Look Before You Build

Geologic Studies for Safer Land Development in the San Francisco Bay Area

PUBLIC ISSUES IN EARTH SCIENCE • U.S. GEOLOGICAL SURVEY CIRCULAR 1130

Cover—Housing development in Alameda County, California. Background is from geologic map of Blue Oaks subdivision in Portola Valley, California, prepared by Harlan-Tait Associates. Copyrighted photograph by John K. Nakata, Sight & Sound Productions.

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By **Martha Blair Tyler***

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Conversion Factors

For readers who wish to convert measurements from the inch-pound system of units to the metric system, the conversion factors are listed below.

Multiply	*By*	*To obtain*
acre	.405	hectare
foot	.3048	meter
square foot	.09290	square meter
mile	1.609	kilometer

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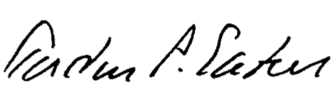
Foreword

When natural disasters occur, the resulting devastation is not distributed uniformly across the landscape. Certain places repeatedly experience more severe losses than others because of their susceptibility to flooding, earthquakes, and landslides. These places are generally identifiable in advance of such natural disasters through geologic studies. Flood damage is generally confined to mapped flood plains, and earthquake losses recur at those locations where geologic conditions promote strong shaking and ground failures. Landslides tend to occur in loosely consolidated, saturated soils on sloped terrain, often in conjunction with strong shaking during earthquakes.

The historical record documents countless examples of substantial losses sustained because geology was not adequately considered. Often, such historical accounts provide clear warning of future loss patterns. The effects of the October 1989 Loma Prieta earthquake in some parts of San Francisco mirror those reported in San Francisco after earthquakes in 1865, 1868, and 1906. The success stories, losses that were prevented because geology was heeded before development, are more difficult to document. However, we know that integrated earth science-economic models of earthquake-triggered landslides during the Loma Prieta earthquake, for example, can be used to outline cost-effective land-use strategies.

The San Francisco Bay Area is a dynamic landscape, at least on geologic time scales. Coastal California, on the Pacific plate, is moving about 2 inches to the northwest each year past the rest of the State, which is resting on the North American plate. These movements, which occur during earthquakes, have created a varied topography that both nature and man have altered to produce conditions particularly susceptible to the destructive forces of nature. Communities in the San Francisco Bay Area have had to address issues of suitable land use and structure design because of the ever-present threat of devastating earthquakes and landslides. Communities throughout northern California, indeed throughout the Nation, face similar threats of natural disaster that can be blunted through the considered use of geologic information in development planning.

Geologic information can be used for safer land development in all parts of the Nation. Such information is available from the U.S. Geological Survey as well as from many state and local agencies. The U.S. Geological Survey is committed to assisting local agencies in the wise use of geologic information in the development of safer communities.



Director, U.S Geological Survey

Look Before You Build

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Introduction

When and how should geologic information be used in making decisions about land development? The answer to this question is important to anyone buying a lot, building a home, or selecting a site for a commercial or industrial building. The answer is also important to those responsible for local land-development decisions—city and county staff members, planning commissioners, elected officials, and concerned citizens. This circular describes how local governments can use geologic information in reviewing land-development projects to help prevent losses from geologic hazards.

Geologic hazards exist in all types of terrain. Nature is still forming mountains, carving hillsides and coastal bluffs, and filling wetlands. Extreme events—earthquakes, floods, volcanic eruptions, landslides—continue to shape and reshape the landscape.

In spite of ample evidence that the Earth is restless, most people live, work, and play as if the ground beneath their feet is firmly in place. For most activities this makes sense; however, it may not work when deciding to construct a home, an office building, a factory, a highway, or a civic center. Unless geologic hazards are understood and heeded in the siting and design of structures, deaths, injuries, and heavy financial losses can result.

PURPOSES OF THIS CIRCULAR

Local governments regulate land use and decide on proposals to develop private land. Local officials often determine the location of streets and utilities and other public improvements needed to serve such development. They can make better decisions if they know the geologic conditions of the development sites and what those conditions mean for the future safety of the proposed development. They can do this *only* if they have appropriate geologic information and include geologists in the process of reviewing land-development projects.

Three categories of geologic hazards are prevalent in the San Francisco Bay Area: earthquakes, landslides, and subsidence. Procedures for local governments to consider these geologic hazards prior to approving development can often be applied in areas faced with these and other geologic hazards.

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Knowing the geology of a proposed development site is one thing; using that information to guide development decisions is another. Effective local programs all feature a rational basis for requiring geologic studies of development sites, independent review of geologic studies, and measures to ensure that projects are designed to reduce the potential impacts of hazards identified in the studies. The specific procedures a local government adopts will vary depending on many factors including:

- nature of local geologic hazards
- geologic hazard maps available for the area
- ability of local staff and consultants to understand and use geologic information
- potential for new development
- community attitudes about risk

This circular describes programs in the San Francisco Bay Area as a means of showing how procedures to use geologic information for project review can be adapted to specific local circumstances.

