional water supplies for the near future, social, economic, and legal factors must be considered, in addition to the hydrologic ones. And much more detailed hydrologic studies will be needed before sound final decisions can be made. Use of these or similar regional maps can nevertheless narrow the targets to which the remaining factors—social, economic, legal—can be directed. The net result of using available maps in the management process will be much saving of time, energy, and money.

Typical water well in Arizona

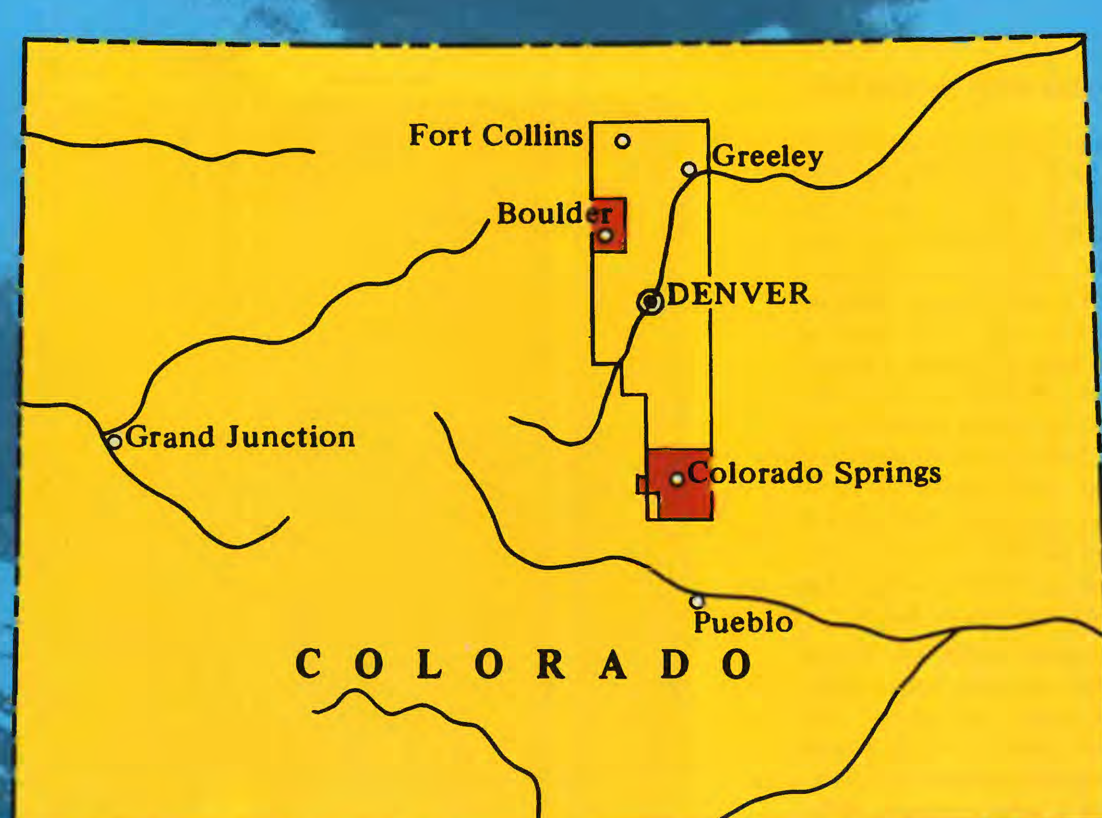
Pumping water to the land surface is costly, the cost depending on the depth to water, on the ease with which water flows through the aquifer to the well, and the cost of power. The city of Tucson, alone, requires about 250 wells and 2,370 miles of transmission pipe to supply a population of about 400,000. An economic balance must be struck between the number and distribution of wells, and the size and distribution of transmission pipes. This balance is hard to achieve because the efficiency of a well decreases erratically with its age and with decline of water level.

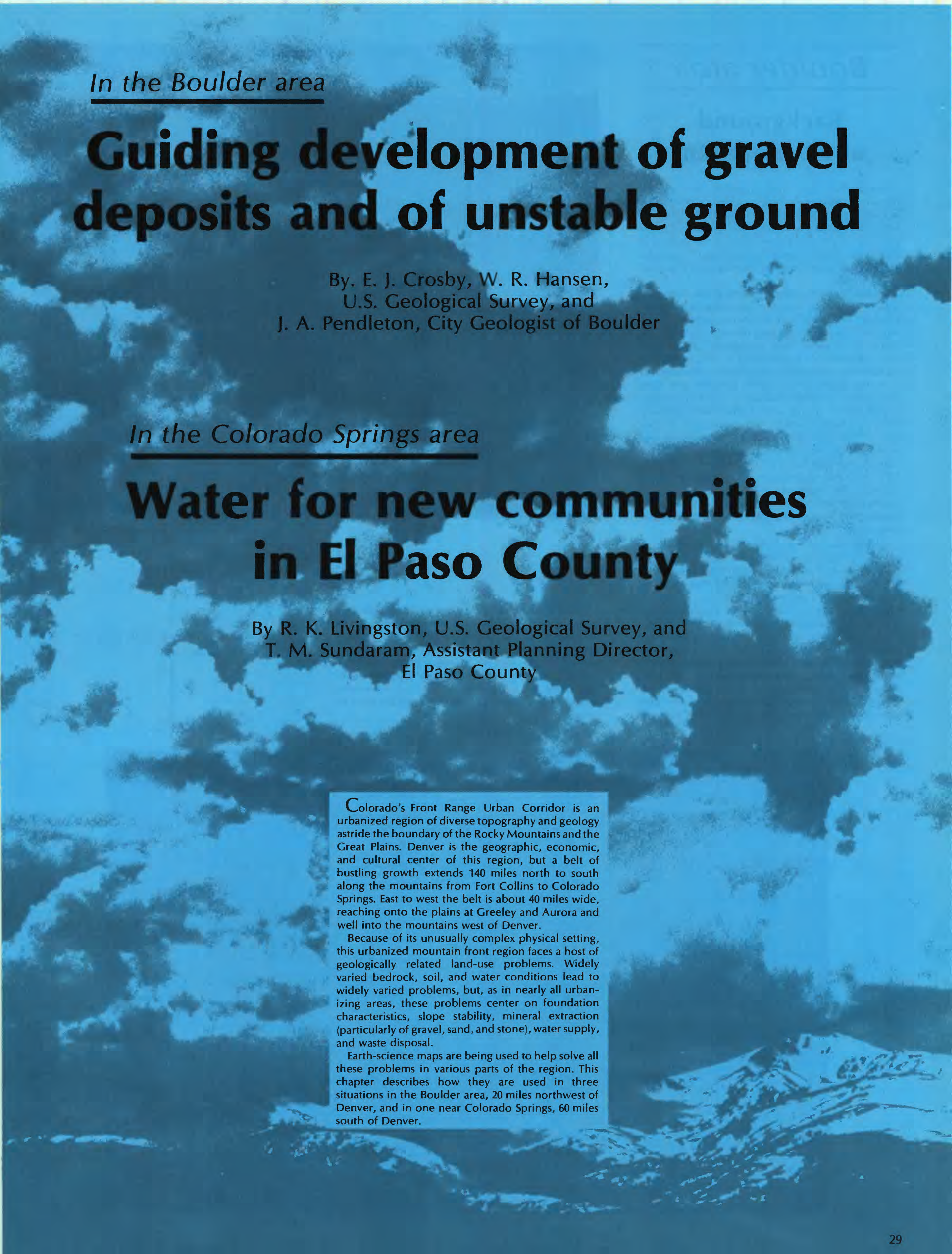
Already, increased cost of energy combined with declining water tables have forced some farmers to shut down irrigation wells. Use for public supply can support higher pumping costs because it offers greater dollar return per unit volume of water.





The Front Range Urban Corridor, Colorado





In the Boulder area

Guiding development of gravel deposits and of unstable ground

By. E. J. Crosby, W. R. Hansen,
U.S. Geological Survey, and
J. A. Pendleton, City Geologist of Boulder

In the Colorado Springs area

Water for new communities in El Paso County

By R. K. Livingston, U.S. Geological Survey, and
T. M. Sundaram, Assistant Planning Director,
El Paso County

Colorado's Front Range Urban Corridor is an urbanized region of diverse topography and geology astride the boundary of the Rocky Mountains and the Great Plains. Denver is the geographic, economic, and cultural center of this region, but a belt of bustling growth extends 140 miles north to south along the mountains from Fort Collins to Colorado Springs. East to west the belt is about 40 miles wide, reaching onto the plains at Greeley and Aurora and well into the mountains west of Denver.

Because of its unusually complex physical setting, this urbanized mountain front region faces a host of geologically related land-use problems. Widely varied bedrock, soil, and water conditions lead to widely varied problems, but, as in nearly all urbanizing areas, these problems center on foundation characteristics, slope stability, mineral extraction (particularly of gravel, sand, and stone), water supply, and waste disposal.

Earth-science maps are being used to help solve all these problems in various parts of the region. This chapter describes how they are used in three situations in the Boulder area, 20 miles northwest of Denver, and in one near Colorado Springs, 60 miles south of Denver.

Boulder area

Background of development

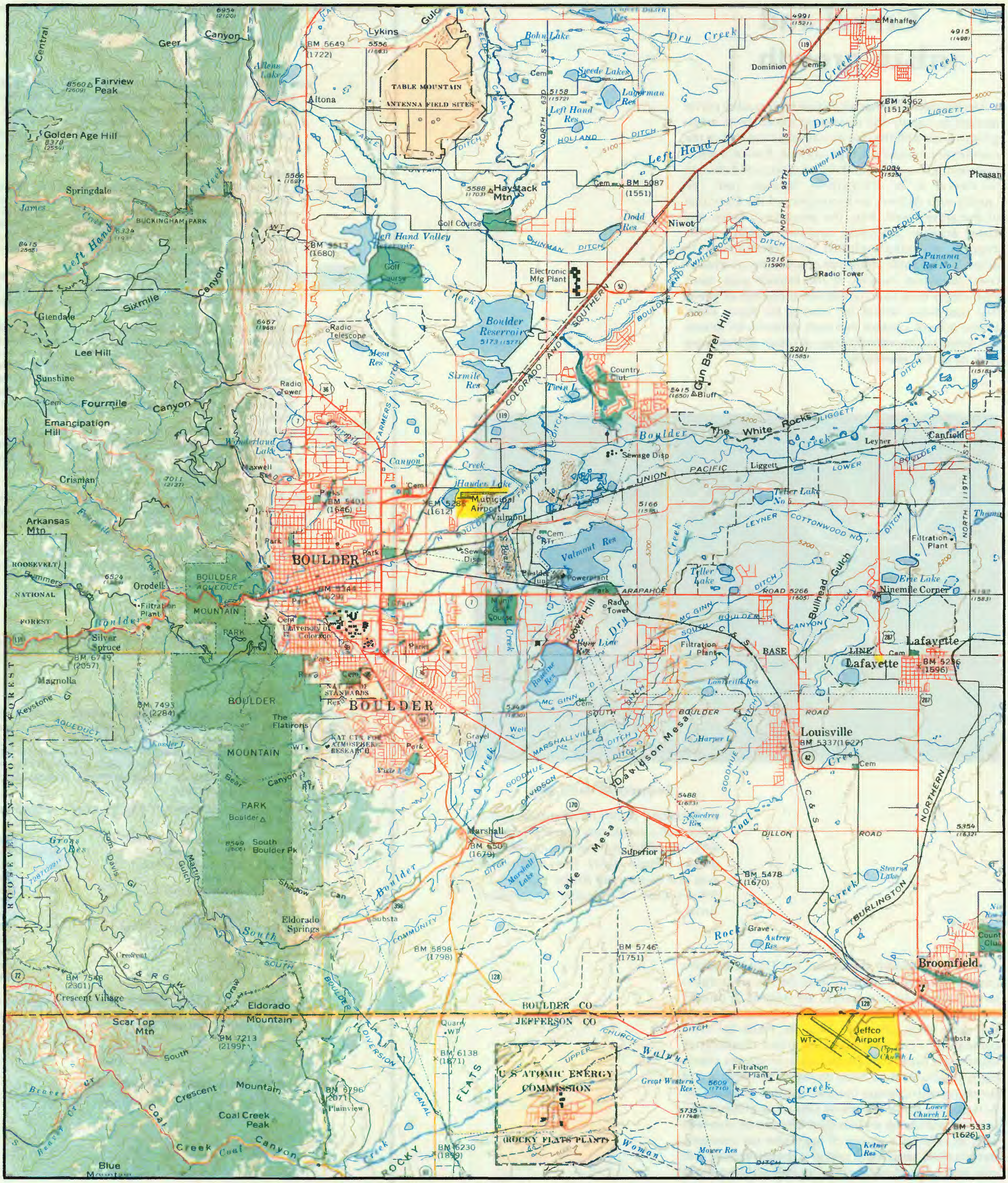
The Boulder area (map opposite) was selected because of the wealth of information available, owing in large part to the early use by that city of earth-science information in land management. Boulder was one of the first communities in the Nation to develop a detailed master plan that incorporates geologic constraints on land development into land-use planning.

Boulder's efforts reflect concern at the State level with earth-science aspects of land development. For example, since 1972 State law (Senate Bill No. 35) has required large proposed land subdivisions to include reports on streams, lakes, topography, and vegetation; on geologic characteristics significantly affecting land use; on suitability of soil types; and adequacy of water supply. For another example, the State interest in "mineral resource areas" and "natural hazard areas," among several other kinds of critical areas, has been formally declared (House Bill No. 1041, 1974), with provisions for designating and administering resource and hazard areas. For a third example, the State has provided (House Bill No. 1529, 1973) for the reclamation of open-mined land, including the requirement that the State Geological Survey study the "commercial mineral deposits (sand, gravel, and quarry aggregate) in the populous counties."

Boulder was also one of the first inland cities to employ a full-time geologist to insure that these constraints—and also the opportunities afforded by the mineral and water resources of the area—are responded to in a professional way.

Boulder is now working toward a permit system that will allow proposals for land development to be considered on the basis of individual site characteristics and current concerns such as pollution control, energy supplies, and controlled-growth policy. In new development areas, this permit system is expected to supersede the more rigid existing system of fixed-factor zoning. In connection with this approach the city geologist is preparing a series of 1:12,000-scale maps (1 inch equals 1,000 feet) that provide much more detailed information than do the 1:100,000-scale and 1:24,000-scale maps of Federal and State agencies. Proposals for development in the Boulder urban area are checked against all these maps for possible geologic hazards or other geologic constraints or opportunities. In turn, new data obtained in required site investigations are used to update the maps.

Boulder, Colorado, from the air.



Topographic map of the Boulder area

From U.S. Geological Survey, Front Range Urban Corridor, Sheet 1 and 2

This is part of a map especially made to be a base for regional planning. The scale of 1:100,000 (1 inch on the map equals about 1½ miles) offers sufficient detail for general planning and shows the entire corridor on a piece of paper small enough to fit on a large conference table.

1 0 1 2 3 4 5 MILES

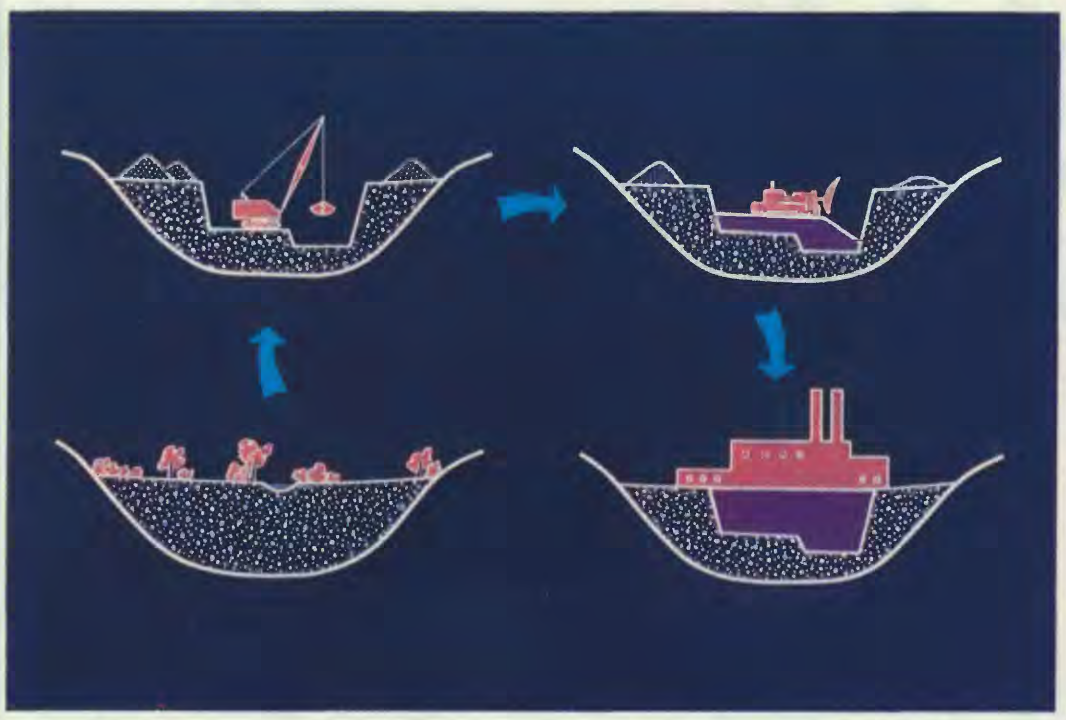
5000 0 5000 10,000 15,000 20,000 25,000 FEET

1 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET

Gravel and urban growth I

The Boulder area has abundant high-quality gravel needed to supply the increasing demands of urban growth and to fill the day-to-day requirements of the community. Gravel is a high-volume, low-unit-value commodity, however, and must be extracted close to its market to be competitive; haulage costs rise rapidly with distance and soon exceed the basic cost of the gravel itself. Also, the resource is finite, and some deposits are being depleted rapidly. Other deposits are being excluded from development by urban overgrowth, restrictive regulations, or adverse court decisions. Nearby, in the Denver area, court injunctions have even prevented extraction of gravel that had been zoned for mining for many years. Urban growth created the high demand for gravel, but some of the beneficiaries of urban growth now seek to curtail production.



Sequential land use

Undisturbed gravel-filled stream valley (lower left); producing gravel pit (upper left); pit filling and restoration of land surface (upper right); use of filled-pit area as a factory site (lower right). S. D. Schwochow, Colorado Geological Survey.

In looking toward the future, the City of Boulder and the County of Boulder must decide what short-term and long-term measures are needed to protect the quality of life in their respective jurisdictions. At the same time, provision must be made for their community's constant need for gravel. Conflicts of interest are inevitable. For example, in an area where many structures have been damaged by swelling and shrinking with changes in water content of some soils or rocks, the value of a gravel deposit as a foundation site, without shrink and swell problems, may compete with its value as a source of aggregate for concrete. But planned sequential use of a gravel-bearing site may reduce or eliminate conflict (see accompanying diagram). Where gravel pits have been reclaimed, they commonly have proved more suitable for industrial, open-space, or recreational use than for residential development. Site value can be enhanced by good environmental design.

Maps play an important part in planning and decisionmaking involving gravel in the region. They have been compiled at scales ranging from very large to very small, depending on the uses to be made. To provide overviews for regional planning, maps showing the extent of gravel and related construction materials along the entire mountain front region have been prepared at the small scale of 1:100,000 (1 inch equals about 1.6 miles); an excerpt of these maps near Boulder is on the facing page.

Gf GRAVEL DEPOSITS UNDERLYING TERRACES AND FLOOD PLAINS – Pebbles generally well rounded, unweathered; deposits contain little deleterious "lime" ($CaCO_3$). Lithologic composition reflects bedrock in source areas along Boulder Creek, St. Vrain Creek, Lefthand Creek, the Little and Big Thompson Rivers, and the Cache La Poudre River; clasts are composed chiefly of quartzite, granite, gneiss, and pegmatite. Few or no reactive constituents. Source of best quality gravel for concrete aggregate and road metal

Gp UPLAND GRAVEL DEPOSITS UNDERLYING PEDIMENTS AND HIGH-LEVEL TERTIARY SURFACES – Poorly stratified and poorly sorted cobble and boulder gravels near mountains. Average size of stones decreases away from mountains. Thick well-developed old soil profiles contain much clayey material and thick deleterious caliche ($CaCO_3$) zones as cement and rinds on stones. Low-quality source of concrete aggregate; source of road metal

Rf FINE-GRAINED IGNEOUS ROCKS – Crop out adjacent to the mountains as dikes and sills. The Valmont dike of shoshonite (alkalic basalt) has been quarried in the past. A sill of rhyodacite 3 miles (4.8 km) southwest of Lyons is quarried for crushed rock

Rc COARSE-GRAINED IGNEOUS ROCKS – The Boulder Creek Granodiorite and the Silver Plume Granite, quartz monzonite, and quartz diorite (tonalite) occur along the west edge of the area, most of these rocks are south of Pinewood Lake. Tonalite or quartz diorite occurs as scattered long narrow bodies north of Pinewood Lake. Many small bodies of pegmatite are along the northwest edge of the area. Most of these rocks are potential sources of high-quality crushed-rock aggregate, although pegmatite may be unsuitable

Rm METAMORPHIC ROCKS – Much of the area of crystalline rocks north of Pinewood Lake is underlain by micaceous metamorphic rocks. Quartz mica schist, various kinds of gneiss, and amphibolite are the common rocks. Foliated rocks are inferior to nonfoliated granitic rocks, but many gneisses have been used for aggregate elsewhere

Rq QUARTZITE – The quartzite of Coal Creek near the mouth of Coal Creek Canyon between Golden and Boulder is a white, gray, red, and black fine- to coarse-grained well-bedded quartzite that is a potential source of high-quality crushed-rock aggregate

SHEAR ZONE – Crushed, broken, or sheared rock along a major fault; much altered locally. Undesirable as a source of crushed rock for concrete aggregate, but might be used locally for road metal or fill

BOUNDARY OF DEPOSIT OR LINE OF CONTACT BETWEEN DEPOSITS

LARGE GRAVEL PIT

× GRAVEL PIT

02-68-03 a — Sand; Granules and pebbles; Clay and silt; Cobbles and boulders

DISTRIBUTION OF GRAIN SIZES IN GRAVEL DEPOSIT, IN PERCENT BY WEIGHT – Diagram indicates analysis of a sample that contained 15-percent clay and silt, 35-percent sand, 30-percent granules and pebbles, and 20-percent cobbles and boulders. Number adjacent to diagram is land-net location: first number is township, second is range, third is section, and letters are sectional subdivisions. Numerical data are found in accompanying table

37 qtzt, 24 peg, 17 ss, 12 gn, 9 gr, 1 cg

PERCENTAGE OF STONE TYPES IN DEPOSIT – Based on one count of 100 pebbles

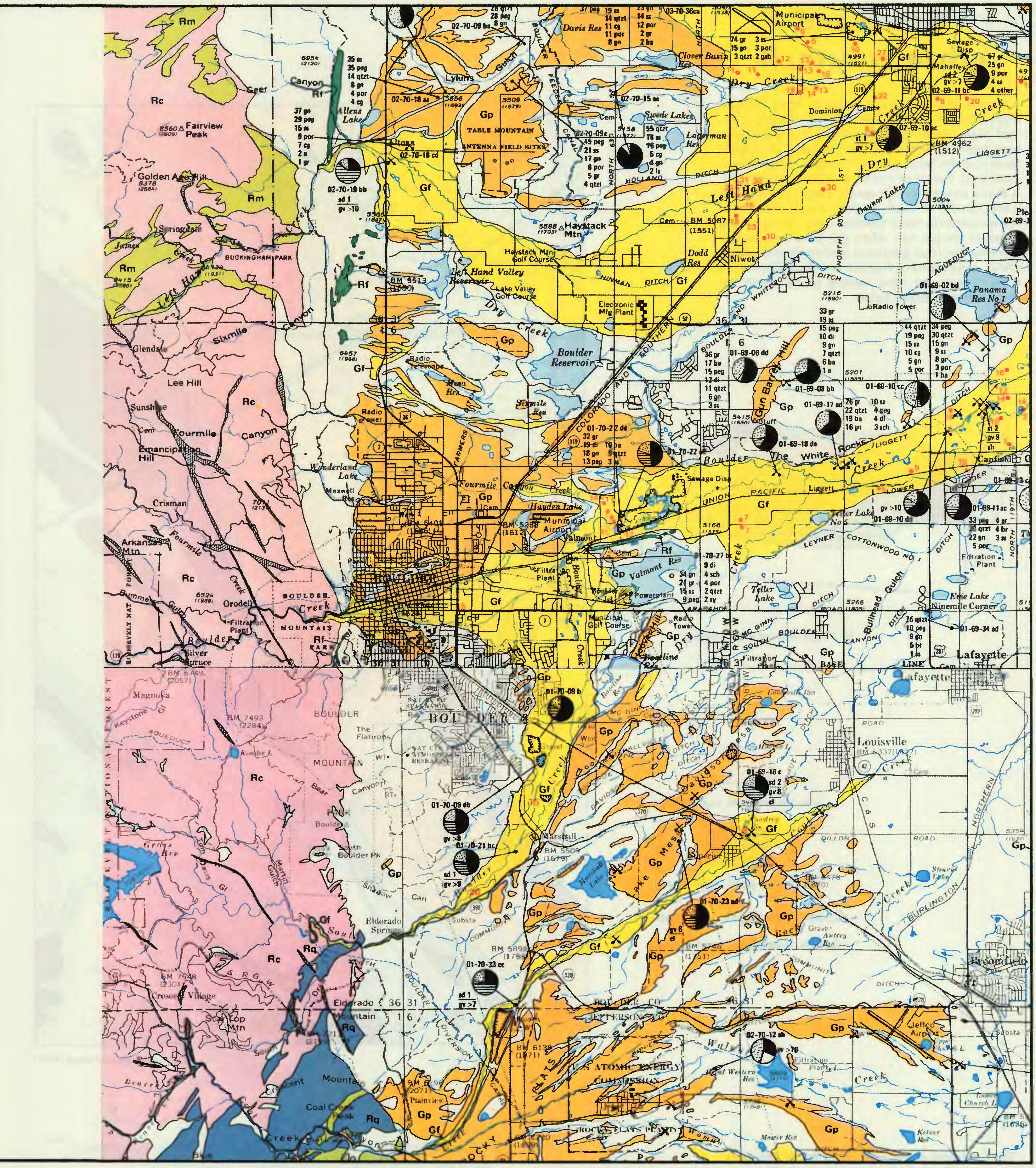
a	Aphanite (any dark-colored very fine grained rock)	peg	Pegmatite
		pet wd	Petrified wood
ba	Basalt (includes gabbro, dolerite)	por	Porphyry
		qtz	Quartz
br	Breccia (siliceous)	qtzt	Quartzite
ca	Caliche	rhy	Rhyolite
cg	Conglomerate	sch	Schist
conc	Concretion (mostly siderite)	sh	Shale
di	Diorite	si	Siderite
gn	Gneiss	ss	Sandstone
gr	Granite	sy	Syenite
ls	Limestone	u	Unknown

sd 2 / gv>6

ABBREVIATED LOG OF DEPOSIT – From well records and other drilling or test data of U.S. Geological Survey and Colorado Division of Highways. Thicknesses shown are in feet

cl	Clay	sd	Sand	ss	Sandstone
gv	Gravel	sh	Shale	st	Silt

30● THICKNESS OF GRAVEL DEPOSIT – In feet



Gravel and aggregate resources near Boulder

From Colton and Fitch (1974) and Trimble and Fitch (1974)

SCALE 1:100 000

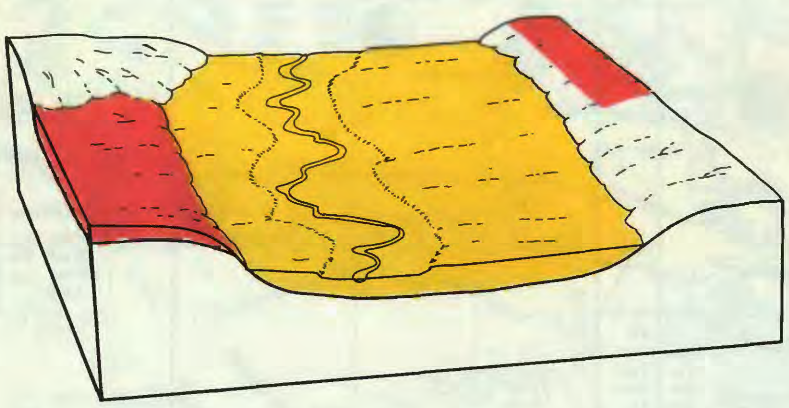
1 0 1 2 3 4 5 MILES

5000 0 5000 10,000 15,000 20,000 25,000 FEET

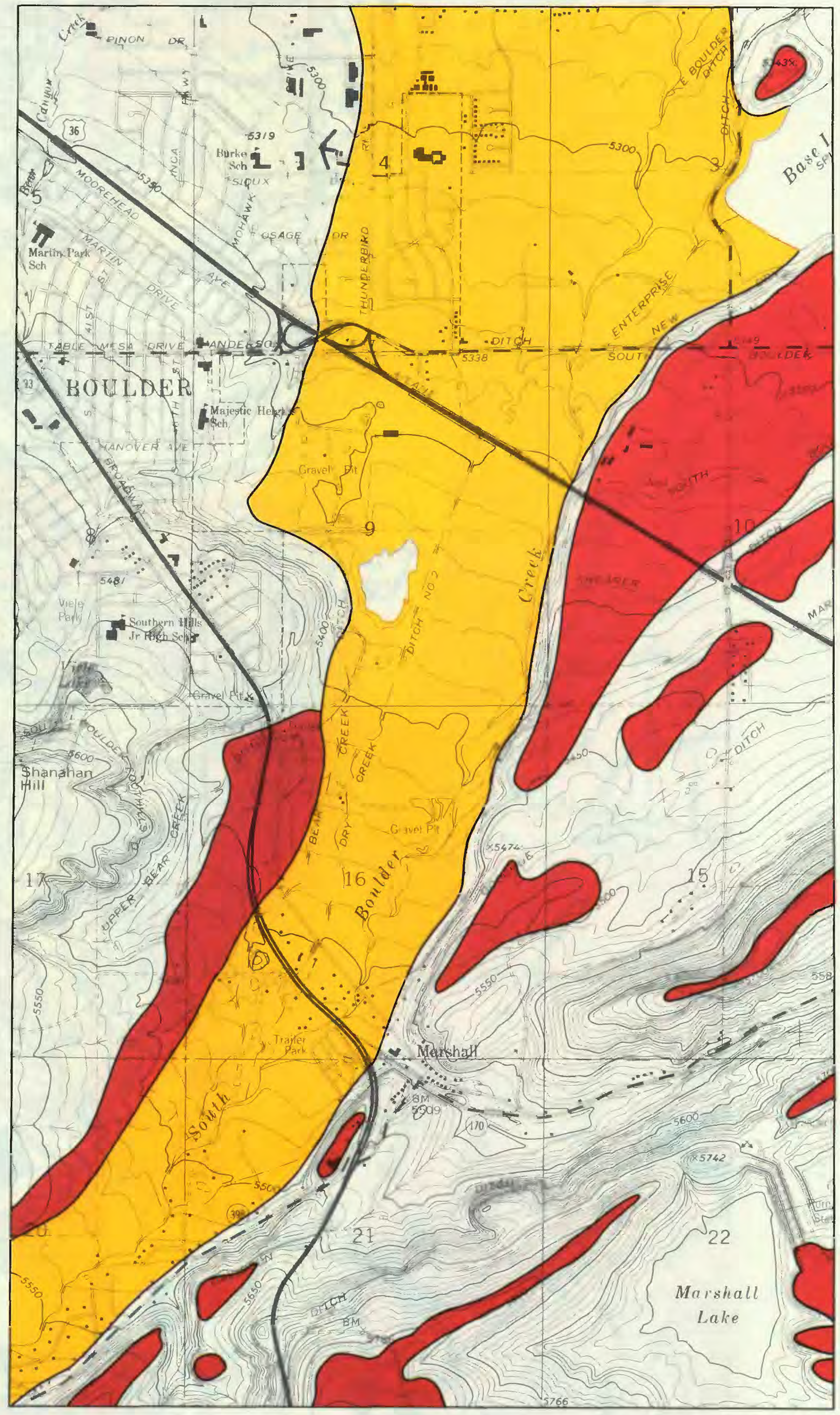
1 0 1 2 3 4 5 KILOMETERS

Gravel and urban growth II

Serving the local needs requires more detailed maps than the regional one on the preceding page. Such maps, useful for general county or city planning, have been compiled, by the Colorado Geological Survey, at the larger scale of 1:24,000 (1 inch equals 2,000 feet). Part of one of these appears to the right. It shows an area of high-quality gravel, in yellow, in a low terrace of South Boulder Creek. This gravel was deposited by South Boulder Creek during waning stages of the Ice Age, when the creek was swollen by meltwater from glaciers in the nearby mountains. Older, lower quality deposits are shown in red. A three-dimensional view, looking north, down the creek valley, is shown below.



Bird's eye view of gravel deposits



Low terrace gravel, high quality

High terrace gravel, lower quality

Gravel deposits in the South Boulder Creek area

From Schwochow and others (1974)

SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

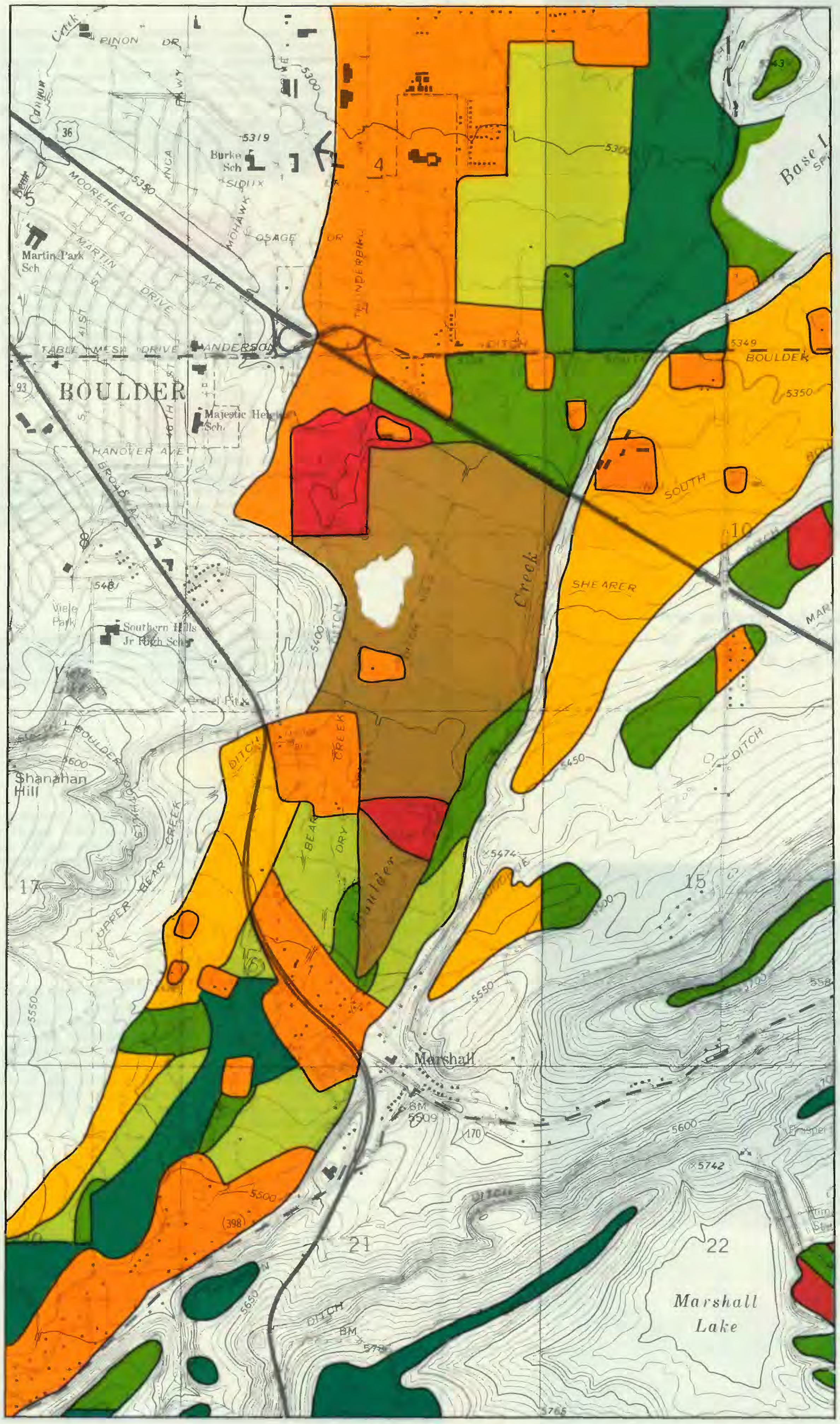
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

The sand and gravel map prepared for planning purposes is displayed on the facing page. This map inventories the historical production of sand and gravel, active extraction sites, deposits precluded from development, and the quality and extent of the available unextracted resources. It is based on one of a series of maps at twice this scale—1:12,000 (1 inch equals 1,000 feet)—that has been prepared by the city geologist, for use in site decisions and in compliance with a 1973 State law that requires a master plan for sand and gravel extraction in urban areas.

The City of Boulder in 1976 authorized a 20-year plan to extract gravel from a 440-acre tract along South Boulder Creek. This plan calls for concurrent step-by-step reclamation of the tract as open space with an artificial lake as a long-term objective.

Private citizen groups that oppose gravel mining in this area, however, contend that South Boulder valley is scenic open space at a major approach to the city and should be retained in its present pastoral form as a part of Boulder's green belt. To mine or not to mine the gravel, therefore, is a complex controversial question that probably will be decided ultimately in the courts, or by ballot on a referred vote of the citizens of Boulder. The physical exploration of the



From J. A. Pendleton, city geologist, Boulder, Colorado (mapping scale 1:12,000)

Extraction precluded by development

Site of previous extraction

Current extraction permit

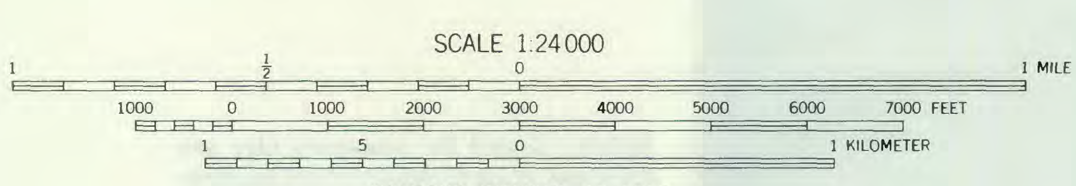
Owned open space

Designated open space

Potentially first-class sand and gravel deposit

Potentially extractable lower class sand and gravel deposit

Sand and gravel planning map for part of the Boulder urban area



deposit, its quality, and its delineation on maps are largely geologic matters, but the ultimate land use will be decided mainly on legal, socioeconomic, environmental, and political grounds.

When mineral resources are involved in land-use decisions, the first step should be to determine the general extent and quality of the resource, in this instance from the gravel maps, and the relation of the resource to urban growth patterns and long-term projected land uses, as determined by urban planners. Colorado law, since July 1, 1973, forbids land uses in populous parts of the State that would interfere with present or future extraction of commercial-grade sand and gravel deposits. Compatible preextraction uses would include agriculture, athletic fields, parking lots, open space, and green belts, among others. The law also requires reclamation plans before the resource is mined. The law is not retroactive and does not apply to lands previously zoned for other uses but does provide a legal basis for communities such as Boulder to plan realistically for the conservation and orderly use of their exploitable mineral resources in ways that are compatible with long-range community objectives.

Land that swells, shrinks, and slides I

Volume changes from wetting and drying of clays cause extensive damage to buildings, pavements and poured concrete slabs (sidewalks, patios, basement floors, highways, and landing strips), buried utility and service lines, and ground surfaces. The plains region east of the Rocky Mountains, within which Boulder lies, has some of the highest potential for shrink-swell damage in the country. Typical damage in Boulder from shrinking and swelling clays is illustrated in the accompanying photographs. The potential of soil and bedrock near Boulder for swelling with changes in moisture content is shown in the map opposite. Where this potential exists, a corresponding potential for slope instability and resultant landslides is also present.

Wall damage caused by shrinking and swelling clay below foundation of house. Photographs by J. A. Pendleton.

NOTE: *The swell potential categories shown below generally apply to the upper 10 ft of soil or rock. However, local variations in thickness of surficial deposits should be expected. Therefore, this information should not be considered adequate for an individual building site. A registered professional soil engineer should be utilized for site investigation and foundation design for every building site in the Front Range Urban Corridor.*

VERY HIGH SWELL POTENTIAL: *This category includes only bedrock or weathered bedrock. The precautions listed below under "high swell potential" must be utilized. Although construction in these areas is often unavoidable, alternate non-construction uses might be considered for such areas.*

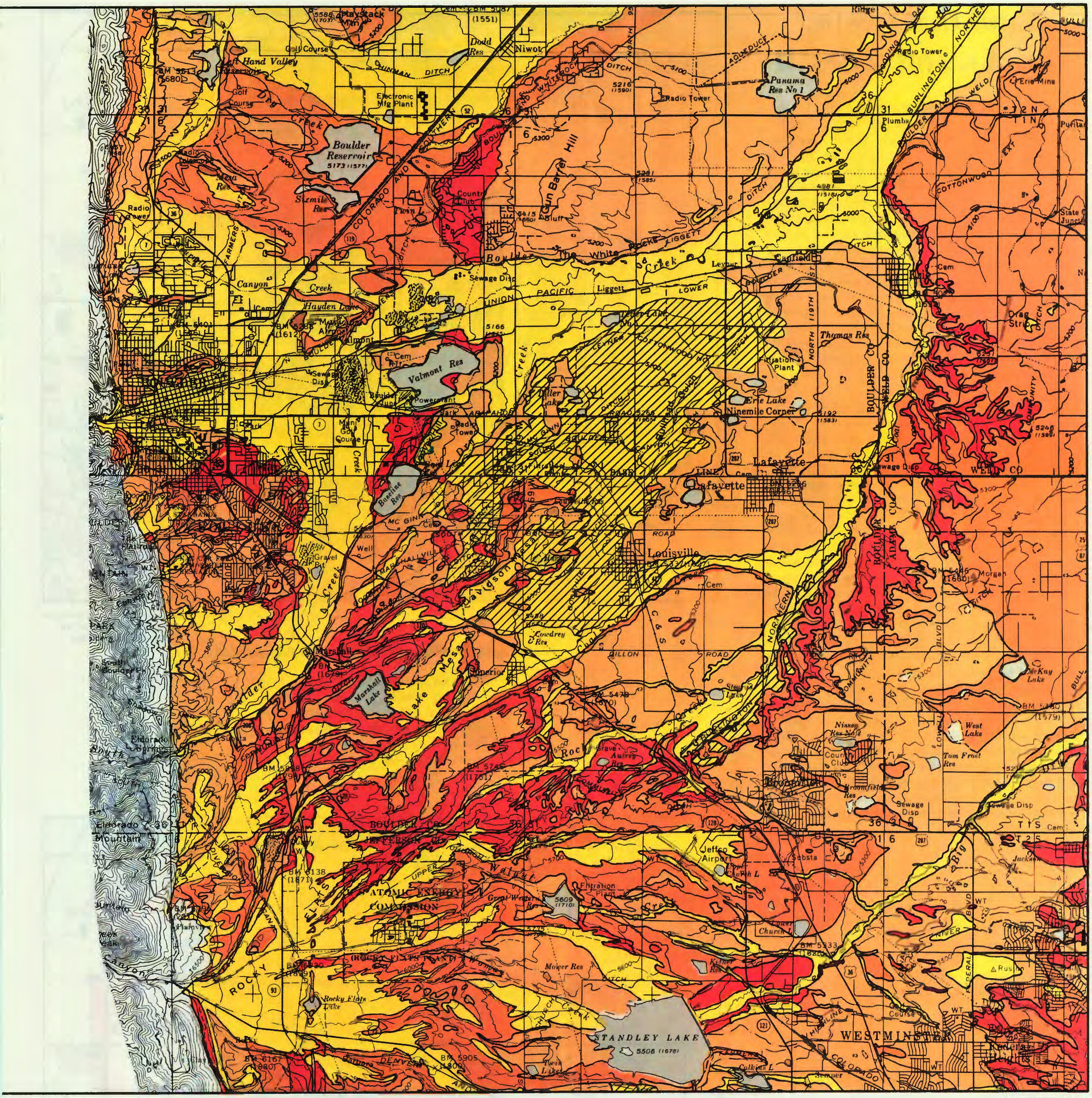
HIGH SWELL POTENTIAL: *This category generally includes only bedrock, weathered bedrock, and colluvium. Careful site investigation, special foundation design, and proper post-construction landscaping and maintenance are required to prevent or minimize damage.*

MODERATE SWELL POTENTIAL: *This category includes several bedrock formations and a few surficial deposits of variable thickness. Special foundation designs are generally ncessary to prevent damage.*

LOW SWELL POTENTIAL: *This category includes several bedrock formations and many surficial deposits. The thickness of the surficial deposits may be variable, therefore, bedrock with a higher swell potential may locally be less than 10 ft below the surface.*

WINDBLOWN SAND OR SILT: *Although this material generally has low swell potential, the upper 6 inches to 12 inches may locally have moderate swell potential. Windblown material may be subject to severe settlement or hydrocompaction when water is allowed to saturate the deposits. The thickness of windblown material may be very variable, therefore, bedrock with higher swell potential may locally be less than 10 ft below the surface.*

Slumps caused by expansive clay are common along highways in the Boulder area. Only a nuisance when small (above), they can lead to large-scale failure of the roadway itself resulting in major damage (below).



From Hart (1974)

Potentially swelling soil and rock in the Boulder area

SCALE 1:100 000

1 0 1 2 3 4 5 MILES

5000 0 5000 10,000 15,000 20,000 25,000 FEET

1 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET

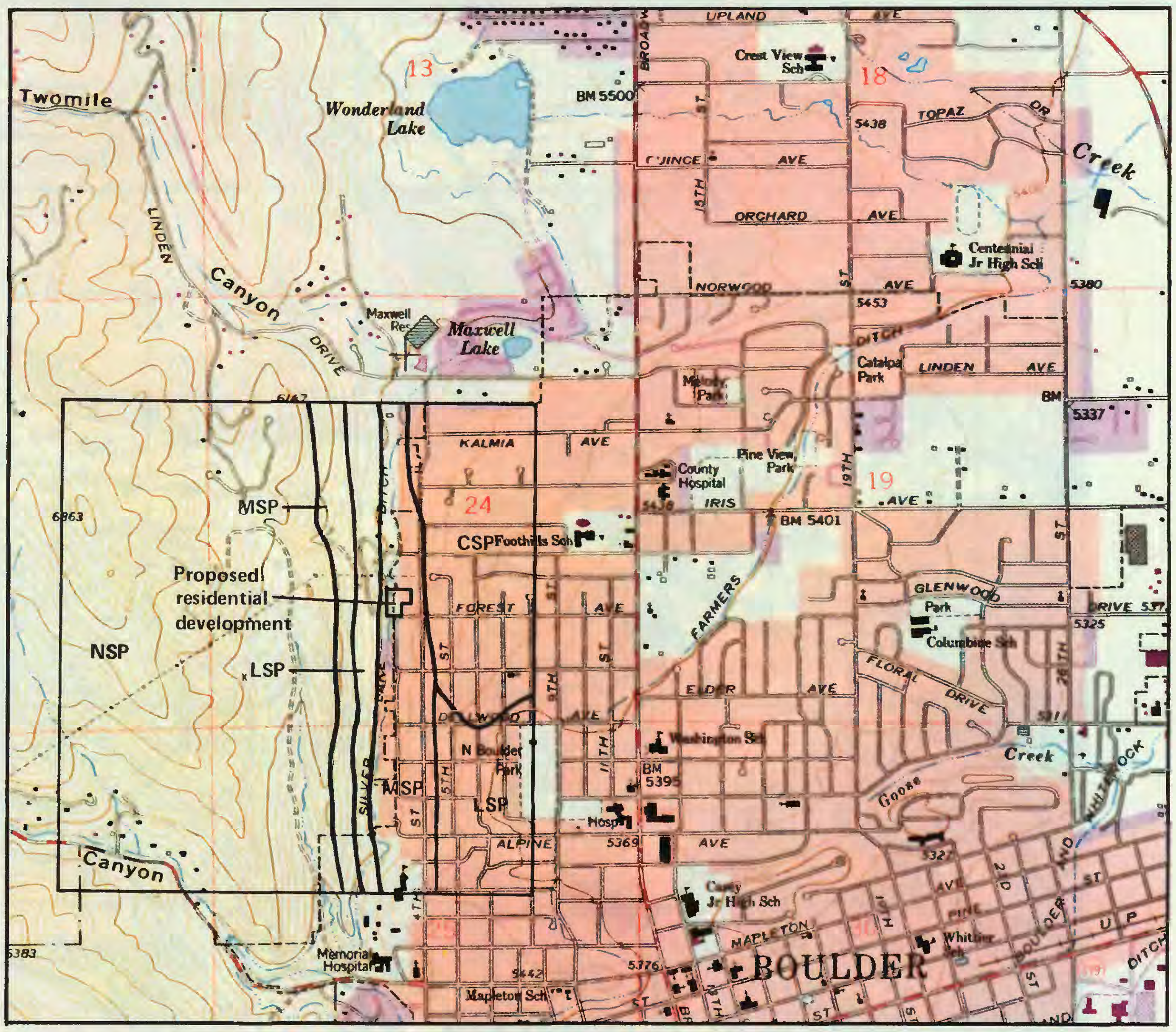
Land that swells, shrinks, and slides II

Application of swell-potential information to land-use management is well illustrated by the small but representative proposed Dakota Ridge residential development, at the west edge of Boulder. Zones of potential swelling ground and unstable slopes in the vicinity of the proposed development are shown in the two maps, right. These maps were used by the city geologist, by the Planning Department and City Council of Boulder, and by property owners seeking approval of the proposed development.