GEOLOGIC HAZARDS

Geologic hazards are natural or manmade geologic conditions or phenomena that can endanger life and property. Geologic hazards include earthquakes, landslides, ground subsidence, floods, tsunamis, volcanic eruptions, coastal erosion, and dam failures. Usually their potential can be identified prior to building, and measures can be taken to forestall damage. Different areas of the United States have different combinations of geologic hazards. Three categories of geologic hazards are prevalent in the San Francisco Bay Area: earthquakes, landslides, and subsidence. This circular focuses on these hazards. Flooding also occurs in the region, but it is considered only as a consequence of ground failure, such as flooding from dam failure caused by ground shaking. Procedures for local governments to consider these geologic hazards prior to approving development can often be applied in areas faced with these and other geologic hazards.

Some of the homes damaged during an earthquake-induced landslide in Anchorage, Alaska, in 1964. Photograph by Robert A. Page.

Earthquakes

Earthquakes cause ground shaking, surface fault rupture, slope failure, and ground failure resulting from liquefaction. Most earthquake damage is caused by *ground shaking*; such damage is usually best mitigated by applying appropriate design and building standards to construction projects. In areas with potential for unusually violent or prolonged ground shaking, geologic studies are needed to establish design and construction requirements for important structures such as dams, highway bridges, hospitals, and highrise buildings.

Surface fault rupture is the breaking of the ground surface along an earthquake fault. The movement may be horizontal, vertical, or some combination of both. Whatever the type of movement, surface rupture normally rips apart structures built directly across a fault. Geologic studies are essential to determine the exact location of a fault so that structures can be sited to either side out of harm's way or engineered to withstand the expected movement.

Earthquakes often cause *slope failures,* such as landslides and rock falls. Even gently sloping terrain can fail under the stress of earthquake ground shaking. Earthquakes can also cause *liquefaction,* which can lead to ground failure. Liquefaction occurs in areas with loose, wet, and sandy soils. When shaken, the soils in such areas flow like a liquid causing the ground surface to sink or pull apart. Damage from slope and liquefaction failures can usually be prevented if the hazards are identified before land is subdivided or buildings are constructed.

Landslides

Slopes also fail at times other than during earthquakes. Inherently unstable slopes are prone to failure as a result of heavy rains, grading, removal of vegetation, or changes in drainage. Failures take the form of landslides, debris flows, soil slumps, rock falls, or rock avalanches, and they vary in the speed, depth, and content of the moving materials. Geologic studies are used to identify slopes prone to failure. Such slopes can then be avoided in siting development, the slopes can be graded or buttressed to prevent failure, or projects on or below unstable slopes can be engineered to prevent damage in the event of slope failure.

A sinkhole that formed near Winter Park, Florida, in 1981. Photograph by John G. Newton.

Subsidence

Subsidence is the sudden or gradual sinking of the ground surface. It occurs suddenly when underground mines collapse or sinkholes form in limestone rock; it occurs gradually as organic soils compact over time or man extracts water, gas, or petroleum from beneath the Earth's surface. Damage from subsidence can generally be avoided if the susceptible soils and rocks are identified prior to development. Geologic studies can identify areas that are likely to subside.

GEOLOGY IN PROJECT REVIEW

Project review is the local government process to make decisions about the development of private land. The process is carried out as part of local government's responsibility to plan and regulate land use. Project review consists of procedures and criteria for approving, approving with conditions, or denying applications for land divisions, zoning changes, grading permits, use permits, building permits, or other authorizations needed for a proposed project.

The purpose of using geologic information in project review is to reduce the vulnerability of buildings and infrastructure to geologic hazards. The geologic component of local project review consists of policies and regulations that define when applicants for development permits must complete geologic studies, the content of those studies, and procedures for reviewing and accepting the geologic studies. This component also provides guidance in avoiding or mitigating identified geologic hazards.

GEOLOGIC STUDIES AND REPORTS

Geologic studies, as the term is used here, are evaluations of sites proposed for development usually conducted by a geologist retained by prospective developers. The studies result in geologic reports, which are submitted to local governments as part of applications for development permits.

The term "geologic studies" does not have a consistent definition in local government policies and regulations. "Geologic" and "geotechnical" are sometimes used interchangeably, and "geologic study" sometimes refers only to the part of a study in which hazards are identified and evaluated. In this circular, the term "geologic studies" is broadly defined as studies that identify and assess geologic conditions and hazards; analyze how they affect the siting, design, and construction of proposed projects; and recommend measures to mitigate the hazards. Geologic studies are done by geologists or engineering geologists, sometimes with the help of geotechnical engineers. Where the term "geologist" is used alone in this circular, it means a geologist or engineering geologist.

Project review is the local government process to make decisions about the development of private land. The process is carried out as part of local government's responsibility to plan and regulate land use.