In 1972, a proposal for city annexation of 0.67 acre (upper plot plan, opposite) of the tract and for construction of a single residence under existing "rural- residential" zoning was refused because of citizen opposition and for geological and technical reasons. A second developer applied for annexation and rezoning in 1974. Citizen opposition again defeated the proposal. The developer then increased the size of the parcel to 1.11 acres.

Examination of the site by the city geologist disclosed several potentially detrimental factors: (1) The tract was on steeply dipping clay rock, called the Pierre Shale, with an average surface grade of 20 percent. Grades greater than 10 percent in Pierre Shale have been susceptible to failure throughout the Boulder urban area, particularly if the rock is wet. The results of debris and landslide movement on steep slopes in Pierre Shale within Boulder are shown in the photographs on the opposite page. (2) The Pierre Shale under the site has a moderate to severe shrink-swell potential. (3) An irrigation ditch, which crosses the tract, leaks in several places and could saturate the rocks forming the slope proposed for development. (4) A distinct swale crosses the northern half of the tract from northwest to southeast. Slope runoff concentrates in this swale, as evidenced by dense vegetation.

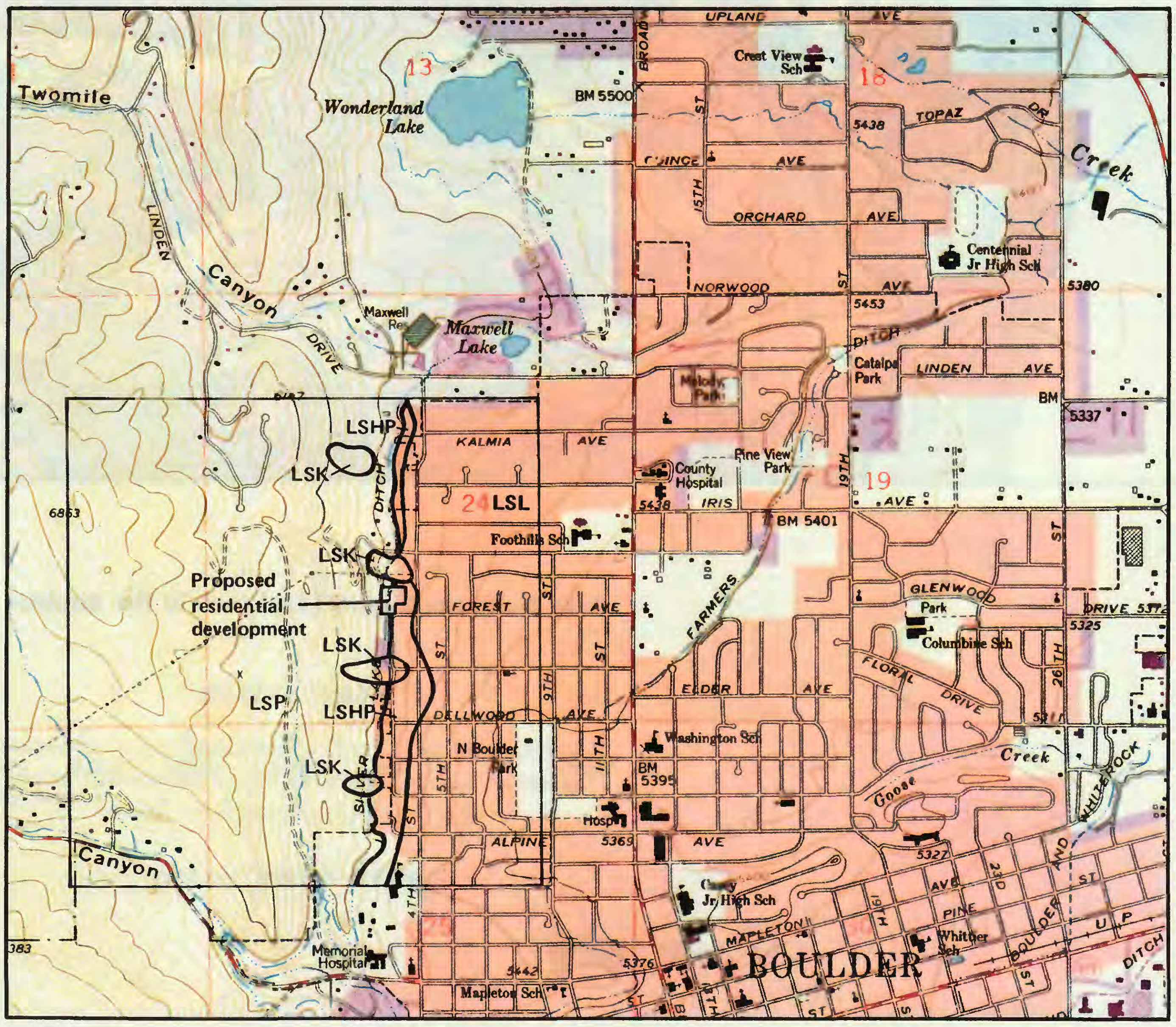
The detrimental factors affecting the tract were clearly interrelated, and development would require careful planning to avoid damage to structures. Leakage from the irrigation ditch could cause slope failure. In addition, seasonal shrinking and swelling of the ground might damage any structure. Construction on the site could also drastically alter the existing drainage pattern, possibly increasing the potential for slope failure, foundation damage, and flooding during severe storms.



From Map by J. A. Pendleton
Publication scale 1:24,000
mapping scale 1:12,000

Potentially swelling ground in part of Boulder

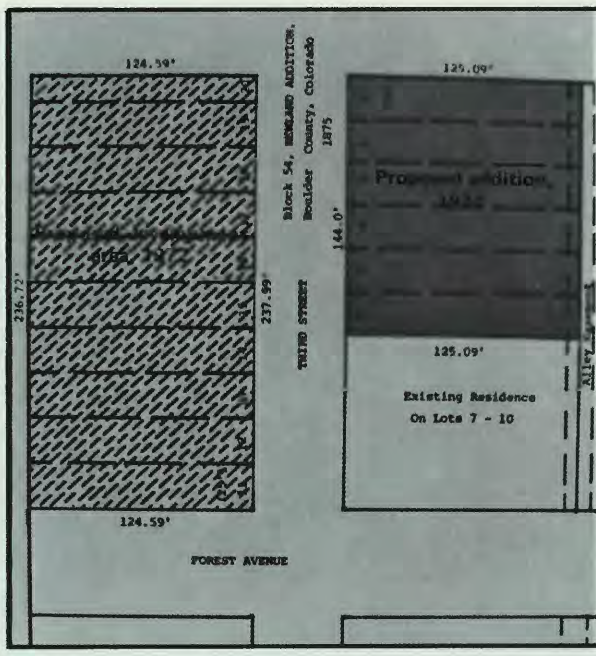
NSP, area of no swell potential; MSP, area of moderate swell potential; LSP, area of low swell potential; CSP, area of potentially swelling ground covered by more than 5 feet of non-swelling surficial material.



Potentially unstable slopes in part of Boulder

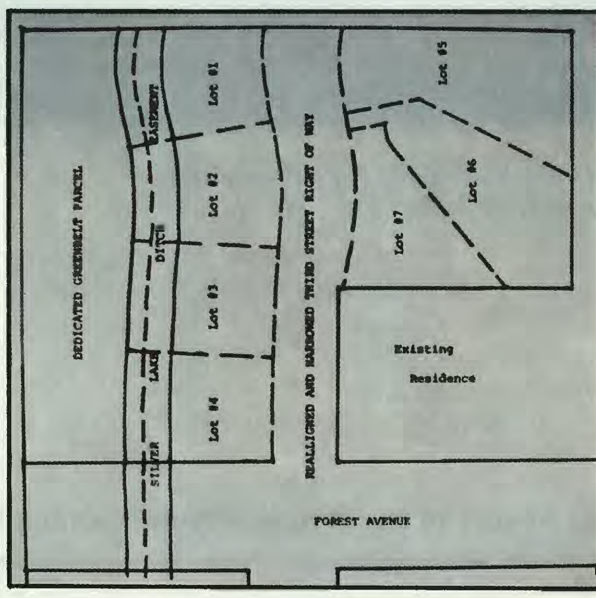
LSK, known landslide deposits; LSHP, area of relatively high potential for landslides, due to leakage from up-slope irrigation ditches; LSP, area of potential for landslides; LSL, area of low potential for landslides.

From Map by J. A. Pendleton
Publication scale 1:24,000
mapping scale 1:12,000

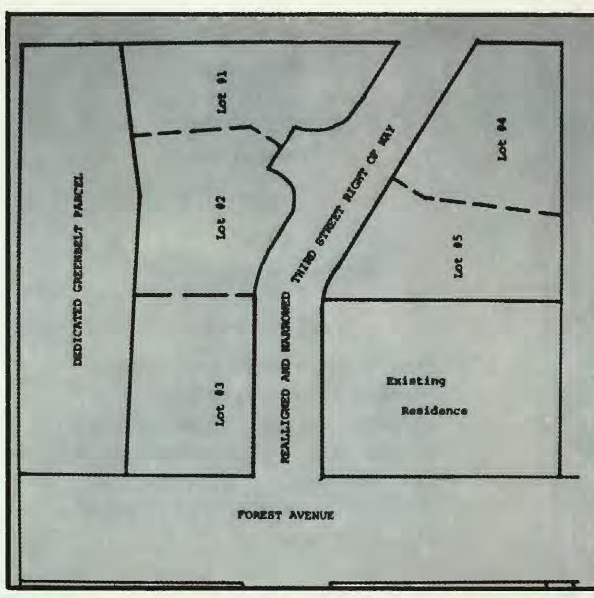


Proposed Dakota Ridge development project in Boulder

Shown are original 1875 subdivision plot, area proposed for development in 1972, and additional area proposed in 1974.



Proposed Dakota Ridge planned residential development, as submitted in 1974



Proposed Dakota Ridge subdivision, as approved by Boulder City Council in 1975

Scale all maps 1:1200 reduced from original scale of 1:600

In June 1974, having realized how costly it would be to develop this site, the developer abandoned the single-unit concept and applied for annexation, rezoning, and approval of a seven-unit planned residential development (middle plot plan at left). This proposal was rejected by the Boulder Planning Board, but the City Council granted annexation and deferred rezoning, unofficially denying the seven-unit density on the basis of geological conditions and lack of applicant information.

In September 1974, the Planning Board recommended that the parcel be zoned "low density residential—established" (minimum lot size 7,000 square feet), without "planned residential development" approval, in order to retain the basic nature of the neighborhood. The owner next submitted a five-unit subdivision plan (lower plot plan at left), including engineering reports on the geological complications. The report (1) confirmed the shrink-swell potential of the ground; (2) stated that "seepage from the Silver Lake Ditch is so severe that this source of ground water must be eliminated to allow development of the property" and recommended replacing the open ditch with a leak-proof culvert; (3) recommended a drainage swale above the culvert to divert runoff into the existing ditch; (4) stated that roadway pavement construction would require chemical stabilization of the subbase and a flexible pavement, 12-inches thick; (5) recommended peripheral drains and drilled pier and grade-beam foundation construction.

The consultants' report was accepted by the city geologist, and in May 1975 the City Council approved the subdivision with the condition that all of the consultants' design recommendations be implemented to the satisfaction of the City Building Department. The owner also had to obtain variances, granted in January 1976, for lot size, height limitations, parking requirements, and open-space requirements. Permits for the construction of the five approved residences were to be granted when complete site analysis, soil testing, foundation designs, and grading plans were all approved.

It was a long and expensive procedure, but it provided greater protection to future residents and to adjacent established homes. Also, as it turned out, the procedure resulted in greater profit to the developer. It would have been much shorter and less costly if the development had been carefully planned from the beginning.

A 7-ton fragment of a 35-ton rock-fall boulder lodged in the patio of a foothills subdivision home on the west edge of Boulder. Photograph by J. A. Pendleton.

Failure on a steep Pierre Shale slope in Boulder. Photograph by J. A. Pendleton.

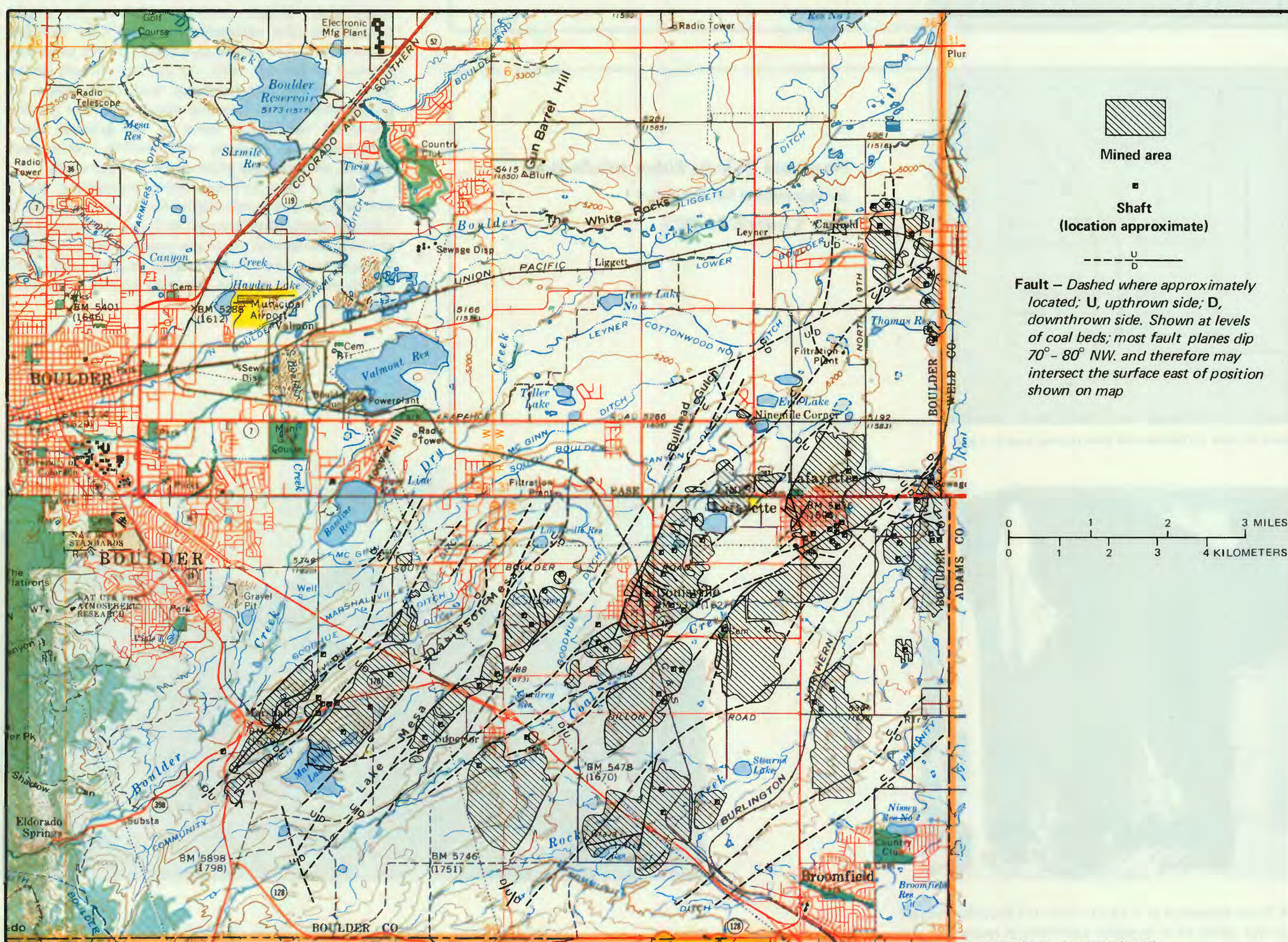
Subsiding land

Underground coal mining was an important industry in the Boulder area from 1863 until the 1940's, and a few small mines still operate. Openings from mined coal are within a few hundred feet of the surface over large areas. The ground over mined coal beds is prone to subside—in some places gradually but in others suddenly and without warning—months, years, or decades after the coal has been removed. Fires in abandoned mines have created additional risk and have extended the area of potential subsidence. This subsidence is a potential hazard that should be weighed carefully before land-use changes are made.

Mined areas in part of the Boulder-Weld coal field are shown on the map below. Most of the area is rural, with a few small former mining towns and rural trade centers. The area, however, is in the path of urbanization spreading eastward from Boulder and northward from Denver, and sizable subdivisions have already been contemplated. The map also shows the many faults which break the country up into long, irregular blocks and greatly complicate both mining of the coal and management of the potentially subsiding land.

Subsidence and collapse of ground surface above old coal workings and mine fires about one-quarter mile east of Marshall. Photograph by R. B. Colton and R. D. Miller, U.S. Geological Survey.

Mined areas of part of the Boulder-Weld coal field



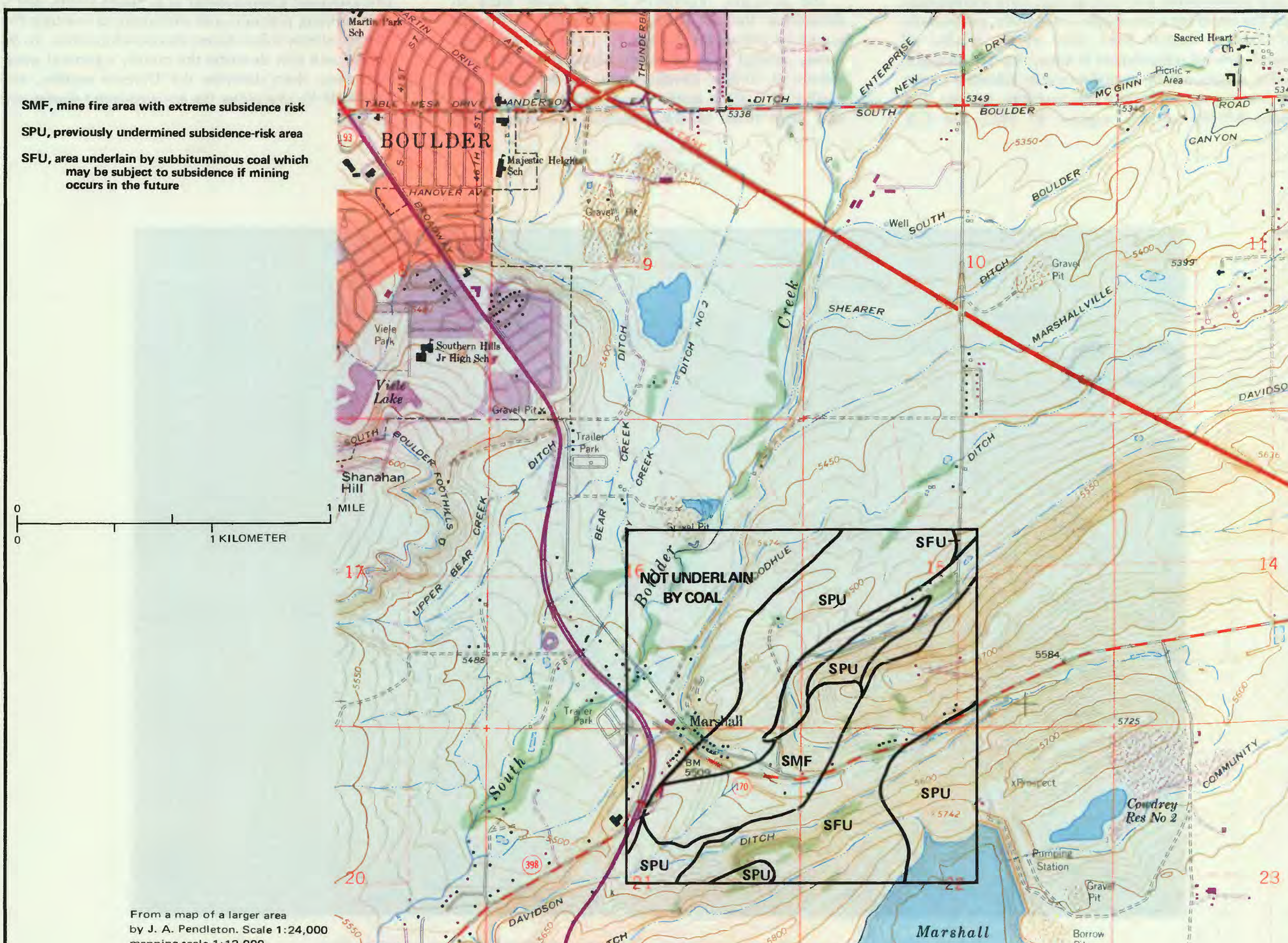
Subsidence and collapse of ground surface above old coal workings and mine fires at east edge of Marshall. Photograph by R. B. Colton and R. D. Miller, U.S. Geological Survey.

A subsidence-potential map has been made by combining the mined-area map with mapping of surface expression of subsidence or other instability, information on the depth of mine workings and distribution of remaining coal, the location of burning areas, and the characteristics of faults. A part of this map near Marshall, a former coal-mining center, is reproduced enlarged below. This map, constantly updated by information from the Colorado Geological Survey, the city geologist of Boulder, and private engineering firms, has provided a basis for zoning decisions in Boulder County, including rejection of some development proposals.

The nature and scale of subsidence above old coal mines is dramatically shown in the photographs. The scenes are from near Marshall, where much of the coal was within 50 to 150 feet of the surface. Here subsidence has led to actual collapse of ground above old shallow workings, some of them burned. Even the room-and-pillar pattern of the mine is evident at the surface. The effect has been devastating.

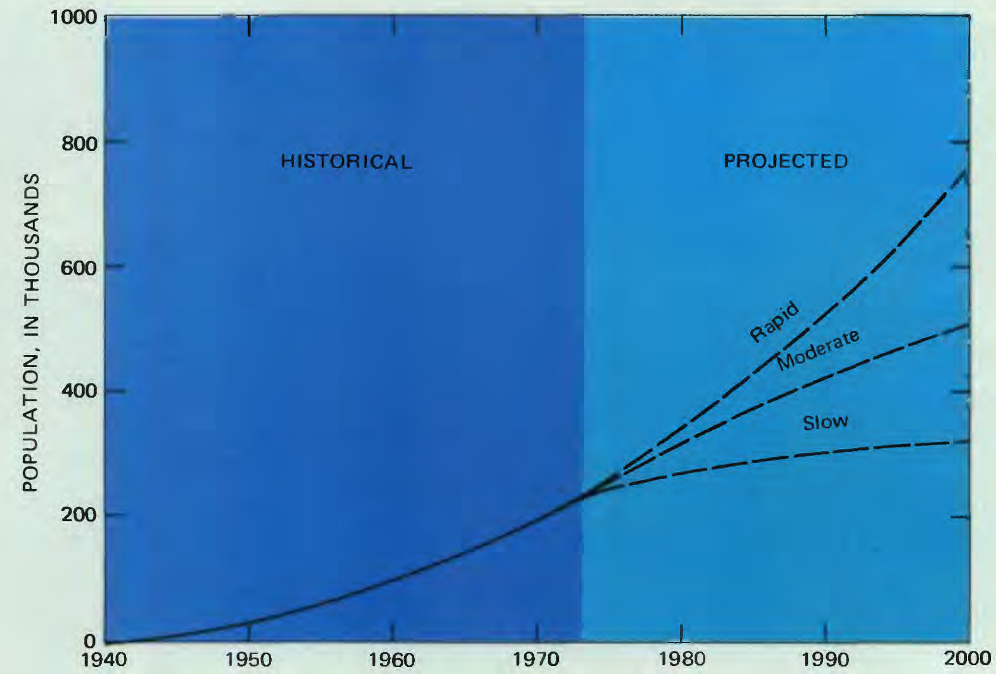
If the coal were being removed today, strip mining might be employed instead of underground methods. Much more coal could be recovered, and the land surface would be much more amenable to reclamation and, therefore, to safe and practical use after mining. But strip mining brings its own environmental problems, and underground mining might be more desirable in some situations.

Areas of potential subsidence over coal field near Marshall



Colorado Springs area

Background of water needs in El Paso County

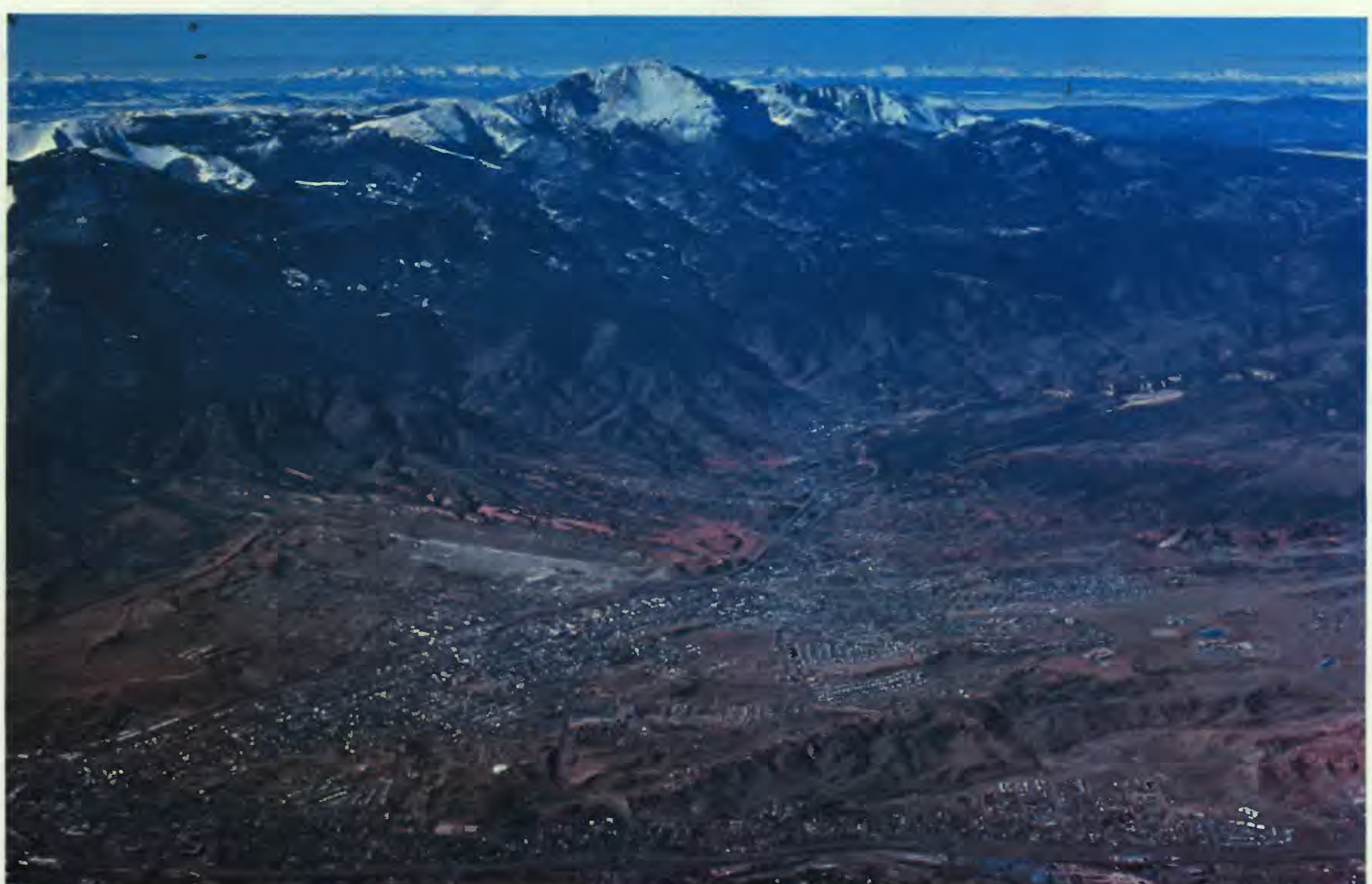


Historical (1940–74) and projected (1975–2000) population of El Paso County

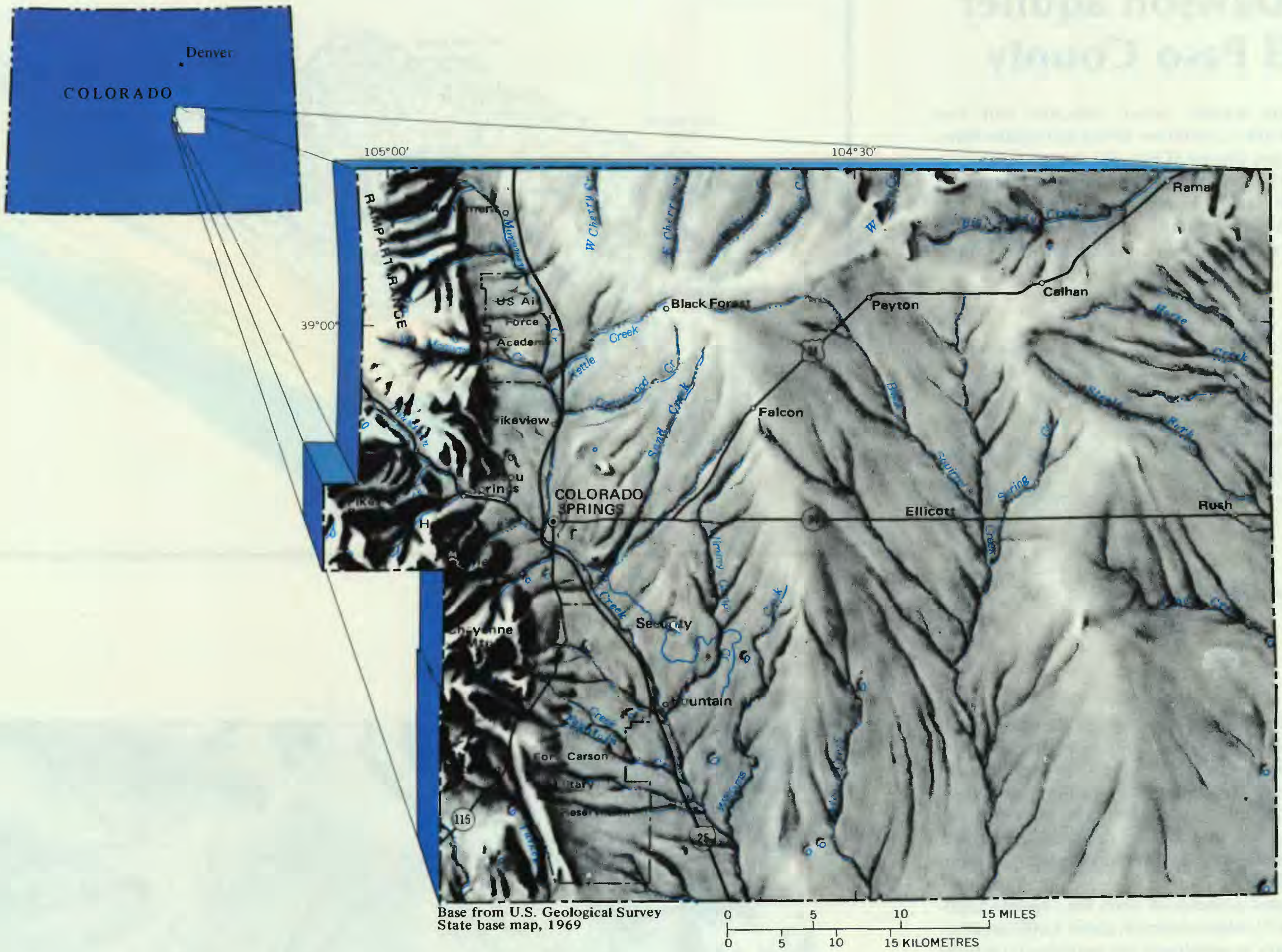
El Paso County, together with Colorado Springs, its largest municipality, is one of the Nation's fastest growing urban areas. From 1950 to 1970, the population of the county more than tripled—from about 74,500 to 245,000. The population by the year 2000 would range from about 360,000 to 800,000, according to alternate projections for slow to rapid growth. The El Paso County Land Use Department is using a "moderate" growth curve, which anticipates a population of about 550,000 by the year 2000, as the basis for its planning program. The current level of growth is straining the area's energy and water resources. In 1973, as a result of a shortage of natural gas for heating, a temporary moratorium was declared on new construction within the metropolitan area of Colorado Springs. This sudden brake on the region's population and economic growth caused great concern among the entire community and resulted in an increased interest in natural resource appraisals. One of the more serious concerns in this semiarid region is the problem of water supply.

Knowledge of the availability and quality of water is vital to planning for the future of this growing region. Local government and civic groups have increasingly felt the need for a thorough water study, particularly in view of recent State laws which require all developers of subdivisions to show that an adequate water supply will be available and to submit a report to the county indicating the quantity, quality, and dependability of this supply. In 1972, the U.S. Geological Survey began a comprehensive 3-year study of ground water and surface water in the county in cooperation with the county, the city of Colorado Springs, the Pikes Peak Area Council of Governments, and the U.S. Air Force Academy.

The principal objectives of this study were to determine the availability and quality of ground water; to document current ground-water development, annual ground-water withdrawal, and the effects of current development; to determine the quality of surface waters; to estimate mean annual and peak flows of the principal streams; and to develop the ability to predict future development alternatives by means of a ground-water computer model. Let us examine how this model is being used to determine the effects of increased pumping on water levels in the Dawson aquifer, the main source of undeveloped ground water in El Paso County, and is thus helping planners and managers to evaluate the impact of new subdivisions and developments. To do so, we will first describe the county's general water resources, then describe the Dawson aquifer, and conclude by discussing the ground-water model and its uses.



Colorado Springs, a rapidly growing Front Range community at the foot of Pikes Peak.



Location and stream system of El Paso County

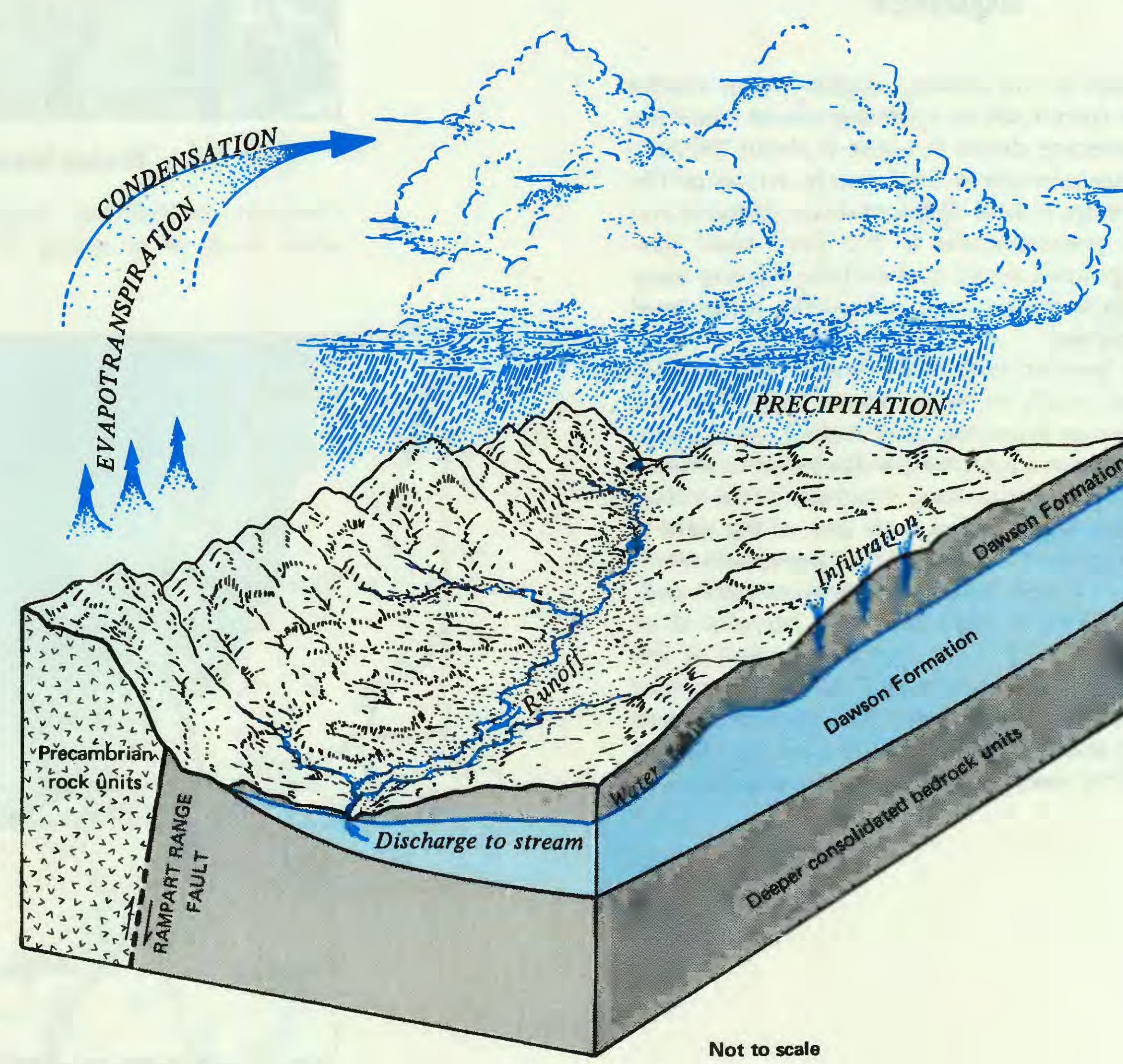
Water resources of El Paso County

Precipitation, the primary source of water in El Paso County, increases with altitude within the county: Mean annual precipitation ranges from less than 12 inches at an altitude of 5,300 feet in the southeastern corner to more than 30 inches at 14,000 feet near Pikes Peak. Most of the county is in the semiarid plains region which lies east of the mountain front, where annual precipitation is only 12–16 inches. Throughout the county about 20 percent of the precipitation occurs as snow.

Runoff similarly increases with altitude. The mountain region contains many perennial streams with fairly abundant surface water, whereas most of the streams in the plains region flow only intermittently. About 95 percent of the county is drained by generally south- and east-flowing tributaries of the Arkansas River, including Fountain Creek, Chico Creek, and Big Sandy Creek. The rest is drained by north-flowing tributaries of the South Platte River.

Most of the water development in the county has resulted from the needs of Colorado Springs. The Colorado Springs water supply, aggregating about 45 million gallons per day in 1974, comes from many sources and reflects, in a general way, total water development in the county. About 40 percent of the supply comes from streams within the county, and only about 9 percent from ground-water sources. The rest is imported.

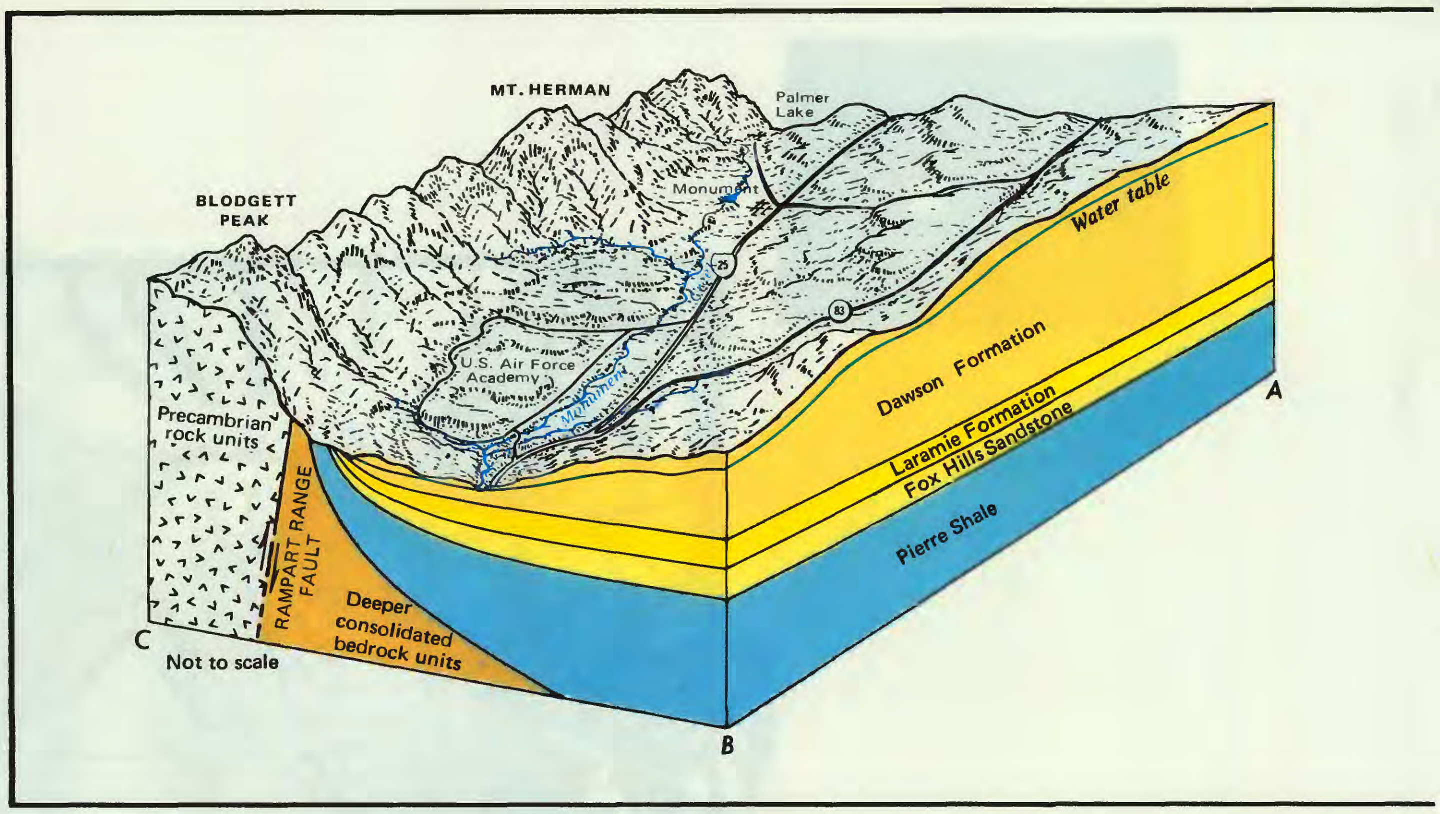
The surface waters in El Paso County have been extensively developed and are generally over-appropriated. For the foreseeable future, the Colorado Springs water supply cannot be expanded much beyond its existing service area because the supply is severely limited by water rights and other restrictions. Therefore, the rapidly growing suburban areas and planned land developments in the county will have to depend on local sources, mostly ground water, for their water supply. A few small thin alluvial aquifers are present, but for most of the developing area the Dawson aquifer will be the principal source of water.

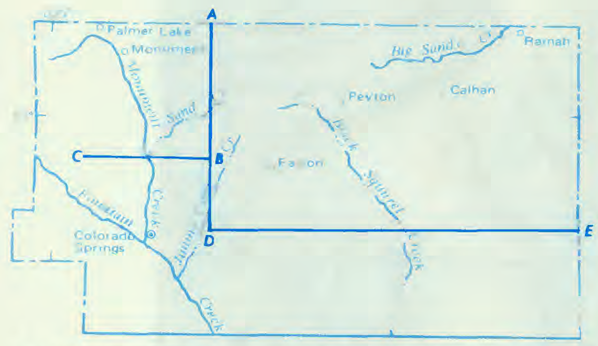


The hydrologic cycle in El Paso County

The Dawson aquifer in El Paso County

The Dawson aquifer, which coincides with the Dawson Formation, underlies about 850 square miles in northern and central El Paso County and contains an estimated 97 million acre-feet of ground water in storage. The water bearing Dawson Formation, shown on the diagrams at upper right, is a great lens-shaped body of sandstone that is variably cemented; it includes a few beds of shale. Only the southern part of the sand lens is in El Paso County, where it is about 2,500 feet thick near Black Forest. The lens thins to zero within 10 miles westward at the mountain front, within about 10 miles southward beneath the city of Colorado Springs, and within about 30 miles eastward; its capacity to store water, of course, diminishes correspondingly.





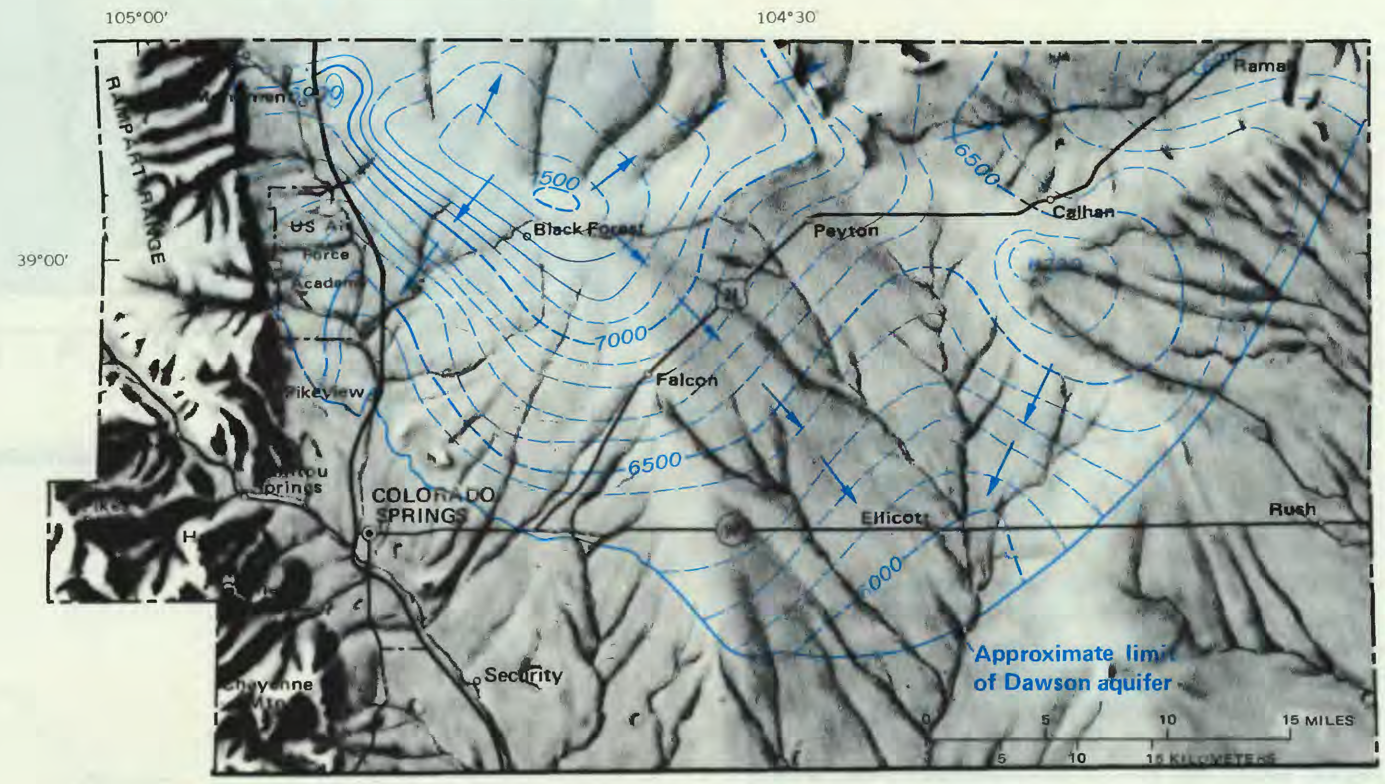
Location of geologic sketches in El Paso County

Ground-water withdrawal from the Dawson aquifer is now (1977) relatively small, about 5,000 acre-feet annually. Water is withdrawn for municipal use from 20 to 30 large-capacity wells and for domestic use from several hundred small-capacity wells. The average well depth is about 330 feet and reported well yields range from 5 to 400 gallons per minute.

Water levels in the Dawson aquifer

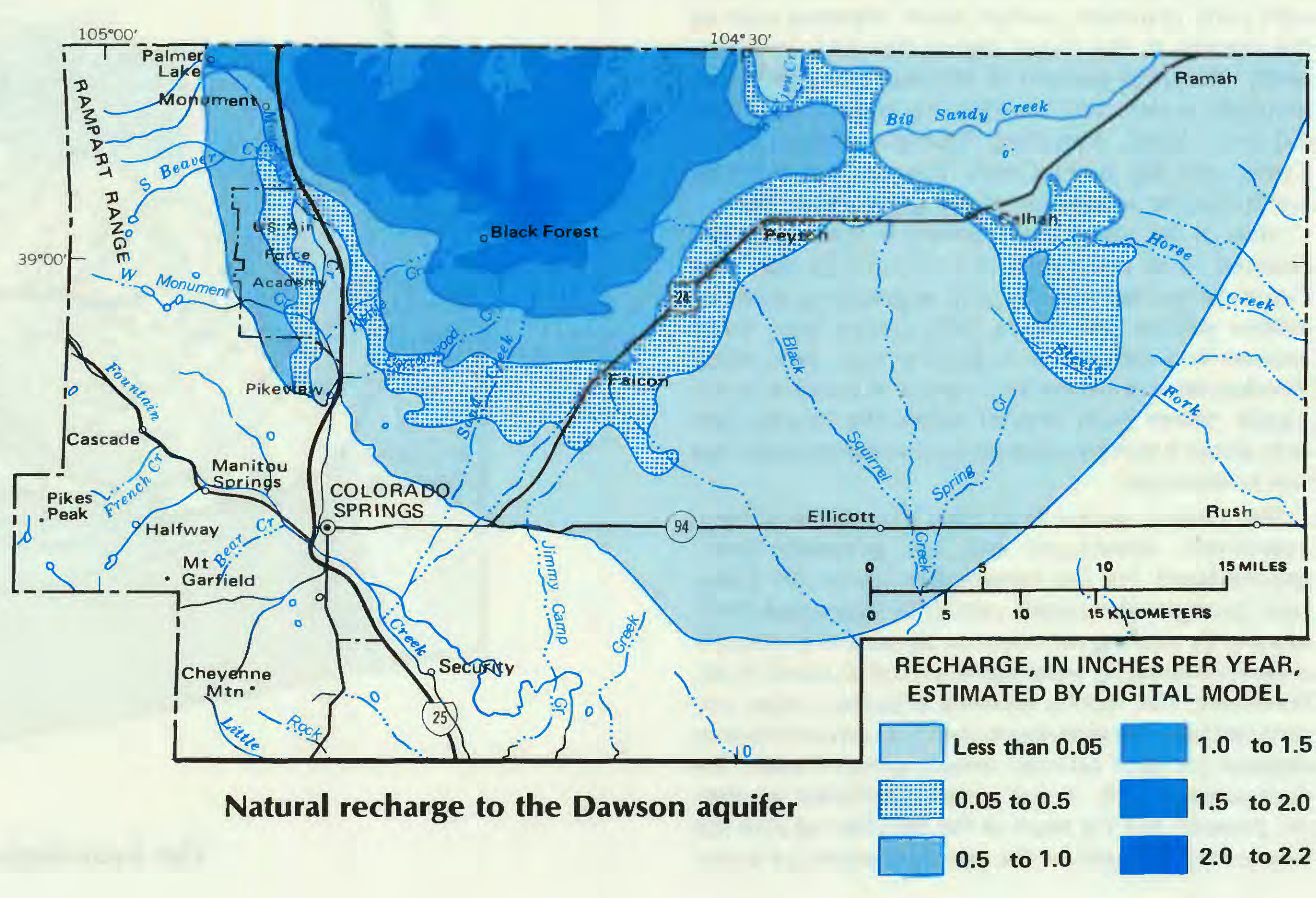
Water levels in the Dawson aquifer (map, middle right) range from 6,400 to 7,500 feet above mean sea level. The average depth to water is about 100 feet. Ground-water movement, as shown by arrows on the water-level map, is from higher to lower altitudes and generally is perpendicular to the water-level contours. The ground water is therefore flowing away from the Black Forest area, where the water-level altitude is highest.

The water levels in wells in the Dawson aquifer have not changed much in recent years, indicating that natural recharge from rain and melted snow (map, lower right) about equals natural discharge to streams and adjacent rock formations. The trend of the water-level contours shows that a large part of the natural discharge of ground water from the Dawson aquifer is to Monument Creek. Seven surface-water gain-and-loss investigations in 1973 and 1974 found that an average of about 7.5 cubic feet per second of the streamflow in upper Monument Creek was flow from ground water to the stream. This measured gain represented about 30 percent of the average flow at the end of this reach during these investigations.

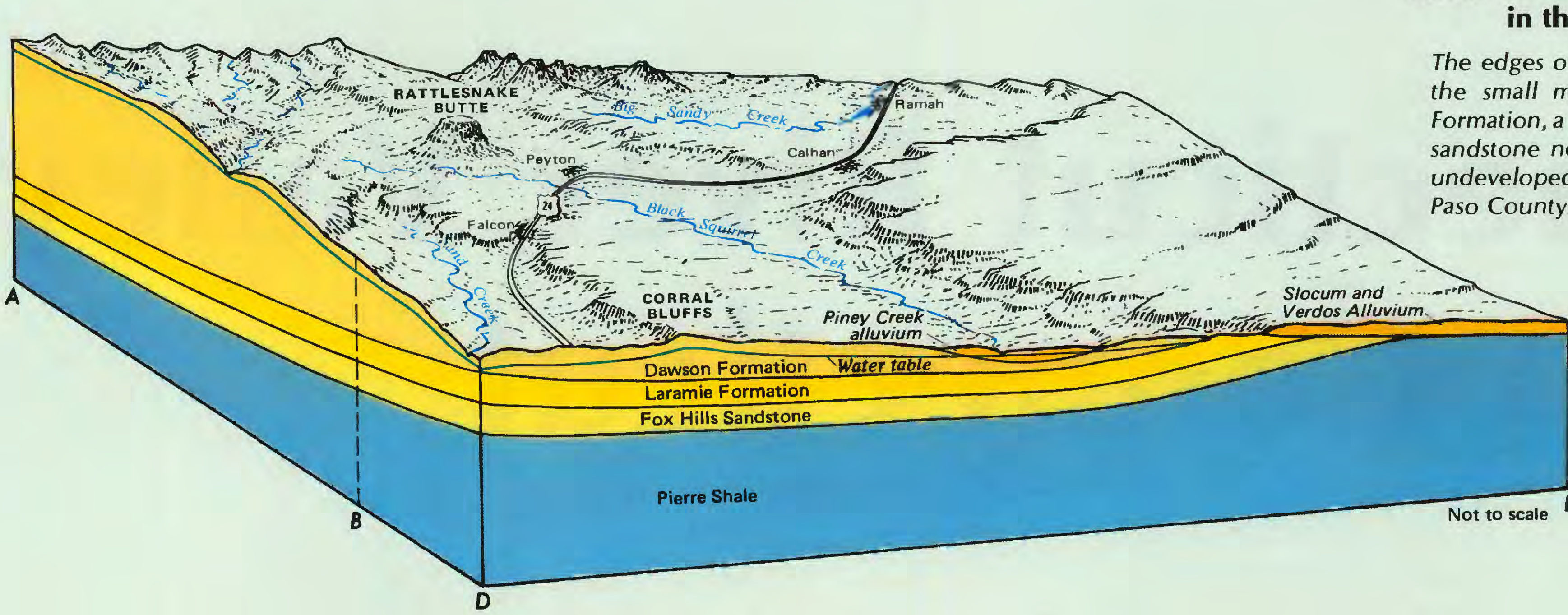


Water level altitudes in the Dawson aquifer

Contours, at 100-foot intervals, show water levels as of spring 1974. Arrows indicate direction of ground-water movement.



Natural recharge to the Dawson aquifer



Rocks of northern El Paso County in three dimensions

The edges of the blocks are located on the small map, far left. The Dawson Formation, a thick body of water-bearing sandstone near the surface, is the only undeveloped large water source in El Paso County.

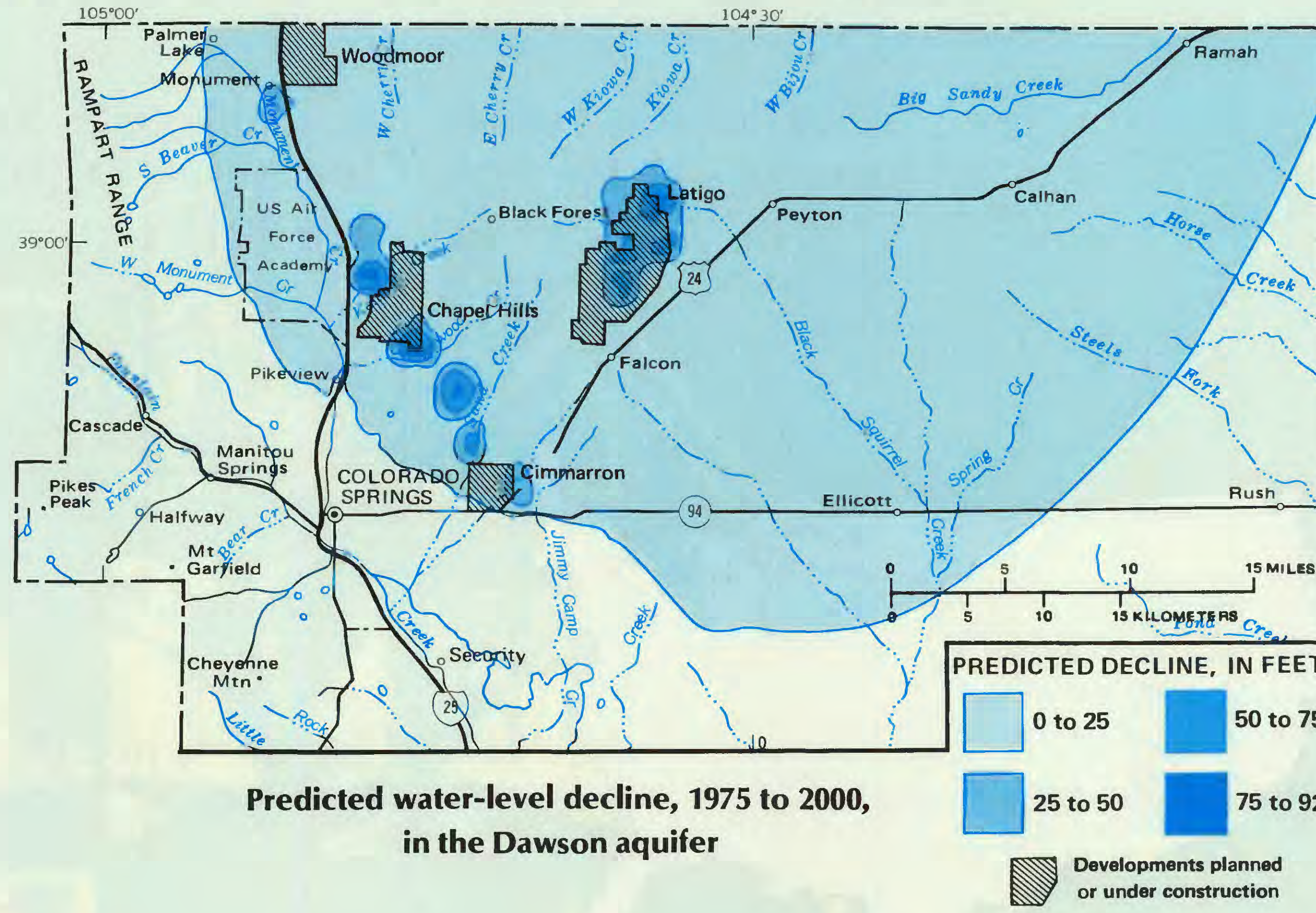
Mathematical model of the Dawson aquifer and its uses

If we know enough about the way hydrologic systems in general work, and about how the Dawson aquifer in particular has worked in the past, we should be able to predict how this aquifer system is likely to respond to future changes. Changes may occur either by gains or losses of water, both of which, in the short term, are more likely to be due to man's activities than to natural events. To make such predictions, however, is difficult, involving as it does not only the physical dimensions and water-bearing properties of the aquifer but also the amount of ground water in storage, the rate and direction of ground-water movement, natural recharge, and discharge by evapotranspiration, flow to surface waters or other aquifers, or withdrawal by wells.

Complicated hydrologic systems can be simulated by mathematical models. Digital computers can then be used to evaluate simultaneously all the factors that influence the systems in a fraction of the time it would take to perform all the calculations by hand. Such a model has been made for the Dawson aquifer and is being used to assist in making decisions about water. The model, for all the power of the computer, is an imperfect simulation of a complex natural system whose characteristics are incompletely known. Predictions made by manipulating the model are therefore only approximations, to be used with due caution.

Basic to all decisions involving the Dawson aquifer are the distribution and rate of natural recharge, for withdrawal of water at a greater rate for very long times will inevitably lead to decline of the water level, increasing the difficulty and cost of pumping and eventually exhausting the supply. Modeling shows that the natural recharge rate is about 2.0 inches per year in the vicinity of Black Forest and decreases with decreasing altitude to less than about 0.05 inch per year near Ellicott and Ramah. This is shown on the natural recharge map just referred to.

To use the hydrologic model for prediction several assumptions must be made. It is assumed that (1) all persons living in an area underlain by the Dawson aquifer and not zoned by the city of Colorado Springs would be supplied by wells tapping the Dawson and within 2 miles of the house, (2) per-capita use of water would be about 170 gallons a day, (3) population would increase in equal increments of 28,530 persons every year, representing 5-year withdrawal increments of 4.85 million gallons per day, and (4) 25 percent of withdrawn water would be returned to the aquifer. These assumptions are based on the projections of local planners.



Predicted water-level decline, 1975 to 2000, in the Dawson aquifer

Given the known rate of recharge and projected water withdrawals, what will be the effect on water levels in the Dawson aquifer? The model predicts that by the year 2000, the water level will decline more than 75 feet in 4 areas and as much as 92 feet in one of these areas, as shown on the map just above. Water-level declines of 50–75 feet are predicted for housing developments now underway at Chapel Hills, Cimmarron, and Woodmoor, and a maximum decline of 92 feet is predicted at the large newly proposed development to be called Latigo, northeast of Falcon. The Latigo proposal visualizes an ultimate population of 55,000 persons on about 9,000 acres, all to be served by water from the Dawson aquifer. The future of this proposal may well hinge on its impact on the aquifer as predicted by use of the hydrologic model.

The model also predicts a decrease in the flow of Monument Creek as a result of increasing withdrawals from the aquifer. By 2000, streamflow can be expected to be reduced by about 2.1 cubic feet per second or 1.36 million gallons per day. Such a depletion would probably affect downstream surface-water rights, and State law might require developers to augment the flow of Monument Creek. This might be accomplished by limiting the size of the development to avoid or reduce streamflow depletion, by recycling sewage effluent and returning it to the stream, by artificial recharge, or by some combination of these. The hydrologic model will no doubt influence selection of the course to be followed.

The model will be used extensively in evaluating all new proposed subdivisions in the unincorporated areas of El Paso County where the main source of water supply is ground water. With it, planners will be able to calculate, within the limits of accuracy of the model, how much water can be withdrawn from the Dawson aquifer in a given area, how this would affect water levels, and thus ultimately how much this withdrawal would affect water supply in surrounding areas. As more and better information becomes available, the accuracy, and therefore the usefulness, of the model will increase.

Connecticut River Valley, Connecticut

East Granby–A plan of development for a rural community

By William H. Langer, U.S. Geological Survey, and Lawrence H. Johnson, Connecticut Department of Community Affairs

Use of drainage-area maps in evaluating waste-disposal conditions, assessing impact of highway salting, and designing bridges and culverts

By Robert L. Melvin, U.S. Geological Survey

East Granby

Background of development

The problems of East Granby, Connecticut, as a rural community are somewhat different from those of large urban areas. Sewer service extends to only a small part of the town, and municipal water service does not exist. Therefore, most of the houses rely upon onsite septic systems for waste disposal and upon onsite wells for water supply. A properly functioning waste disposal system and a safe, reliable water supply, both on the same property, require careful planning. With urban population growth demanding land, rural areas are under pressure. Urban development strongly competes with farming and also spreads into sensitive areas where it may have harmful effects on the natural environment. Rural town planning must carefully consider these special problems, as well as those that are common to both rural and urban areas.

Therefore, a somewhat different approach to planning may be taken in East Granby from that used in large urban areas. Here, large areas of land are available for growth, so it is easier to plan around natural constraints, rather than engineer through them. Development can be located in areas of minimum constraints, or development can be at a density that is low enough to minimize environmental impact. Of course, a sound plan of development for a rural community, like that for a city, should determine how development can be adjusted to the natural environment and should also determine how the environment can be used most effectively by the community.

Connecticut is one of the States that officially recognizes natural factors in the community planning process and encourages the development and use of earth-science information. Further, the State possesses a wealth of natural-resources data. The U.S. Geological Survey has had cooperative programs in geology and hydrology with the State for more than 20 years. From 1971 to 1976 the Survey also funded and staffed the Connecticut Valley Urban Area Project, which was headquartered in Middletown, Connecticut. In this pilot project, geologic and hydrologic maps were prepared in a format designed for land-use planners and decisionmakers in central Connecticut as well as in parts of Massachusetts, New Hampshire, and Vermont. The Soil Conservation Service is also active in Connecticut and has been preparing detailed soils surveys for many years.

In addition, in 1969, several geologists, hydrologists, soil scientists, and planners from State and Federal agencies formed an ad hoc group known as the "Geology-Soil Task Force" which prepared a report titled "Use of Natural Resource Data in Land and Water Planning." A few years later, the State Department of Environmental Protection jointly sponsored a series of workshops with the Cooperative Extension Service of the University of Connecticut. These workshops, held at various locations throughout the State with representatives from every town in Connecticut, pointed out the importance and demonstrated the use of natural resource data in the planning process.

Shortly after these workshops were held, the town of East Granby revised its existing plan of development. The new plan included consideration of the natural environment, and as a result the town now has a plan of development that not only accounts for the projected growth of the community, but also protects and utilizes the surrounding environment in the interest of the community.

Setting of East Granby

The town of East Granby is a rural, residential New England community about 15 miles north of Hartford, Connecticut. East Granby is adjacent to Bradley International Airport and is easily reached by state and interstate highways. The town has an area of 17.4 square miles, with less than 25 percent of the land being developed. There are extensive areas of woodland, pasture, and farmland, and in spite of the more obvious evidences of development, many sections of town retain their rural character.

Since 1970, some 250 units of multifamily housing and 170 single-family houses have been built in East Granby. An estimated 870 more housing units probably will be constructed by 1990. A new town hall was recently built in the town center, which also has a small business nucleus. East Granby experienced a 45 percent increase in population from 1960 to 1970, and between 1970 and 1974 the population increased by nearly 1,000 people to approximately 4,500 residents. By 1990 the population of East Granby may be more than 7,500.

The land in East Granby is for the most part level to gently sloping, with the exception of the Talcott Mountain Ridge, which divides the town from north to south and consists of thick layers of ancient basalt lava flows. Rock is at the surface in many places on the ridge, and the soil is seldom more than a few feet thick. The presence of the ridge has dictated the existing road network and has directed development to the valleys to the east and west. These valleys are filled with thick glacial deposits of sand, gravel, silt, clay, and till, so that the underlying sedimentary bedrock is almost entirely covered.

Planning activities

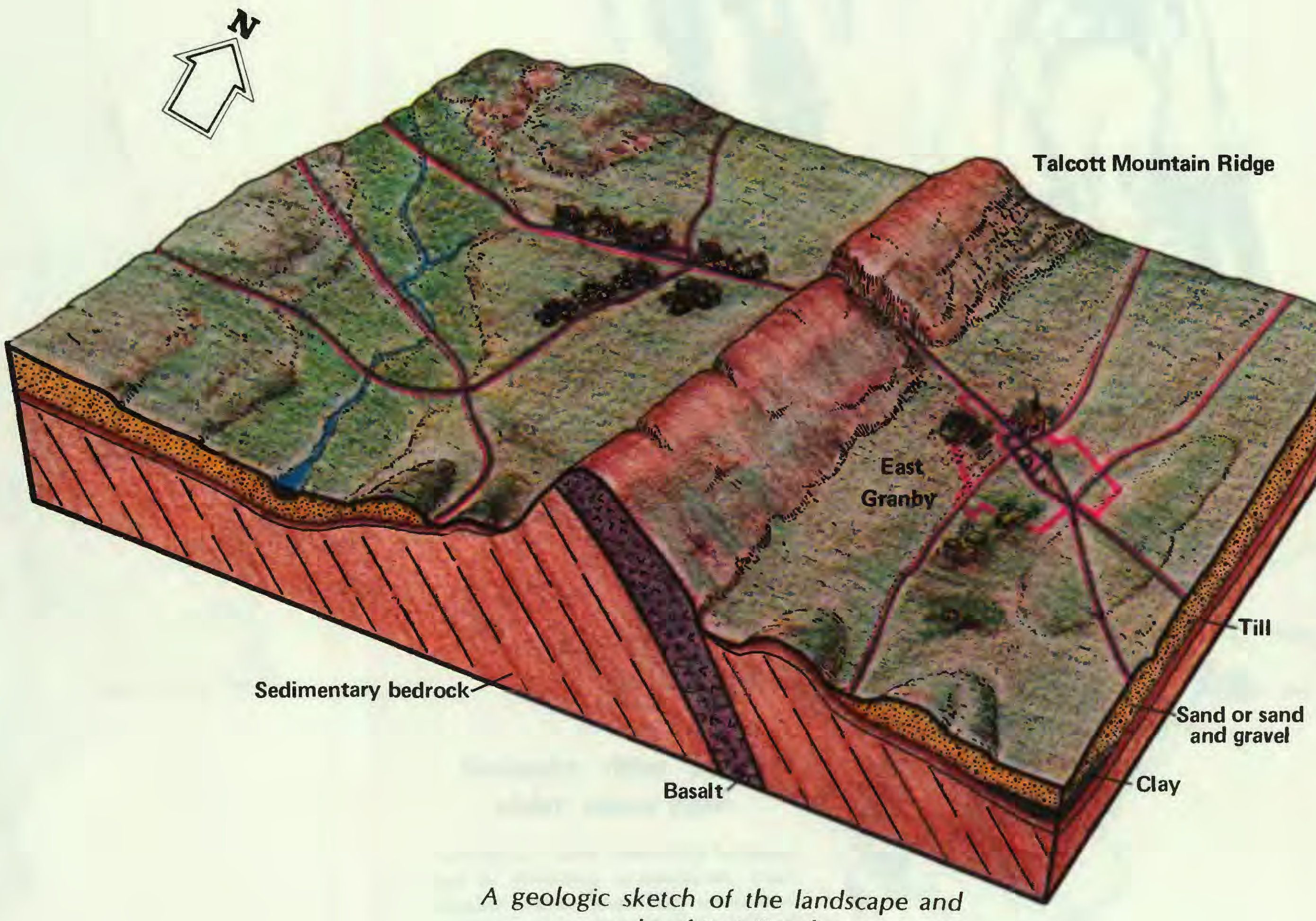
East Granby established a zoning commission in 1941 and changed this to a combined planning and zoning commission in 1953. Many Connecticut communities were severely damaged by floods in 1955, stimulating much planning and development activity. Salmon Brook in East Granby overflowed its banks, destroying a vacation-cottage development which was being occupied year-round. The town relocated the residents and converted the area into a park. Zoning and subdivision regulations were adopted in 1956, and a plan of development was adopted the following year. The area affected by the flood was included in a special flood-plain zone.

Several years ago the planning and zoning commission decided that the 1957 plan was no longer valid. It became apparent that multifamily housing was needed in East Granby, and this was not recognized in the old plan. Applications were being received for commercial establishments at locations scattered throughout the town, and it became necessary to reassess the town's commercial needs. In addition, just as environmental awareness was increasing generally throughout the Nation, the town of East Granby was experiencing interest in the conservation and preservation of special areas. Because of the shortcomings of the old plan and because of the new interests in town, the planning and zoning commission began to prepare a new plan. This work was undertaken with technical assistance from the Bureau of Local Government of the Connecticut Department of Community Affairs.

In preparing the new plan, the planning and zoning commission solicited the ideas, projections, and goals of other town agencies and mailed a plan of development questionnaire to all East Granby residents. The commission then adopted three overall goals which closely express the citizen response to the questionnaire. These goals were:

- "Maintain and enhance the rural character of East Granby."
- "Provide for a balanced growth of population, housing, commercial and industrial development. Develop the town facilities and utilities to serve planned growth."
- "Protect the natural resources and ecology of East Granby."

In order to give more detail to these generalized goals, the commission also adopted a series of goals and actions for 12 areas of concern. These areas include housing, commercial development, industrial development, agriculture, recreation, conservation and open space, community facilities, public utilities, town center, airports, quarrying, and historic preservation. Actions to be taken to reach these goals were also decided upon. These actions and goals were then combined with land-use information, socioeconomic data, and soil and geologic information to develop a picture of the town's future physical development.



A geologic sketch of the landscape and rocks of East Granby.

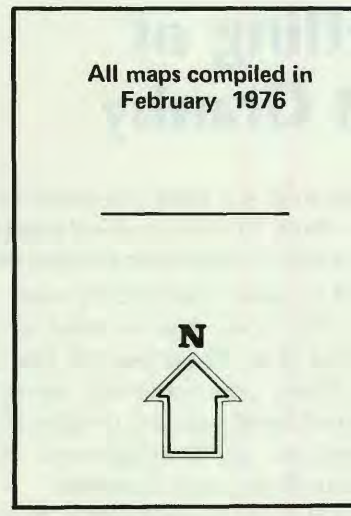
Natural-resources mapping and natural land-use intensities

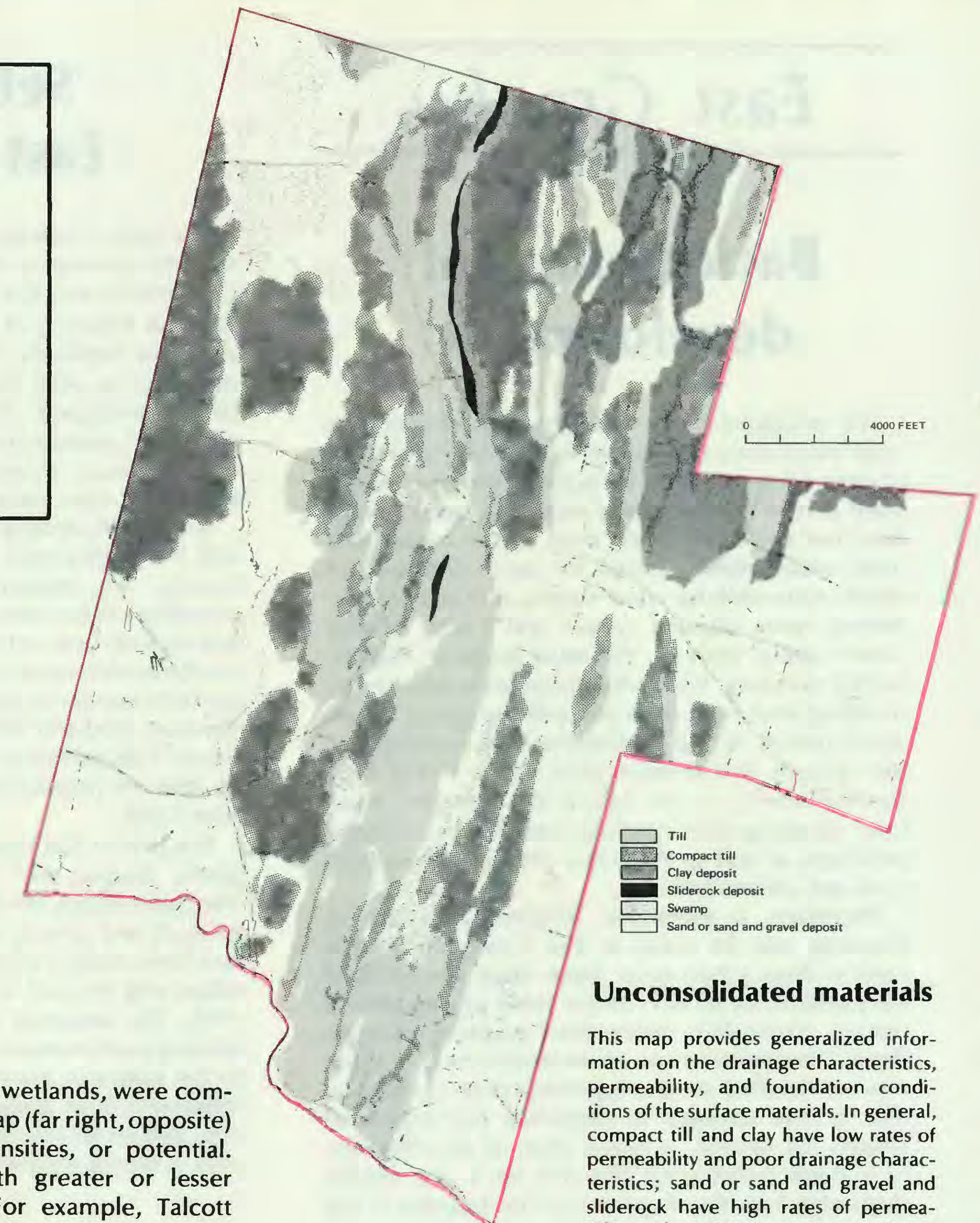
The natural-resource data used for the plan of development for East Granby were obtained from a detailed soil survey, surficial geologic maps, and hydrologic reports . A base map at a scale of 1:12,000 (1 inch equals 1,000 feet) was prepared by splicing together and reducing negatives of the town assessor's property maps, and a topographic overlay was prepared by enlarging and splicing together sections of two U.S. Geological Survey topographic maps.

From the natural-resources data available, seven maps were prepared. Each map is discussed separately in the plan of development, which describes the impact of development on the natural factors and the impact of the natural factors on development. Five of of these maps—showing unconsolidated materials, depth to bedrock, slope, areas having seasonal high-water table, and ground-water potential—are presented here, at reduced scale. The two other maps—one showing flood plains and one inland wetlands and watercourses—are currently included in the town regulations but are not shown separately here. Their information, however, appears on the final map showing future land use (p. 51).

The natural-resources maps describe single elements of the natural environment that interact in response to the stresses of development. For example, the rapid percolation rates of sands and gravels may be a positive factor in the location of septic systems; however, if an area also has high ground-water potential, the rapid movement of waste liquid may have a harmful effect on the water supply. This problem would be further complicated if the area were one of seasonal high-water table. For another example, areas underlain by till generally have good foundation conditions. However, in areas of steep slope, and especially where water levels are high, till often is less stable, resulting in poor foundation conditions.

To assist in the analysis of the combined effects of the natural factors, the five natural-factor maps, plus data on flood plains and major wetlands, were combined and summarized in the map (far right, opposite) showing natural land-use intensities, or potential. This map identifies areas with greater or lesser problems for development. For example, Talcott Mountain Ridge has limited land-use intensity owing to shallow bedrock and steep slopes. In contrast, the area just west of Bradley International Airport has high land-use intensity because it is in an area of sand and gravel (good drainage, good foundation conditions) and a moderate-yield aquifer (sewers could prevent pollution) and there are no wetlands to restrict development.



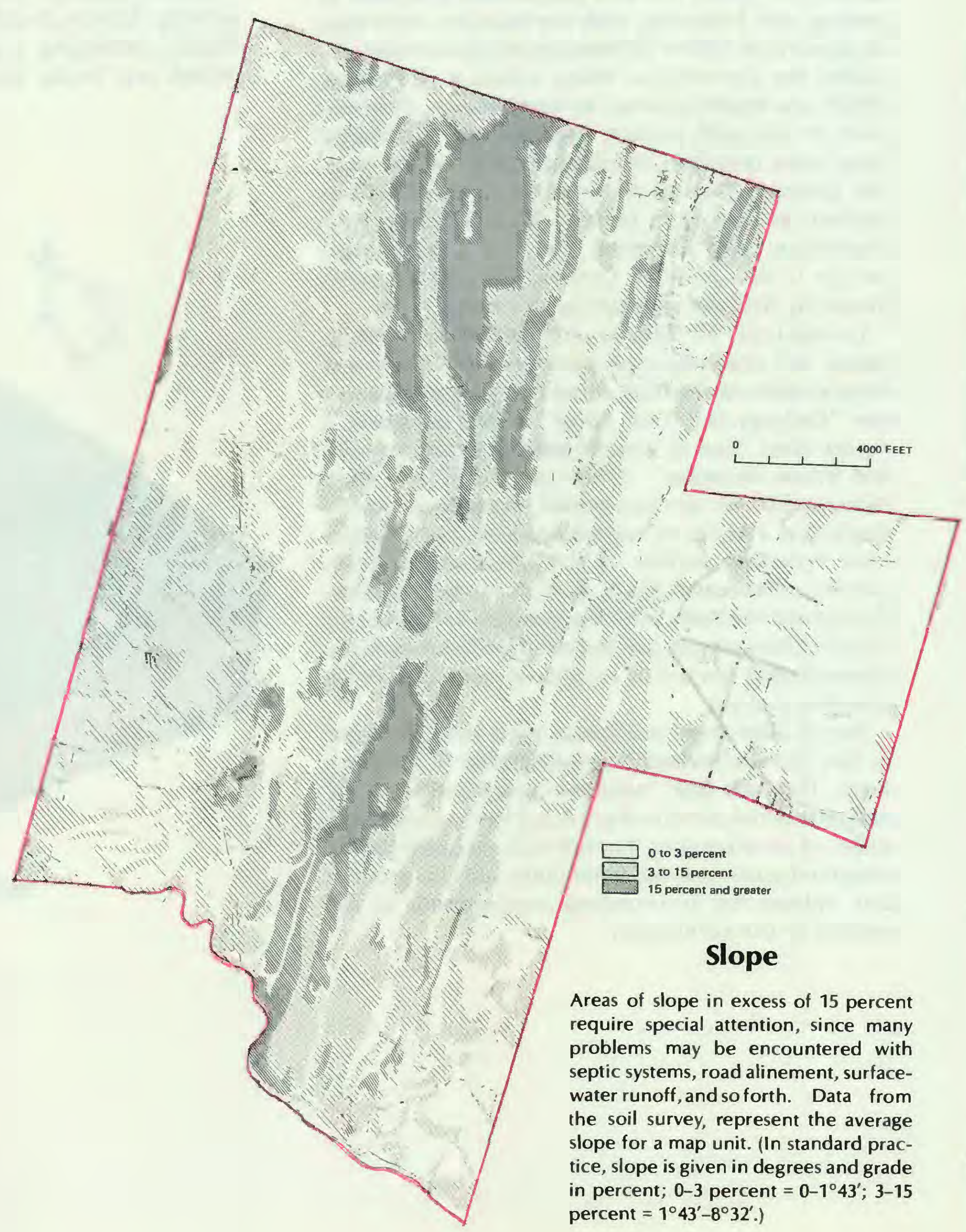


Unconsolidated materials

This map provides generalized information on the drainage characteristics, permeability, and foundation conditions of the surface materials. In general, compact till and clay have low rates of permeability and poor drainage characteristics; sand or sand and gravel and sliderock have high rates of permeability and good drainage characteristics; in general, clay, sliderock, and swamps have poor foundation conditions. Data from surficial geologic maps. Additional information on compact till from the soil survey.

Areas with seasonal high water table

Seasonal high-water areas may present such development problems as wet basements and septic system failures. In addition, these areas are among those regulated by Connecticut's Inland Wetland and Watercourses Act (Public Act 155 of 1972, as amended). Data from the soil survey.

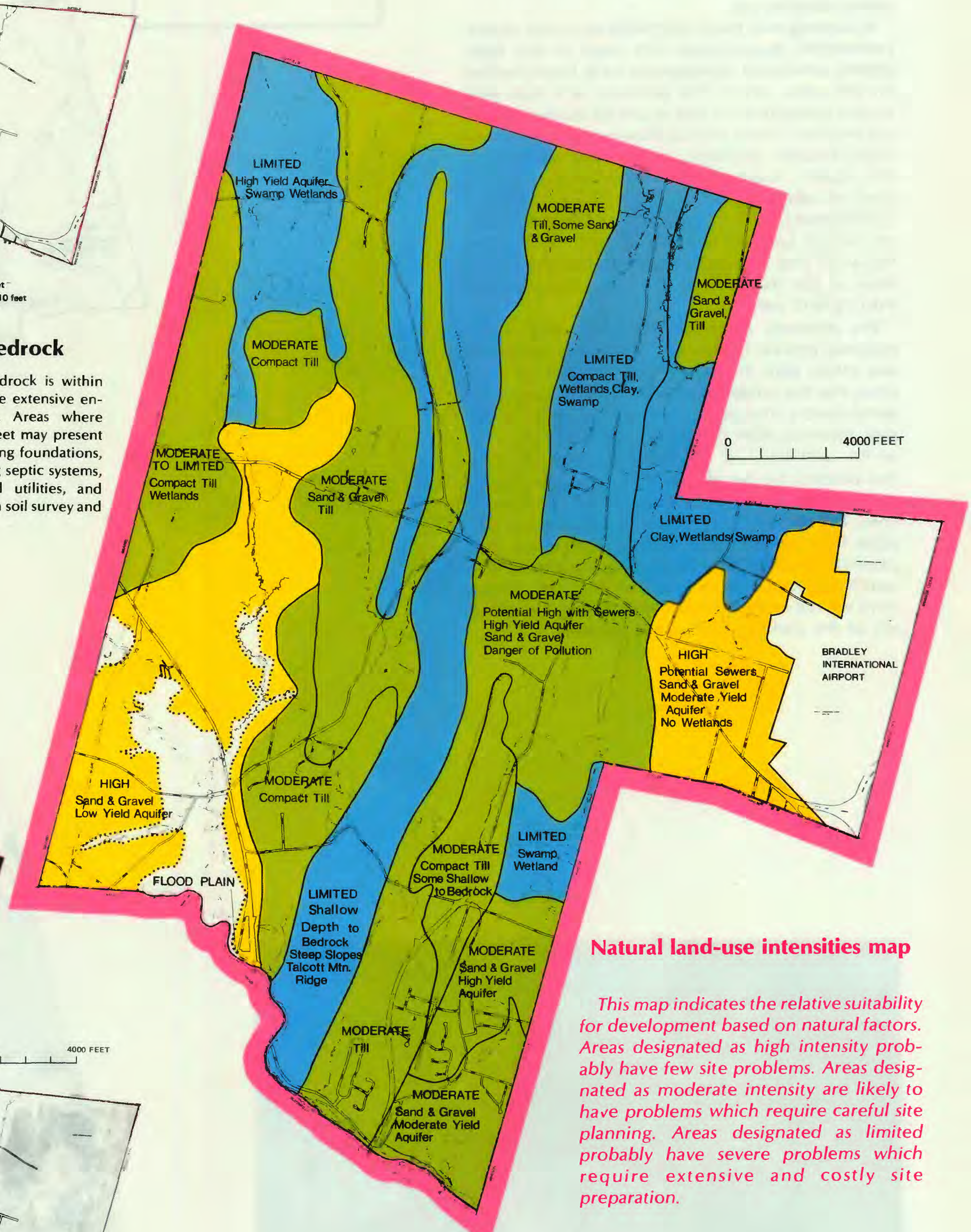


Slope

Areas of slope in excess of 15 percent require special attention, since many problems may be encountered with septic systems, road alinement, surface-water runoff, and so forth. Data from the soil survey, represent the average slope for a map unit. (In standard practice, slope is given in degrees and grade in percent; 0–3 percent = 0–1°43′; 3–15 percent = 1°43′–8°32′.)

Depth to bedrock

Those areas where bedrock is within 2 feet generally require extensive engineering preparation. Areas where bedrock is within 10 feet may present problems with excavating foundations, installing and operating septic systems, installing underground utilities, and alining roads. Data from soil survey and surficial geologic maps.



Natural land-use intensities map

This map indicates the relative suitability for development based on natural factors. Areas designated as high intensity probably have few site problems. Areas designated as moderate intensity are likely to have problems which require careful site planning. Areas designated as limited probably have severe problems which require extensive and costly site preparation.

Ground water potential

Units are shown in gallons per minute (GPM). Map indicates those areas of saturated sand and gravel most suitable for community water supplies, although actual yields of wells in these areas have not been confirmed by extensive testing. Because ground-water pollution could pose serious problems in these areas, development should be carefully planned. Data from hydrologic reports.

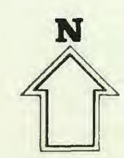
Future land use

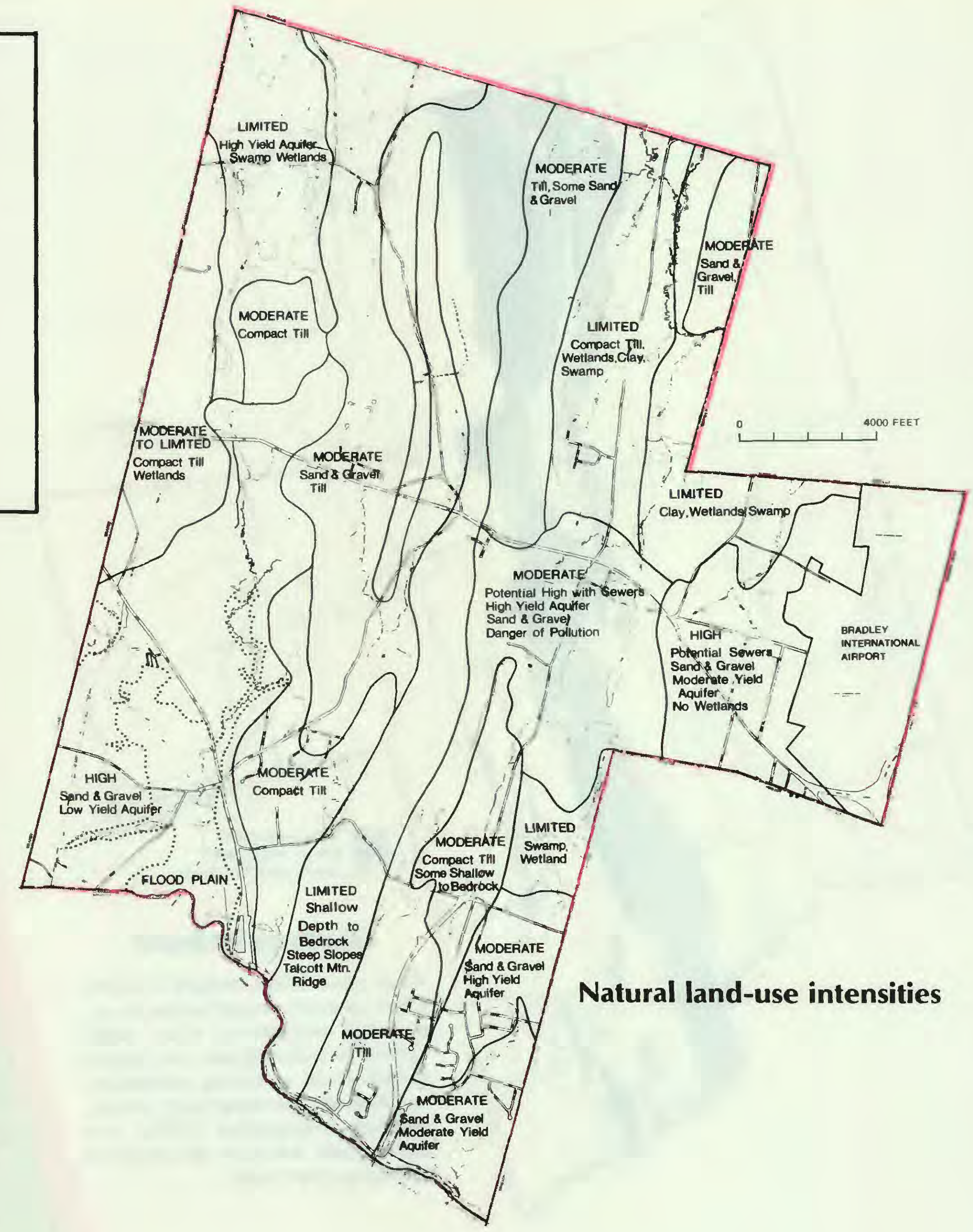
By combining the natural land-use intensities map with the existing land-use map, the transportation plan, and the public utilities map, and incorporating socioeconomic data determined from the planning survey, the planning and zoning commission prepared a future land-use map. Talcott Mountain Ridge was designed for open-space acquisition and low-density residential use. Agricultural land was identified and will probably be given short-term protection through zoning. The aquifers and overlying marshes in the northwest were not given special consideration because they are adequately regulated under the Inland Wetland Act.

In keeping with the strong desire for a town center, commercial development and most of the high-density residential development have been planned for the town center. The presence of a high-yield aquifer designates this area as one for moderate land-use intensity; sewer service, however, would reduce waste-disposal discharge and thereby help protect the aquifer. Another area in the western part of town was also designated for high-density residential development. This designation was based largely on natural land-use intensity factors. In addition, industrial area boundaries were established on the basis of the natural land-use intensities map and existing land use.

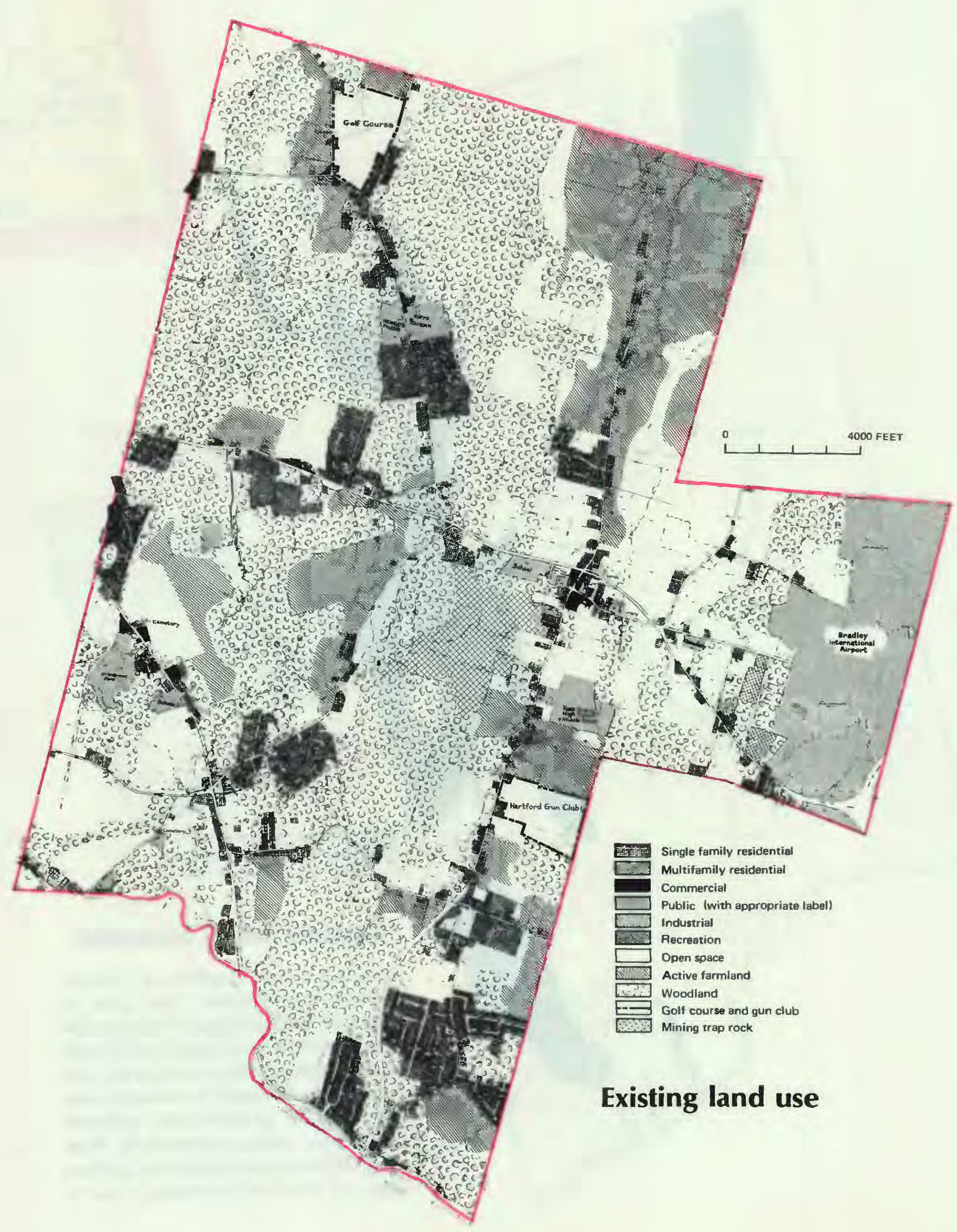
The inclusion of natural land-use factors in the planning process familiarized commission members and others with the natural characteristics of their town and the influence of those facts of nature on development. The preparation and adoption of the plan, however, does not end the process of planning or the usefulness of the information obtained in that process, for the plan itself must now be implemented and will need to be revised from time to time. The natural-factor maps are available and will allow town agencies and officials, landowners, and potential developers to obtain a good idea of the conditions they can expect to find in an area. These maps will not replace detailed site reviews, but rather will be the starting point for site reviews.