NEED FOR GEOLOGIC STUDIES THROUGHOUT THE NATION

All parts of the United States have geologic hazards and can benefit from geologic studies before building. Earthquakes occur in all states, flooding is nearly universal, landsliding is a potential hazard in all states expect Florida, and subsidence plagues most states.

States and local governments in many parts of the United States have adopted measures to consider geologic information before approving development projects. For example:

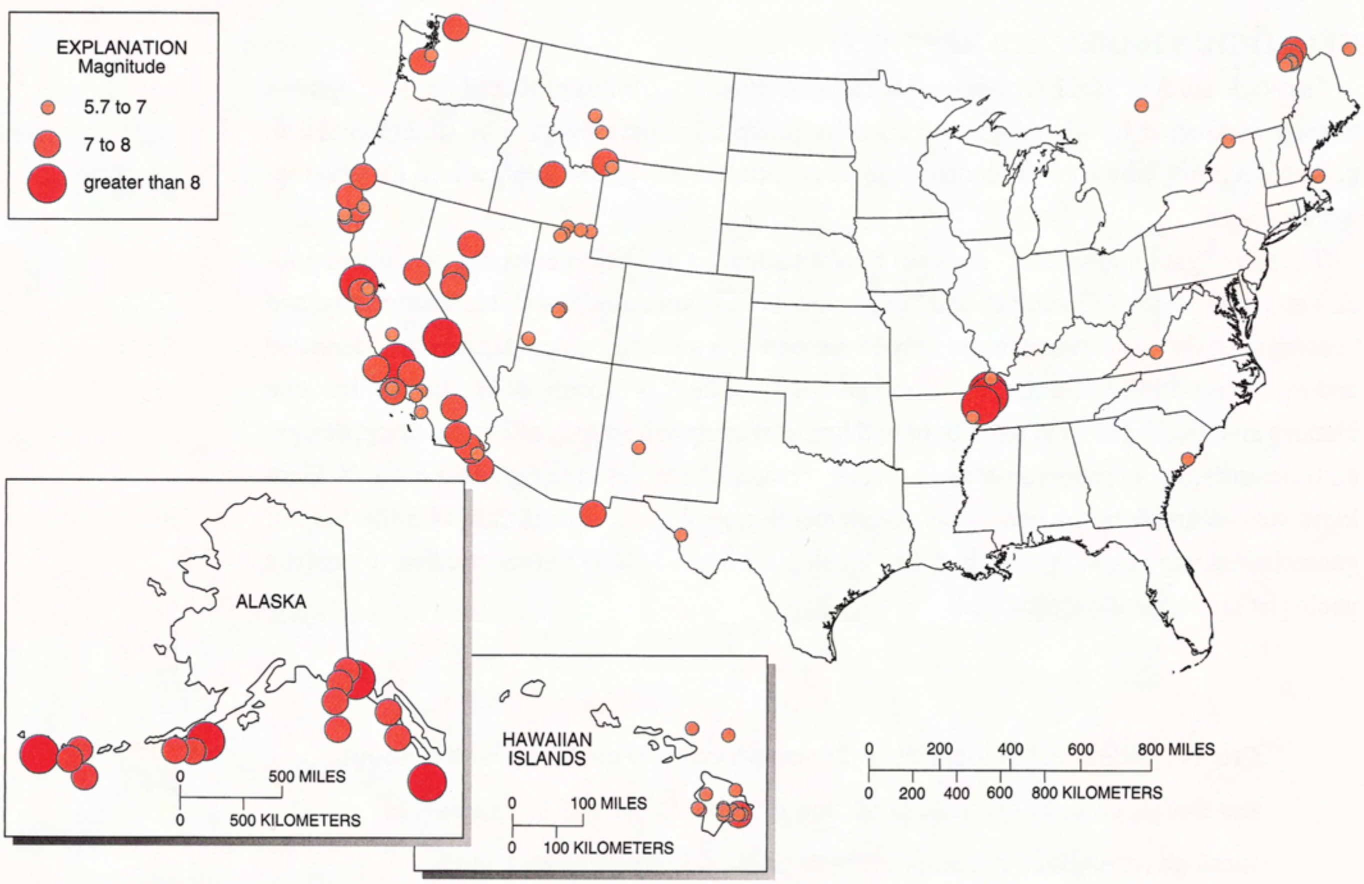
• Anchorage, Alaska, has a Geotechnical Advisory Commission appointed by the mayor to advise on development proposals for hazardous lands.

• Utah counties along the Wasatch Fault have adopted ordinances requiring geologic studies with development applications in hazardous areas. When requested by local governments, the Utah Geological Survey reviews proposed projects.

• Colorado has prepared model geologic hazard control regulations and distributed copies to local governments as a recommended guide for local regulations.

• Oregon requires that local governments inventory geologic hazards and avoid development in hazardous areas. In recent legislation, the State requires geotechnical studies of all sites proposed for facilities such as hospitals and schools.

• Cincinnati, Ohio, established a geotechnical office responsible for reviewing all development projects in the city's hillside areas prior to approval.