All maps compiled in February 1976



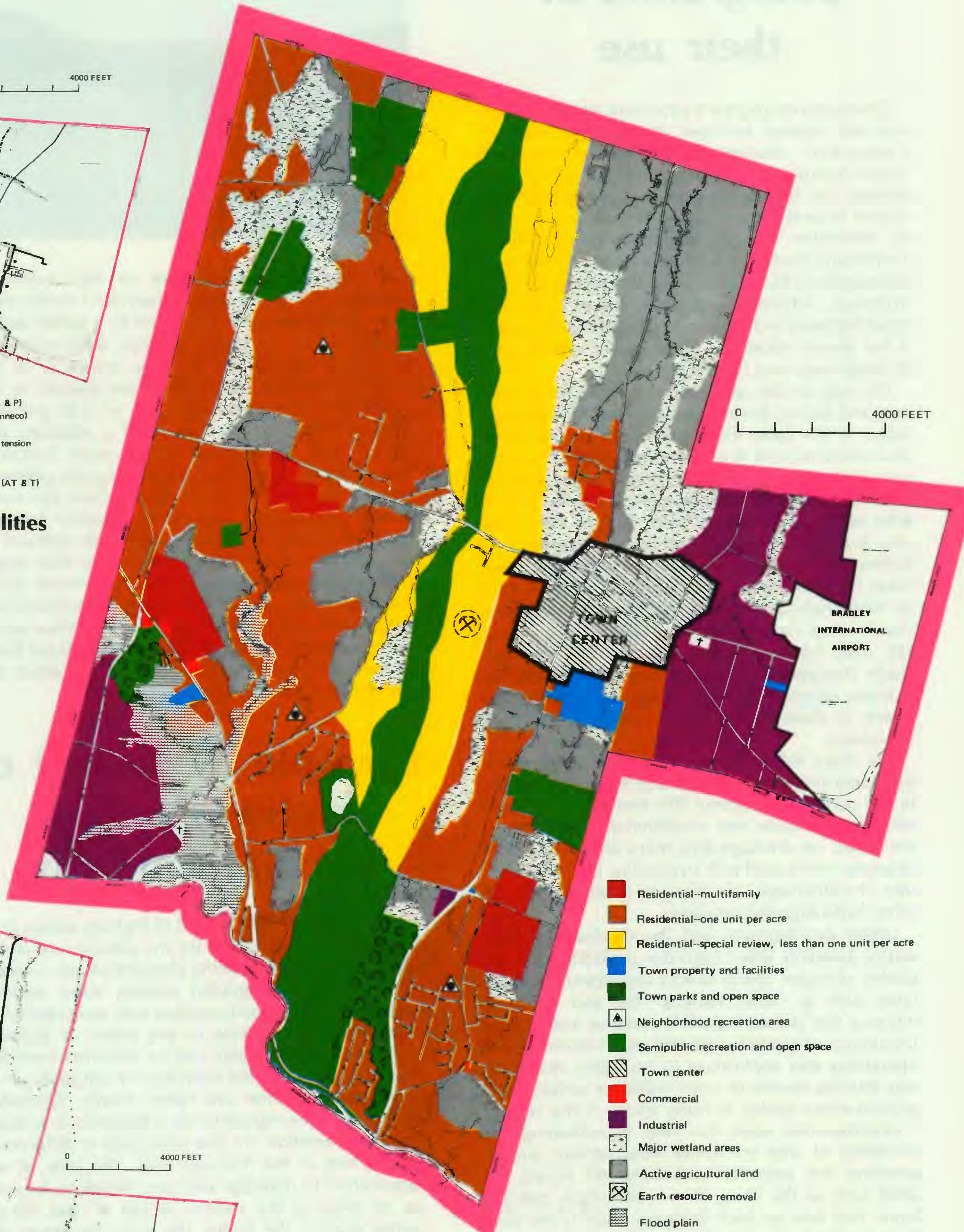


Natural land-use intensities



Existing land use

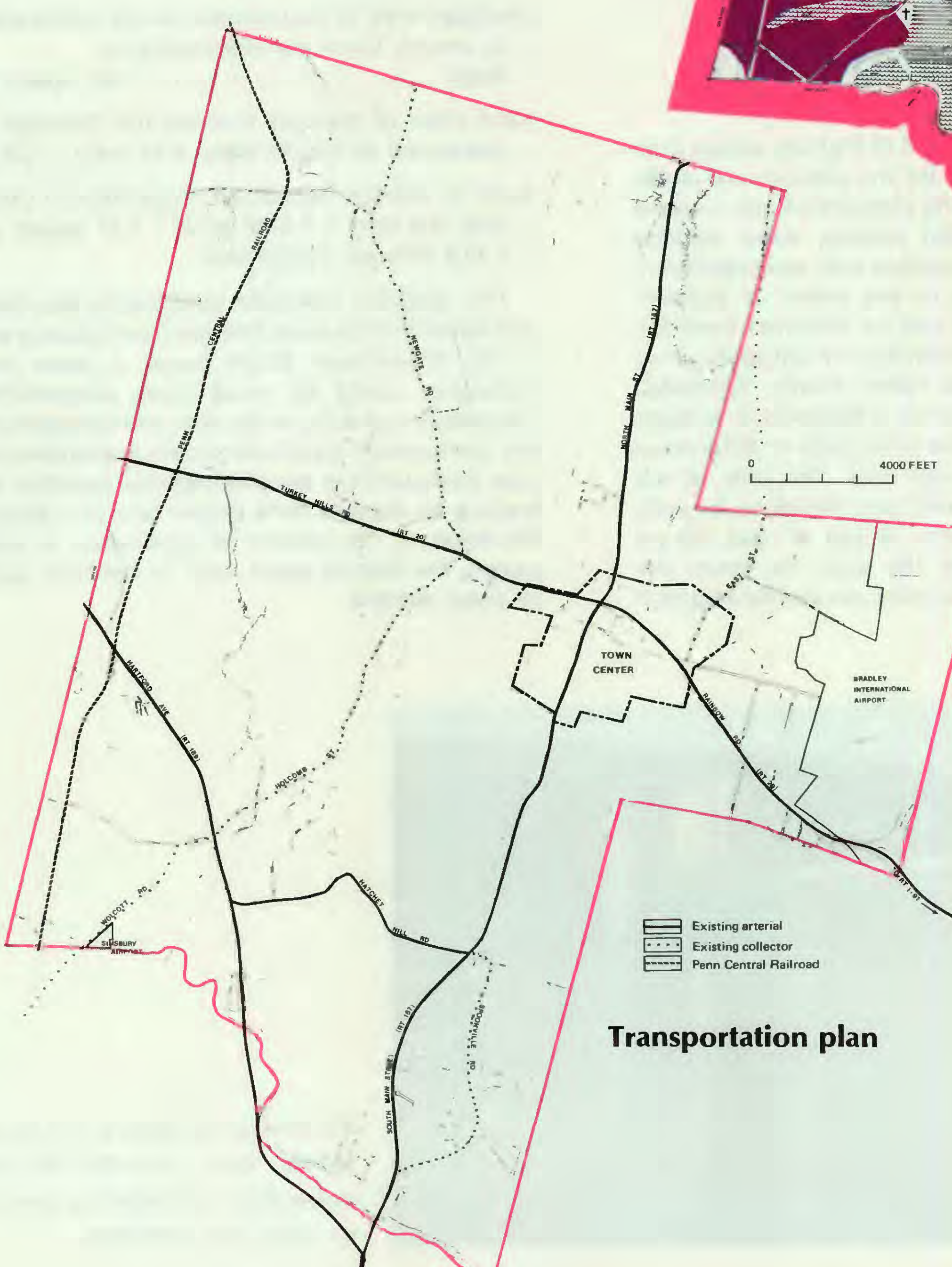
Public utilities



Future land use

The future land-use map was made by combining the four maps on these pages, and considering the following socioeconomic factors:

- *Population*
- *Housing*
- *Commerce*
- *Industry*
- *Agriculture*
- *Transportation*
- *Recreation, conservation, and open space*
- *Community facilities*
- *Public utilities*
- *Town center*
- *Airports*
- *Quarrying*
- *Historic preservation*



Transportation plan

Drainage-area maps

Background of their use

Drainage-area maps are important tools for water-use and related land-use planning. In southern Connecticut, drainage divides define essentially closed hydrologic systems; maps delineating these divides can be used to assess the environmental impact of land-use and waste-disposal activities and to determine various streamflow characteristics. Technically trained people are needed to delineate drainage-area boundaries, to collect and compile the hydrologic information needed, and to review the resulting maps and reports. Great technical expertise is not always necessary, however, for one to use a drainage-area map for planning.

The map on the opposite page shows the boundaries and natural drainage areas of the major drainage basins in the Deep River quadrangle. It also shows sites where records of quantity and quality of streamflow are available. The boundaries of larger drainage basins are shown by the heavy lines, and the boundaries of smaller drainage areas by light lines. (The area drained by the Salmon River is shown by a pattern.) The measured drainage areas are those areas contributing to surface runoff. In most parts of New England, they are the same as those areas contributing to ground-water runoff. The drainage areas have not been adjusted for any man-made changes such as storm sewers, road ditches, culverts, diversion dams, canals, and tunnels. The effects of these changes in this example, however, are minor.

The three following examples illustrate some of the applications of drainage-area maps to planning in this part of Connecticut. The first two, concerned with site selection and environmental assessment, are based on drainage-area maps alone. The third example, concerned with streamflow characteristics, uses the drainage-area maps in combination with other hydrologic information.

Urban development and the disposal of urban wastes generally affect both the availability and the quality of water. Storm sewers and impervious surfaces such as roads, parking lots, and buildings increase the surface runoff to streams and reduce the amount of ground-water recharge. Waste-disposal operations and application of fertilizers and highway deicing chemicals have impaired surface- and ground-water quality at many places in the region.

Drainage-area maps can help in evaluating the suitability of sites for future development and in assessing the potential environmental impact. In areas such as the Deep River quadrangle, precipitation that falls on each drainage basin is the only source of inflow, and ground-water circulation is confined within the drainage area. The direction of ground-water movement is generally away from the drainage divides and toward the streams, lakes, swamps, and estuaries.

Example 1—evaluating waste-disposal conditions

The potential impact of waste disposal is a common problem in areas of proposed development. The effect of effluent discharge on local water quality depends on a number of factors. One of the most significant is the ability of the receiving waters to dilute the effluent. Information on the dilution capacity can be obtained from the drainage-area map.

Nutrients flushed from residences and farmlands in New England often cause algal blooms in lakes and ponds.

A residential development of 400 homes is proposed in the area labeled example 1 on the map. The development will be served by a public water-supply system and sewers. Sewage, after treatment, is to be discharged to a nearby stream or to the ground. The map shows that those streams to the north have small drainage areas of 0.26 and 0.22 square miles and therefore have a relatively low natural flow. Great Brook to the south, however, has a drainage area larger than 4.25 square miles and therefore several times the natural flow and much greater potential for waste-water dilution. Furthermore, discharge of sewage either to the ground or to streams in the northern part of the tract might contaminate Waterhouse Pond or Upper Pond. These impoundments would receive the nutrient-rich waste water with minimal dilution. No surface-water impoundments are located in the Great Brook basin to the south, but waste discharge could affect the balance of stream plants and animals.

Example 2—impact of highway salting on water quality

The environmental impact of highway salting is an important consideration for the planner and water manager. Highway deicing chemicals have, in some places, severely degraded existing water supplies and have also harmed roadside soils and vegetation. Qualitative assessments of the effect of highway salting on water quality can be obtained from the drainage area map and from data on salt application.

As rain and snow are rather evenly distributed throughout the mapped area, differences in average annual streamflow are due principally to differences in the size of the drainage area. The ratio of salt application to drainage area can, therefore, be used as an index of the relative impact of road salt on water quality: the higher the ratio, the lower the relative dilution. The ratio index can also be weighted where necessary for variations in average annual streamflow owing to factors other than drainage area. The following example uses the ratio between salt applied and drainage area to compare the relative effect of salting of Route 9 in the Pattaconk Brook drainage basin (site 2a on map) with salting of Route 9A in the Waterhouse Brook drainage basin (site 2b on map). Route 9 is a four-lane highway with single-lane ramps, and Route 9A is a two-lane highway. The average annual salt application per lane mile of highway is approximately 8.8 tons.

Route 9, Pattaconk Brook

Drainage area of Pattaconk Brook upstream of Jennings Pond (from the drainage-area map) .... 8.41 square miles

Lane miles of highway crossing the drainage basin (measured on the drainage area map)... 6.5 miles

Ratio of average annual salt application to drainage area (8.8 tons x 6.5 lane-miles ÷ 8.41 square miles) = 6.8 tons per square mile

Route 9A, Waterhouse Brook

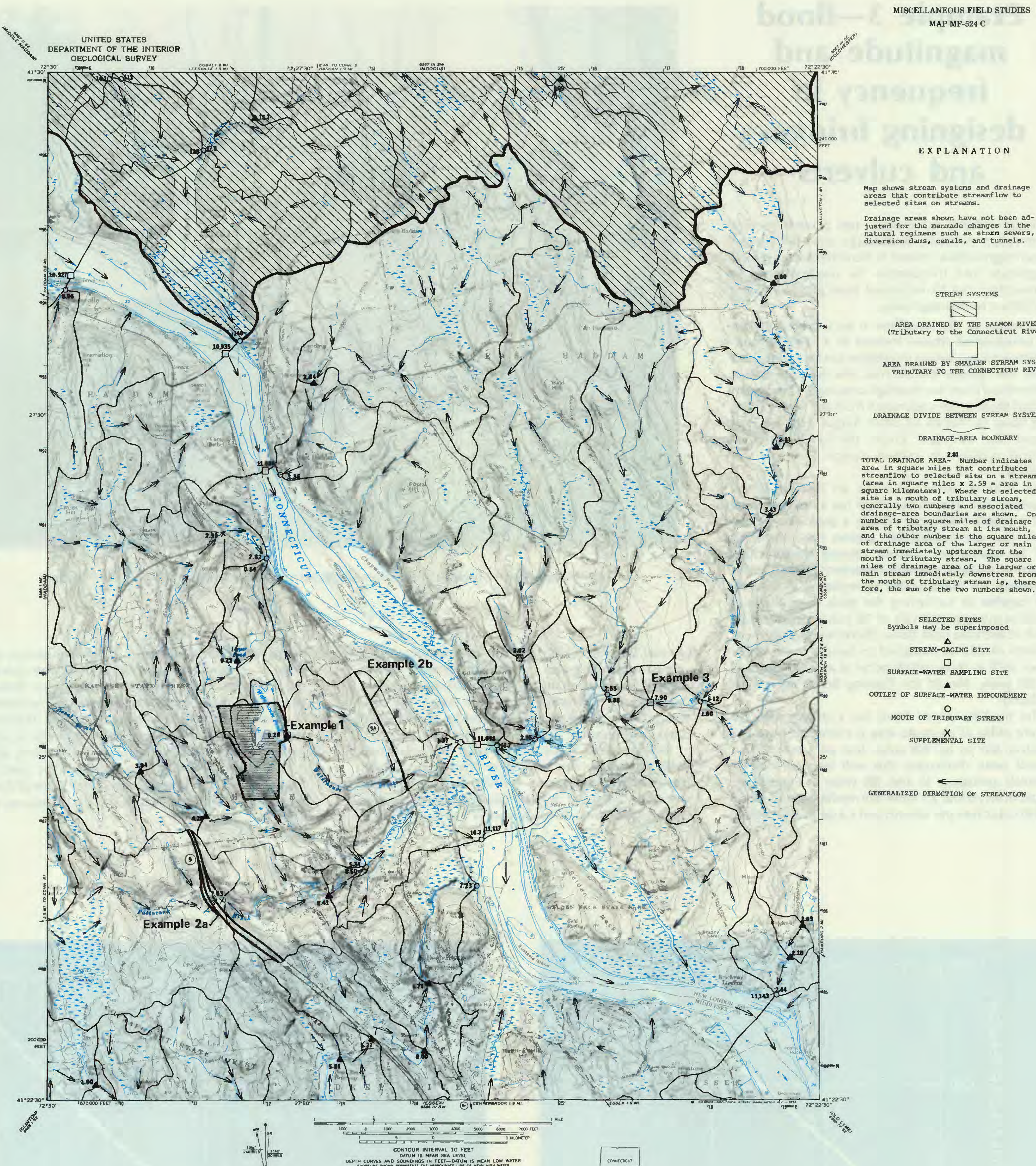
Drainage area of Waterhouse Brook upstream from its mouth (from the drainage-area map) .... 1.37 square miles

Lane miles of highway crossing the drainage basin (measured on the drainage area map)... 2.0 miles

Ratio of average annual salt application to drainage area (8.8 tons × 2 lane miles ÷ 1.37 square miles) = 12.8 tons per square mile.

This appraisal indicates significantly less dilution and more environmental impact from highway salting in the Waterhouse Brook basin. A more precise evaluation could be made using information on streamflow variability at the sites and salt applications per storm event. Relatively simple evaluations of the type described can identify potential problem areas, leading to detailed field studies and to subsequent alteration of the pattern of application of deicing agents, the kind of agent used, or the total quantity of agent applied.

Stream-gaging stations, as the one shown here, provide the basic streamflow information essential in land-use planning.



Drainage-area map of the Deep River quadrangle

Example 3—flood magnitude and frequency in designing bridges and culverts

Engineering design of bridges and culverts is based on flood magnitude and frequency criteria.

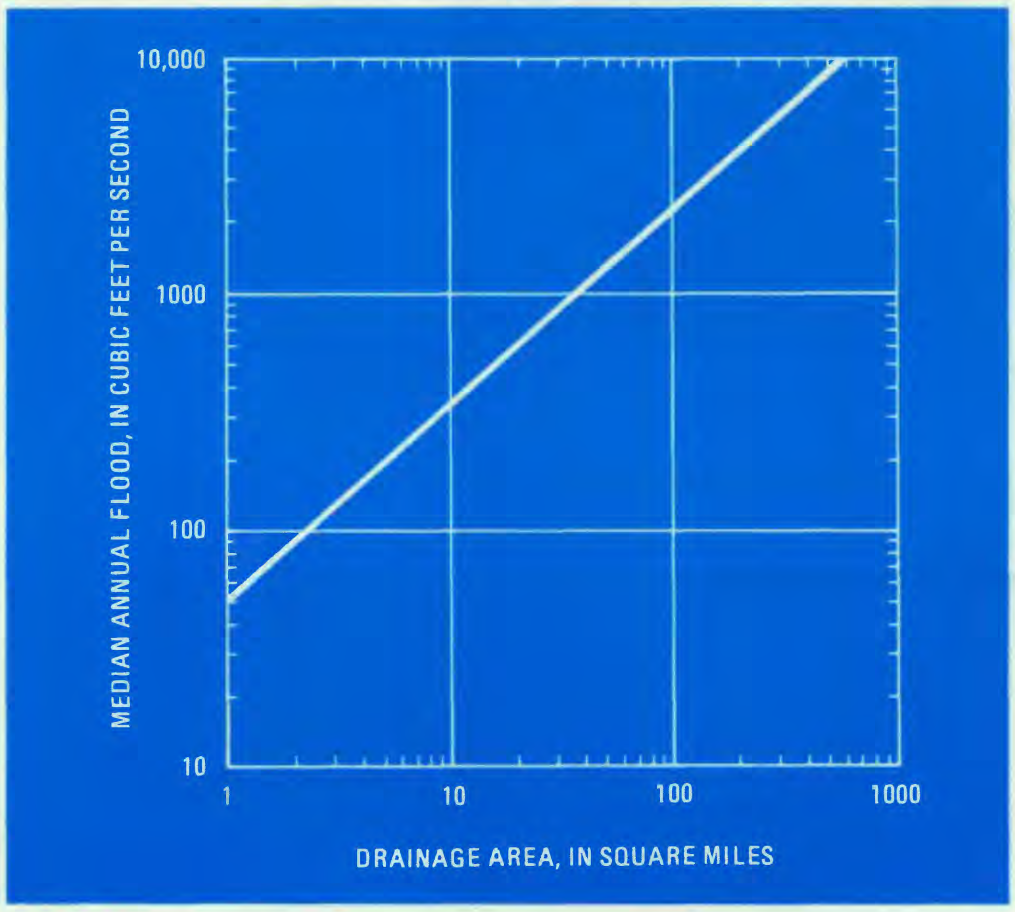
Design criteria for bridges and culverts require information not only on drainage areas but also on flood magnitude as related to flood frequency. Flood magnitude and frequencies for ungaged sites in Connecticut can be estimated from graphs relating floodflows to drainage areas.

Estimates of the floodflow at an ungaged site on an unregulated stream located in a virtually non-urbanized basin within this region can be determined from the graphs below. First, the drainage area is determined from the drainage-area map. The median annual flood is then estimated from the left graph and flows for floods of other frequencies are estimated from the right graph. The following hypothetical problem in culvert design illustrates this method.

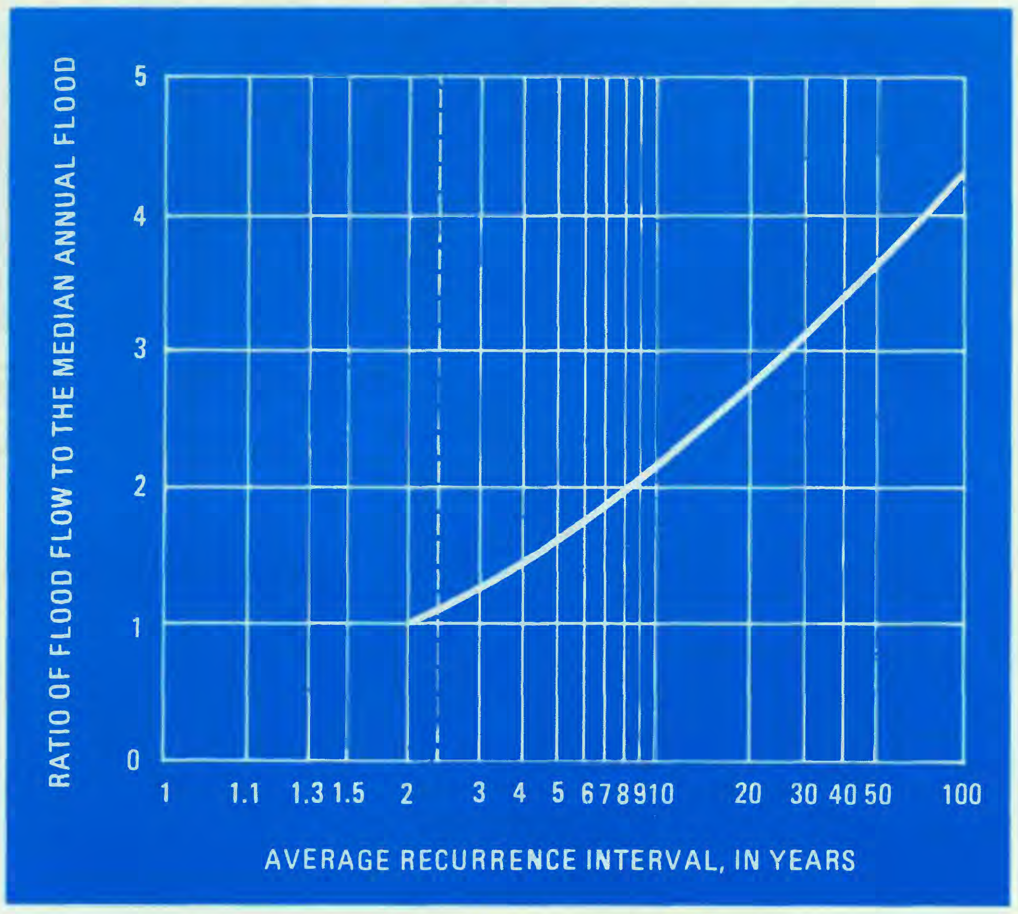
An existing culvert at a site on Roaring Brook (example 3 on the map), which has a drainage area of 7.9 square miles, can convey a peak flow of 500 cubic feet per second, but greater flows than this will be obstructed, thereby causing flooding upstream. A regional water-management plan proposes to reduce the flood hazard by replacing all culverts not capable of conveying the peak flows that will occur at average intervals of 10 years. Urbanization tends to increase peak flows. Therefore, replacement culverts should be designed to handle much larger flows, such as those which occur at average intervals of 100 years. Should the Roaring Brook culvert be replaced?

The median annual flood for a stream with 7.9 square miles of drainage area is estimated from the graph at left to be 280 cubic feet per second. The annual peak discharges that will be exceeded at intervals averaging 10 and 100 years in length are, respectively, about 2.1 times the median annual flood or 590 cubic feet per second and 4.4 times the median annual flood or 1,230 cubic feet per second, as estimated from the graph at right. The existing culvert cannot convey even the 10-year floodflow and should be replaced. To avoid backup of water, the new culverts should be designed to handle an estimated peak discharge of 1,230 cubic feet per second.

Drainage-area maps can be used in conjunction with peak flow data and other hydrologic data in many other applications. Among such applications are the design of waste-treatment plants, water-supply reservoirs, flood-detention works, impoundments for power generation, and storm sewers; the siting of powerplants or other facilities with specific requirements of processing or cooling water; delineating flood-prone land, determining the suitability of rivers and estuaries for commercial fisheries, assessing water pollution; drafting water-quality standards and enforcing regulations; assisting agriculture; and providing information to be used in litigation over water rights. Examples of some of these applications can be found in the list of sources on page 94.



Relationship between drainage area and median annual flood in the lower Connecticut River basin



Flood magnitude frequency curve for the lower Connecticut River basin

Nassau County, Long Island, New York

Water problems in humid country

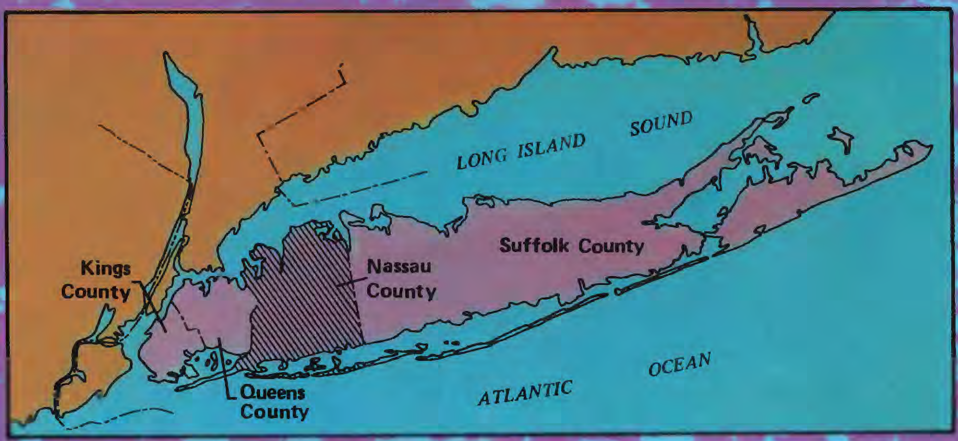
By B. L. Foxworthy

Background of water use

Ground water has been a major continuing concern on Long Island, New York, for many decades. For most of the time since the arrival of the first European settlers, the population of the island has been completely dependent on local water resources for fresh-water supplies. The present aqueducts from the mainland to supply Kings and Queens Counties on western Long Island were completed only after intensive pumping from wells in Kings County had resulted in serious salt-water intrusion and a water-supply crisis. That crisis also led to legislation, in 1933, enabling the State to regulate the drilling of new wells on the island and requiring water conservation measures. The legislation was founded on, and certainly was one of the most important uses of, the then-existent information on the geology and ground-water conditions of Long Island.

Significant water-related problems still remain for Long Island, especially for Nassau and Suffolk Counties (see map), where a very large and still growing population remains dependent on ground water for virtually all fresh-water supplies.

The ground-water resource is capable of providing abundant good-quality water for the anticipated needs during this century and beyond. However, much depends on how well the ground water is conserved and protected from contamination. Wise planning and sound management to achieve the greatest benefit from this invaluable resource will require the best obtainable scientific guidance, including the kinds of information listed in the adjacent statement by Lee Koppleman, Executive Director of the Nassau-Suffolk Regional Planning Board. Examples in map form of the kinds of information that have been developed in response to that need, and how they were combined and applied, are presented on the following pages, focussed on the "middle" county of Long Island—Nassau County.



Ground water has been used extensively in western Long Island for about 100 years, significant water records have been kept for more than 70 years, and intensive studies of the ground-water system have continued for about the last 40 years. Partly as a result, most of the laws, public policies, and plans for water management were already formulated and established at both the State and county levels of government by the 1950's. Consequently, although much additional geologic and hydrologic information has been needed and produced in the last two decades to improve the understanding of the ground-water system, that information has been used mainly to enhance the administration of preexisting plans and policies, rather than to develop new ones.

Unlike most of the other examples in this book, this chapter on Long Island cites few specific examples of governmental actions based on earth-science information. Using such information is a "way of life" on Long Island, which could well serve as a model for similar use elsewhere.

On Long Island, more than for most areas, a knowledge of the water resources and planning to ensure future dependable supplies of good-quality water are dominant elements in long-range planning.

At present [1975] about 2.8 million people in two counties on Long Island are entirely dependent on ground water for all their water supplies, and that part of the population is likely to grow to 3.3 million by 1985.

The types of ground-water information that are most useful in long-range planning for Long Island include:

1. **Character and size of the reservoir of fresh water**
2. **Recharge of the ground-water system**
3. **Water-level changes associated with man's activities**
4. **Water-quality changes associated with man's activities**
5. **Problems of sea-water intrusion.**

Lee Koppleman, Executive Director
Nassau-Suffolk Regional Planning Board

The ground-water reservoir I

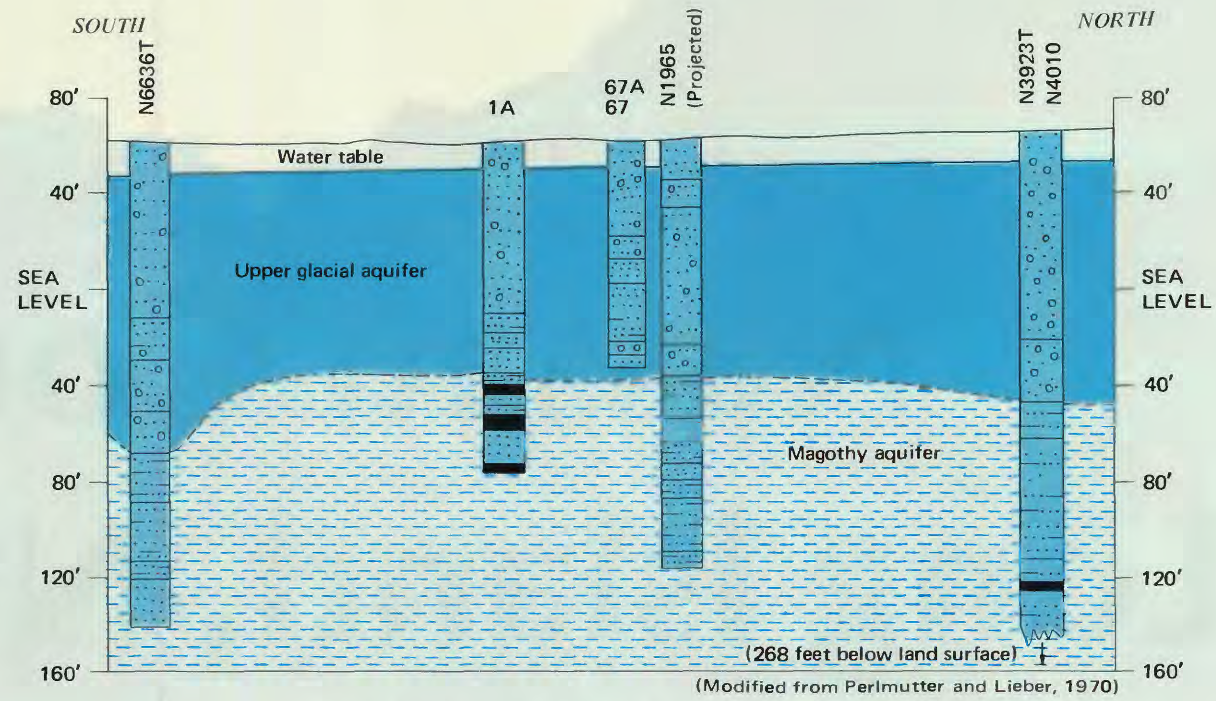
Long Island's fresh ground-water resource is one of the world's largest in terms of the volume of water and the number of people who use it. The rocks beneath the island constitute a huge reservoir, filled by nature over the centuries and now being manipulated by man. A basic requirement for interpreting man's impacts on the ground-water reservoir and for making sound management decisions about this resource is an adequate understanding of the ground-water system and how it has functioned over the years. This means understanding the ground-water situation under natural (predevelopment) conditions, the ground-water situation under present conditions, the geologic framework in which the ground water occurs and through which it moves, and how the water enters and discharges from that framework. The information needed to understand the shallow and deeper parts of the ground-water reservoir of Nassau County under essentially natural conditions are shown on these two pages and the next two. Information that pertains more to man's impacts on, and use and management of, the ground-water system is presented later.

The shallow part

Much of Nassau County is blanketed with deposits left by glaciers many thousands of years ago. These glacial sediments yield large amounts of water at depths of less than 100 feet. This shallow water-bearing zone, or aquifer, overlies other important aquifers in older rocks formed in the ocean 60–70 million years ago. Different combinations of information are needed for understanding these different water zones. Some of the maps and cross-sections used to define the shallow ground-water system in Nassau County are shown here.

The shallow aquifer can be portrayed by combining three maps—one of the topography (lower left), one of the geology (opposite, upper), and one of the altitude of the water table (lower right)—with cross-sections made up from logs of shallow wells (immediately below). The result of bringing this information together is a model of the shallow aquifer (opposite, lower).

Most of the water, fresh or polluted, that is added to the lower aquifers must pass through and leak out of the shallow aquifer. The shallow aquifer therefore exerts strong controls on the recharge to, or replenishment of, the entire ground-water reservoir and on the movement of pollutants to it from the land surface. In following pages, we will see how the kinds of data shown here have been combined to guide a State and county policy for effective disposal of storm runoff in Nassau County through nearly 700 recharge basins. We will also see how water moves through the reservoir, and how our knowledge of its path makes it possible to trace pollutants in the ground water to their sources.



Typical cross section in Nassau County

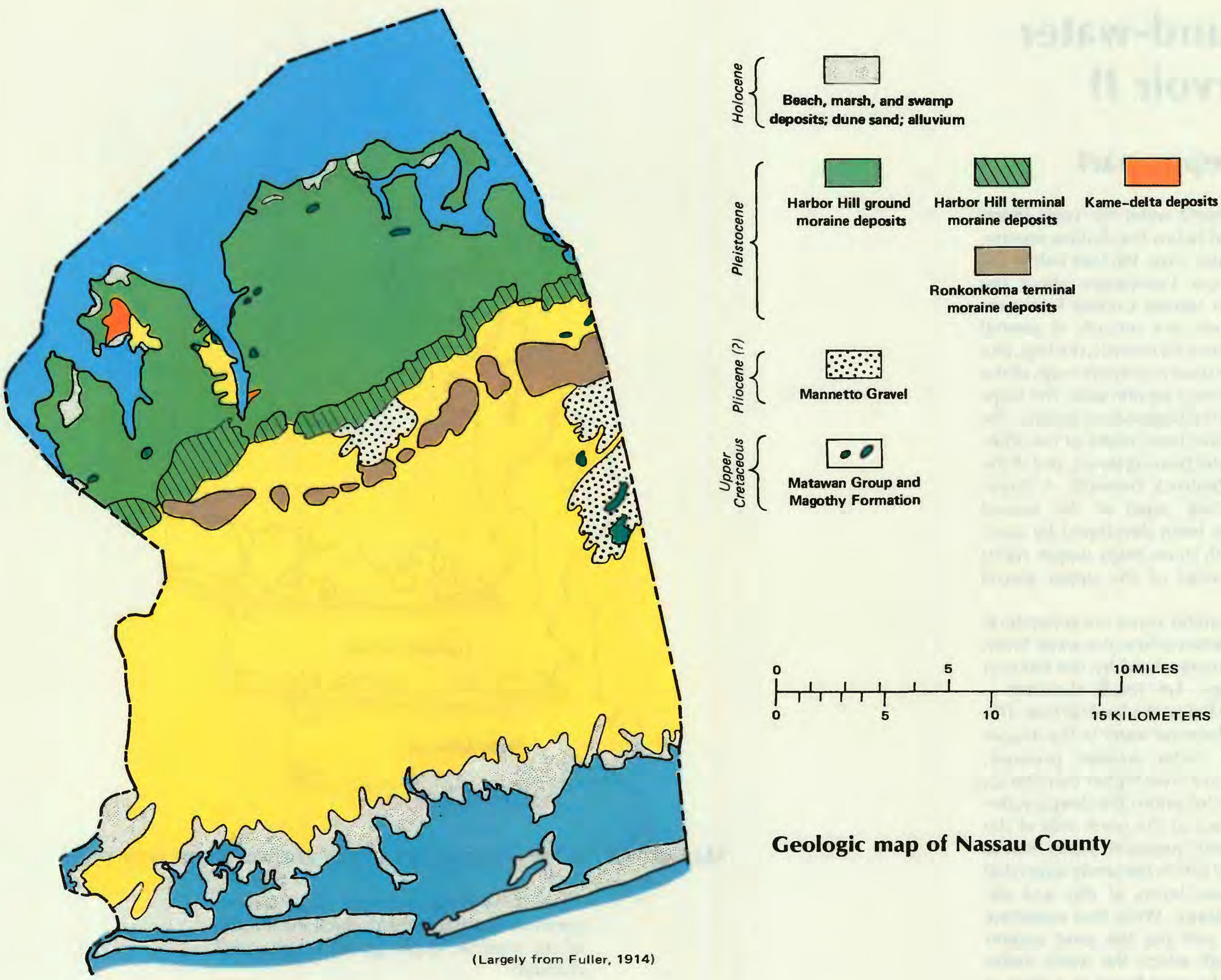
Subsurface data from shallow to moderately deep wells, including materials penetrated (strip patterns), position of water table, and different aquifer zones. Vertical scale is greatly exaggerated.

Topographic map of Nassau County

Contours are in feet above mean sea level.

Water-table map of Nassau County

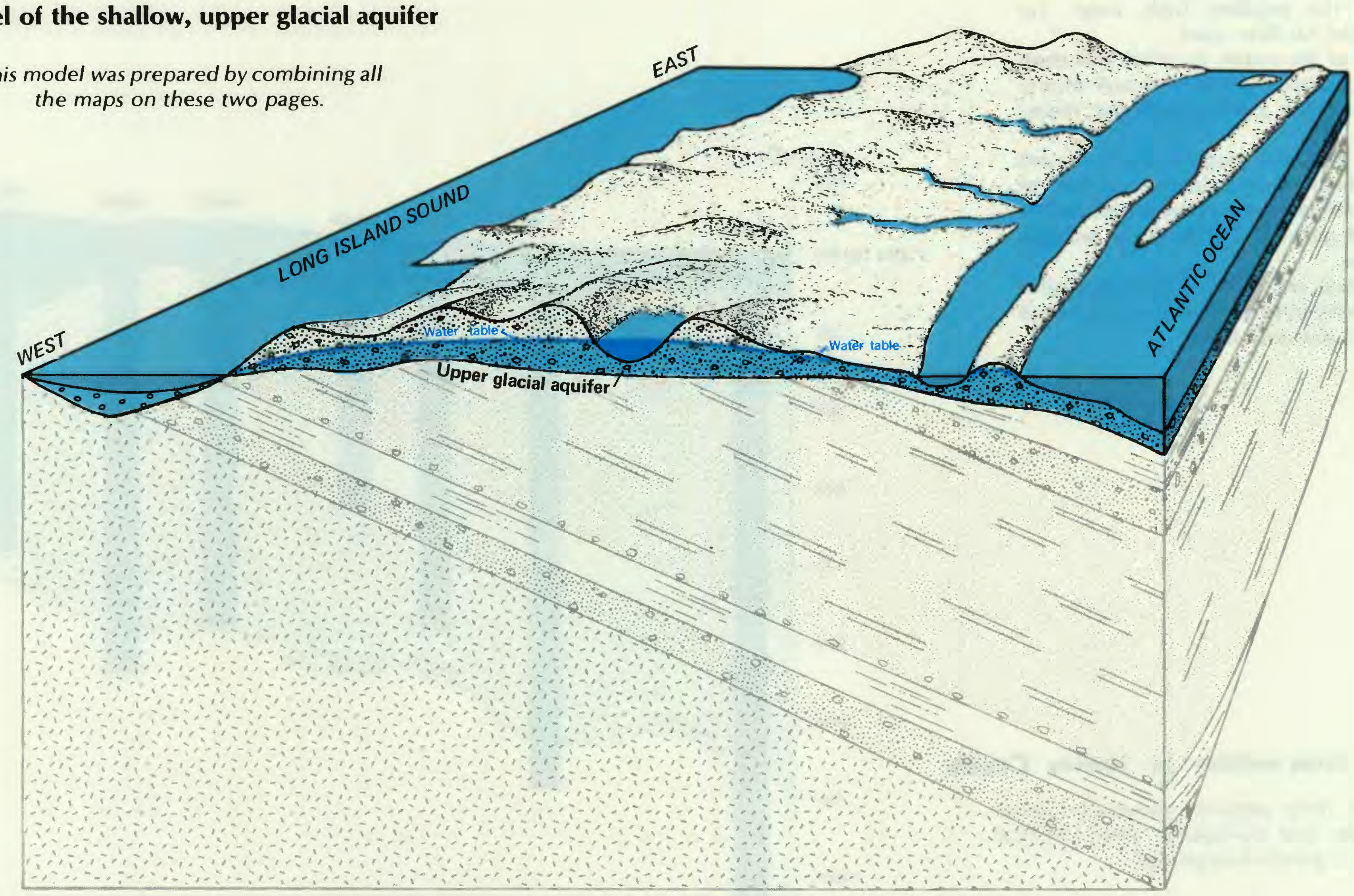
Contours show the altitude of the water table, in feet, at vertical intervals as labeled. Dots show the location of wells used to measure the water table.



Geologic map of Nassau County

Model of the shallow, upper glacial aquifer

This model was prepared by combining all the maps on these two pages.



Not to scale; large vertical exaggeration

(Modified from Cohen and others, 1970)

The ground-water reservoir II

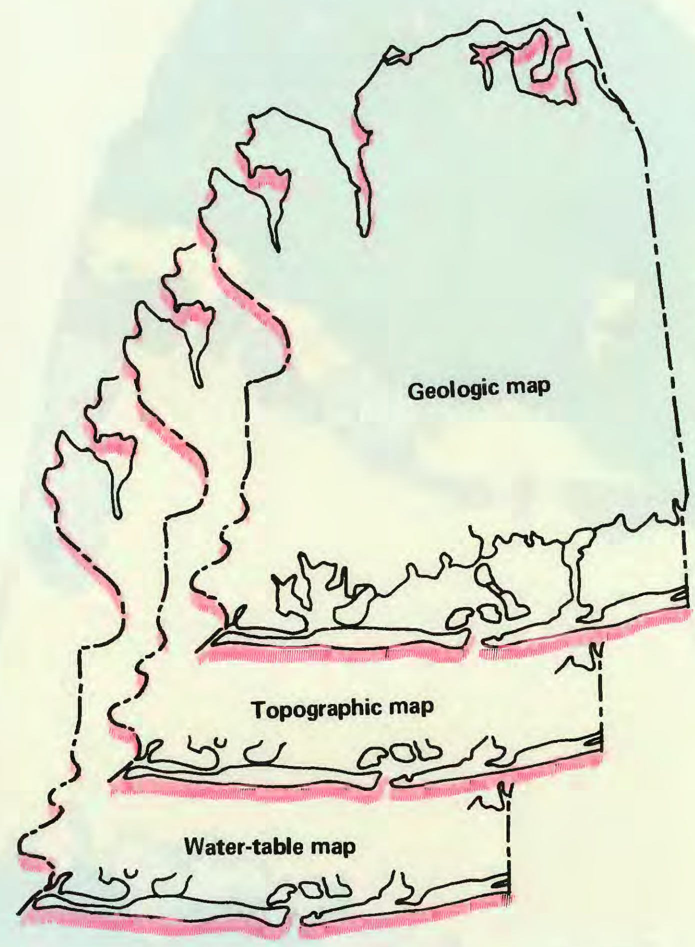
The deeper part

Most of the fresh ground water for Long Island comes from layers of sand below the shallow aquifer, at depths generally greater than 100 feet below the land surface. Most of our knowledge about the deeper aquifer zones in Nassau County has come directly or indirectly from the records of several thousand wells. From these well records, the logs, like those shown below, were used to prepare maps of the top and bottom of each lower aquifer unit. The maps on the facing page are of the largest deep aquifer, the Magothy. Similar maps have been made of the other deep aquifers, of non-water bearing layers, and of the surface of the ancient bedrock beneath. A three-dimensional model (facing page) of the natural ground-water system has been developed by combining all these maps with those maps (upper right) which produced the model of the upper glacial aquifer.

Although the deeper aquifer zones are generally at least 100 feet below the land surface, the water levels in the deeper wells, as represented by the contour map on the facing page, are much shallower—generally less than 50 feet below the land surface. This apparent anomaly exists because water in the deeper sand units is confined under artesian pressure, causing it to rise in wells to a level higher than the top of the sand layers. Water that enters the deep aquifer where it is near the surface at the north side of the island (see model, bottom opposite page) moves downward and southward within the sandy layers that are beneath discontinuous layers of clay and silt, which retard upward leakage. Wells that penetrate the clay and silt layers and tap the sand aquifer provide a conduit through which the water under pressure can rise above the sand layers to a level of equilibrium.

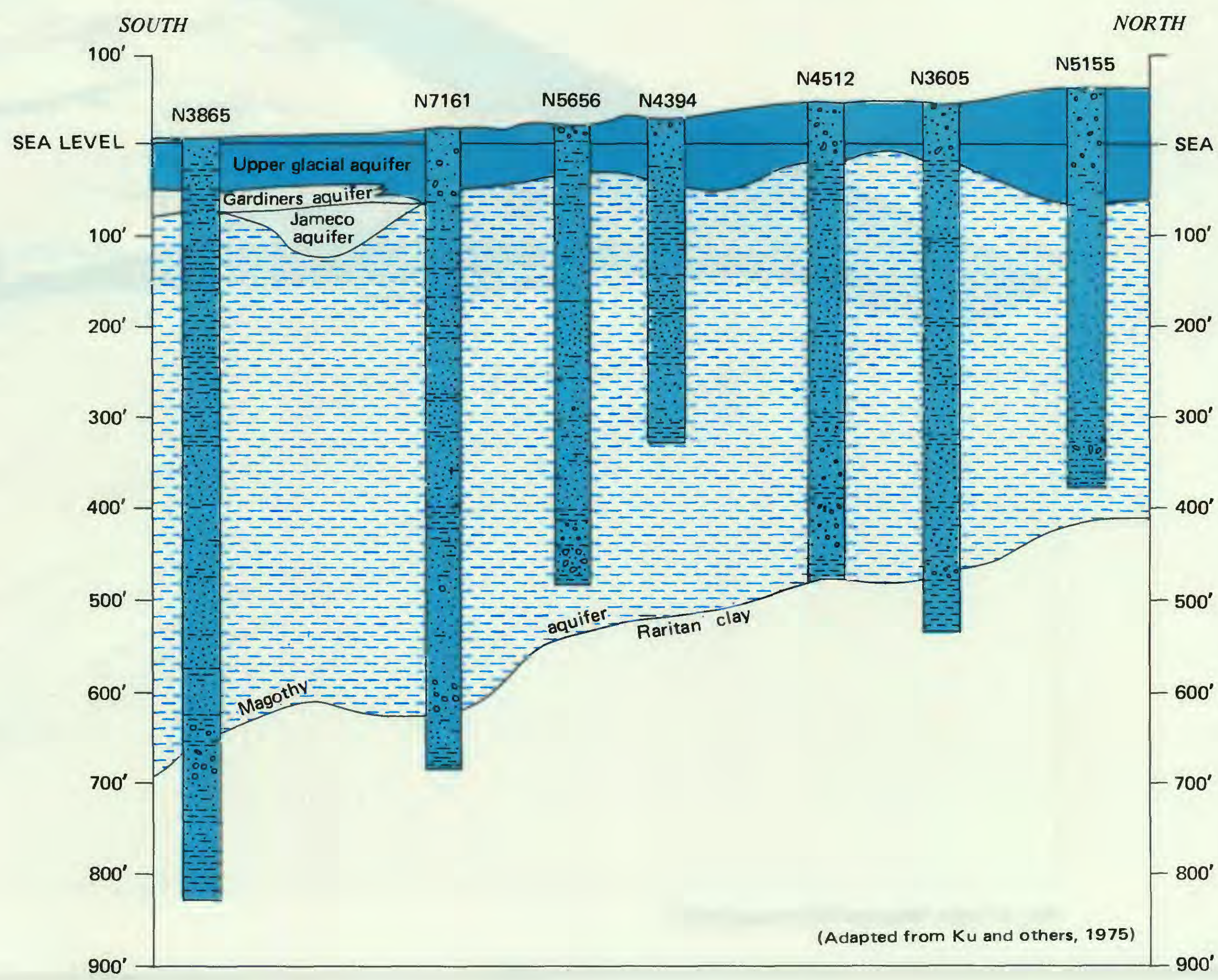
The conceptual model of the ground-water reservoir, while lacking the elegance and flexibility of a mathematical model such as that described earlier for El Paso County, Colorado, has been a reliable basis for detailed study of the ground-water system, leading to decisions regarding the management and conservation of the priceless fresh water. For example, the model has been used:

- To locate parts of the system to which pollutants had not yet migrated so that a picture of pre-development water quality could be reconstructed.
- To estimate the decline of ground-water levels and probable reductions in streamflow caused by present and planned sanitary sewer construction.
- To estimate the quantity and quality of available water supplies.
- To help formulate and judge several alternative schemes for long-term management of the fresh ground water, discussed later.



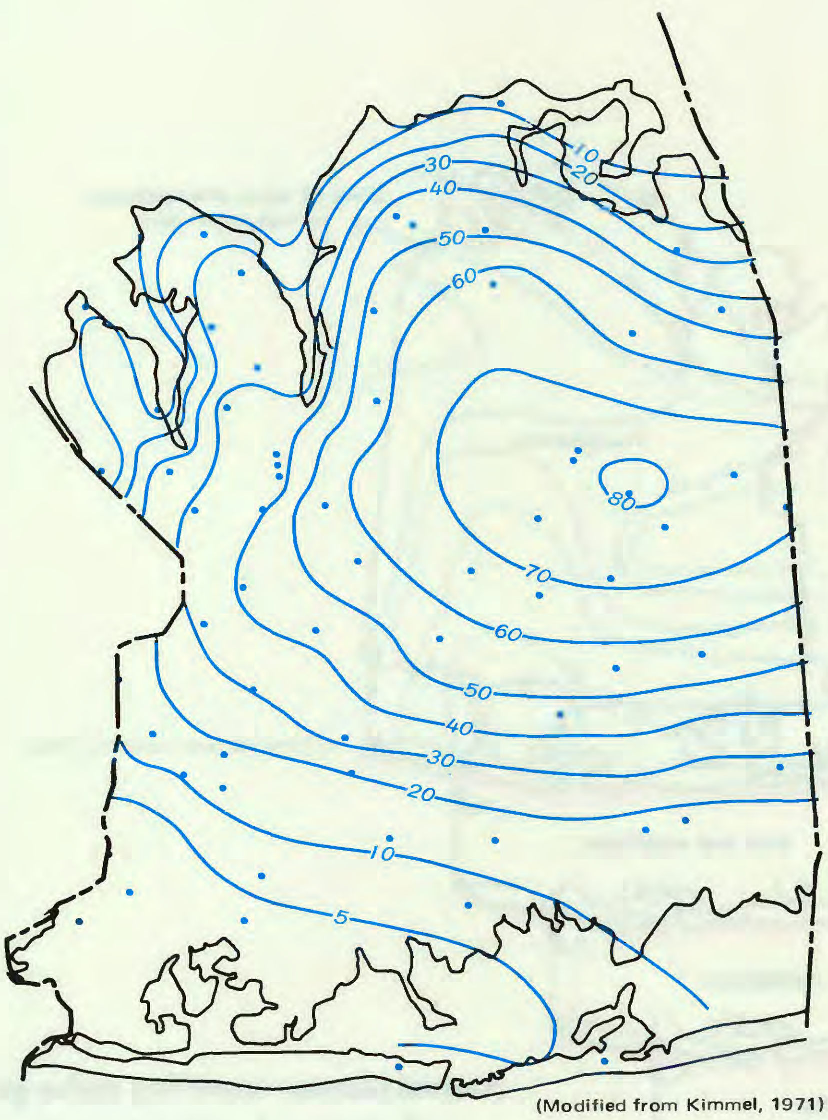
Map group for the shallow part of the ground-water reservoir

These three maps represent those on the previous two pages from which the model of the shallow, upper glacial aquifer was derived.



Typical cross section in Nassau County

Wells (strip patterns) penetrate various aquifer and nonaquifer zones. Vertical scale is greatly exaggerated.



(Modified from Kimmel, 1971)

Water-level contours (in feet) for deeper (Magothy) aquifer

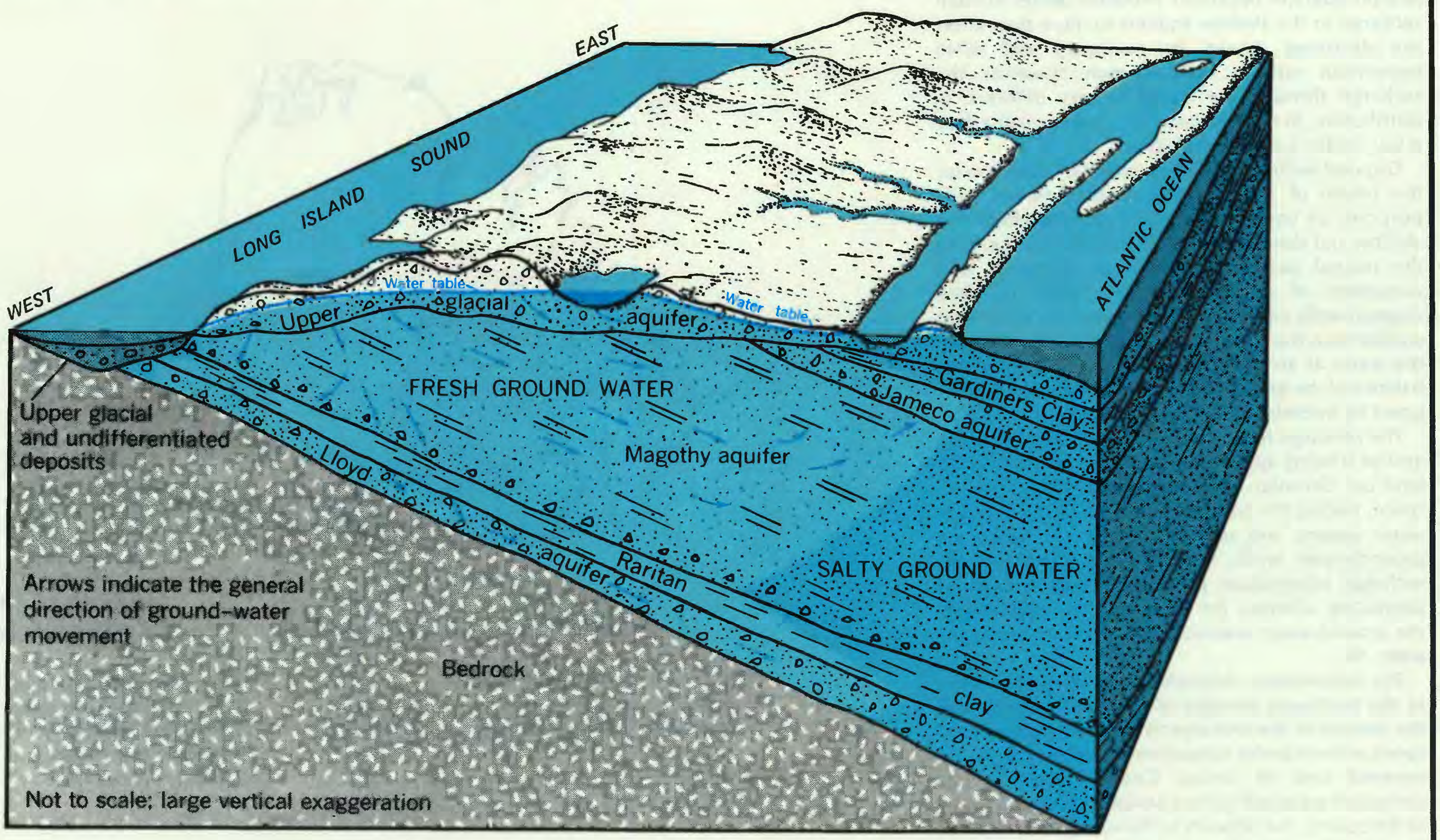
Dots indicate location of wells used to derive the measurements.

0 5 MILES

(From U.S. Geological Survey unpublished map, 1960)

Thickness of Magothy aquifer, in feet

Model of the structure, form, and functioning of the ground-water reservoir of central Long Island



(Adapted from Cohen and others, 1970)

Recharge and discharge

The ground-water reservoir acts as a water bank for the people of Nassau County. Like a financial bank, it receives "deposits" (recharge) and has "withdrawals" (pumpage and natural ground-water discharge), and it also has "reserves" in the form of huge volumes of fresh water stored in the ground. As with a financial bank, effective management of the water bank and planning for its future require the best possible knowledge of the deposits (recharge) and withdrawals (discharge), as well as the reserves (water in storage). These two pages summarize the ways in which recharge and discharge information about the Nassau County water bank has been compiled and applied.

Recharge

To understand the recharge situation in Nassau County today, consider the natural recharge to the ground-water reservoir, pictured in the group of maps to the upper right, and man-caused changes to the natural recharge, pictured in the group of maps to the lower right. Rain and melted snow which infiltrate the ground are the main sources of water for Long Island, as they were before man, and the deeper aquifer zones are still replenished mainly by ground water passing downward from shallow zones. However, the ways in which the water reaches—or does not reach—the ground-water reservoir have been greatly affected by man's activities.

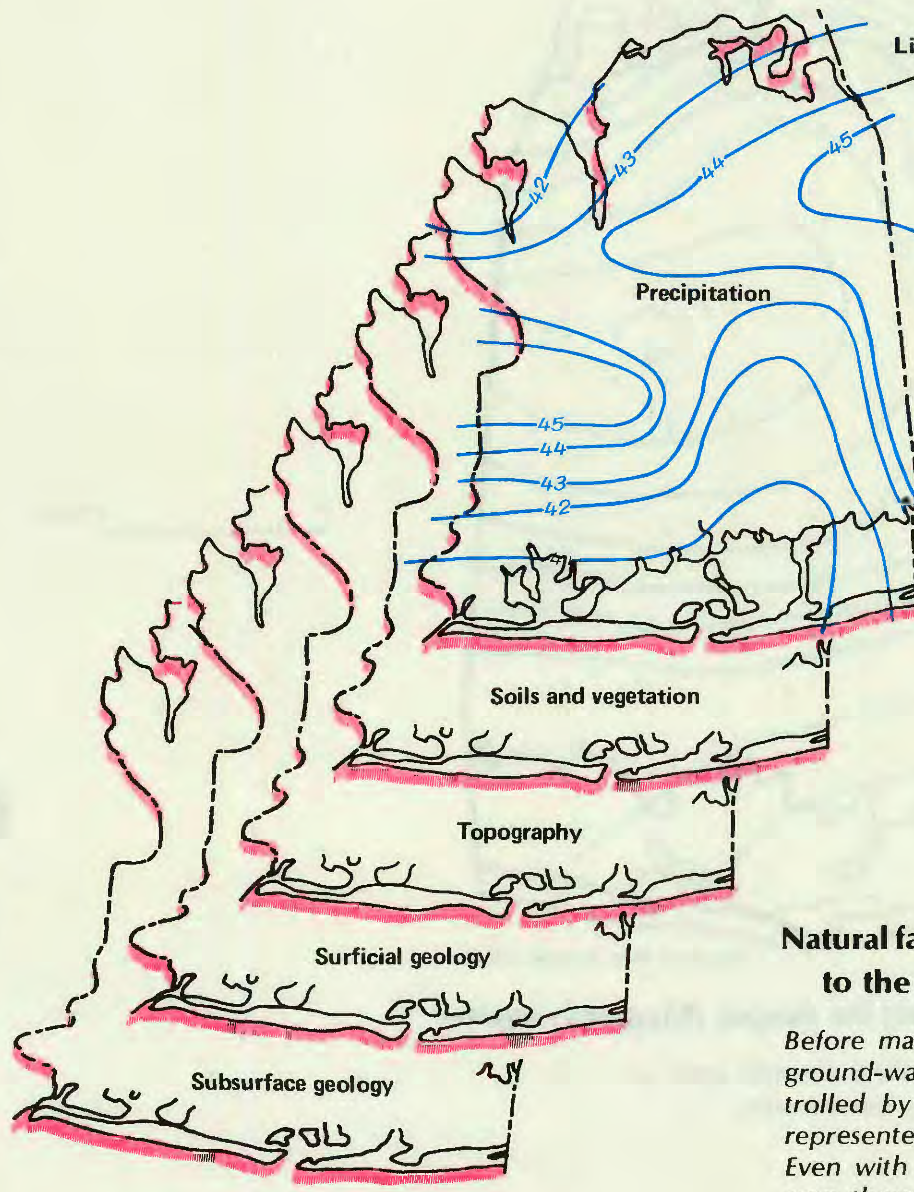
Urban development in the county has resulted in increased recharge at some places and decreased recharge at others. Where the normally permeable soil has been covered extensively by buildings, pavement, and other impervious materials, recharge to the shallow aquifers has been reduced. Recharge to shallow aquifers also has decreased in parts of the county where household sewage disposal has been changed from individual cesspool and septic tank systems, which returned the waste water underground, to sewer systems that eventually discharge the waste into the ocean.

The widespread use of excavated, unlined pits, or "recharge basins" for disposal of storm-runoff water (see photograph opposite) probably causes enough recharge to the shallow aquifers to more than offset the decreases caused by pavement and other impervious surfaces built by man. However, the recharge through the basins is very different in distribution, in rate of movement, and in quality than it was under natural conditions.

Disposal wells, which are required by State law for the return of most ground water used for such purposes as cooling, artificially recharge both the shallow and deeper aquifers. In addition to changing the natural patterns of recharge, discharge, and movement of the ground water, many of these disposal wells commonly return water to a different aquifer than the water was pumped from, and return the water at an unnaturally high temperature. The balance of the ground-water system has been further upset by intensive pumping from wells.

The recharge information summarized in the map groups is being applied to needs such as planning of land-use densities, including preservation of open space, tracing the paths of pollutants in the ground-water system, and analyzing causes of changes in ground-water levels. Perhaps most important, the recharge information plays a key role in various alternative schemes for long-term management of the ground-water reservoir, which are discussed on page 68.

The information obtainable, including the effects of the Northeast drought of 1962–66, indicates that the amount of the recharge to the shallow aquifers is about as it was under natural conditions, except in the sewered area of Nassau County where it has decreased measurably since about 1953. Thus, in most of the county, the deposits to the water bank have not been much changed by urban development. In the next discussions, we see how the withdrawals and reserves of the water bank have been affected.



Natural factors controlling recharge to the ground-water reservoir

Before man intervened, recharge to the ground-water reservoir was wholly controlled by natural factors, mainly those represented here as layers of map data. Even with significant changes caused by man, these data are still essential to understanding the recharge process.

Man-caused changes to the natural recharge

Data include different disposal methods for sewage water, recharge basins for handling storm runoff, and disposal wells for returning water to the ground after using it for cooling.

A typical recharge basin in Nassau County

Discharge

Even before man, the ground-water reservoir constantly lost water, to the air and to the ocean, as shown in the diagram at right. Most of the water that infiltrated the land surface and recharged the ground water moved laterally through the shallow aquifer and discharged to streams or the salt water without ever reaching the deeper aquifers. Water in the deep aquifers, after moving downward from shallower zones in the central and northern parts of the county, reversed its flow in south-shore areas and discharged water by upward leakage to shallow aquifer zones, as shown by the small arrows on the diagram. The other major form of fresh-water discharge from the deep aquifers was the mixing with and assimilation into adjacent salty ground water (discussed later, p. 66).

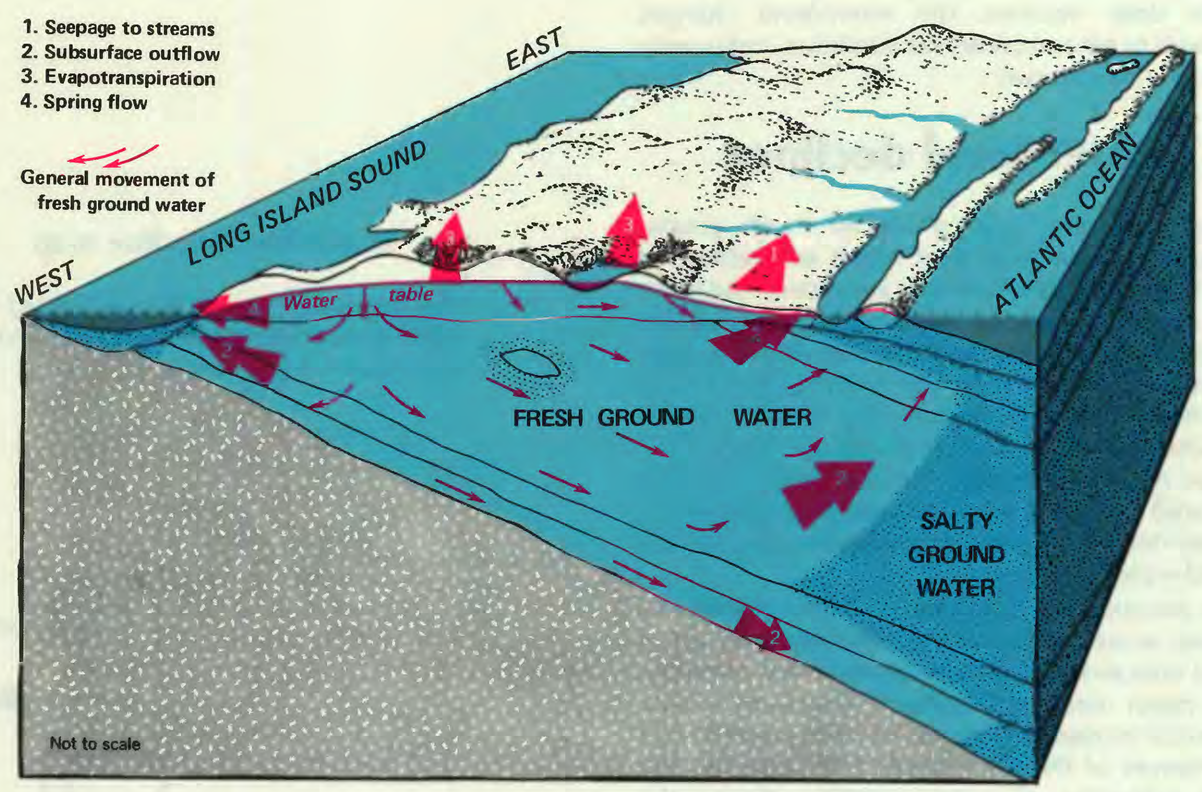
Urban development in Nassau County has added another major form of ground-water discharge—the large-scale pumping from wells for industrial and public water supplies. Most of the pumping is from the deeper aquifers. The intensive pumping from those aquifers has increased the rate of downward leakage from the shallow aquifers at places. Similarly, the natural upward leakage from the deeper aquifers has decreased at other places, mainly in the southern part of the county.

Besides managing the artificial ground-water discharge—the pumping and other discharge caused by man—it is also possible to affect the natural discharge. For example, making major withdrawals from the water bank results in the interception and use of some ground water that otherwise would discharge to the sea or sky without serving man. The ability to modify the natural discharge by using artificial discharge (mainly pumping) and adequate knowledge of the ground-water reservoir is fundamental to several of the long-term water-management alternatives being considered for Long Island (discussed later, p. 68).

The information available on ground-water discharge includes:

Pumpage amounts—Required by the New York State Department of Environmental Conservation (see graph to the right).

Distribution of pumpage—Locations of pumped wells and identification of the aquifers tapped by those wells.



(Modified from Cohen and others, 1968)

Natural modes of ground-water discharge

These modes and the pumping from thousands of wells constitute nearly all discharge in Nassau County.

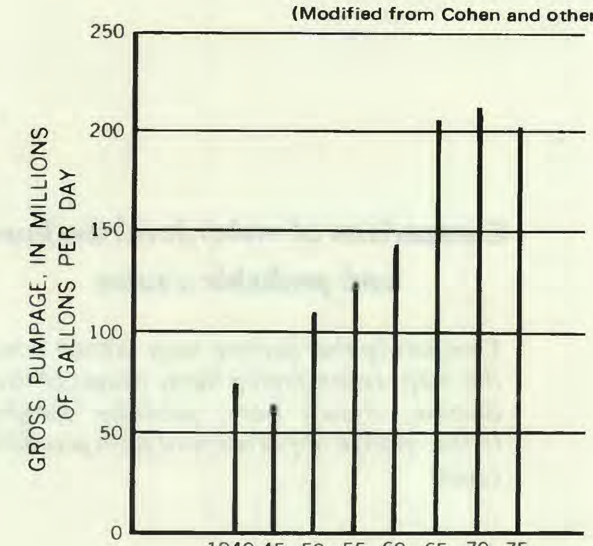
Streamflow measurements—The most reliable of all available data on the various kinds of natural discharge.

Estimates of subsurface outflow—Rough calculations based on knowledge that has been developed about the ground-water reservoir and how water moves through it (see previous four pages).

The major uses of the information on discharge are for regulating pumping in accordance with New York State regulations and for evaluating long-term water-management alternatives.

As we shall see in the following two pages, information on water levels and their changes has been instrumental in understanding the variation of the reserves in and withdrawals from the Nassau County water bank, as it has been in understanding other aspects of the water bank.

(Modified from Cohen and others, 1968)



Water-level changes

Many of man's and nature's influences on the ground-water reservoir are reflected in water-level changes. On Long Island, records of changes in ground-water levels, plotted on maps, have been essential tools for water-related predictions and planning.

Water levels measured about the same time in a network of observation wells are commonly shown on a map in the form of water-level contours—that is, lines of equal water-level elevations—for the entire county. A water-level contour map for a specific aquifer zone, such as that to the right, is used to determine the general pattern of movement of ground water, and of any contaminants it may contain. Similarly, water-level contour maps for shallower and deeper aquifer zones are regularly compared to find where water is moving between aquifer zones. For this discussion, only data for one deep aquifer zone are shown; similar data are available and used for the shallow aquifer and for the other deep aquifers.

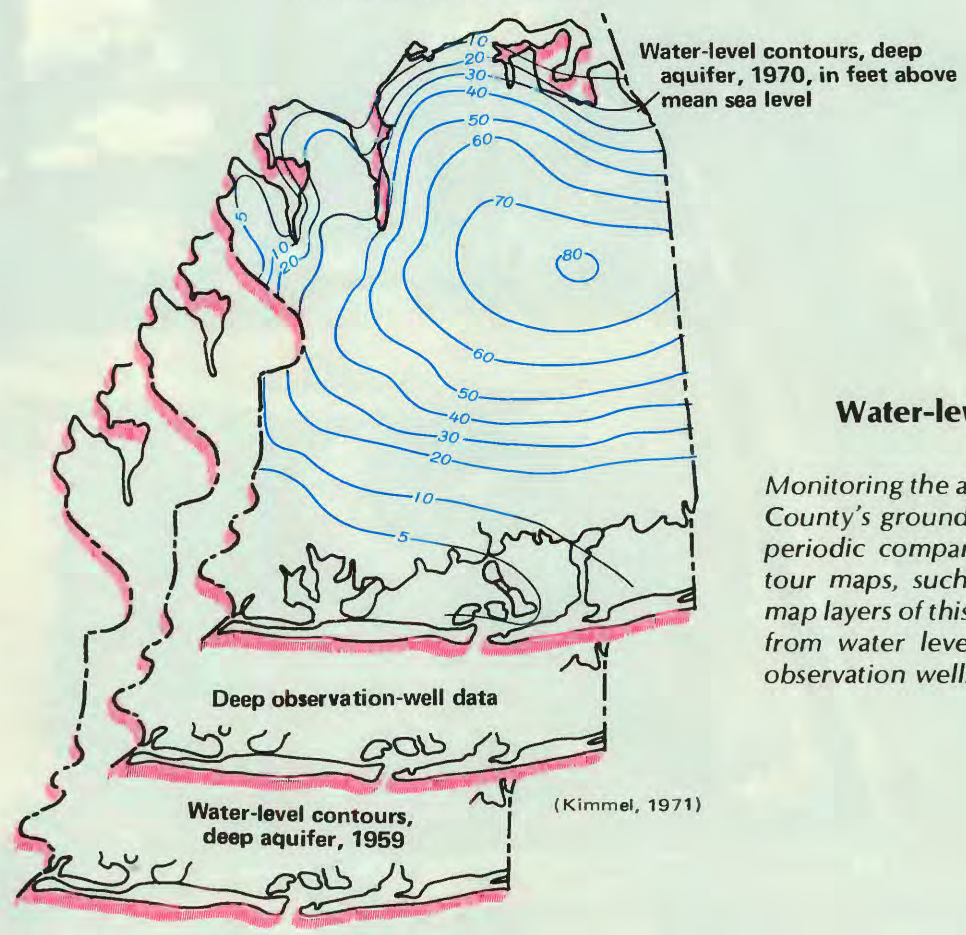
Where ground-water conditions are not much affected by man's activities, changes in ground-water levels are relatively small and reflect mainly the seasonal and year-to-year differences in recharge from precipitation. This means that, under natural conditions, the ground-water reservoir was in balance, with discharge about equaling recharge—in other words, the reserves of the water bank were relatively constant. The greatest recorded natural changes in water levels were a decline of more than 10 feet in shallow aquifers in the central part of the county during the severe drought of 1962–66 and a general rise to virtually average levels by the early 1970's. In shallow aquifers nearer the shorelines and in the deep aquifers, the water-level changes attributed to natural causes are much less, commonly less than a foot or two.

Water-level declines

Man's activities have produced much greater changes, the most critical of which are declines of more than 20 feet (by 1970) that are widespread in the deep aquifer zones (see maps to right and below). The distribution and amount of the declines were determined by comparing water-level contour maps for different times and compiling the water-level differences in the form of "net-change" maps. Net-change maps for different aquifer zones also are compared to analyze the similarities or differences in water-level changes within different parts of the ground-water reservoir.

The amount and distribution of major water-level declines, as well as the aquifer zones involved, are of critical concern to the water planner and manager. Such major declines represent decreases in the amount of storage in the ground-water reservoir—in the reserves of the water bank. They diminish the future adequacy of water supplies, change the movement of water (and contaminants) through the ground-water reservoir, and, in nearshore areas such as parts of Long Island, decrease the natural discharge by subsurface outflow and increase the threat of salt-water intrusion. However, little can be done to reduce or otherwise respond to such declines until their causes are known.

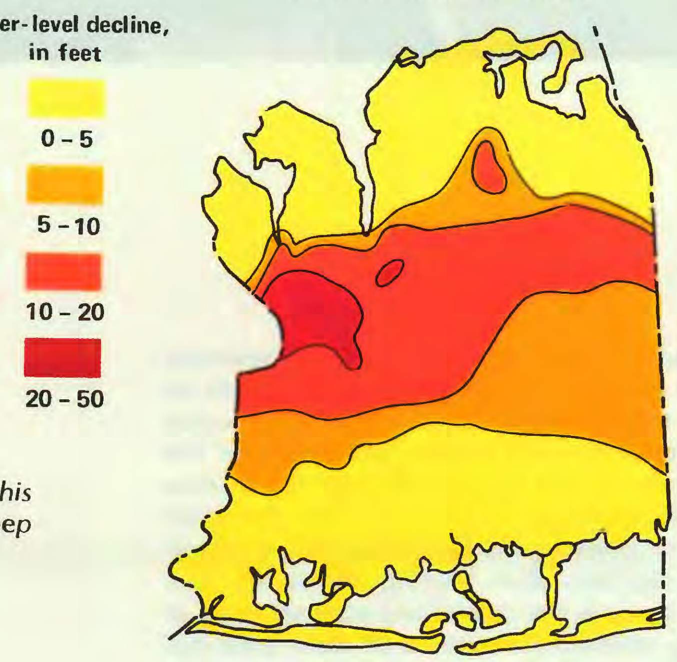
DETERMINING CHANGES



Water-level contour maps

Monitoring the amount of water in Nassau County's ground-water reservoir includes periodic comparison of water-level contour maps, such as the top and bottom map layers of this figure. These are derived from water levels measured in selected observation wells (middle map layer).

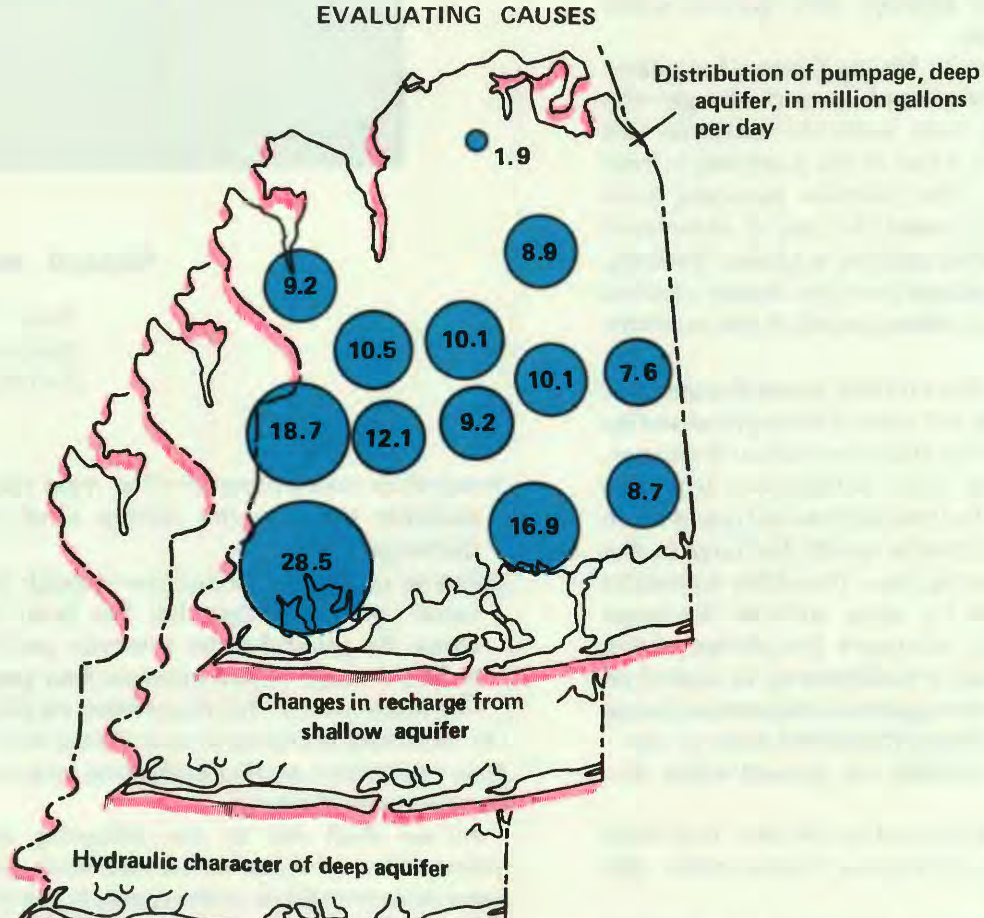
INTERPRETING CHANGES



Water-level decline map

The water-level maps above yielded this map of water-level declines in the deep observation wells during 1959–70.

EVALUATING CAUSES



Comparison of water-level declines and probable causes

Comparing the decline map above with the maps representing likely causes of the decline, shown here, provides insight to the relative importance of each possible cause.

Artificial recharge test facility at Bay Park

Water-level recorders in foreground measure water-level changes in observation wells tapping different aquifer zones.

Causes of water-level declines

In Nassau County, the declines in ground-water levels have had several causes, some major and continuing, others minor and temporary. The relative importance of each has been estimated by graphically comparing the distribution of the decline to the distribution of the presumed cause. A simple example is a comparison of the net-change, or net-decline, map for the deep aquifer zone (facing page, middle) with a map showing distribution of pumpage from the deep zone (facing page, bottom).

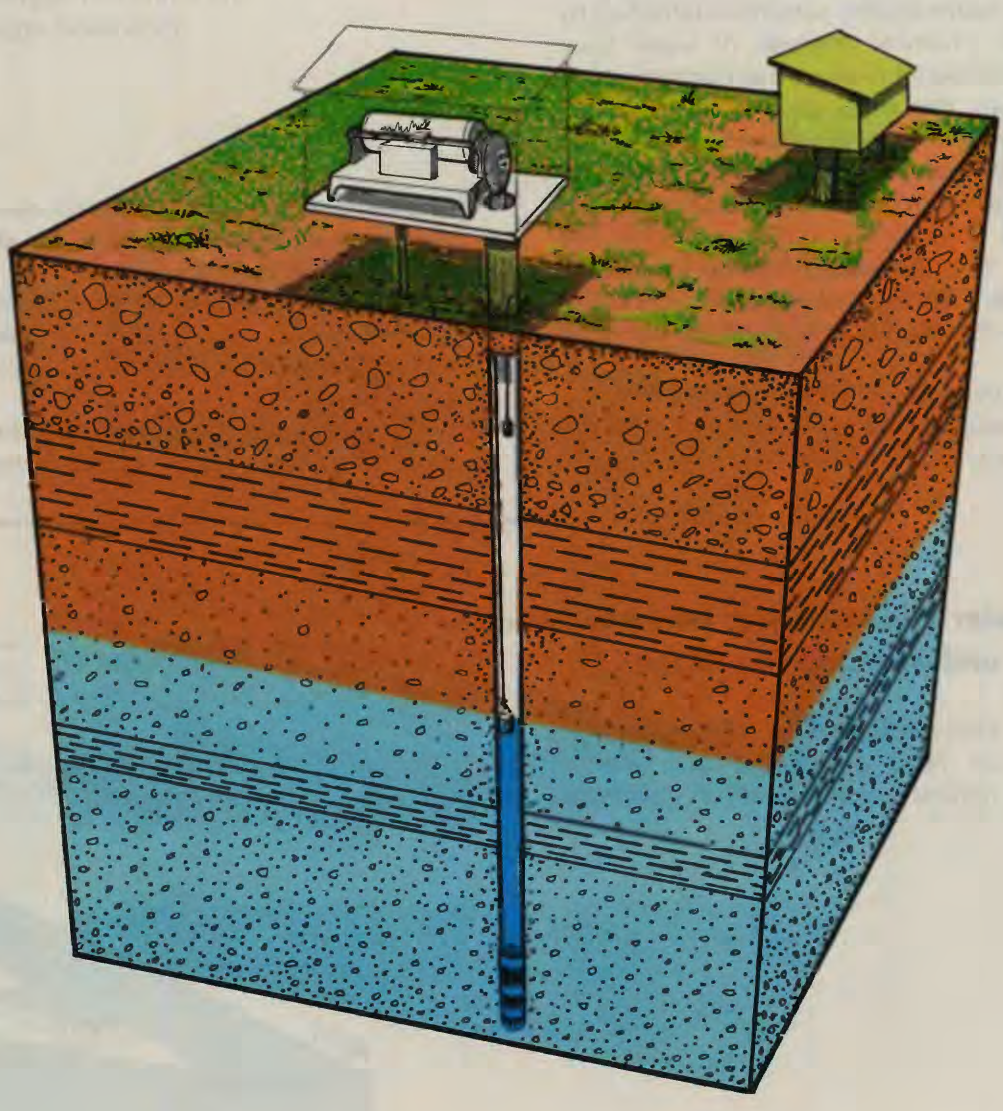
The comparison demonstrates that intensive pumping from deep wells in and adjacent to Nassau County is the main cause of water-level declines in the deep aquifer zone. Another possible cause of decline is a decrease in recharge to the deep zones at places where the decline of levels in shallower zones has been comparatively large.

Water-level contour maps, because they can be translated into patterns of ground-water movement, have been widely used in Nassau County to trace contaminants in the ground water (see p. 64–65) and have thus been instruments in water-quality surveillance and enforcement of public-health regulations.

Knowledge of the water-level declines caused by the shift to sewer systems in southwestern Nassau County has warned officials of what to expect when other areas are sewered.

Relationships that have been found between pumpage and water-level declines have been used for many management and predictive purposes, such as:

- Predicting long-term water-level declines that are likely to result from providing water supplies to future population.
- Estimating changes in the rates of water movement within the ground-water reservoir.
- Determining the needs for, and timing of, future water-conservation plans, such as artificial recharge.
- Decisions, during the severe drought of 1962–66, to allow virtually unrestricted use of well-water supplies in Nassau County while New York City's stream-water supplies from upstate New York were sharply curtailed; also a decision to use a shallow-well system in Nassau County for emergency water supplies for New York City.
- A prohibition on the development of additional water supplies from the deepest (Lloyd) aquifer, except in near-shore areas that have no other dependable source of fresh water.



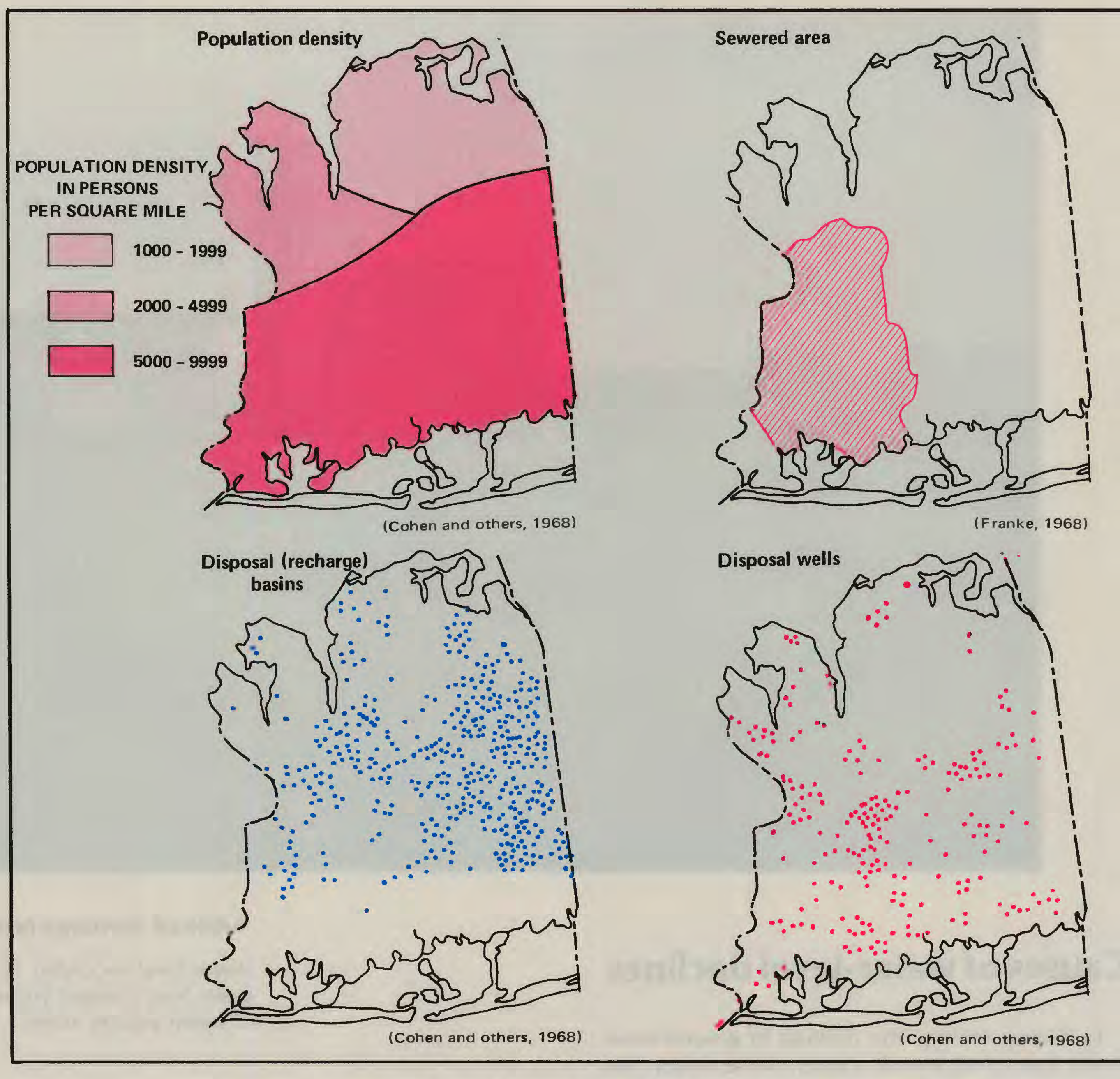
Typical continuous water-level recorder attached to an observation well

As the water level in the well fluctuates, a float causes the drum to rotate. A pen driven by a clock (in box in front of drum) moves horizontally across the rotating drum, keeping a continuous record of the water level.

Contamination

Contamination of the ground water is probably the most serious element in the planning and management for Nassau County's present and future water supplies. We tend to think that all contamination is caused by man, but this is far from true. From the moment a raindrop or snowflake falls over Nassau County, it is assailed by natural contaminating influences, displayed below on the now-familiar model of Long Island. These influences must be taken into account in attacking water-quality problems. Most of the county's water-quality problems, however, do result from human activity at or near the land surface (see maps to the upper right); for example:

- Storm runoff carries contaminants into recharge (disposal) basins, where some of them percolate down to the ground water.
- Household sewage enters the shallow aquifers through leaky sewer pipes and many thousands of cesspools and septic tanks.
- Precipitation leaches contaminants of many kinds from solid-waste disposal sites and carries them downward into the ground water.
- Some industrial disposal basins and wells have provided routes for contamination of the ground water.
- Contamination results from accidental spills and casual dumping of contaminating materials.
- Even the precipitation that recharges the ground water is often more acidic than it was in pre-industrial days. It also contains other pollutants such as heavy metals and hydrocarbons, some of which are toxic in rather small concentrations.
- Other important sources of contamination are automotive wastes, excessive and improper application of road salts, pesticides, and fertilizers.



Man-caused contamination sources

The kinds and degree of man-caused contamination in Nassau County depend upon local situations, such as those shown by the four maps above.

Once in the ground water, the contaminants move along the flow paths in the ground-water reservoir (upper diagram on facing page) and are superimposed on the water-quality patterns established by nature. Periodic chemical analyses of water from deep wells have shown, however, that contamination is spreading into the deep ground water which formerly contained very small amounts of dissolved material (lower diagram and map on facing page). The contaminants are being carried to the deeper aquifers by the shallow ground water that recharges the deeper zones. The downward movement of the contaminants has been increased by a lowering of the deep ground-water levels as a result of intensive pumping.

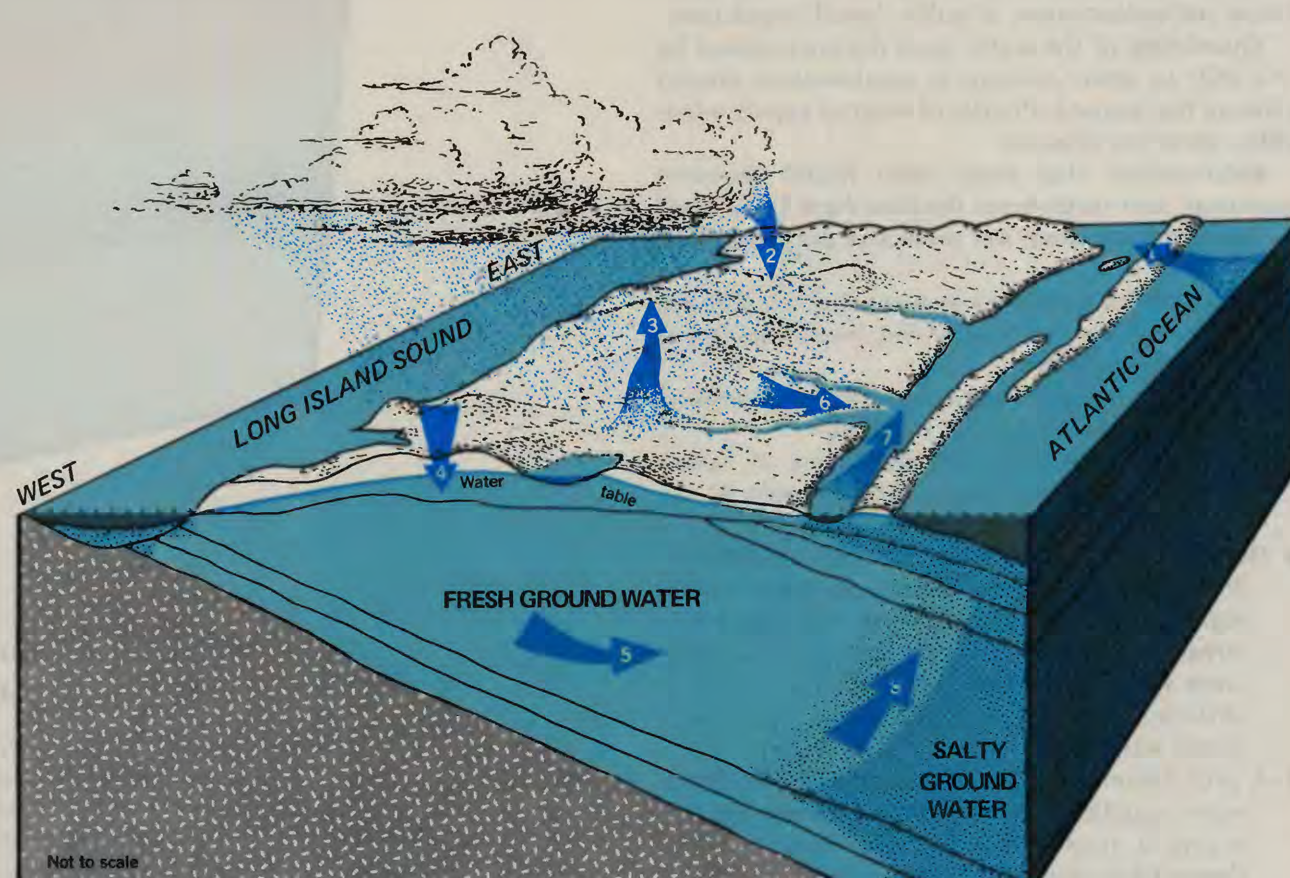
Temperature increases, a special kind of ground-water contamination, result partly from the recharge through cesspools and recharge basins, but mostly through disposal wells that inject warm or hot water underground following its use for air conditioning and industrial cooling.

Another special kind of ground-water contamination in Nassau County, related mainly to ground-water pumpage, is salt-water intrusion, discussed on pages 66–67.

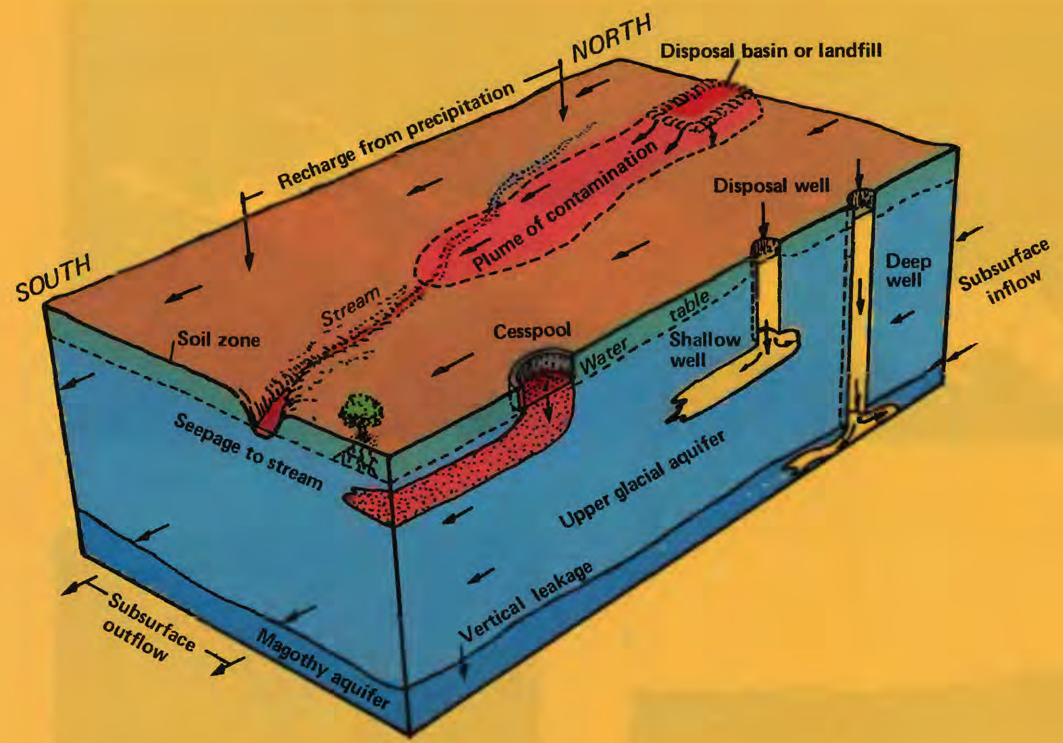
The spread of contamination in the deep aquifer zones is a major concern because these zones yield nearly all of the county's public water supplies. Sound planning for future water supplies requires reliable information about the types and degree of contamination, as well as predictions of when and where additional contamination is likely to appear. Such information is obtained by combining water-quality data, ground-water flow estimates, and the model, shown earlier, of how the ground-water reservoir functions.

Ground-water contamination on Long Island under natural conditions

To deal effectively with man-caused contamination, we must understand and take into account natural conditions which affect water quality.



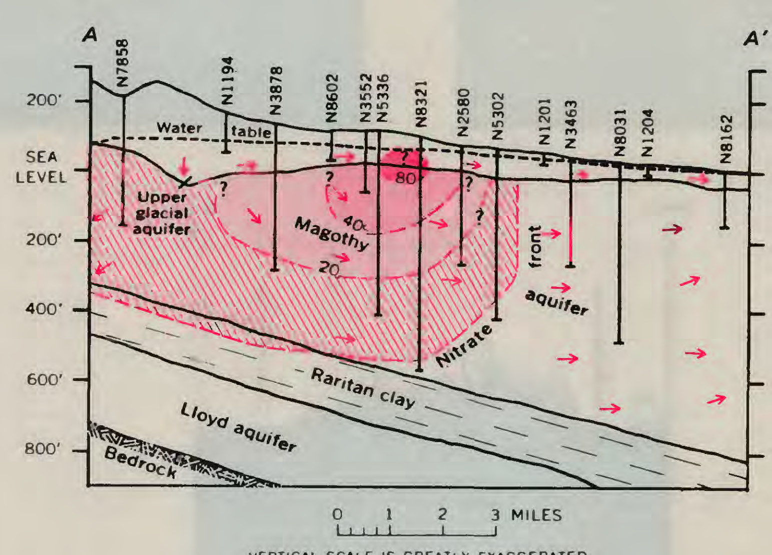
1 Air moving over the ocean picks up salty spray
2 Rain and snow pick up dust and gases from the atmosphere
3 Evaporation and transpiration of precipitation from the land surface and from the soil zone increase the dissolved-solids content of the water
4 Physical, chemical, and biological processes modify the dissolved-solids content of the water percolating through the zone of aeration
5 Flow through sedimentary deposits in the zone of saturation modifies the total dissolved-solids content of the ground water only slightly
6 Physical, chemical, and biological process modify the dissolved-solids content of streamflow
7 Fresh stream water and salty water mix in estuarine reaches
8 Fresh ground water and salty ground water mix in the zone of diffusion



Localized contamination routes in Nassau County

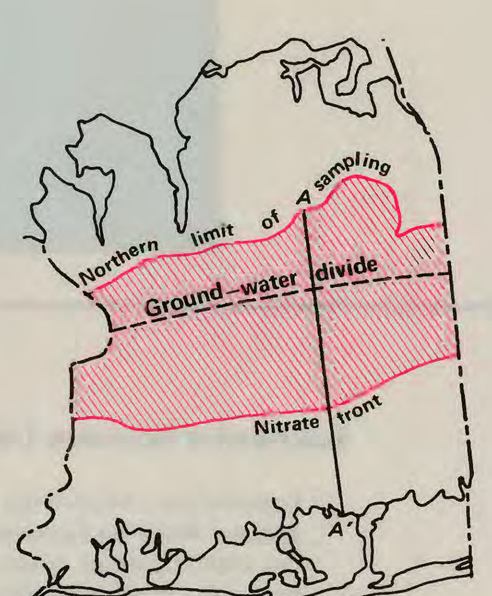
Contaminants that reach the ground water move along the general paths of ground-water flow (arrows), spreading in the form of "plumes" (red pattern). A major effect of most disposal wells is the addition of heated water (yellow pattern).

(Modified from Perlmutter and Lieber, 1970)



Regional contamination routes in Nassau County

From the shallow ground water, contamination reaches the deeper aquifer zones with water recharging the deep zones (cross-section). In this way, contamination is spreading in Nassau County, as shown by the extent of high concentrations of dissolved nitrate in deep zones (map). The zone of greatest concentration is beneath an area of dense suburban population that adds nitrates in cesspools, septic tanks, and fertilized lawns.



(Modified from Perlmutter and Koch, 1972)

Map applications

Here are some specific examples of ground-water contamination problems attacked with the help of maps:

Detergents

Household detergents in the ground water, though not known to be health hazards, indicate the presence of household sewage. Data on the widespread presence and the movement of detergents in the shallow ground water led to the establishment of recommended limits for the amount of detergent compounds in public water supplies. The data also caused strong public and official reactions that were a major factor in decisions by the detergent industry to produce detergents that are more biodegradable than those formerly sold.

Deicing salt

Salt used to deice highways has contaminated the ground water in some places. But snow-melt water containing highway deicing salt was found in one study to be "fresher" than the ground water it entered. This unexpected finding results from the extensive contamination of the surrounding ground water from other sources and was used to support decisions to continue use of deicing salt.