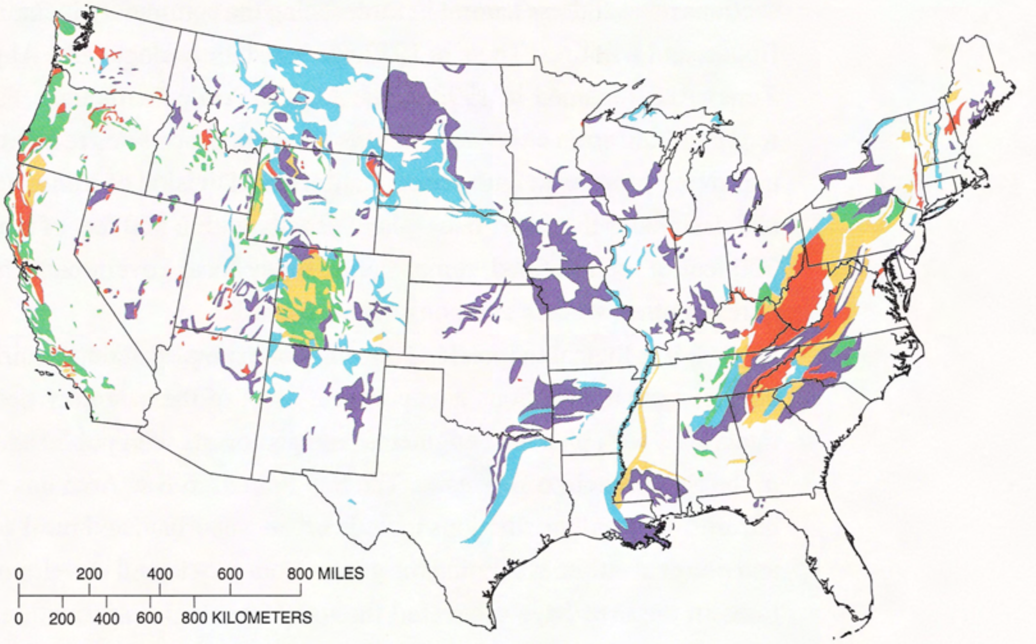


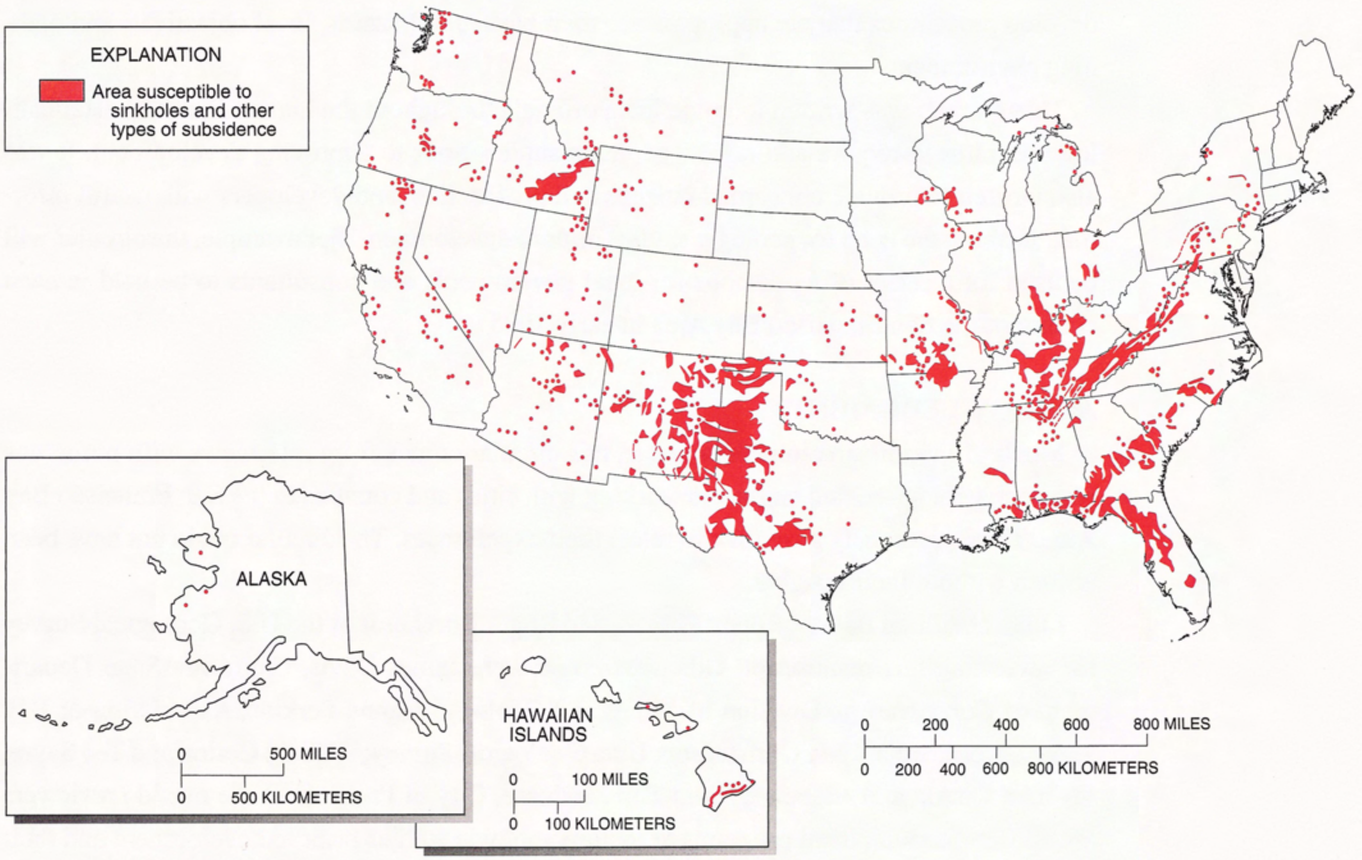
Locations of some historical earthquakes with magnitudes of 5.7 or greater in the United States. Earthquakes happen most frequently in Alaska and California. Earthquakes cause loss from ground shaking, surface faulting, ground failures, and tsunamis. Communities throughout the Nation face the threat of potential loss from earthquakes. Magnitude is a measure of the strength of an earthquake.

All parts of the United States have geologic hazards and can benefit from geologic studies before building.

(right) Location of areas in the conterminous United States susceptible to landslides. Potential is highest in areas shown in red and decreases in order of yellow, green, blue, and purple. All states except Florida have at least some potential for landsliding. Some areas that are susceptible to landslides are too small to show at the scale of the map.

(below) Location of areas of the United States susceptible to subsidence. Most states are susceptible to this hazard.





California has more than its share of geologic hazards, so it is not surprising that it has often led the way in acting to reduce potential damage from these hazards. After the 1971 San Fernando earthquake, the State legislature required all cities and counties in California to adopt "seismic safety elements" as a part of local general plans. Now called "safety elements," these plan sections must address natural hazards facing the community including earthquakes, landslides, floods, and wildfires. Then, in 1972, the legislature adopted the Alquist-Priolo Special Studies Zones Act (renamed in 1993 as the Alquist-Priolo Earthquake Fault Zoning Act). This Act requires California cities and counties to adopt procedures requiring geologic studies prior to approving projects in fault zones. California's Division of Mines and Geology maps the faults and designates the fault zones—land usually within 500 feet of major active faults and 200 to 300 feet of well-defined, minor faults. Many local governments have applied similar procedures to other seismic and non-seismic hazards.

It is logical to look to California for examples about requiring geologic studies before development applications are approved. Most of the examples described here come from 30 interviews with planners, engineers, and geologists with public agencies and consulting firms in the San Francisco Bay Area. The San Francisco Bay Area has a full spectrum of geologic hazards. Its local jurisdictions include urban, suburban, and rural areas; large and small cities; and political attitudes running the gamut from pro- to anti-development. Several local jurisdictions in the area have pioneered the use of geologic information. The experiences of local governments in the San Francisco Bay Area can help local officials in other regions and states develop procedures that are appropriate to their particular hazards, local objectives, and planning environment.

This circular was written to guide local officials throughout the United States in establishing programs to require and review geologic studies prior to approving development. It was also written to provide concerned citizens and prospective land developers with useful information about the need for geologic studies prior to development. For example, the circular will be used for a series of workshops for local governments and consultants to be held in each county of the San Francisco Bay Area in early 1995.

ACKNOWLEDGMENTS

Much of the information contained in this circular comes from interviews with numerous planners, geologists, and engineers working with cities and counties in the San Francisco Bay Area. They generously gave time to relate their experiences. The circular could not have been written without their insights.

I thank William Bakun, Robert Brown, and Roger Borcherdt of the U.S. Geological Survey for reviewing this manuscript. Other reviewers were James Davis, California State Department of Conservation, Division of Mines and Geology; Jeanne Perkins, Association of Bay Area Governments; Gary Christenson, Utah Geological Survey; William Cotton and Ted Sayre, William Cotton and Associates; and Tim Molinare, City of Pacifica. These outside reviewers are all familiar with local programs to require geologic studies prior to development and their comments helped keep the circular relevant to real life.

Laurie Johnson, Spangle Associates, helped conduct information-gathering interviews for this project in addition to providing helpful review comments. George Mader and Thomas Vlasic, both of Spangle Associates, assisted with comments and support.

This publication builds on the contributions of William Kockelman over his 20-year tenure as an urban planner at the U.S. Geological Survey. His dedication to the practical application of U.S. Geological Survey products influenced efforts to provide data for hazard reduction—first in the San Francisco Bay Area and later along the Wasatch Fault in Utah, in the Puget Sound area of Washington, in Oregon, and in the Central United States. He tracked the actual use of U.S. Geological Survey products and became a key resource on information transfer. For this circular, he provided lists of relevant USGS products, reviewed the interview guide, and shared his own earlier work during which he surveyed applications of geologic information. His untimely death in 1993 deprived this project of an important source of encouragement and support.