Nitrate

Dissolved nitrate compounds from household sewage and other sources have caused water from some public-supply wells to exceed recommended limits for nitrate in drinking water. Knowledge of the movement of the contaminants through the ground-water reservoir has allowed identification of source areas for the nitrate (diagram to the left) and of aquifer zones where nitrate content is likely to increase. The data also have provided a basis for selecting as alternative water supplies aquifer zones and wells that are less likely to be contaminated.

Industrial and solid wastes

Industrial waste products, such as metal salts and organic chemicals, as well as leachate from solid-waste landfills, have reached the ground water in concentrations considered to be undesirable. Knowledge of the presence and movement of these contaminants has assisted officials in setting recommended limits for concentrations of certain dissolved materials in public water supplies, tracing the contaminants to their sources and imposing regulations to reduce future contamination, warning against taking drinking water from wells within the plumes of contamination, and ordering the cessation of pumping from certain public supply wells that tap contaminated aquifer zones.

Salt-water intrusion

Because fresh-water supplies on Long Island are obtained from aquifer zones below sea level, water use is accompanied by the threat of salt-water intrusion—that is, the landward movement of salty ground water beneath the ocean into fresh-water aquifers beneath the land. At places in Nassau County, and especially in Kings and Queens Counties in western Long Island, salt-water intrusion has been more than a threat, it has been a harsh reality. Sound management and conservation of the fresh-water supplies, as well as effective long-range planning, require the reliable prediction of salt-water problems under various management schemes.

The relationship between fresh and salty ground water along the sea coast depends not only on near-shore conditions but also on any large changes, as in recharge or pumping, elsewhere in the ground-water reservoir. No extensive impermeable barriers in western Long Island separate the fresh ground-water reservoir from adjacent salty ground water, and the salt water is held in check only because large amounts of fresh water are constantly flowing seaward to mix with and discharge into the surrounding bodies of salty water, as the diagrams (right) show. Anything that reduces the outflow of fresh ground water allows salty ground water to intrude landward through the aquifers.

Two parts of Nassau County where troublesome salt-water intrusion has occurred in the deep aquifer zones (the main source of water supplies) are in the northwestern part (at Kings Point) and in the southwestern part of the county (see top map, opposite). Where it is invading the fresh-water aquifers, the salt-water front does not have the smooth shape that is shown in the preceding generalized models of the ground-water reservoir. Instead, it invades as a series of tongues, or wedges, moving along the more permeable aquifer layers toward the intensively pumped wells farther inland.

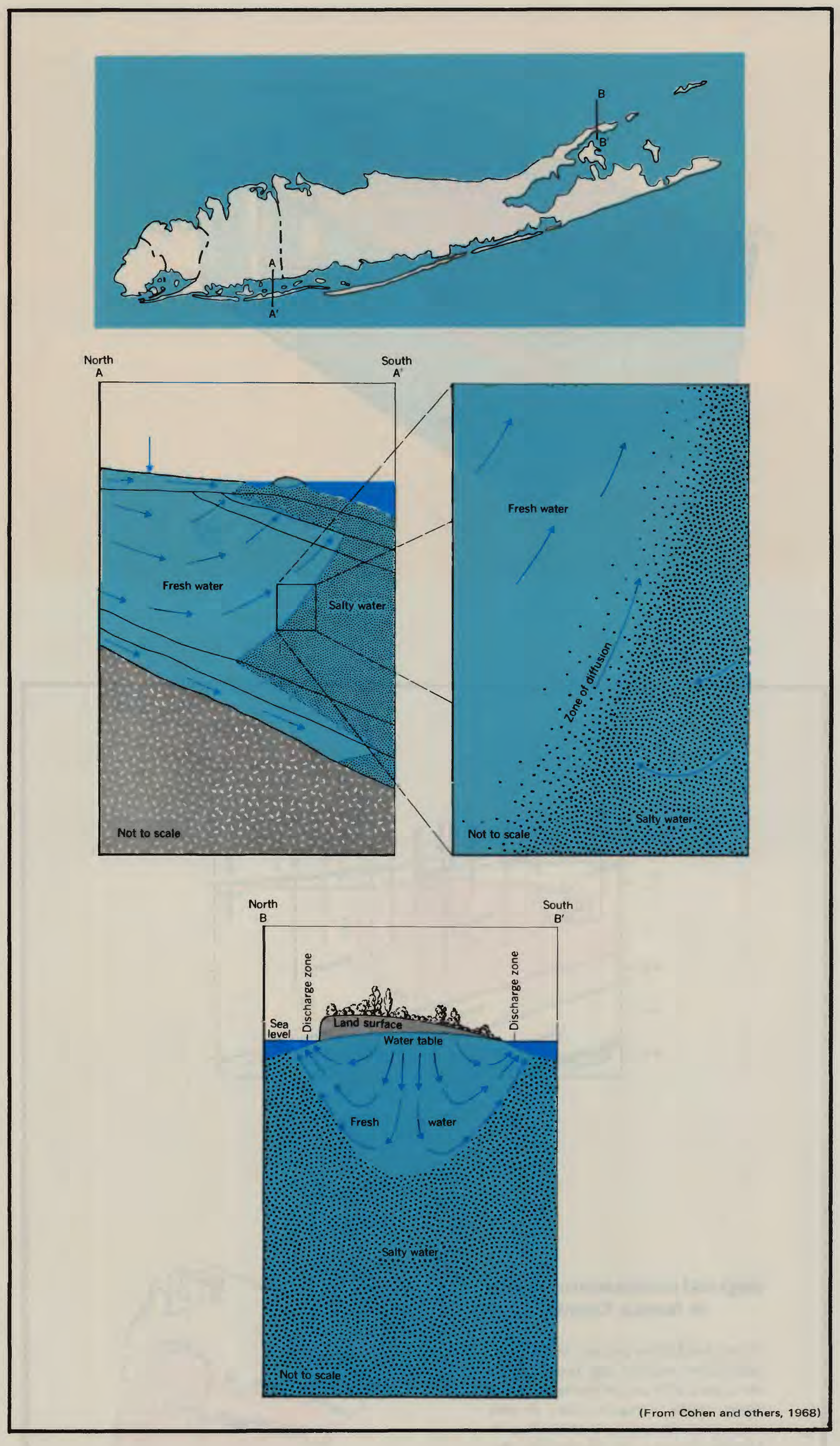
Monitoring the salt-water front

The lower illustrations on the opposite page show the approximate position of the salt-water front in a deep aquifer as interpreted in the late 1960's. The salt water in the deep aquifers was then thought to be advancing slowly along a rather broad front, presenting a threat to much of southern Nassau County. More recent information, including data from offshore drilling, now indicates that the salt-water front in the deeper aquifers is considerably farther offshore along most of southern Nassau County, although no map has yet been compiled to show the revised location of the front. Therefore, the threat represented by salt-water intrusion in southern Nassau County, at least in the near future, probably is mainly to the shallower near-shore zones and outlying areas such as islands and peninsulas.

Monitoring the salt-water front and predicting its position has required information on and interpretations of such things as the salinity of water from the aquifer zones that are likely to be affected (requiring sampling and chemical analysis), pumpage from wells tapping those aquifers, and water-level changes in those wells. To be effective for management and planning, all these data must be combined with an adequate understanding of how the ground-water reservoir functions.

Responding to intrusion

One possible response to salt-water intrusion is simply to shut down the pump on the salty well and find an alternative water supply, probably farther inland. This was actually done at Kings Point and at places in southwest Nassau and southeast Queens Counties. Or intensive pumping can be partly offset by adding more water to the aquifers between the salty ground water and the threatened well or wells.



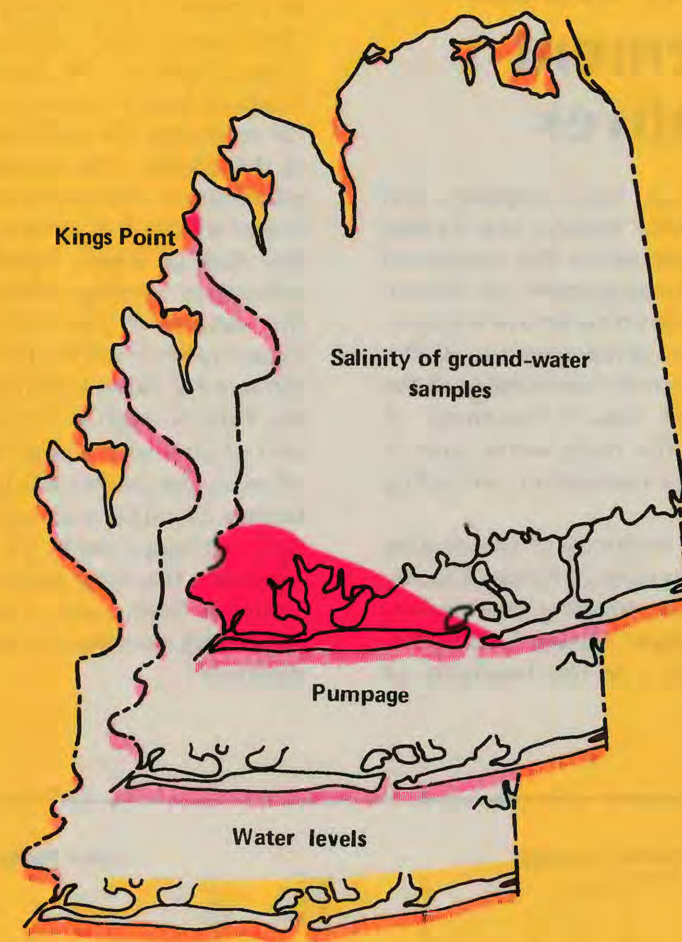
Boundaries between fresh and salty ground water

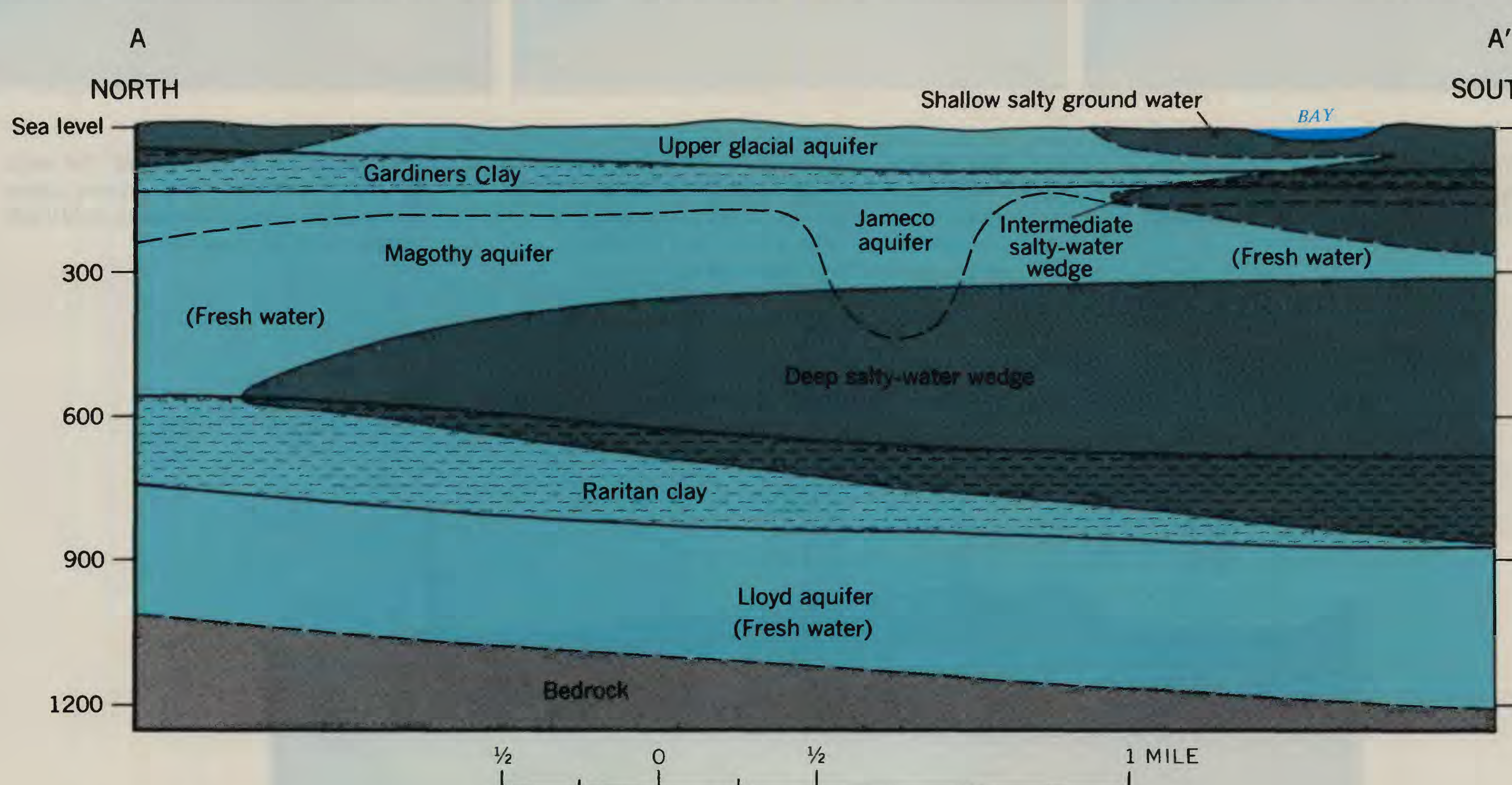
Generalized boundaries between fresh and salty ground water and natural movement of water along the south shore of Nassau County (upper left), in and near the zone of diffusion, which separates fresh ground water from salty ground water (upper right), and on eastern Long Island (below).

Proposals for artificially recharging the aquifers to conserve fresh water and thereby prevent or slow salt-water intrusion are basic parts of some of the long-term water-management alternatives that have been considered for Nassau County, and which are discussed in the concluding section.

Monitoring salt-water intrusion

Among the information needed to monitor the salty ground water (red areas) and predict its movement are repeated measurements of the salt content and of water levels in the affected aquifer zones and data on the amount and distribution of pumping from those zones.

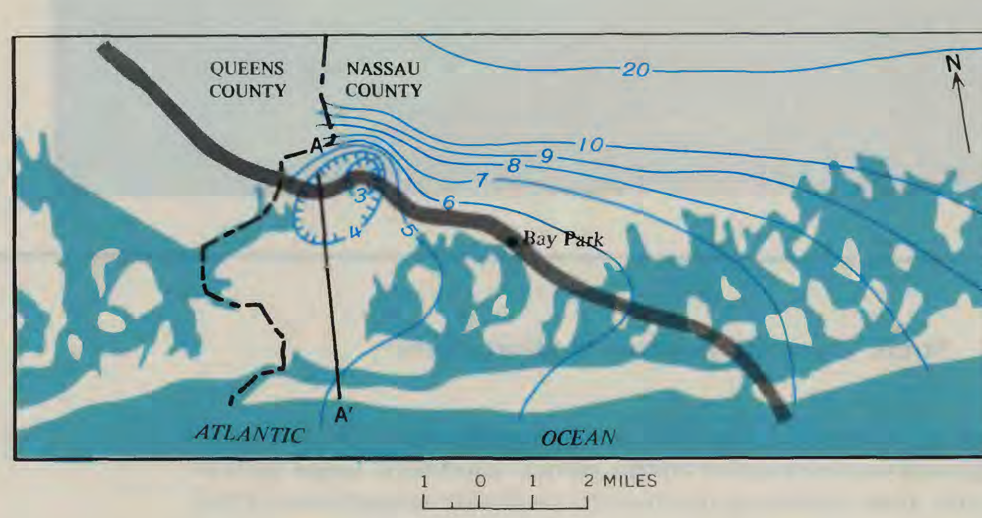




EXPLANATION

Approximate landward limit of deep salt-water wedge

Water-level contour
Shows altitude of water level above mean sea level



Landward extent of salty ground water

Near the southwestern corner of Nassau County as interpreted in the late 1960's, salty water was farthest landward near the centers of pumping from a deep aquifer (cross section), where the water levels were drawn down the most (circular depressions in the water-level contour lines). Data now available indicate that, for areas east of the line of section (line A–A' on the map), the salt-water front actually is considerably south of the position shown here.

(From Cohen and others, 1968)

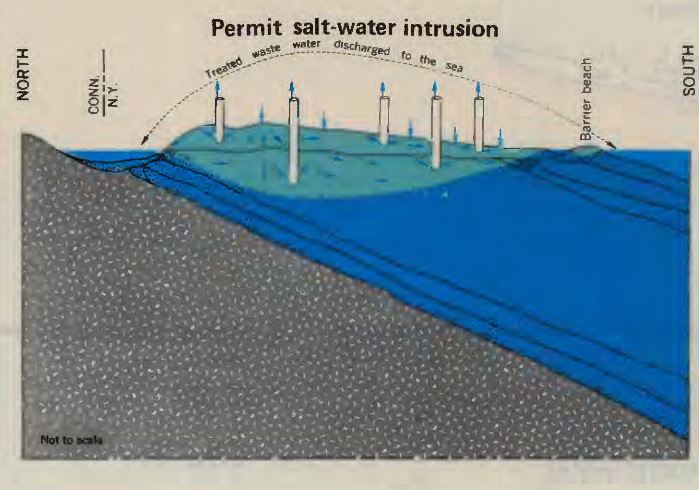
Long-term water management alternatives

Increases in the demand for water supplies, and deterioration in ground-water quality, are forcing critical decisions to be made about the continued development and future management of Nassau County's ground water. Sound and effective management will require the wise application of all the information previously discussed—knowledge of the ground-water reservoir and how it functions, of recharge and discharge of the fresh water, and of present and threatened contamination, including salt-water intrusion.

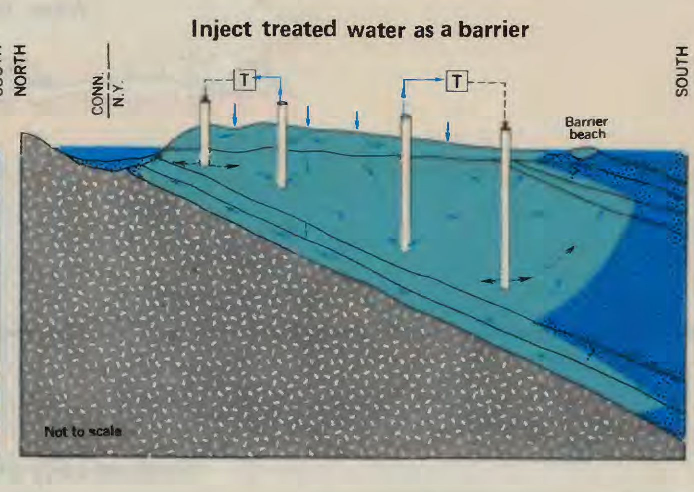
Several major alternative methods of developing and managing the water resources of Nassau County have been proposed. Three contrasting schemes are outlined in the diagrams below. Nassau County has spearheaded intensive studies of the feasibility of artificial recharge using water reclaimed from sewage as a means of conserving the fresh ground water of the county. Such artificial recharge would be an integral part of the barrier injection wells scheme (diagram below center) and an alternative scheme for returning the reclaimed water in the middle part of the county. The studies have used all the kinds of information mentioned here and have also included construction of a tertiary sewage-treatment plant at Bay Park to supply injection water; analysis of the subsurface geology and ground-water conditions in the vicinity of the injection well; and numerous experiments in which the highly treated sewage-plant effluent has been injected into a deep aquifer zone at Bay Park through an elaborate experimental well. As part of an evaluation of the barrier injection wells scheme, the studies also included analysis of the subsurface conditions along the proposed alinement for such recharge wells. To date (1977), these studies represent the most positive local action to meet the need for fresh-water conservation in the face of an expanding demand on the Long Island ground-water reservoir.

Since the studies were begun in the Bay Park area, two changes have occurred to shift the emphasis in water-resources management and planning for Nassau County. One is an increase in cases of water-quality degradation in the deep aquifers, as described in the discussion of ground-water contamination. The other is the finding of the apparently decreased threat of salt-water invasion of the intensively pumped deeper aquifers (see previous two pages). The major impact on water management and planning that these changes represent is to demonstrate the high value of authoritative, up-to-date information when planning involves a dynamic natural system such as a ground-water reservoir.

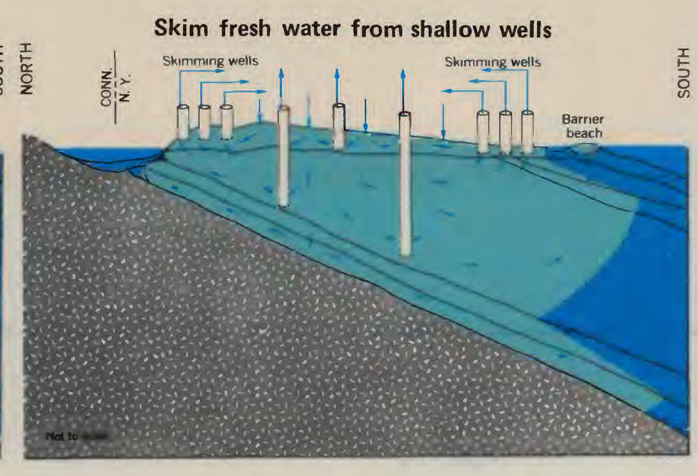
The stakes in conserving the fresh ground-water reservoir are high. The final selection of one or more water-management plans for the county doubtless will be guided by economic, political, sociological and other factors. However, choices based on the best obtainable scientific information about the ground-water reservoir and geologic framework offer the best hope for the future water resources of Nassau County.



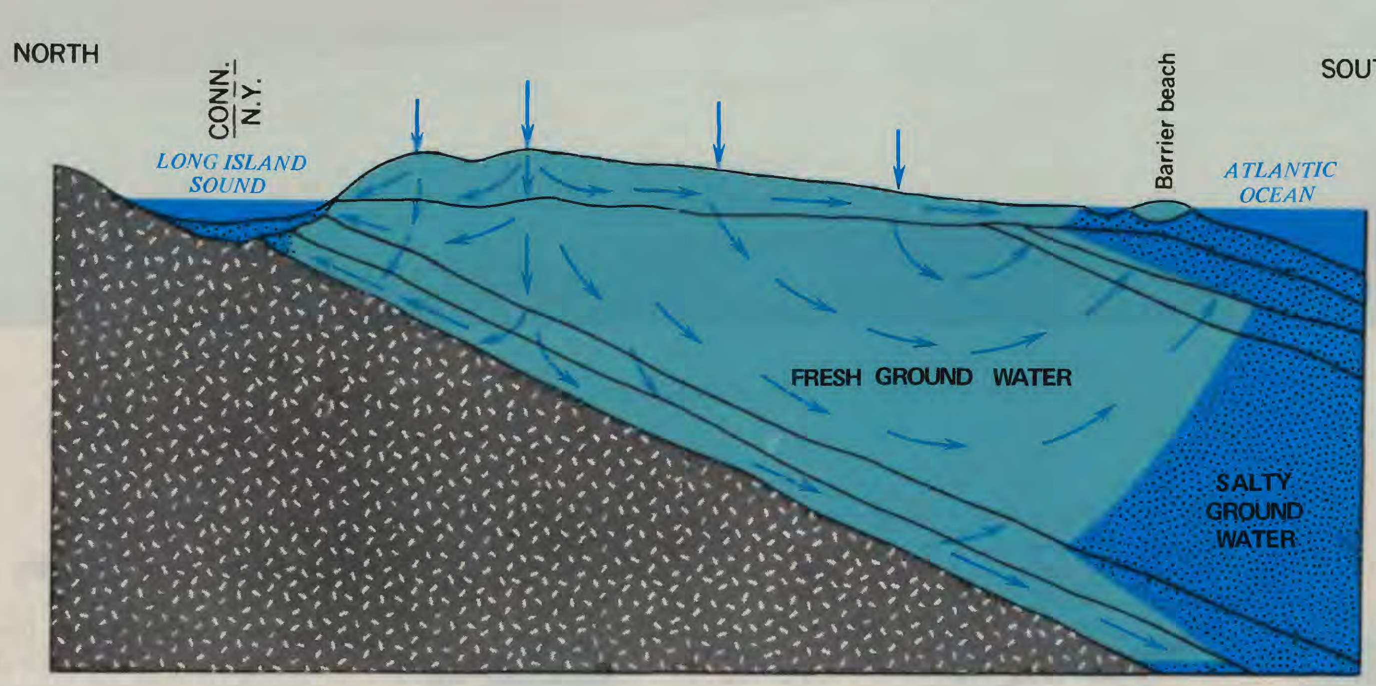
Permitting the salt water to move inland to new equilibrium positions could substantially increase the long-term fresh-water yield.



Recharging the reservoir with highly treated sewage-plant effluent (T) by means of a network of injection wells could check contamination by salty water and increase the long-term fresh-water yield.



Drilling shallow wells to "skim" the water that now discharges into streams would increase long-term fresh-water yield if side effects could be tolerated.



Some water-management alternatives

General patterns of recharge from the land surface and movement of fresh water through the ground-water reservoir under natural conditions (large section above) and under three alternative schemes for long-term management of the reservoir (small sections above). The most thoroughly evaluated scheme is the one of barrier injection.

APPLICATIONS IN AN ATLANTIC COAST ENVIRONMENT II

Franconia area, Fairfax County, Virginia

Planning a new community in an urban setting: Lehigh

By A. J. Froelich, U.S. Geological Survey; A. D. Garnaas, Office of Comprehensive Planning, Fairfax County, Virginia; and J. N. Van Driel, U.S. Geological Survey

Background of the project

An application for development of more than 1,000 acres of undeveloped land into a high-density new town in the Franconia area of Fairfax County, Virginia, was rejected in 1972 by the County Board of Supervisors. In early 1975, however, rezoning for lower density planned development housing on the site was approved on the recommendation of the county's Office of Comprehensive Planning. In mid-1975, a conceptual development plan (below) was submitted to the county for review. Subsequently, a revised conceptual development plan, which incorporates most of the county's recommendations, was submitted for approval in mid-1976. The main reasons for the county's subsequent approval were that the proposed new community could now be integrated with existing land-use and available public facilities and that development would be tailored to the natural limitations and opportunities inherent in the site. Newly available earth-science maps and related geotechnical data were used by the county environmental planning staff to analyze the rezoning application; this information was used even more extensively to modify the development plan so that it became more acceptable to all interested participants—citizens, developer, and county staff. The specific role that earth-science data played in achieving this harmonious result is the subject of this chapter. The new plan itself, renamed "Lehigh," appears at the end of the chapter.

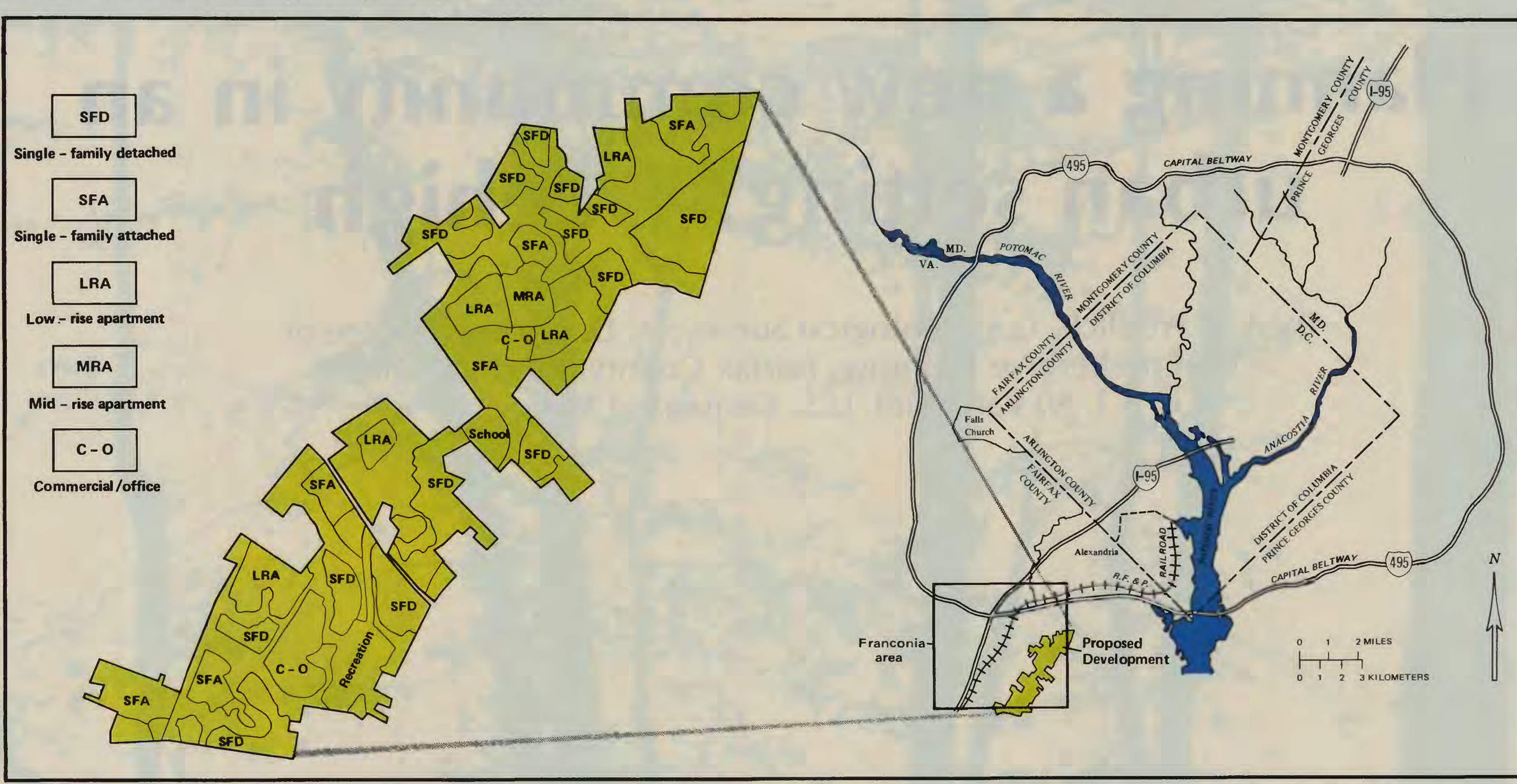
The Franconia area lies less than 10 miles southwest of the center of the District of Columbia. It is mainly a gently undulating, grassy upland capped by gravel and scarred by abandoned gravel pits. Its margins are incised by steeply sloping wooded ravines and gullies (see photograph right). The upland offers pleasant unobstructed vistas south and east across the Coastal Plain to the broad Potomac estuary and glimpses of the rolling wooded hills of the Piedmont area to the west.

The generalized current land-use map (upper map, opposite page) shows that most of the Franconia area is urbanized, some is low-density residential, and most of the undeveloped land is abandoned gravel pits. The northern part is crossed from east to west by the Capital Beltway Route 495, a limited-access freeway, and the central part is crossed from north to south by the Richmond, Fredericksburg, and Potomac Railroad and by Interstate 95. Nearness to the Nation's fast-growing capital and relative ease of access makes the vacant land in the southeast part a prime target for residential development. Such a use is compatible with the comprehensive land-use plan for this part of Fairfax County (simplified on lower map, opposite page), provided that development is economically feasible without irreparable harm to potential homeowners or to the environment. The problem facing Fairfax County, then, was how best to help guide additional development in the Franconia area and how to integrate it with the character and facilities of the surrounding region.

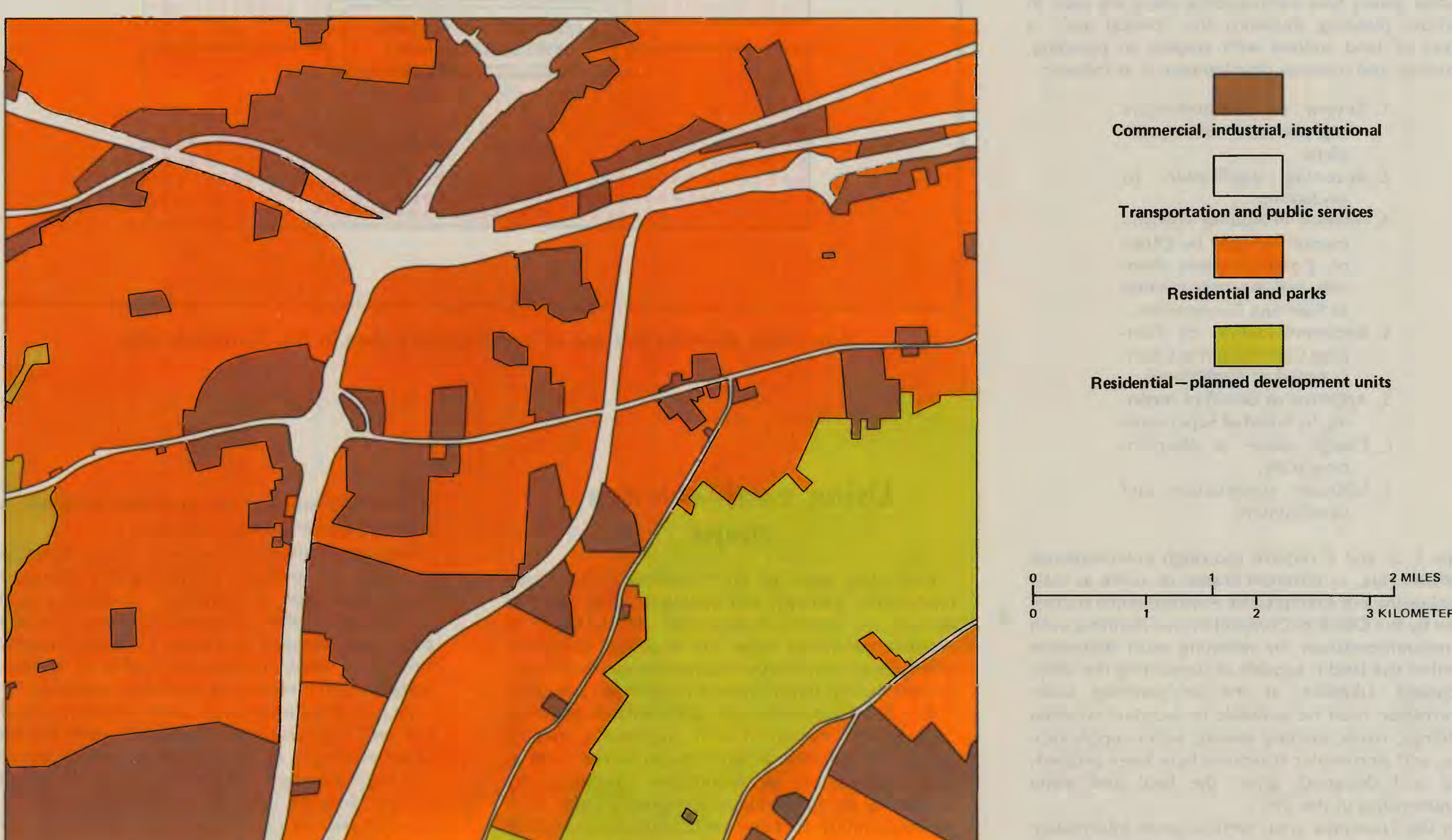
Several geologic conditions will affect development of this area. Because the upland area lies at the headwaters of three drainage basins, the probability of downstream flooding and siltation—a common problem where urbanization increases the area of impervious surface—will require a comprehensive storm-water management program. The area also has many slopes underlain by expansive clay that has a history of recurrent failure by landslide, slump, and creep. Even level terrain underlain by clay that shrinks and swells may have foundation-stability problems.

Aerial view looking northward across the vacant pitted upland and incised wooded eastern margin of the Franconia area.

"New Franconia": development plan rejected in 1975



Generalized land-use map, Franconia area, 1974



Simplified land-use plan, Franconia area

Development of the project

The issues

As viewed by the Fairfax County Office of Comprehensive Planning, the matters most relevant to further development of the Franconia area are:

1. Serving regional and countywide planning objectives such as planned development housing, environmental quality corridors (open-space system), and intracounty employment opportunities
2. Insuring compatibility with adjacent land uses
3. Making proper use of and upgrading existing transportation and public facilities

Earth-science information is especially useful for determining if space is adequate and appropriate for planned development housing; for providing data to help delineate environmental quality corridors, if present; and for identifying environmental or other physical constraints to transportation and public facilities.

Earth-science maps do not, of course, provide the total basis for the environmental aspects of land-use planning in Fairfax County; considerations such as air quality, noise, vegetation, wildlife habitats, and historical sites also bear on planning decisions. Even so, earth-science data provide the foundation upon which many other land-use aspects are based.

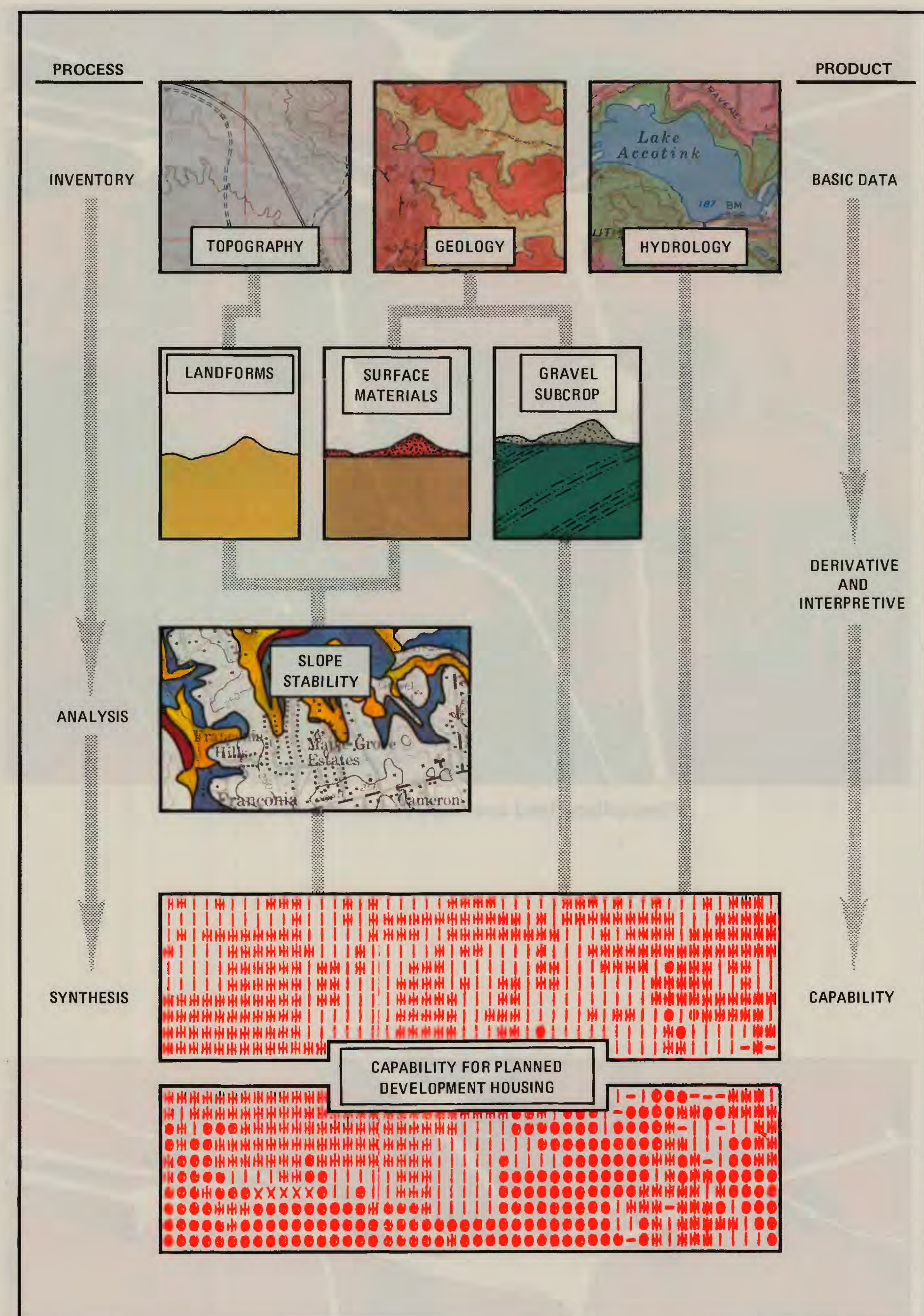
The planning process

A brief review of how environmental analysis and earth-science data fit into the Fairfax County planning process shows how earth-science maps are used in land-use planning decisions. The "critical path" a parcel of land follows with respect to planning, rezoning, and ultimate development is as follows:

1. Review of comprehensive regional and countywide plans.
2. Rezoning application by landowner.
3. Analysis (including environmental analysis) by Office of Comprehensive Planning and recommendation to Planning Commission.
4. Recommendation by Planning Commission to County Board of Supervisors.
5. Approval or denial of rezoning by Board of Supervisors
6. Design review at site-planning scale.
7. Ultimate construction and development

Steps 1, 3, and 6 require thorough environmental baseline data, at different scales, to arrive at valid conclusions. For example, the environmental analysis done by the Office of Comprehensive Planning prior to recommendation for rezoning must determine whether the land is capable of supporting the use(s) proposed. Likewise, at the site-planning scale, information must be available to ascertain whether buildings, roads, sanitary sewers, water-supply facilities, and stormwater structures have been properly sited and designed, given the land and water characteristics of the site.

In the Franconia area, earth-science information has played a role at both levels of review and continues to affect modifications of the development plan.



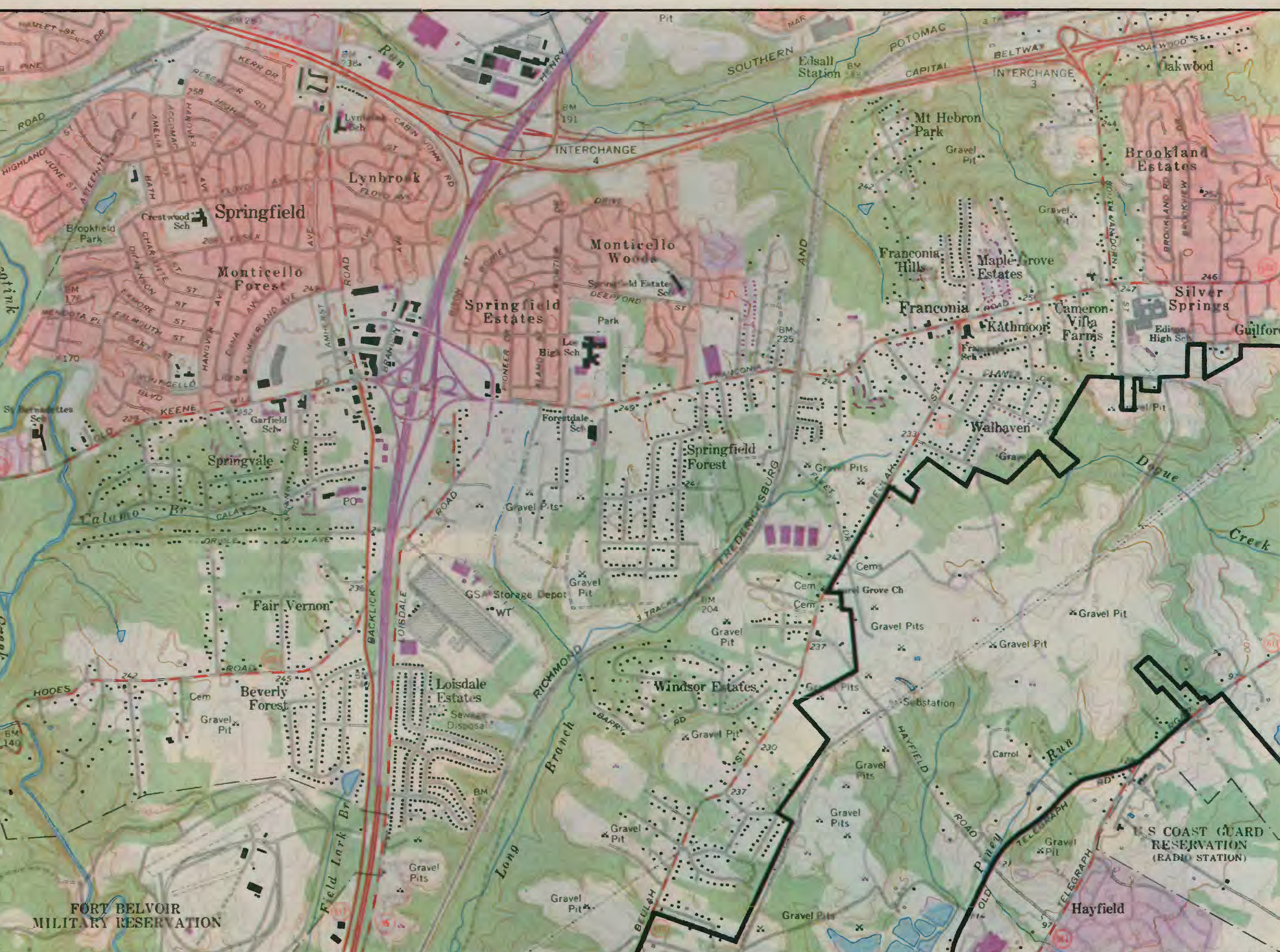
Flow chart showing the use of earth-science data in the Franconia area

Using earth-science maps

Basic data maps of the Franconia area include topography, geology, and hydrology. They serve as sources for specific factors that are extracted to produce derivative maps. For example, the topographic map provides the information needed for the landforms map, which shows critical slope categories. Other derivative maps, such as the surface-materials map, can be combined with engineering data to provide information about relevant factors such as mineral resources or foundation conditions. By combining derivative maps, interpretive maps, such as slope stability, are generated. Finally, by combining derivative maps and selected basic data, a synthesis of information provides some possible solutions to land-use planning problems. The rest of this chapter presents the basic and derivative maps used in review of the proposed development plan.

The process starts with "inventory" (basic data maps), proceeds to "analysis" (derivative and interpretive maps), and then to "synthesis" (capability maps). In evaluating the Franconia proposal, computer processing was used to prepare composite maps and provide a rapid, inexpensive means of weighting variables and considering alternative solutions.

As part of the inventory process, planners consider not only the earth-science capability data but such other aspects as air quality, noise, wildlife habitats, and vegetation type to determine land-use suitability for the area. In turn, this environmental input is incorporated with such other factors as adjacent land use, economics, housing needs, transportation, and public facilities to reach final land-use recommendations.



SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty — Light-duty

Medium-duty — Unimproved dirt

Interstate Route — U. S. Route — State Route

ANNANDALE, VA.
N3845—W7707.5/7.5

1965
PHOTOREVISED 1971
AMS 5561 I SW—SERIES V834

Topographic map showing the Franconia area
Proposed development outlined.

Topographic map

The topographic map provides a wealth of information fundamental to land-use planning. In the Franconia area the topographic map (above) is accurate to the publication date, 1965, with photo-revisions of cultural changes added in 1971. At the scale of 1:24,000 (1 inch=2,000 feet), it is the base on which all other map data have been compiled. It depicts the topography, the road and rail network, the densely urbanized areas, and the wooded parklands which constitute the framework within which development of the barren gravel pits and other undeveloped tracts must be harmoniously integrated.

Most of the proposed Lehigh development is outlined in the southeast (lower right) part of the map, and on all the maps that follow. The eastern and southern limits of the development go slightly beyond the map edges, so they have been omitted.

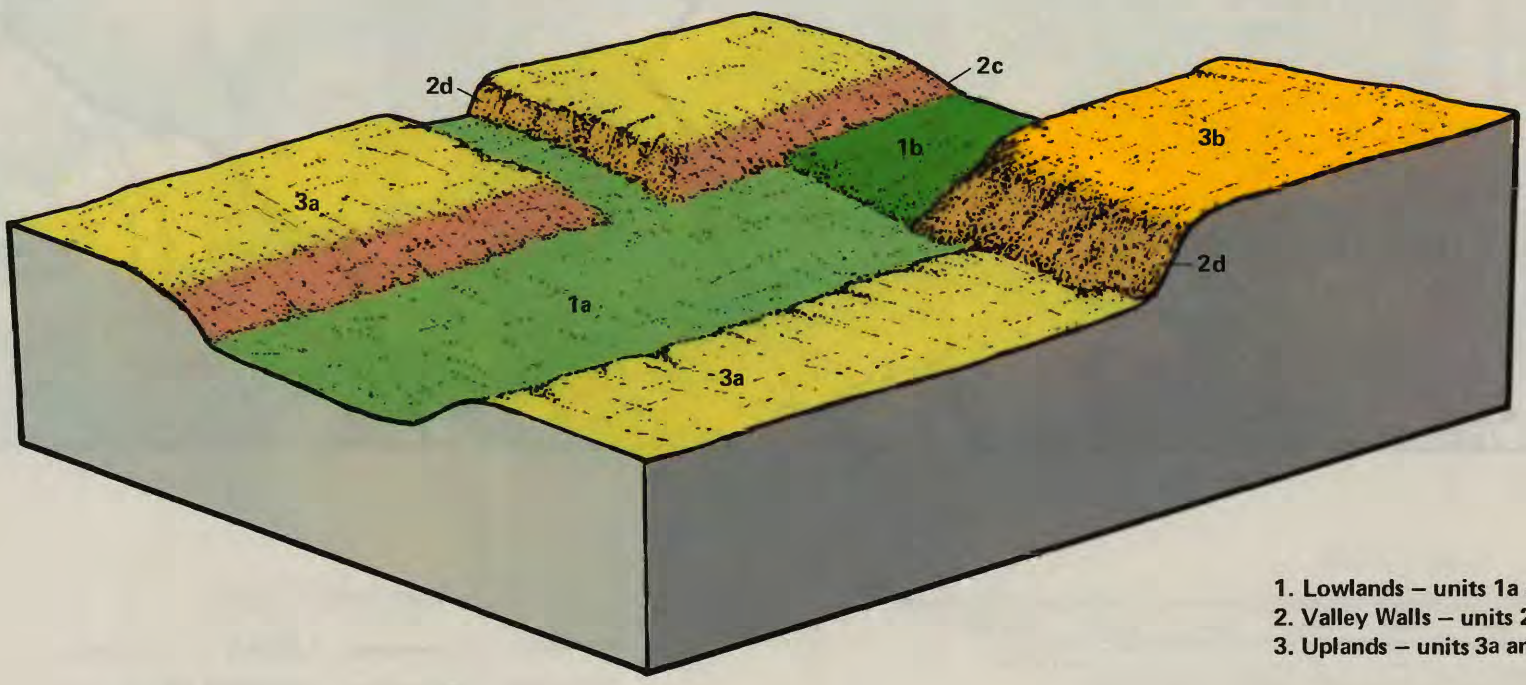
Landforms map

The landforms map (opposite page) is derived directly from the contours on the topographic map. The slope categories mapped, and illustrated on the sketch shown below, were selected by the Fairfax County Office of Comprehensive Planning to satisfy the greatest number of requirements for planning and for engineering design review. Delineation of slopes greater and less than 15 percent (about 8½°) is needed to prepare a slope-stability map, as steeper slopes are less stable where underlain by most near-surface materials.