The experiences of local governments in the San Francisco Bay Area can help local officials in other regions and states develop procedures that are appropriate to their particular hazards, local objectives, and planning environment.

Why Require Geologic Studies?

Increasingly, procedures to require geologic studies are becoming standard practice of local governments in California and in other states as well. More than 70 percent of the local governments in the San Francisco Bay Area have adopted procedures for requiring geologic studies. The reason for this is simple—the consequences of ignoring geologic hazards have been very painful.

IGNORING GEOLOGIC HAZARDS

Earthquakes, landslides, and subsidence are natural processes. Natural processes can sometimes be controlled, but the best approach is usually to focus on controlling their effects. This means avoiding construction in hazardous areas or engineering structures to withstand the effects of hazards. No form of control is possible without recognition of the hazard and its likely consequences. Failure to recognize and do something about geologic hazards prior to building has over the years caused personal tragedy and property loss. Many disasters or near-disasters have been caused by ignoring geologic hazards.

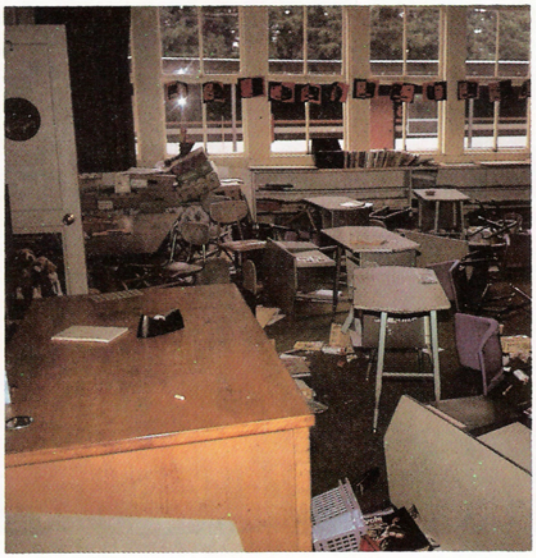
Fault Rupture—Loma Prieta Elementary School, Santa Cruz County, California

Both the Loma Prieta Elementary School and the 1989 Loma Prieta earthquake take their names from a peak in the Santa Cruz Mountains near the epicenter of the earthquake. The school, constructed before geologic studies of school sites were required, served the growing community near the earthquake's epicenter. About a year before the earthquake, the school district decided to add portable classrooms to accommodate a growing number of students. Because the site is in an Alquist-Priolo Earthquake Fault Zone, the Office of the State Architect required a geologic investigation. Trenching revealed at least a dozen fault traces running through the site, and many of these ran directly under the permanent school building. The school district planned to abandon the site and move the school to a nearby middle-school site. The Loma Prieta earthquake intervened and the school was seriously damaged by cracking and heaving of the ground. Fortunately, the earthquake occurred after school was out for the day, and no children or teachers were injured.

After the earthquake, the district decided to implement its plan to construct a new elementary school at the middle-school site. However, post-earthquake studies revealed faults running through the middle-school site, which, according to State standards, rendered most of its classroom space unsafe. Portable classrooms were installed at least 50 feet from any fault trace

Many disasters or near-disasters have been caused by ignoring geologic hazards.

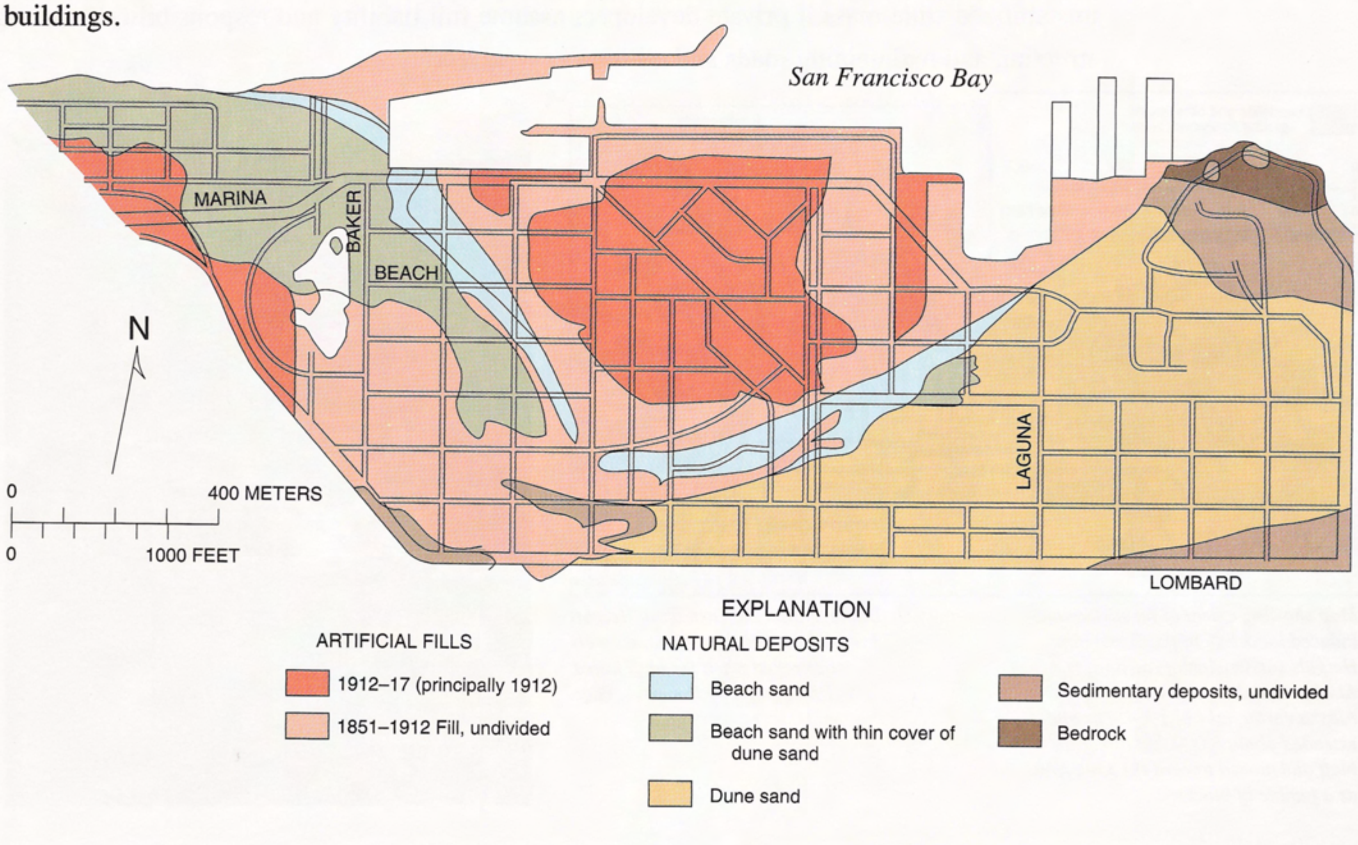
on the middle-school site. Both the elementary and the middle-school classes are being held in these portable classrooms pending construction of new buildings in safer locations. The loss of school buildings, expense, and disruption could have been avoided if the appropriate geologic studies had been done before the school site was selected.



Classroom at Loma Prieta Elementary School after the Loma Prieta earthquake in 1989. The school is located in the Santa Cruz Mountains near the epicenter of the earthquake and was damaged by ground cracking. Photograph by William Cole, William Cotton Associates.

Liquefaction—Marina District, San Francisco, California

The 1989 Loma Prieta earthquake disproportionately damaged the Marina district in San Francisco—a 1.5 square mile area on the edge of San Francisco Bay. Part of the Marina is a former lagoon. After the 1906 San Francisco earthquake, this lagoon was filled with sand (beginning in 1912) and became the site for the 1915 Panama Pacific Exposition, which was held to celebrate the opening of the Panama Canal and San Francisco's recovery from the earthquake. After the exposition, more artificial fill was added and the site was developed as a residential district with single-family homes and two- to four-story apartment buildings. Geologic conditions were not considered in decisions to develop the area or in the design of the buildings.



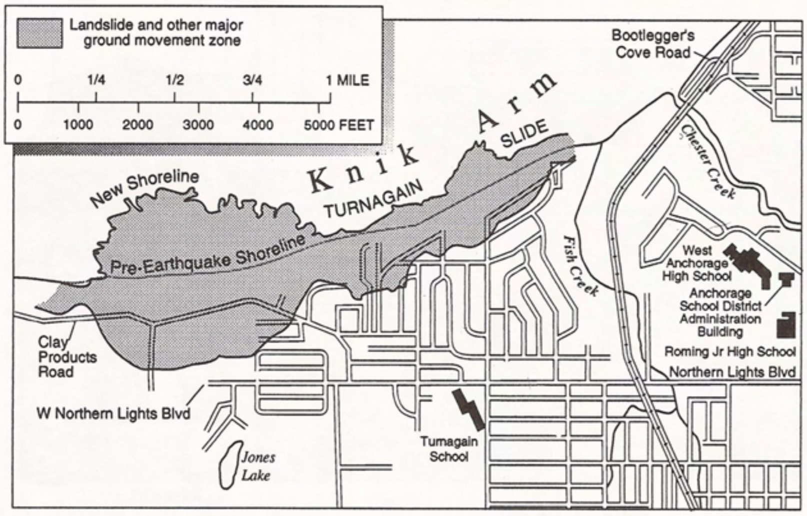
Map showing landfill history of Marina district, San Francisco, California. The district suffered extensive damage during the Loma Prieta earthquake in 1989. Damage was heaviest in areas of artificial fill. Buildings not shown.