The map shows planners at a glance, by color, where the steep slopes are that may prevent or constrain certain types of development. It also shows the broad, nearly flat upland and lowland areas where topography poses few constraints to transportation or construction.

Landforms in the Franconia area are intimately related to earth-shaping processes—stream erosion and deposition being dominant in the lowlands, slow gravitational movement of earth materials most important on valley walls, and weathering in place most significant on the uplands.

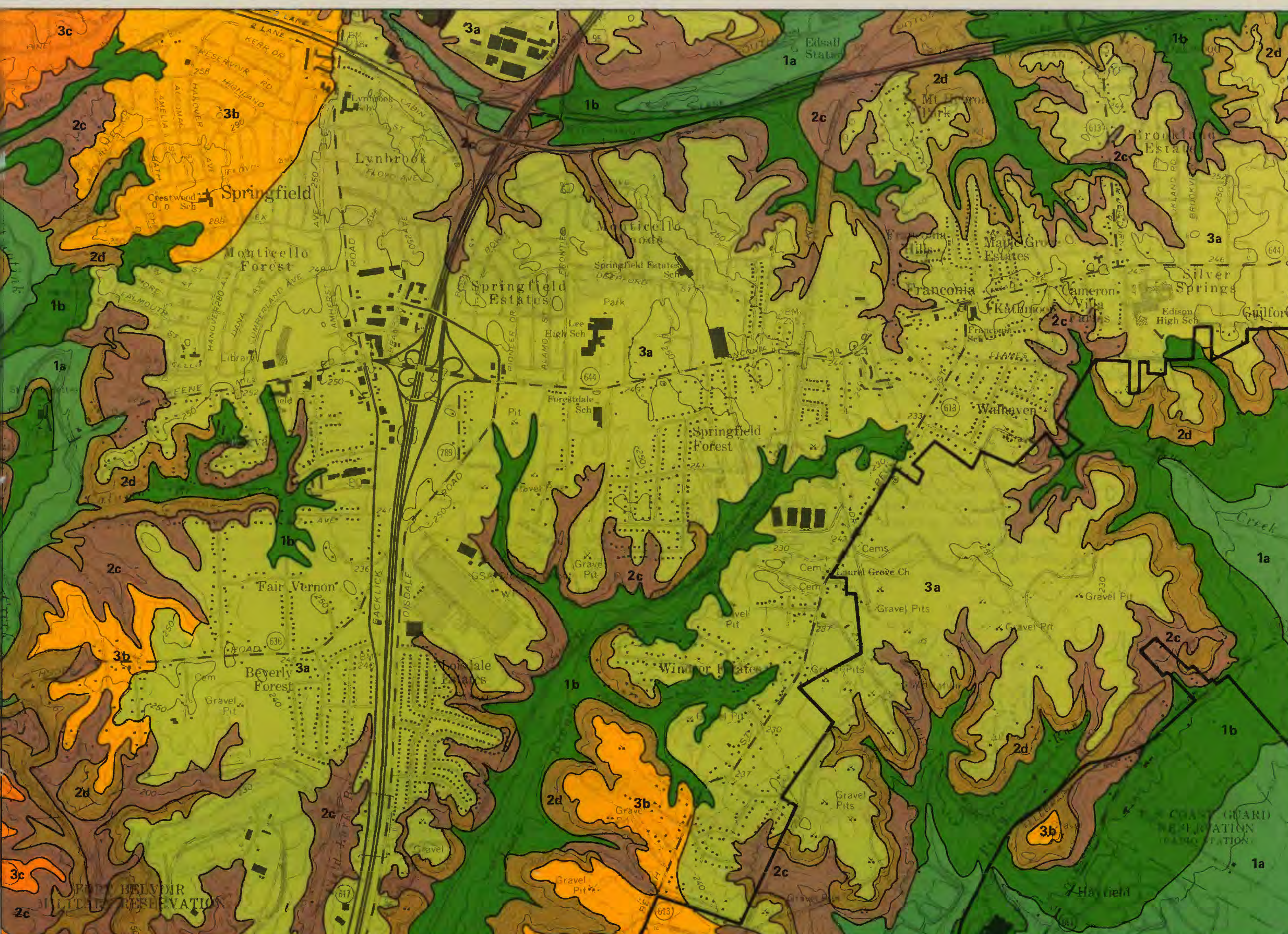
Some landforms of the Franconia area: level uplands, in the foreground, descending by moderately sloping valley walls to gently sloping lowlands.



1. Lowlands – units 1a and 1b
2. Valley Walls – units 2c and 2d
3. Uplands – units 3a and 3b

Diagrammatic sketch illustrating landforms

LANDFORM UNIT	SLOPES	DESCRIPTION
Lowlands		
1a	Less than 3 percent	Nearly level flood plains of major streams; underlain by alluvium and subject to periodic flooding of varying intensity
1b	Less than 8 percent	Gently sloping plains; locally underlain by alluvium and subject to flooding by major storms
Valley Walls		
2c	8 to 15 percent	Moderately sloping valley walls; transitional between valley flood plains and the adjacent uplands
2d	15 percent or more	Includes the steeper valley walls, with slopes generally 15 - 30 percent, with maximum of 40 percent



From Rogers (1975)

SCALE 1:24 000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

Landforms map, Franconia area

LANDFORM UNIT	SLOPES	DESCRIPTION
Uplands		
3a	Less than 3 percent	Nearly level upland: broad open terrain, marked by gravel pits; dissected by streams that have flat-bottom valleys
3b	3 to 8 percent	Undulating upland, dissected by streams that have cut deep valleys of varying width
3c	8 to 15 percent	Rolling to hilly upland, with locally steep slopes (not shown on sketch)

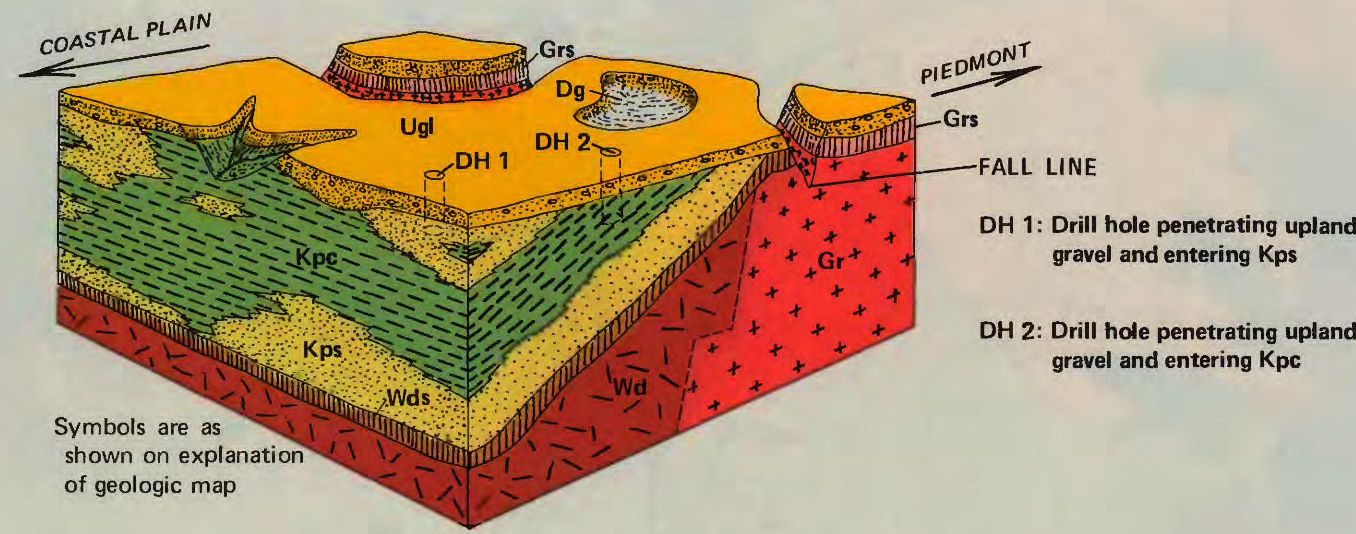
Geologic map

The geologic map of the Franconia area (opposite page) shows the distribution of earth materials. Although the terms and symbols are generally familiar only to earth scientists, the map provides the factual background needed for further environmental analysis and for preparation of the derivative and interpretive maps more directly usable by planners. Hard crystalline metamorphic and igneous rocks (Gr, Wm, Wd) are exposed along Accotink Creek, and soft red-brown saprolite (Grs, Wms, Wds) occurs at the surface in the northwestern and western part of the area. (Saprolite is a porous clay-rich residual material, formed by chemical weathering of crystalline bedrock in which the structure of the original rock is preserved.)

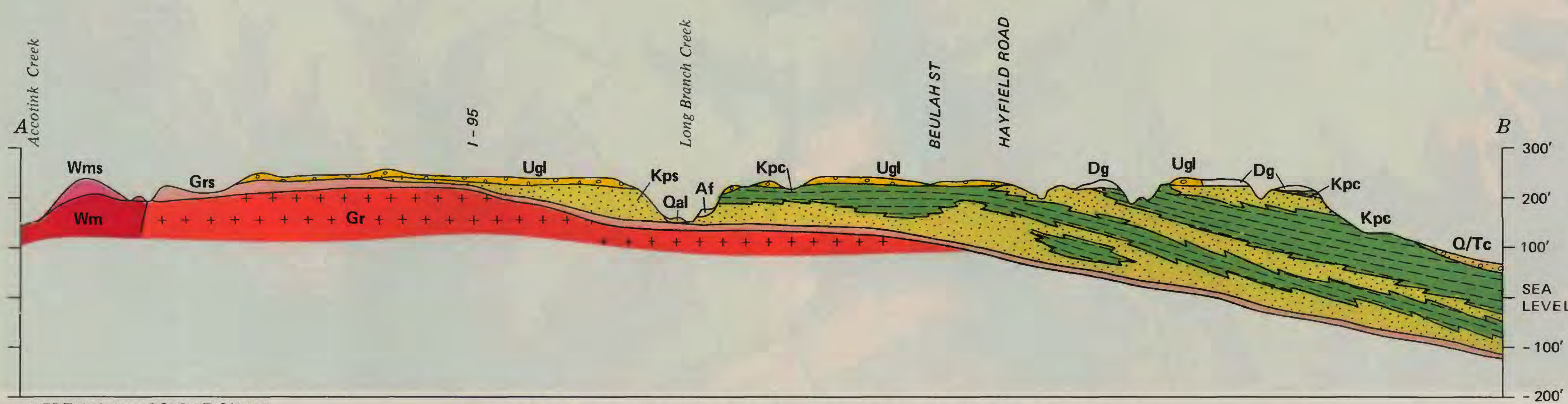
Saprolite is overlain by poorly consolidated much younger sediments of the Coastal Plain along the Fall Line, an imaginary line formed by joining the low falls or rapids of major streams that form a barrier to navigation at the boundary between the soft younger rocks of the Coastal Plain and the harder rocks of the Piedmont. In the Franconia area, the Coastal Plain deposits consist of a wedge of sediments that thickens to the east. Beds or layers of sediment within this wedge are inclined, or dip, gently to the southeast, parallel to the slope of the base of saprolite, as shown on the simplified geologic cross-section *A–B* (below) and the geologic sketch (right). These sediments have been subdivided into two units, one mainly sand with scattered quartz and clay pebbles (Kps), the other mainly silty or sandy clay (Kpc). Each unit grades laterally into the other, the sand unit containing interbeds of sandy clay and the clay unit containing thin interbeds of sand (see photograph below).

Younger upland gravels (Ugl) overlap the Coastal Plain sediments and rest directly on saprolite in the western part of the Franconia area. The upland gravels blanket the surface, forming the top of the plateau. Underlying units are exposed mainly along ravine and gully sides.

Terrace gravels (Qt) that locally include thin colluvium or deposits of slopewash (Q/Tc) border deposits of stream valley alluvium (Qal). Disturbed ground (Dg) and fine-grained sediment pond fill (As) occur near abandoned gravel pits, and artificial fill (Af) is present in low areas along railroads and highways.

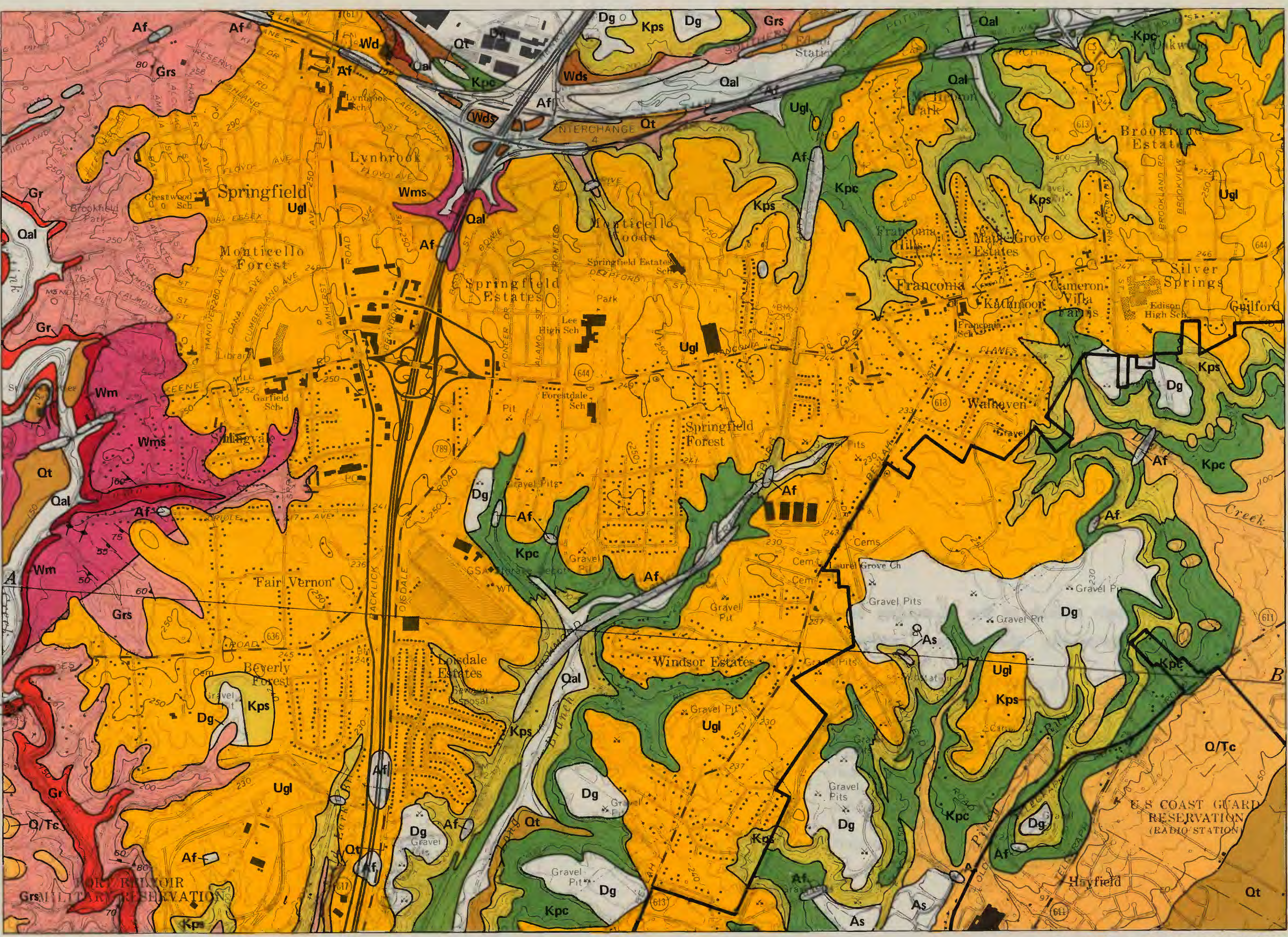


Geologic sketch of Franconia area



Simplified geologic cross section along line A–B, Franconia area

Coastal Plain sediments in the Franconia area, consisting of interbedded sand (light color) and clay.



From Huffman, Froelich, and Force (1975)

SCALE 1:24 000

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1 .5 0 1 KILOMETER

Geologic map of Franconia area

ARTIFICIALLY CHANGED GROUND

- Af — Artificial fill
- As — Sediment pond fill
- Dg — Disturbed ground

SEDIMENTARY ROCKS

- Qal — Alluvium (Quaternary)
- Qt — Terrace deposits (Quaternary)
- Ugl — Upland gravel (Quaternary)
- Q/Tc — Q/Tc-colluvium (Quaternary and (or) Tertiary)

COASTAL PLAIN DEPOSITS

- Kps / Kpc — Potomac Group (Cretaceous)
  - Kps – sand and gravel
  - Kpc – clay and silt

METAMORPHIC AND IGNEOUS ROCKS (Precambrian and (or) Lower Paleozoic)

PIEDMONT ROCKS

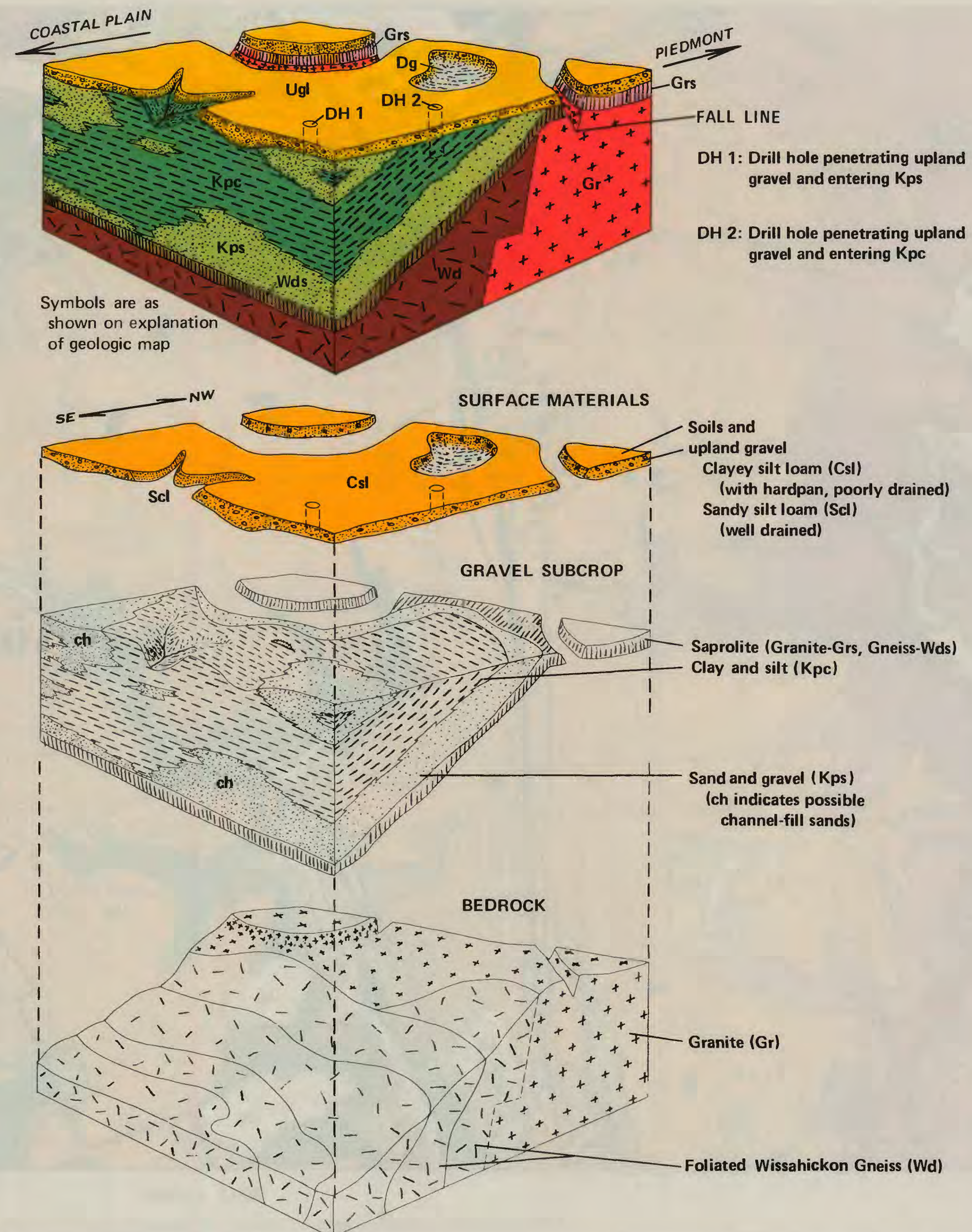
- Grs / Gr
  - Gr – granitoid rocks (Clarendon granite, Occoquan granite, aplite, pegmatite, quartz diorite, etc.)
  - Grs – saprolite on granitoid rocks
- Wms / Wm — Wissahickon Formation
  - Wm – metagraywacke
  - Wms – saprolite on metagraywacke
- Wds / Wd
  - Wd – diamictite gneiss
  - Wds – saprolite on diamictite gneiss

Symbols

- Contact, approximately located
- 70 — Strike and dip of predominant foliation
- Strike of vertical foliation
- 70 — Strike and dip of predominant joint set
- Strike of vertical joint set
- Gravel pit
- A——B Cross section on opposite page

Surface materials map

The surface materials map (opposite page) is derived mainly from the geologic map but also incorporates relevant soils data. Definition of map units is based largely on their engineering characteristics (see table below). For example, different geologic units such as Occoquan Granite and Wissahickon Formation are grouped together as unit 7, bedrock, because their engineering properties are similar to one another but are very different from other surface units. By using the surface materials map and accompanying table in conjunction with additional field observations, other maps can be derived that deal with specific properties applicable to solving many different problems.



Geologic sketch of the Franconia area, emphasizing the surface materials

The wedge edge of Coastal Plain sediments overlies saprolite formed on much older gneiss and granite and underlies much younger upland gravels. The upland gravels have been dug as a source of sand and gravel, and the granite is locally quarried as crushed stone. Soils on the upland gravel locally contain a shallow hardpan which impedes downward percolation of rainwater and locally protects the swelling clay from moisture.

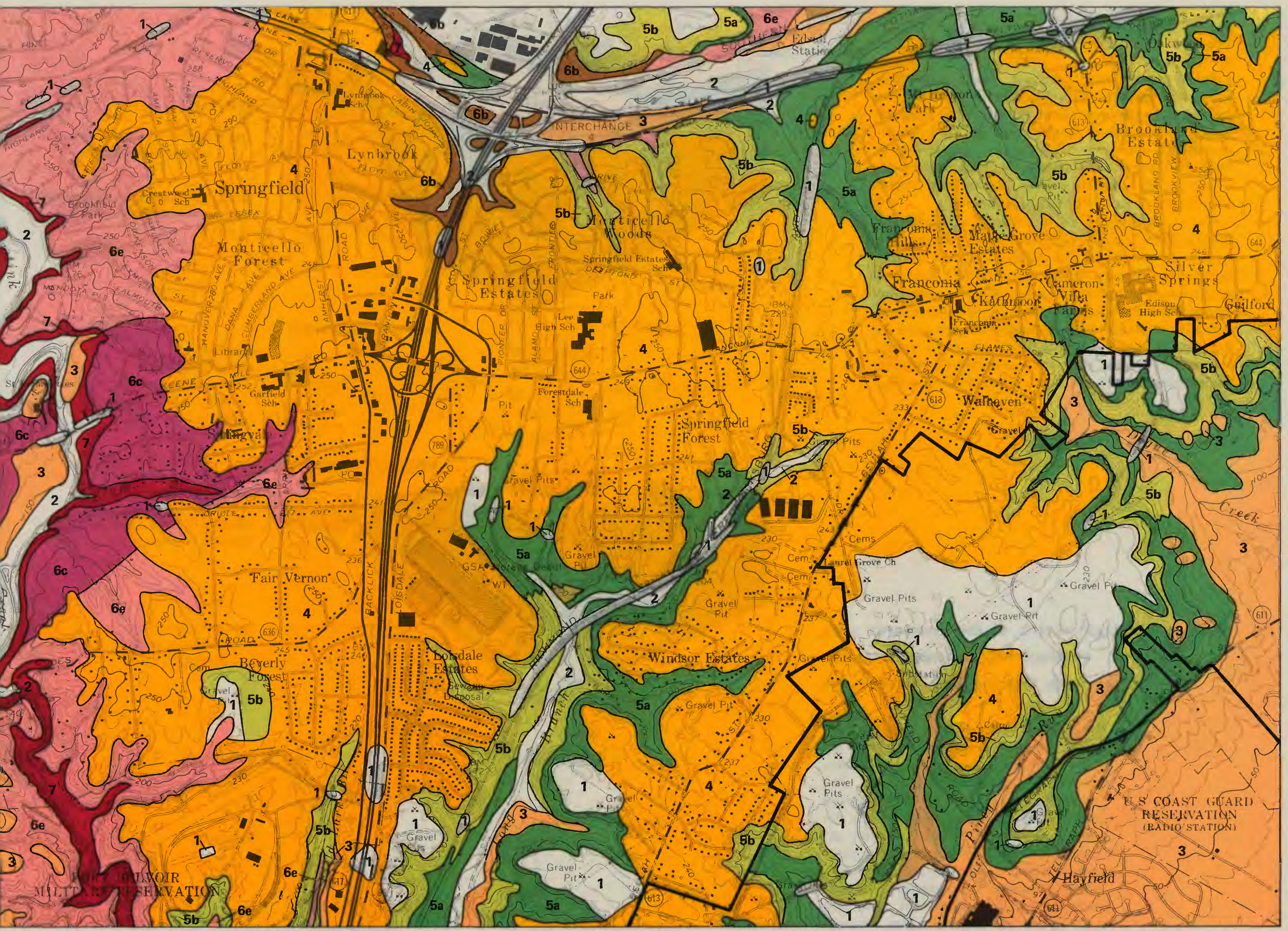
An example of a specific properties map would be one of potential mineral resources in the Franconia area that might show only the available surface sources of sand and gravel (unit 4), sand (unit 5b), crushed stone or building stone (unit 7); or a map showing shallow foundation conditions in the Franconia area that might define saturated alluvium (unit 2) as "low strength," sand and gravel (units 4 and 5b) as "moderate strength," and bedrock (unit 7) as "high strength" (see table right).

Soil characteristics can be incorporated into this map, particularly by means of the columns on unified soil classification and "permeability." A derivative map of surface drainage and infiltration characteristics might classify "poorly drained soils" as those found on units 1, 2, 4, 5a, and 7, "well-drained soils" on units 3 and 5b, and "fairly well-drained soils" on units 6b, 6c, and 6e.

Planners frequently need information related to road construction and slope stability, which can be major development cost items. The unified soil classification column is a useful indicator of the soil support characteristics for city streets. Slope-stability characteristics of fine-grained soils during construction can be estimated from the strength properties column. The strength properties column can also be used by engineers to estimate which units are adequate for deep foundations where piles are needed.

Characteristics of surface

Map symbol	Name of unit (symbol on geologic map)	Topographic form and mode of occurrence	Maximum thickness (feet)	Unified soil classification[1]	"Permeability"[2]	Ease of excavation
1	Artificially changed ground:					
	Af	Narrow dams or wedges where roads and railroads cross streams and saddles; extensions of flat land for buildings.	50	Variable	Good to fair	Easily moved with heavy power equipment.
	As	Flat; in artificial ponds near gravel and washing plants.	30	CH, CL	Poor	do
	Dg	Variable; excavated gravel pits, in places refilled.	20	Variable	Variable	do
2	Alluvium (Qal)	Nearly level plains along streams.	50	SW, SP, SM, GW, CP, CL, OL	Excessive to good	do
3	Terraces and colluvium (Qt, Q/Tc).	Nearly level plains. Terraces are river deposits; colluvium includes slump and creep deposits on slopes, lag gravel on flat uplands.	30	GP, GM, SP, SM, ML, CL	Excessive to poor.	do
4	Upland gravel (Ugl)	Extensive flat plateaus with eroded borders. Sheetlike deposits of gravel and sand.	30–50	GP, GM, SP, SM, ML, CL	Excessive to good except through hardpan; hardpan may change seasonally.	do
5a	Clay and silt (Kpc) Unconsolidated sand and clay (Kpc)	Gently southeast sloping surface locally dissected by modern streams; outcrops in steep sides of valleys and scarps between upland and lowland surfaces; former river channel and flood-plain deposits; may be deltaic in part.	120	CL, CH, SC	Poor	Easy to moderately difficult with heavy power equipment, depending on soil stiffness.
5b	Sand and gravel (Kps)	do	150	SW, SM, SC, GM	Good	Easy with heavy power equipment.
6b	Saprolite:					
	Wds	Rolling, hilly upland surfaces; gentle to steep sided valleys. Saprolite (weathered rock) more than 10 feet thick on various fresh crystalline bedrock types.	80±	SM, SL, ML, CL	Fair to poor	Easy to moderately difficult with heavy power equipment, depending on hardness.
6c	Wms	do	80±	SM, SC, ML, CL		do
6e	Grs	do	120±	SM, SC, ML	Fair to good	do
7	Fresh bedrock outcrop (Wd, Wm, Gr).	Walls or ledges in sides of large valleys and in smaller stream banks. Fresh bedrock with less than 10 feet of overburden.			Poor	Difficult; usually requires blasting.



SCALE 1:24 000

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From Force and Froelich (1975)

materials, Franconia area

Strength properties[3]		Allowable footing loads [tons per square foot (TSF)]	Remarks
Fine grained	Coarse grained		
Medium	Medium	To 1.5 TSF; low to moderate.	
Very soft	....	None	Includes swelling clay.
Very soft to medium.	Loose to medium.	None to 1.5 TSF; none to moderate	Changes natural drainage.
........do........	........do........	None for organic silt and clay to 2 TSF for coarse-grained soils; allowable loads generally low.	Subject to recurrent flooding; usually saturated.
Soft to medium.	Loose to compact.	Less than 1 TSF for fine-grained soils, 1.5–3 TSF for coarse-grained soils; allowable loads generally low to moderate.	May be saturated at base. Can be used as aggregate if fresh and sized.
Medium to very stiff.	........do........	0.5–3 TSF for fine-grained soils, 1.5–4 TSF for coarse-grained soils; allowable loads generally moderate to high.	Removing hardpan may permit water to enter underlying swelling clay (5a). Can be used as aggregate if fresh and sized. Color usually red, brown, or yellowish brown (matrix).
Medium to extremely stiff.	....	1–5 for plastic clay,[4] 4–7 TSF for sandy clay; allowable loads generally moderate to high.	Includes much swelling clay which expands when wet, shrinks when dry; landslide prone; tends to crack foundations. Some clay may be used for lining retention ponds. Unweathered color: light gray to light olive gray; weathered: reddish brown.
....	Medium to very compact.	5–8 TSF; allowable loads generally high.	Porous; readily absorbs surface water; potential infiltration ponds where properly engineered. Potential aquifer. Aggregate for concrete where fresh and washed. Unweathered color: light gray; weathered: brown, reddish brown, yellowish brown.
Medium to extremely stiff. (Joints may be filled with weak soil or clay)	Loose to very compact.	1.5 TSF at ground surface to 5 TSF at depth where rock fabric is retained; allowable loads moderate to high.	Used as fill, difficult to compact owing to high mica content. Significant quantities of ground water in porous, relatively permeable units.
....	....	....	Do.
....	....	....	Do.
(Compressive strength range, 5,000–15,000 lb/in²)	....	10–60 TSF; allowable loads very high.	Can be crushed for use as aggregate; granite formerly quarried. Generally poor as road metal owing to rapid weathering characteristics. Some ground water available in fractures and joints.

Footnotes to table:

[1]Unified soil classification of Corps of Engineers 1953–57:
[Sequence of symbols in opposite table indicates relative abundance]

Major division		Group symbol	Soil description
Coarse grained (over 50 percent by weight coarser than No. 200 sieve).	Gravelly soils (over half of coarse fraction larger than No. 4 seive).	GW	Well-graded gravels, sandy gravels.
		GP	Gap-graded or uniform gravels, sandy gravels.
		GM	Silty gravels, silty sandy gravels.
		GC	Clayey gravels, clayey sandy gravels.
	Sandy soils (over half of coarse fraction finer than No. 4 sieve).	SW	Well-graded sands, gravelly sands.
		SP	Gap-graded or uniform sands, gravelly sands.
		SM	Silty sands, silty gravelly sands.
		SC	Clayey sands, clayey gravelly sands.
Fine grained (over 50 percent by weight finer than No. 200 sieve).	Low compressibility.	ML	Silts, very fine sands, silty or clayey fine sands, micaceous silts.
		CL	Low plasticity clays, sandy or silty clays.
		OL	Organic silts and clays of low plasticity.
	High compressibility.	MH	Micaceous silts, diatomaceous silts, volcanic ash.
		CH	Highly plastic clays and sandy clays.

[2]Permeability is the quality of a soil that enables it to transmit water and air; in this table, the term refers to percolation rates in septic tank drain fields.

[3]Consistency and compactness scales:

Fine-grained soils		
Silt and clay consistency	Unconfined compressive strength (TSF)	Coarse-grained soils, sand, and gravel compactness
Very soft	0.25	Very loose
Soft	0.25–0.5	Loose
Medium	0.5–1.0	Medium compact
Stiff	1.0–2.0	Compact
Very stiff	2.0–4.0	Very compact
Extremely stiff	4.0	

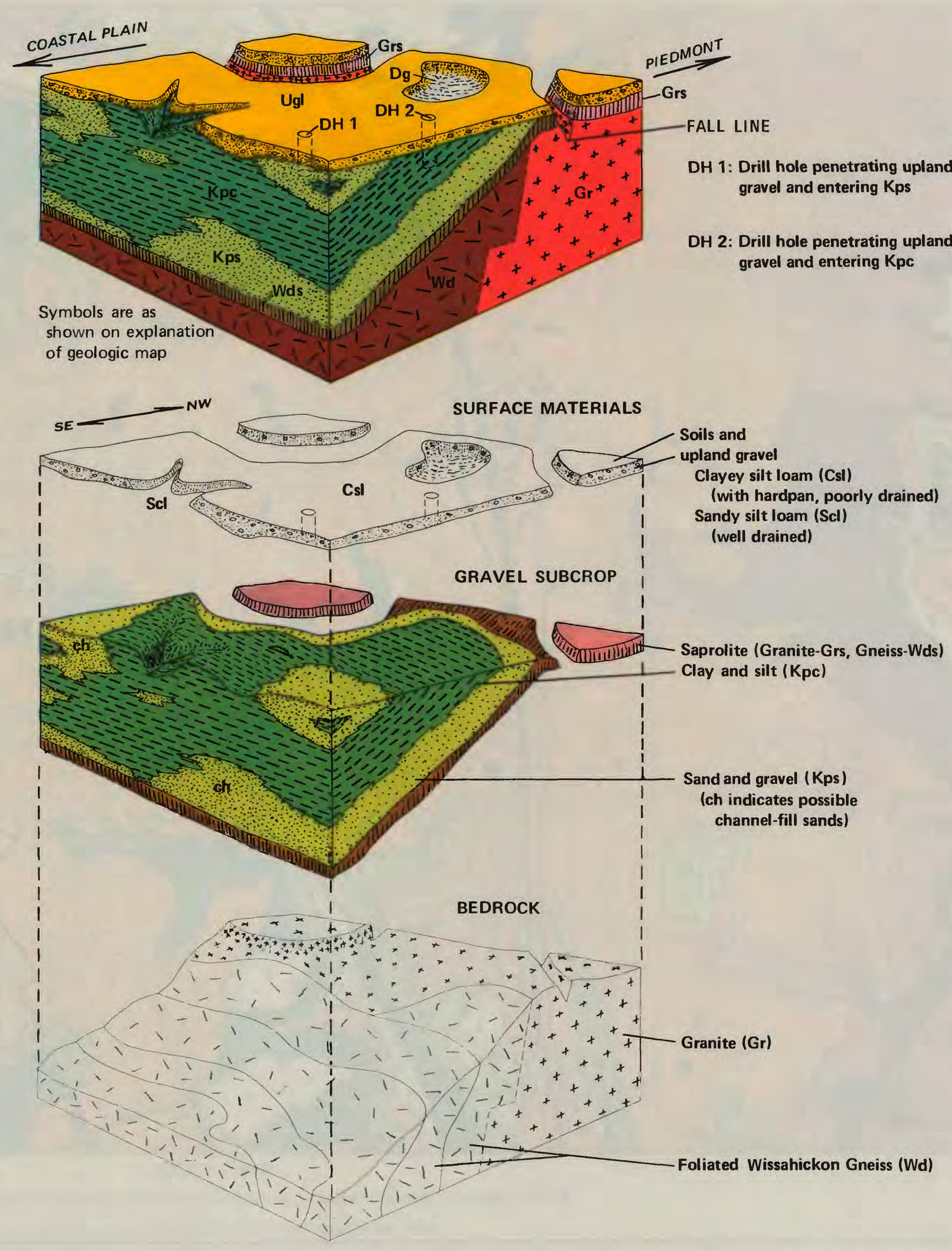
[4]The swelling potential of highly plastic clays must also be considered in engineering design.

Surface materials map, Franconia area

Subcrop map

The subcrop map (opposite page) shows the subsurface material that lies directly beneath the surface materials units of the upland. If the soils, the entire upland gravel deposit, and the fill in abandoned pits could be peeled away, as sketched at right, the saprolite, clay, and sand units beneath them would appear as shown on the subcrop map. This is also illustrated by the photograph below.

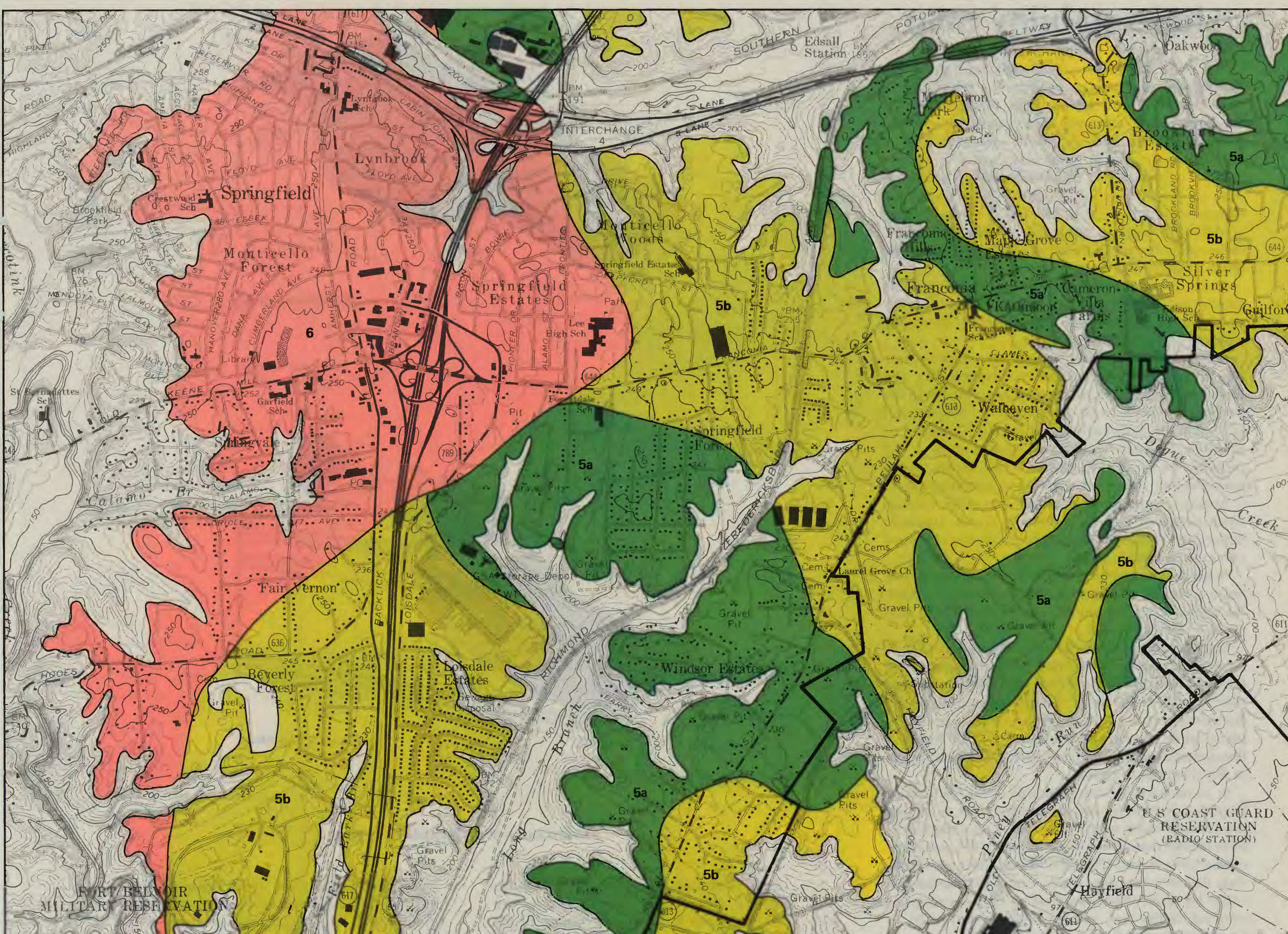
The chief purpose of the map is to show the distribution of impermeable clay, which is critical to evaluating infiltration and shallow drainage characteristics. Another use for the map is to help assess the general deep foundation conditions, where piles and caissons must be used, by matching the subcrop unit with the column on strength properties (see table on surface materials) relating to bearing strength. Information for specific sites, of course, would require engineering studies at a much more detailed scale.



Geologic sketch of the Franconia area, emphasizing subcrop materials beneath the soil and gravel cover

The wedge edge of the Coastal Plain sediments overlies saprolite formed on much older gneiss and granite and underlies much younger upland gravels. The Coastal Plain rocks consist of interfingering sand and silty clay beds which were deposited by rivers. The sand may fill old channels and the clay and silt may be overbank floodplain deposits, natural levees, oxbow deposits, and possibly deltaic. Under certain conditions the sand acts as an aquifer for ground water, whereas the clay, which swells when wet and is slide prone, forms confining beds.

Crossbedded sand beds beneath gravel cover.



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1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

Subcrop map, Franconia area

5a — Clay beneath upland gravel (4) or fill (1)

5b — Sand beneath upland gravel (4) or fill (1)

6 — Saprolite beneath upland gravel (4) or fill (1)

Slope-stability map

The slope-stability map (opposite page) shows the distribution of materials of different relative slope stabilities in four categories: high, moderately high, moderately low, and low. These categories indicate the relative possibility of future problems both in natural slopes and in manmade cuts. The relative stability is determined by combining the landforms map (p. 75) that includes slope categories with the surface-materials map (p. 79) and the related table, as different materials are stable at different slopes. Information for specific sites naturally requires much more detailed engineering studies.

Areas of high stability are generally level or slope gently regardless of the type of underlying material, or slope moderately but are underlain by strong material such as bedrock.

Areas of moderately high stability generally include clay on gentle slopes, sand on moderate slopes, and saprolite and bedrock on steep slopes. Failures in the bedrock are likely to be in the form of rockfalls, and failures in the saprolite will probably be controlled by joints or foliation. Failures in clay and sand will probably be by local slumps or creep, except where gentle slopes are oversteepened by construction.

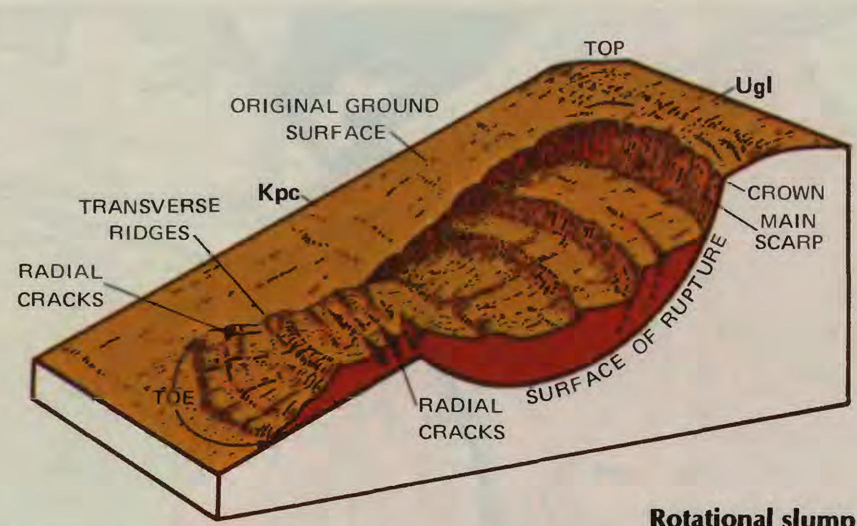
Areas of moderately low stability are either sand on steep slopes or clay on moderate slopes. Naturally occurring slumps and progressive failure by creep are common in this category.

Areas of low stability, which are extensive in this region, are those where clay occurs on steep slopes. Naturally occurring slumps, both recent and old, cover a significant part of such areas.

Small landslides are shallow, perhaps not more than 5 feet deep. Larger landslides, more than about 100 feet long from the top to the toe of the slide, may be as much as 30 feet deep. Large landslides in the Franconia area are of three types: rotational slumps, planar glide blocks, and combinations of these two. Rotational slumps and planar glide blocks are shown in the diagrams at right.

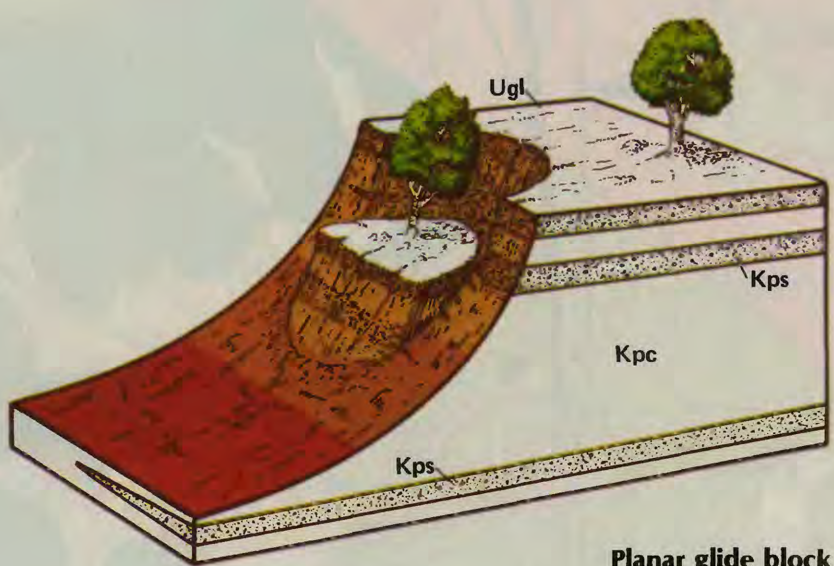
In some parts of the Franconia area, the toes of large slumps have moved hundreds of feet, as though the soil had been nearly liquefied. Two glide blocks have moved downslope more than 400 feet, and many others have moved 200 feet or more. Most such landslide deposits consist of weak, fractured material that could be reactivated. Reactivation can be caused by removal of the toe, overloading the crown, or by blockage of natural ground-water seepage.

Almost all moderate and steep slopes on clay show evidence that surface materials have slowly moved downslope. Disturbing these slopes further by construction may cause renewed movement, acceleration of soil creep, or induce new slides.



Rotational slump

Diagrams modified from Varnes (1958)



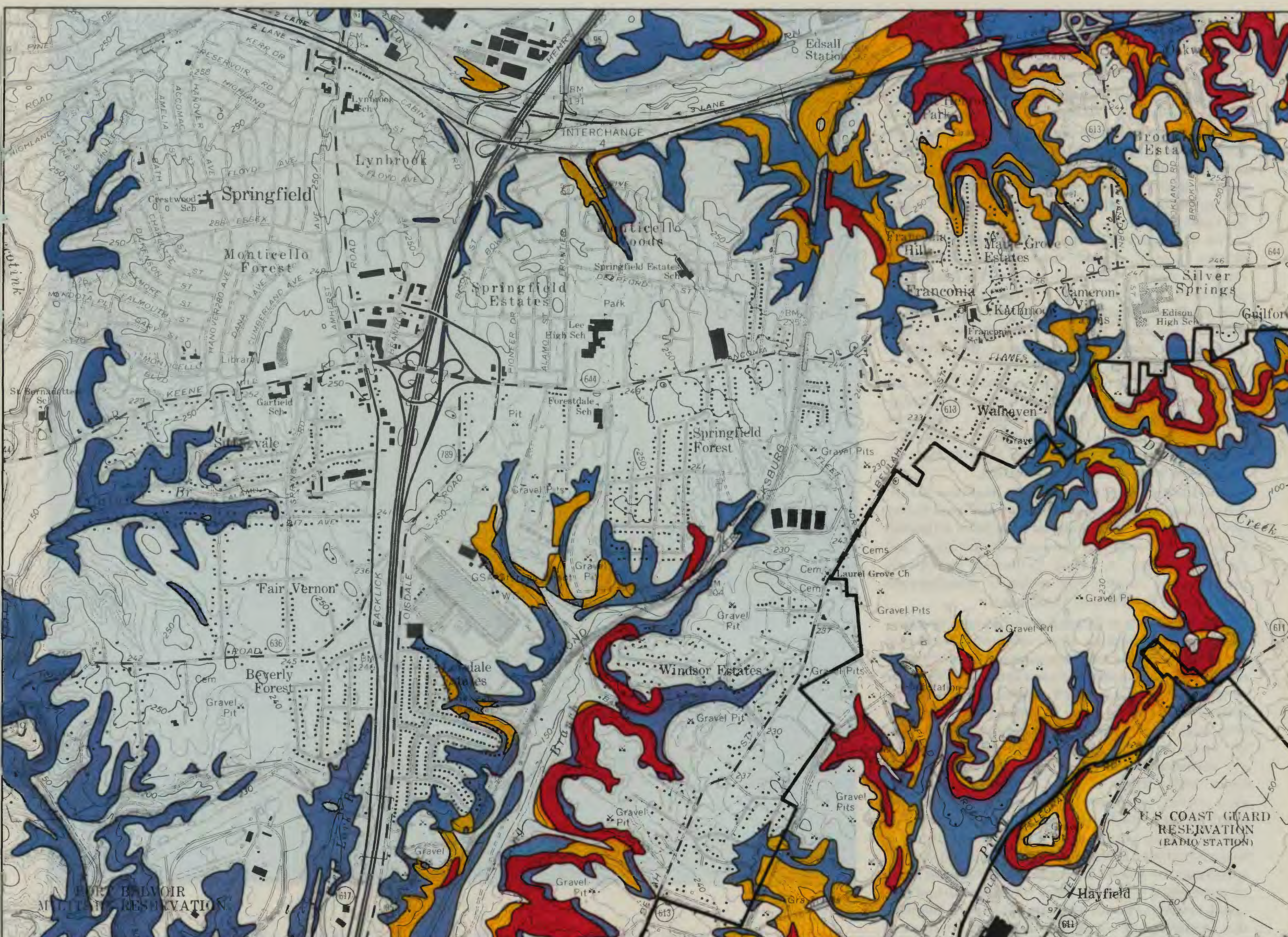
Planar glide block

Franconia area landslide types

Rotational slumps consist of highly disturbed mixtures of materials; they are characterized by a scarp at the top of the slide, by transverse cracks and ridges, and radial cracks and hummocky ground at the toe. The surface of rupture is arcuate in cross section. This type of landslide is commonly present in the Kpc unit, and in Kpc capped by the Ugl unit.

Planar glide blocks are slides composed of essentially intact material that moved in the manner of a block sliding down a plane. Planar glide blocks may be evidenced by the displaced topographic position of Ugl and are commonly underlain by the Kpc unit. Numerous planar glide blocks are present on the steep slopes near Dogue Creek.

Typical landslides on steep slopes underlain by clay in the Franconia area.



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Slope-stability map, Franconia area

RELATIVE SLOPE STABILITY	SURFACE MATERIAL UNIT	GEOLOGIC MAP SYMBOL	LANDFORM UNIT[1]
Low (red)	5a (Clay)	Kpc	2d
Moderately low (orange)	5a (Clay) 5b (Sand)	Kpc Kps	2c, 3c 2d
Moderately high (blue)	1 (Fill) 3 (Gravel) 5a (Clay) 5b (Sand) 6 (Saprolite) 7 (Bedrock)	Dg, Af Qt, Q/Tc Kpc Kps Wds, Wms, Grs Wd, Wm, Gr	2d 2c, 2d 1b, 3b 2c, 3c 2d 2d
High (white)	All other combinations of surface material units and landform units		

[1] Slopes associated with different landform map units are as follows:

- 1a, less than 3 percent
- 1b, 3 to 8 percent
- 2c, 8 to 15 percent
- 2d, greater than 15 percent
- 3a, less than 3 percent
- 3b, 3 to 8 percent
- 3c, 8 to 15 percent

Note: *Although an area is designated as being in a relatively low stability category, engineering studies at a given site may establish that the site is suitable for homes or other types of construction activity.*

Hydrologic map

The hydrologic map (opposite page) provides information on surface water for land-use planning in the Franconia area. The map shows the drainage net and flood-prone areas—the chief hydrologic conditions that have influenced the development patterns and construction plans in the Franconia area. Several aspects of ground water are significant for planning, but unfortunately the available data are insufficient for confident use.

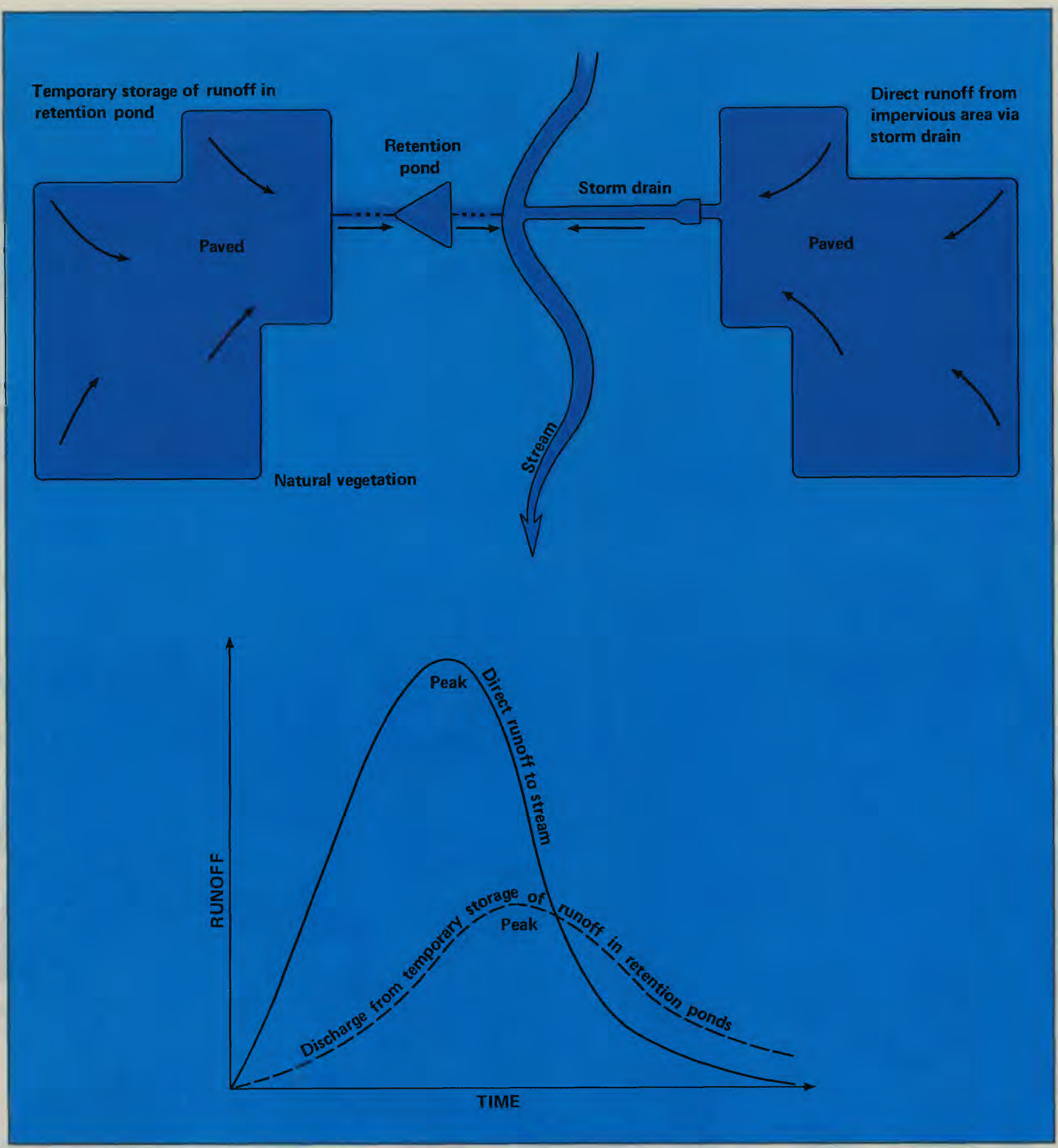
The drainage net shows the location of drainage divides, ponds, streams, and gullies. The net is obtained directly from the topographic map, with additional data interpreted from contours that indicate the shape of the eroded land surface sloping toward perennial streams. The inferred surface drainage in shallow gullies shows the probable avenues of overland flow.

Nearly all the proposed development lies in the headwaters of Dogue Creek and several of its tributaries. Development here is likely to aggravate downstream flooding and deposition of silt. This is a common problem wherever urbanization increases the area of impervious surface.

Flood-prone areas shown on the map have a 1-in-100 chance on the average of being inundated during any year. The flood boundaries have been estimated from regional relations between stream stage and flood frequency. A county ordinance specifically prohibits any construction within or unauthorized alteration of the 100-year flood plain.

Another county ordinance prohibits new developments from increasing peak overland runoff that may result in increased downstream erosion, sedimentation, and flooding. To insure that storm-water runoff will not cause such adverse effects downstream, excess storm water has been managed in the Franconia area by means of onsite retention ponds, or onsite recharge or infiltration pits that permit the collected runoff to percolate downward to the water table. Either of these methods will reduce peak runoff, as shown on the hypothetical hydrograph at right. Recharge pits can be constructed at any site where porous sand (Kps) extends from the bottom of the pit to the water table. To function best, a recharge site should have a depth to the water table of more than 10 feet to allow for excavation. (Only onsite retention ponds are considered here, because the feasibility of using recharge pits involves a complicated determination of the depth to the water table and evaluation of the near-surface thickness and permeability of sand.)

Retention ponds can be constructed at any site where clay beds impede the downward movement of water. Overlaying the distribution of clay (Kpc, 5a) shown on the surface-materials map (p. 79) with the gravel on the subcrop map (p. 81) and on the drainage net defines the potential sites for surface retention ponds. Shallow test borings and percolation tests are needed to confirm the capability of any site selected as a possible retention pond. Using natural surface runoff channels to drain storm water from paved areas to retention ponds makes it possible to manage natural storm waters with less adverse downstream impact. Ultimate disposal may be by both evapotranspiration and controlled discharge.



Hypothetical hydrograph showing reduction of flood peak resulting from use of retention ponds, Franconia area

Typical retention pond designed to reduce flood peaks.

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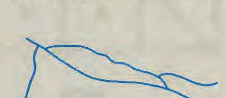
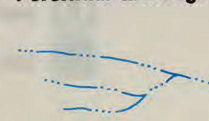
Hydrologic map, Franconia area

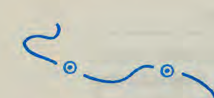
100-year flood limit



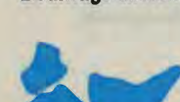
Perennial drainage



Intermittent drainage



Drainage divide



Surface impoundments

Springs

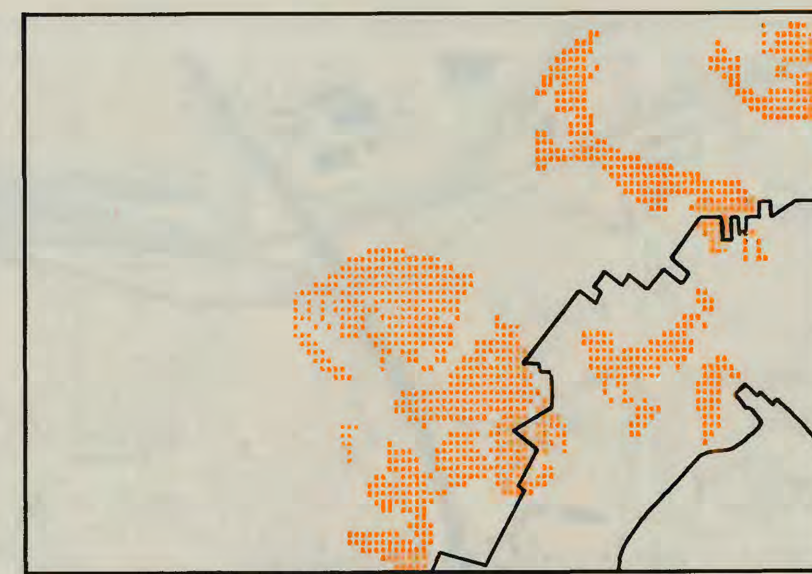
Capability map for planned development housing

In considering the Lehigh proposal, the constraints posed by the existing environment were taken into account, as were the effects on the environment which are likely to follow. The constraints are illustrated by the slope-stability problem: Construction on unstable slopes will be subject to damage from slope movement. Likely future environmental effects are illustrated by the probability of increased frequency and severity of flooding resulting from increased runoff from built-over surfaces. The earth-science factors that require consideration to insure sensitive planning and development are listed in the table below; associated with each factor are related problems and suggestions. All of these factors have entered into preparation of the capability map for planned development housing (opposite page). As a synthesis of the earth-science data and interpretations relevant to development in general, the map was used by the county planners to make substantive recommendations and proposals bearing on the proposed Lehigh development.

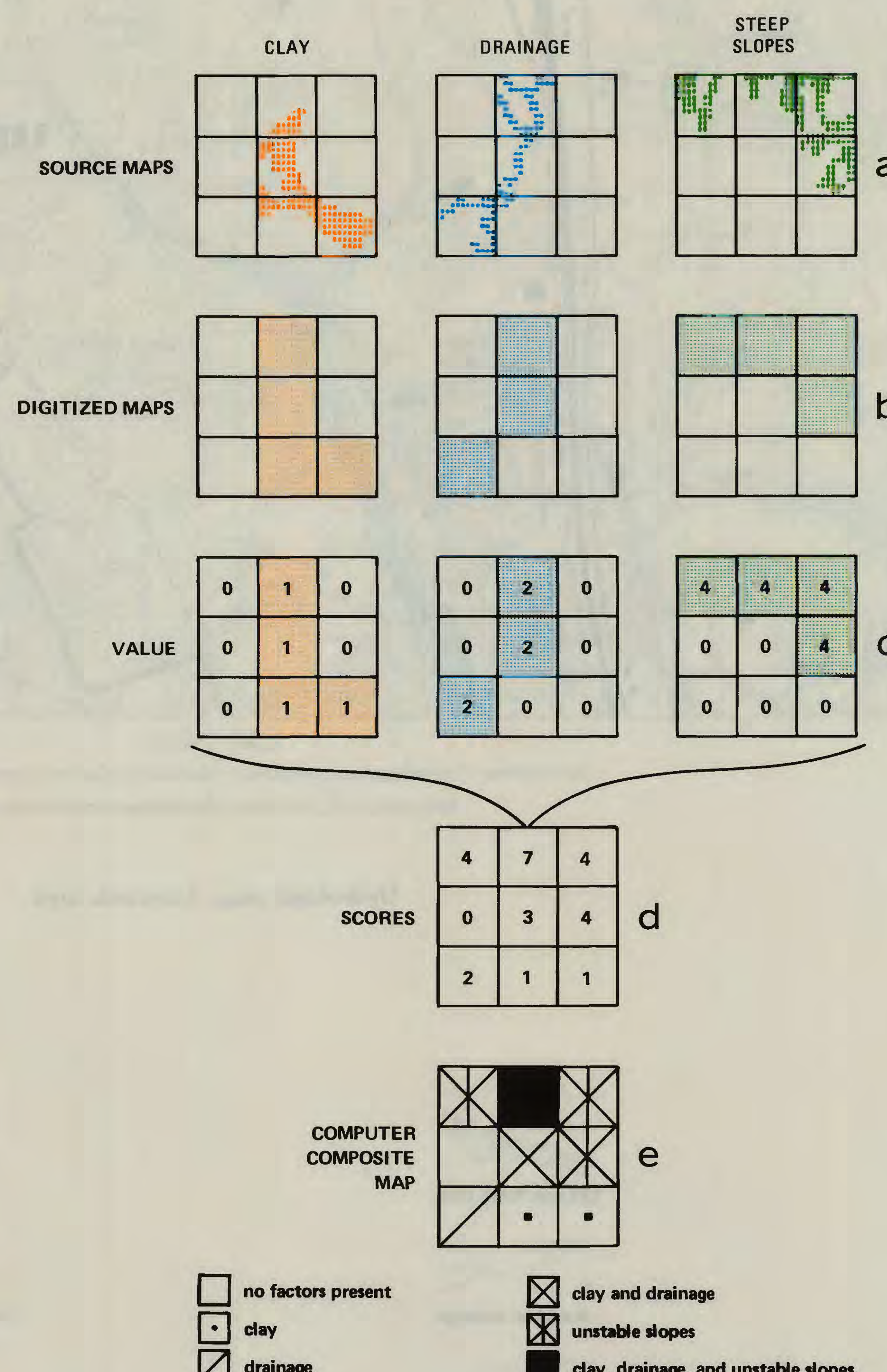
Because of the number of factors involved, the synthesis was carried out by computer composite mapping. This mapping technique is demonstrated by a hypothetical example (right). For the Franconia area, the computer stored the data in the form of three factor maps (above right) which in turn yielded the composite capability map.

In the computer composite map (opposite), the lighter toned areas are the more favorable for planned housing. Favorable areas are on the upland in zones of moderately high and high slope stability that are underlain by gravel and sand. Potential sites for storm-water retention ponds are shown in low-lying areas which are underlain by clay.

Using these earth-science considerations as a base, the other environmental factors mentioned previously—wildlife habitats, air quality, noise, vegetation type—are then brought to bear to determine optimal land use for the area. In turn, land-use planners weigh this environmental input with such other factors as adjacent land use, economics, housing needs, transportation adequacy, and public facilities to arrive at final land-use recommendations.



Subcrop map showing distribution of clay beneath the gravel cap

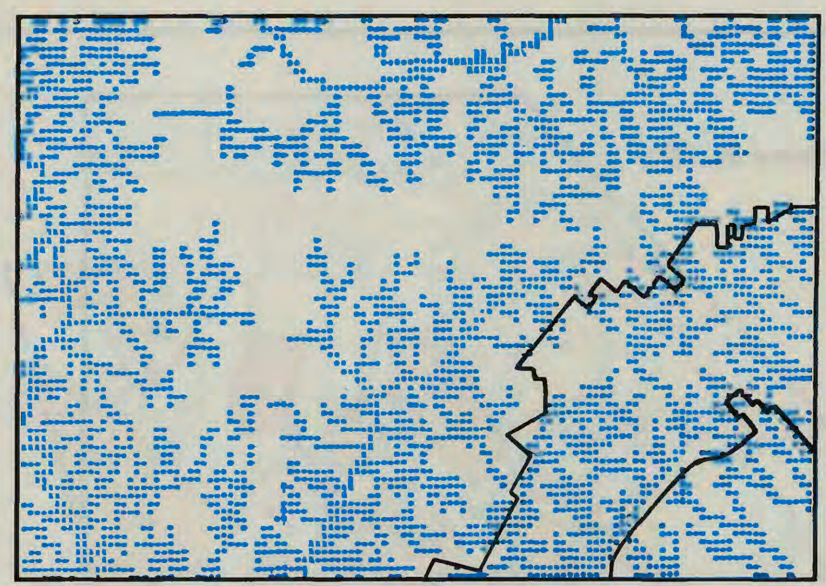


Computer composite mapping technique for a hypothetical area

Source maps are divided into cells of a preselected size (a) and map units are stored as numeric codes, represented diagrammatically by shading (b). Weighted numeric values are assigned to the digitized map units, based on their relative importance (c), and the computer sums these values to produce a "score" for each cell (d). The composite map (e) is produced on a computer line printer, with a different symbol to represent each score, or combination of factors.

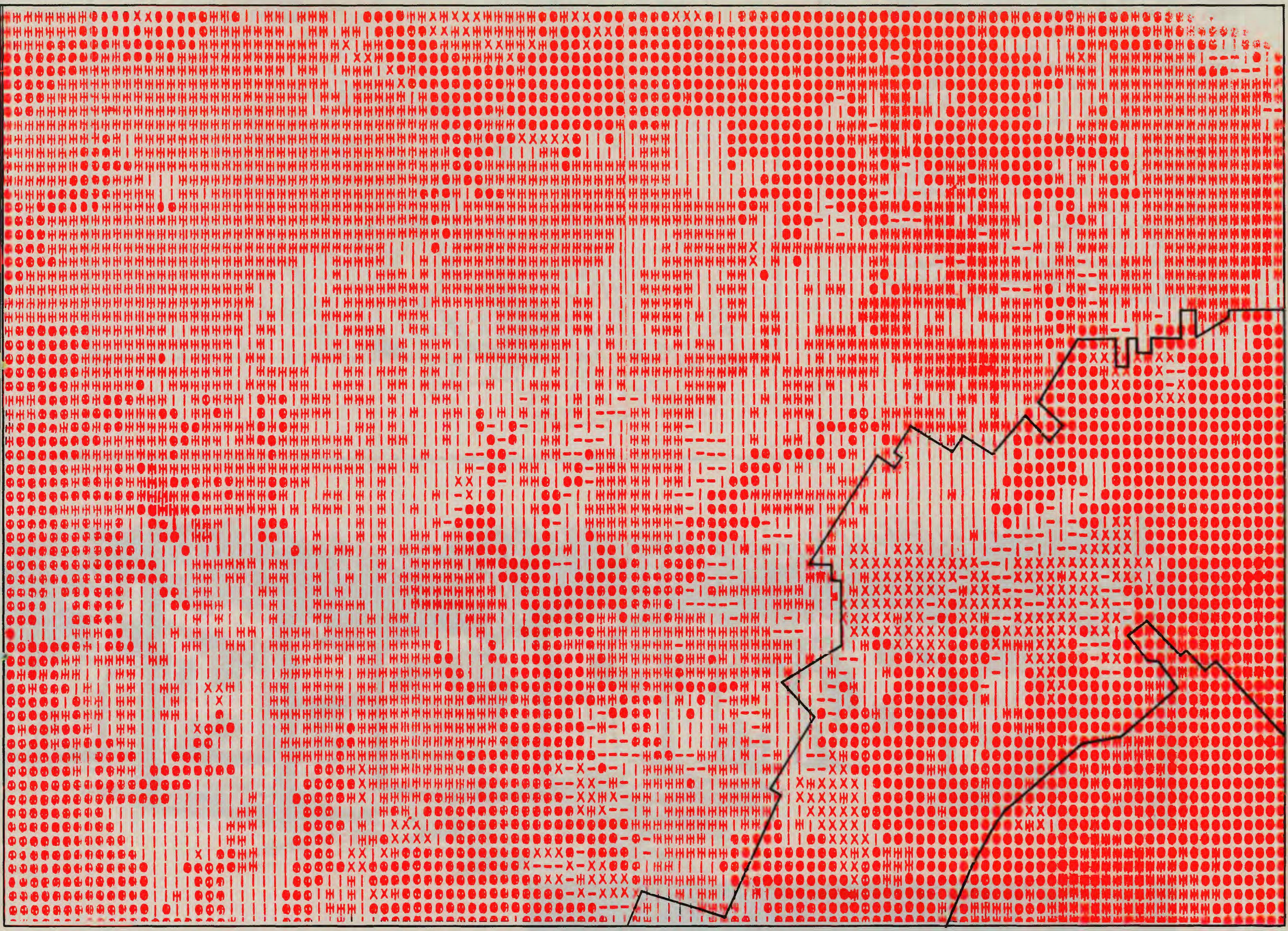
Earth-science factors, attendant problems, and suggestions, Franconia area

Earth-science factors	Problems	Suggestions
Expansive clay on slopes >15 percent.	Slope instability	Low-density development; retain as wooded area. Engineering geologic site studies required.
Expansive clay on slopes <15 percent or beneath abandoned pits or upland gravel.	Foundation instability; drainage problems.	Engineering study for all structures; use as retention ponds.
Variable distribution of sand and clay layers beneath upland gravel or fill.	Inconsistent, variable strength properties.	Cluster units on best available upland sites, based on drilling program to minimize construction on expansive clay.
Distribution of expansive clay.	Complicates storm-water runoff collection and retention; unstable foundations for surface structures.	Retain water onsite using natural catchment areas underlain by expansive clays as retention ponds. Design foundations for swelling conditions.
Distribution of flood-prone areas, alluvial soils, and steep slopes.	Flood hazard, high-water table, low-strength properties.	Retain areas as environmental quality corridor and park lands; integrate with storm-water runoff program.



Hydrologic map showing location of natural drainageways and surface water

Slope-stability map showing distribution of unstable slopes



Scale 1:24,000

Composite capability map for planned development housing, Franconia area

Developed areas

Potential retention pond sites

Favorable areas for planned development housing

Favorable areas for planned development housing; special engineering studies required

Unfavorable areas for planned development housing

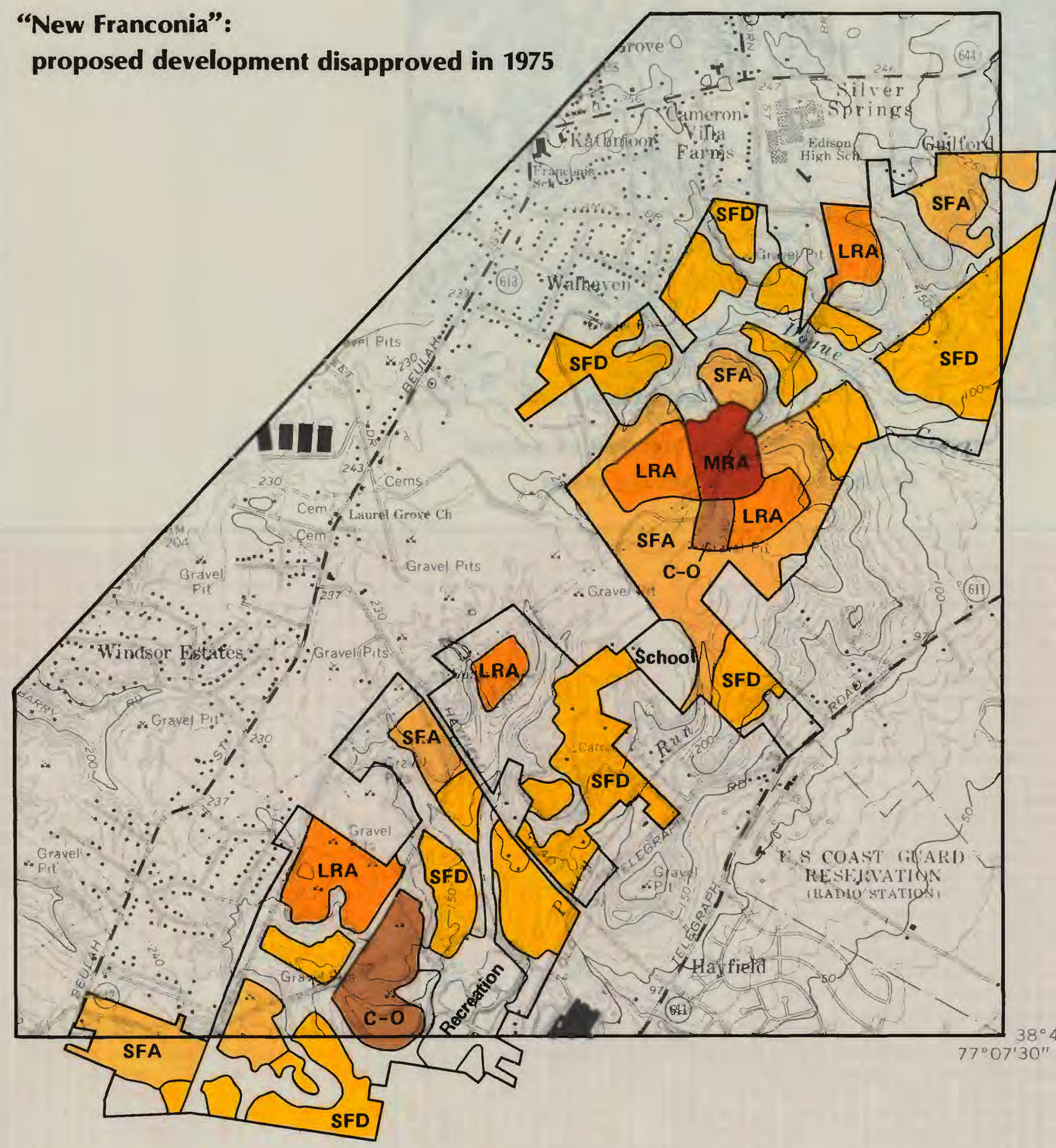
Multiscale data analysis and mapping program by Glenn H. Beavers, for Land Use Analysis Laboratory and Agricultural and Home Economics Experiment Station, Iowa State University

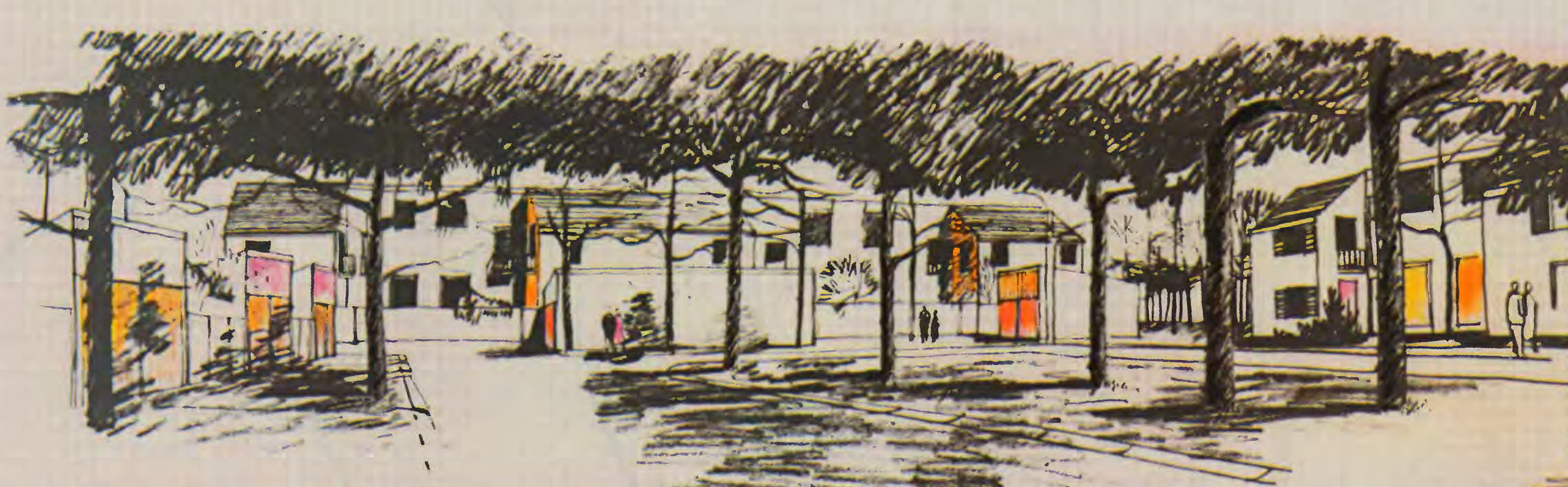
Conclusion

Earth-science data used in the inventory-analysis-synthesis process provide the foundation on which land-use planners and developers can plan, design, and build in a manner harmonious with and sensitive to the natural environment. In Fairfax County such data will also provide the basis for formulating and implementing new ordinances and strengthening existing ordinances related to significant earth-science factors. The computer-assisted preparation of a capability map illustrates how the complex interrelations between the natural environment and man's use of the land can be dealt with in an objective, consistent, and time-saving manner.

In the Franconia area, earth-science information has significantly influenced the decisions related to the rezoning application for planned development housing. At the two levels of the Fairfax County planning process where environmental analysis occurs—rezoning application review and development plan approval—these data and related interpretive maps were critically important for determining appropriate land uses and subsequently modifying the detailed development plan. The slope-stability map identified areas on which development is now discouraged; the gravel subcrop map defined areas with potential foundation and drainage problems. The hydrologic analysis provided a low-cost alternative using natural drainageways for managing increased storm-water runoff. The resulting environmental quality corridor is interconnected throughout, with stream valleys joined by wooded areas on hazardous slopes. These objectives were attained while retaining the density requested by the developer and approved by the county. Thus, the Lehigh plan takes far greater account of the natural setting and processes than did the "New Franconia" plan.

"New Franconia": proposed development disapproved in 1975



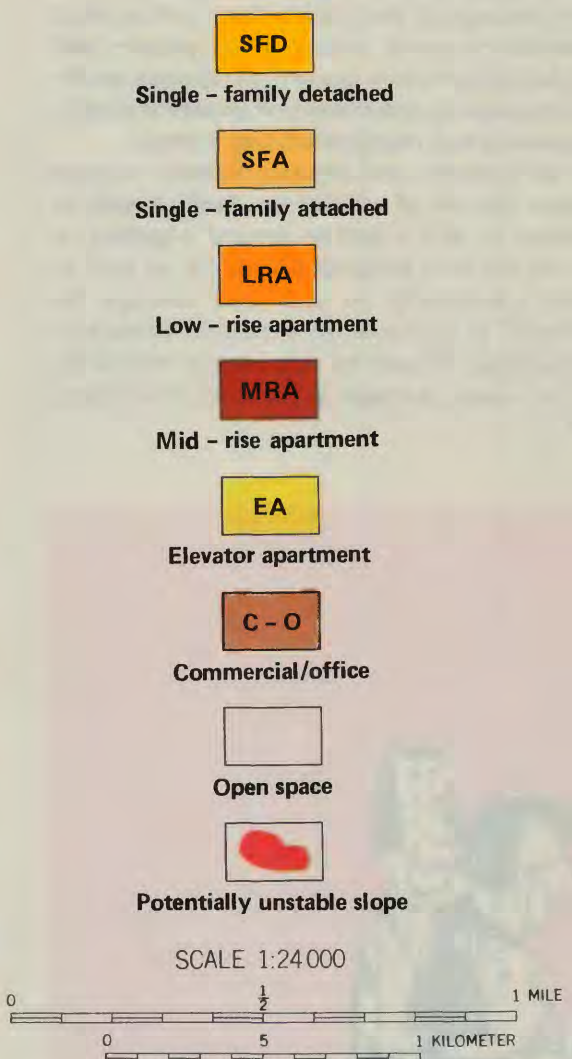


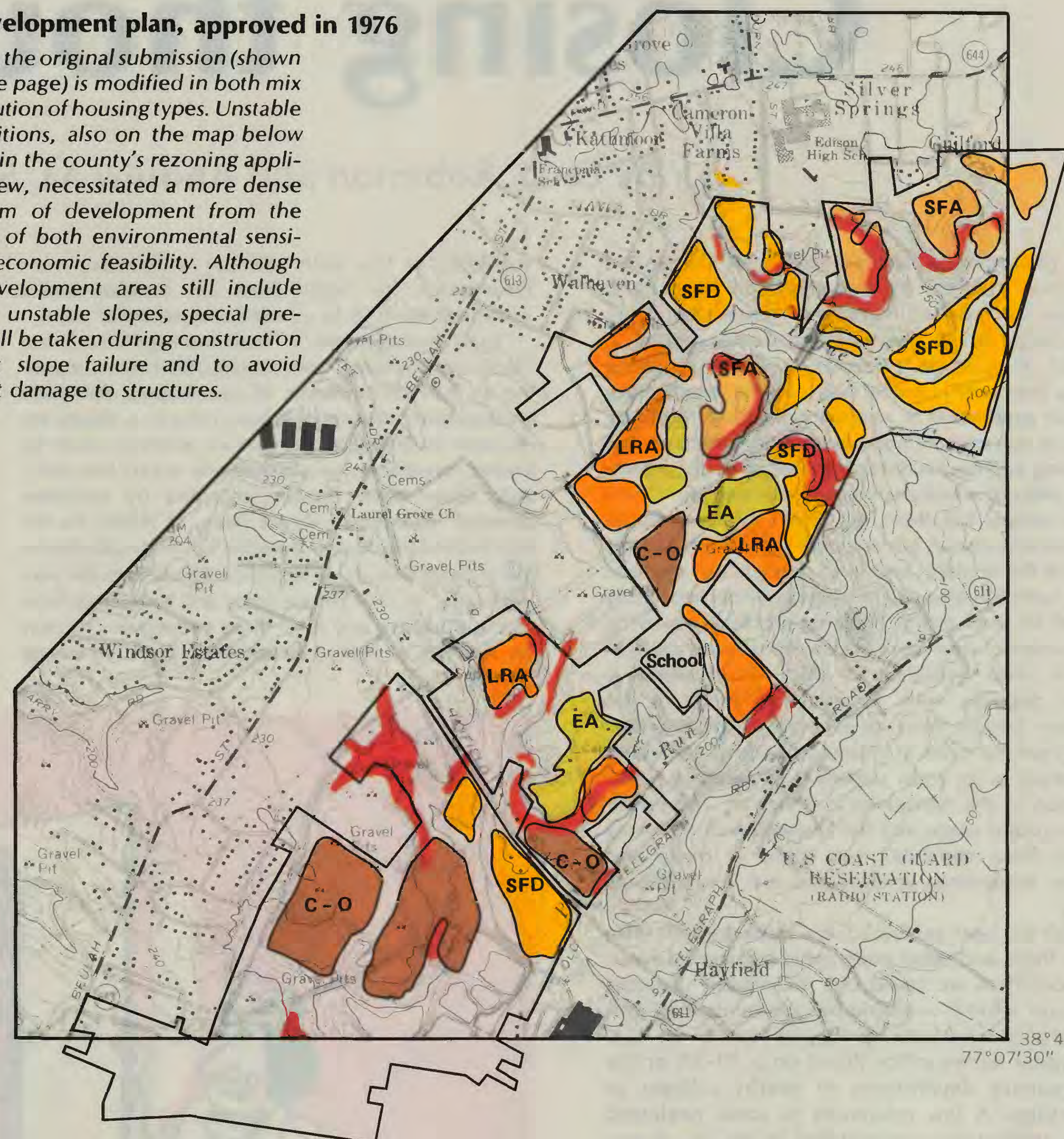
Townhouse construction in Fairfax County

The single-family attached residences of Lehigh will probably be similar.

Lehigh development plan, approved in 1976

In this plan, the original submission (shown on opposite page) is modified in both mix and distribution of housing types. Unstable slope conditions, also on the map below and noted in the county's rezoning application review, necessitated a more dense cluster form of development from the standpoint of both environmental sensitivity and economic feasibility. Although several development areas still include potentially unstable slopes, special precautions will be taken during construction to prevent slope failure and to avoid subsequent damage to structures.





Communities in Fairfax County

The single-family homes of Lehigh will likely resemble them.

Closing thoughts

By G. D. Robinson and Andrew M. Spieker

We presented our samples from west to east. This is not only a natural reading order, from left to right, but also an order of increasing complexity: from such comparatively simple applications as regulating setback of buildings on eroding seacliffs, requiring only a few earth-science maps, to the much more difficult application of new town planning, requiring many. In this way, we hope to have demonstrated the planning and decisionmaking value of earth-science maps without wholly exhausting our readers.

The sample has been, we think, sufficient for its illustrative purpose, but it is only a sample. It ignores most of the country, and in so doing it also neglects some common geologic settings and touches lightly if at all on some major planning problems involving earth science. Thus there are no examples of application in areas underlain by thick and continuous glacial deposits, such as prevail in much of the northern Middle West; or examples in areas underlain by natural caves in limestone, widespread in the Southeast; or in areas underlain by igneous rocks, common in the Northwest and Hawaii. The use of underground space and the management of wastes (which often coincide), two topics of major and rapidly expanding proportions, are treated only briefly.

Much has been published or is available in file form about these and other geographic and topical areas, far more than we could cite individually. Readers can learn what is available by communicating with the appropriate State geological survey or U.S. Geological Survey office (listed on p. 91–92) or the earth-science departments of nearby colleges or universities. A few references to some neglected major applications are included in the list of suggested reading that follows.

Readers should be aware that their chances of finding all the earth-science maps they need are only fair. Topographic maps or orthophotoquads are almost universally available for urban and urbanizing areas, and flood-prone area maps can be had for most areas commonly subject to flooding, but the same cannot be said for geologic maps or for maps pertaining to ground water. It follows, then, that interpretive maps, like the many in this book, that translate earth-science information into forms and terms useful to planners and managers are even less widely available. Further, as noted in the "Introduction," little new mapping is being added in urban areas because the earth-science profession has not been directed to do more. Significant increase in the capability of the earth sciences to produce more information for better land use decision awaits increased demand by present and potential users.

"Land management," "water management," and "land-use planning" are emotion-filled terms, touching as they do on some of the deepest and most contradictory aspects of human nature. A significant decision involving land or water, whether made by owner, developer, or government entity, has probably never been happily accepted by everyone affected. Somebody always loses, or thinks he has lost. Indeed, the fear of possible loss often permeates the atmosphere of significant decisions from the very beginning, so that the geologic and hydrologic facts of the situation, and their likely consequences, may be ignored or never ascertained. With increasing frequency, this neglect is made apparent in legal and political contests of land and water decisions.

The main message of this book is that more sensible and defensible—if never universally popular—land and water decisions will be made if all relevant earth-science information is assembled and applied throughout the planning and decisionmaking process.

We are all planners and decisionmakers. Anyone who changes the use of a bit of the Earth, if only to build a house or drill a well to irrigate a garden, is both. It is in his own long-term interest, as well as that of the community, to plan and manage his "development" in accord with the natural limitations and opportunities offered by the setting. Not to do so is to court waste, damage, sometimes even injury and death.

Engineers Testing Laboratories, 1960

"...and we can save 700 lira by not taking soil tests."

Acknowledgments

This book is an outgrowth of an idea put forth several years ago by John D'Agostino, to produce a comprehensive guide to the use of earth-science maps for users who are not earth scientists. Such a comprehensive work was not yet feasible, but the present more limited venture has profited greatly from D'Agostino's experience and ideas.

The editors are deeply indebted to the authors who interrupted their busy lives to produce the various chapters, and especially to the non-Survey authors, who did so with token compensation or none. We are also grateful for the cooperation and understanding of their supervisors.

The authors of two chapters in turn wish to acknowledge special assistance from associates outside the Geological Survey. Donald A. Woolfe, Planning Director, San Mateo County, explained the role played by earth-science information in that county's planning process, and Anne A. Parke, Planner, San Mateo County, reviewed the Central San Mateo County chapter. Much information for the Tucson, Arizona, chapter was provided by Alex R. Garcia, Director of the Pima County Planning Department, and the chapter was reviewed by Lance McVittie and Robert C. Johnson, Pima County Planning Department; by Frank Brooks, former Director, Tucson Water Department; and by Kirk Guild and Walter Stein, City of Tucson Water Production Department.

Throughout the report, illustrations not specifically credited were prepared by the authors of the respective chapters.

Finally, the authors and editors are indebted to scores of associates for assistance in all aspects of this rather unusual book. As it is hopeless to acknowledge the contributions of all, and impossible not to overlook some, we will note only extraordinary contributions from within. Vincent E. McKelvey, who was Director of the Geological Survey while the book was being written and made ready for the press, vigorously encouraged its preparation and reviewed the manuscript in detail, offering many productive suggestions. Paul Y. W. Ho and Jeffrey A. Troll were largely responsible for the design of the book, and Ho created most of the art work. The cover is the work of James L. Caldwell. Helpful reviews of the entire manuscript were made by Robert D. Brown, Jr., Rachel Barker, and Donald R. Nichols, geologists; John H. Feth, L. A. Heindl, and Eugene R. Hampton, hydrologists; Gerald Greenberg, geographer; William J. Kockelman, planner (all of the Geological Survey). Constructive reviews were also made by Kurt W. Bauer, Planner and Executive Director, Southeastern Wisconsin Regional Planning Commission, and by Professor James E. Hackett, geologist, College of Architecture and Urban Studies, Virginia Polytechnic Institute and State University.

Sources

Listed below are sources of two kinds: first, places to go for earth-science information; second, references. The references, in turn, are of two sorts: first, suggested readings to supplement this book; second, literature used in preparing this book, arranged by chapters.

Offices for information

State Geological Surveys (or equivalents) and District Offices of the U.S. Geological Survey Water Resources Division

State	*State Organization*	*District Office*
Alabama	Geological Survey of Alabama P.O. Drawer O University, AL 35486 (205) 349-2852	1317 McFarland Blvd. East Tuscaloosa, AL 35401 (205) 759-5739
Alaska	Division of Geological and Geophysical Surveys 3001 Porcupine Drive Anchorage, AK 99501 (907) 274-8602	218 E Street Anchorage, AK 99501 (907) 277-5526
Arizona	Arizona Bureau of Geology and Mineral Technology University of Arizona Tucson, AZ 85721 (602) 884-1401	Federal Bldg. 301 W. Congress St. Tucson, AZ 85701 (602) 792-6671
Arkansas	Arkansas Geological Commission Vardelle Parham Geological Center 3815 W. Roosevelt Road Little Rock, AR 72204 (501) 371-1488	Rm. 2301 Federal Office Bldg. 700 W. Capital Ave. Little Rock, AR 72201 (501) 378-5246
California	California Department of Conservation Division of Mines and Geology Resources Buildings, Room 1341 1416 Ninth Street Sacramento, CA 95814 (916) 445-1825	855 Oak Grove Ave. Menlo Park, CA 94025 (415) 323-8111, ext. 2326
Colorado	Colorado Geological Survey 1313 Sherman Street, Room 715 Denver, CO 80203 (303) 892-2611	Bldg. 53 Denver Federal Center Box 25046, STOP 415 Denver, CO 80225 (303) 234-5092
Connecticut	Department of Environmental Protection State Office Building, Rm. 561 Hartford, CT 06115 (203) 566-3540	Rm. 235 Post Office Bldg. 135 High St. Hartford, CT 06103 (203) 244-2528
Delaware	Delaware Geological Survey University of Delaware 101 Penny Hall Newark, DE 19711 (302) 738-2833	Rm. 208 Carroll Bldg. 8600 La Salle Rd. Towson, MD 21204 (301) 828-1535
Florida	Department of Natural Resources 903 W. Tennessee St. Tallahassee, FL 32304 (904) 488-4191	Suite F-240, 325 John Knox Rd. Tallahassee, FL 32303 (904) 386-1118
Georgia	Georgia Department of Natural Resources Earth and Water Division 19 Hunter St., S.W. Atlanta, GA 30334 (404) 656-3214	6481 Peachtree Industrial Blvd. Doraville, GA 30360 (404) 221-4858
Hawaii	Department of Land and Natural Resources Division of Water and Land Development P.O. Box 373 Honolulu, HI 96809 (808) 548-7533	5th Floor, 1833 Kalakaua Ave. Honolulu, HI 96815 (808) 955-0251
Idaho	Idaho Bureau of Mines and Geology Moscow, ID 83843 (208) 885-6785 or 885-6195	Rm. 365 Federal Bldg. 550 W. Fort St. Box 036 Boise, ID 83724 (208) 384-1750
Illinois	Illinois State Geological Survey 121 Natural Resources Building Urbana, IL 61801 (217) 344-1481	605 N. Neil St. P.O. Box 1026 Champaign, IL 61820 (217) 359-3918
Indiana	Department of Natural Resources Geological Survey 611 N. Walnut Grove Bloomington, IN 47401 (812) 337-2862	1819 N. Meridian St. Indianapolis, IN 46202 (317) 269-7101
Iowa	Iowa Geological Survey Geological Survey Building 123 North Capitol Iowa City, IA 52242 (319) 338-1173	Rm. 269 Federal Bldg. 400 S. Clinton St. P.O. Box 1230 Iowa City, IA 52240 (319) 338-0581, ext. 521
Kansas	Kansas Geological Survey Raymond C. Moore Hall 1930 Ave. A, Campus West University of Kansas Lawrence, KS 66044 (913) 864-3965	1950 Ave. A-Campus West University of Kansas Lawrence, KS 66045 (913) 864-4321
Kentucky	Kentucky Geological Survey University of Kentucky 307 Mineral Industries Bldg. 120 Graham Avenue Lexington, KY 40506 (606) 258-8991	Rm. 572 Federal Bldg. 600 Federal Pl. Louisville, KY 40202 (502) 582-5241
Louisiana	Louisiana Geological Survey Box G, University Station Baton Rouge, LA 70803 (504) 389-5812	6554 Florida Blvd. P.O. Box 66492 Baton Rouge, LA 70896 (504) 387-0181, ext. 281
Maine	Maine Geological Survey State Office Bldg., Room 211 Augusta, ME 04330 (207) 289-2801	Suite 1001, 150 Causeway St. Boston, MA 02114 (617) 223-2822
Maryland	Maryland Geological Survey Merryman Hall, Johns Hopkins University Baltimore, MD 21218 (301) 235-0771	208 Carroll Bldg. 8600 La Salle Rd. Towson, MD 21204 (301) 828-1535
Massachusetts	Department of Environmental Quality Engineering Division of Waterways 100 Nashua St., Room 532 Boston, MA 02114	Suite 1001, 150 Causeway St. Boston, MA 02114 (617) 223-2822
Michigan	Michigan Department of Natural Resources Geological Survey Division Stevens T. Mason Bldg. Lansing, MI 48926 (517) 373-1256	2400 Science Parkway Red Cedar Research Park Okemos, MI 48864 (517) 372-1910, ext. 561
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Spreading urbanization in

Looking north, from above Saratoga toward Sunnyvale. Airplane hangars at Moffett Field Naval Air Station at left background, with tidal flats at south end of San Francisco Bay beyond. When the photograph at left was taken in 1959, the area was mostly orchard, but urbanization had already begun, spreading from San Jose off to the right, and from Moffett Field. By 1977, when the photo-

Santa Clara County, California

graph at right was taken, nearly all the land except the tidal flats had been developed. Exchanging fruit trees for buildings and pavement changes much more than the scenery. When those changes are anticipated and the development is guided by knowledge of the controlling geologic and hydrologic conditions, it is certain to be more economical, safer, and cleaner. (Photographs courtesy Air Photo Co., Mountain View, Calif.)

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