In 1989, the Loma Prieta earthquake caused strong ground shaking in the Marina district. Buildings distorted, utility lines snapped, and sidewalks and streets buckled. Four people died, 7 buildings collapsed, 4 were destroyed by fire, and 63 were unsafe to occupy or enter. Liquefaction and amplified ground shaking contributed to these losses. The painful lessons from the 1906 earthquake were repeated in 1989.

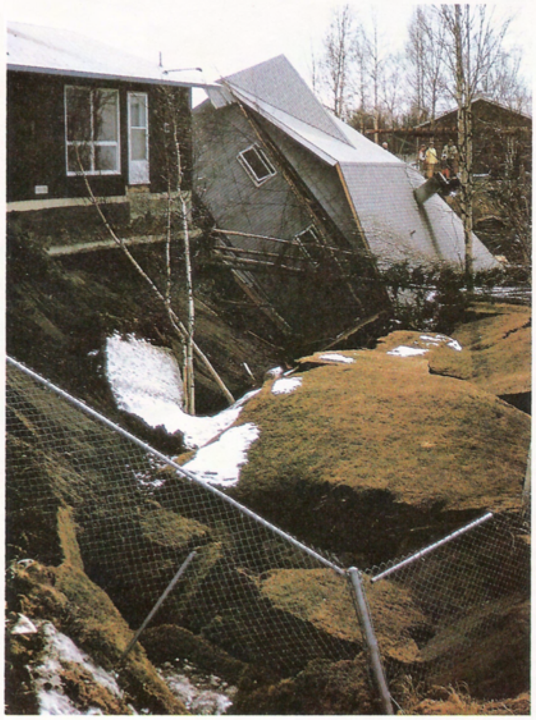
One of over 70 buildings in the Marina district, San Francisco, California, damaged during the Loma Prieta earthquake in 1989. Liquefaction and structural design contributed to the collapse of first stories of many apartment buildings like this one in the district. Photograph by John K. Nakata.

Earthquake-Induced Landslide—Turnagain Heights, Anchorage, Alaska

In the 1964 Alaska earthquake, three lives were lost as the bluff along Knik Arm in Anchorage disintegrated as a result of ground shaking. More than 75 homes in the Turnagain Heights subdivision—especially the bluffside houses with expansive views across the arm—were destroyed. The subdivision's roads and utilities were also destroyed. A layer of clay, called Bootlegger Cove Clay by geologists, was the culprit. The clay lost its cohesion as it shook, and as a result, the bluff disintegrated and tumbled in blocks into Knik Arm. No studies prior to subdividing were done to evaluate this hazard, although the clay's potential for failure was discussed in a 1959 U.S. Geological Survey report. Now Anchorage permits rebuilding on the unstabilized slide mass if private developers assume full liability and responsibility for constructing and maintaining roads and utilities.



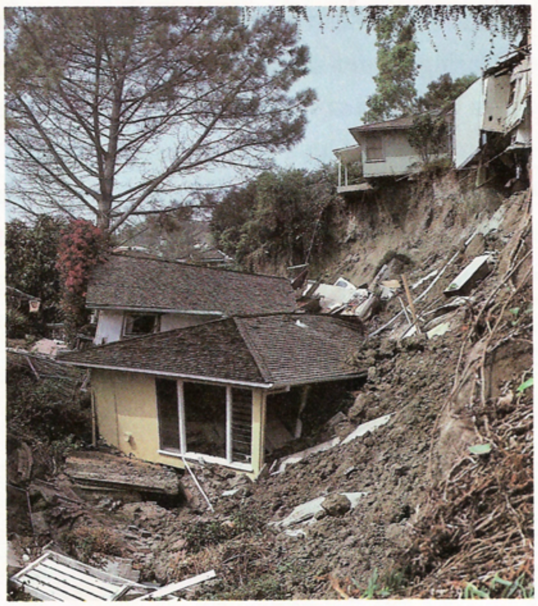
Map showing extent of an earthquake-induced landslide in the Turnagain Heights subdivision of Anchorage, Alaska. The slide was caused by the Alaska earthquake of 1964. The slide extended about 8,000 feet along the bluff and moved toward the Knik Arm as a jumble of blocks.



Damage from the Turnagain Heights landslide. More than 75 homes were destroyed when the bluff failed. Photograph by Robert A. Page.

Landslide—Bluebird Canyon, Laguna Beach, California

In 1978, as the result of heavy winter rainfall saturating the ground, a giant landslide broke loose in the Bluebird Canyon subdivision of Laguna Beach in southern California. The landslide destroyed 24 homes, several roads, and all utilities serving the hillside subdivision. The slide moved slowly enough that all the residents were able to escape, but the property loss exceeded $15 million in 1978 dollars. The Federal Emergency Management Agency (FEMA) spent over $1 million buttressing the slide mass. In late 1979, the city began issuing permits to rebuild homes on the stabilized slide mass. Bluebird Canyon was subdivided in 1947 without benefit of geologic studies, which could have shown the unsafe slope conditions.



Homes damaged by a 1978 landslide in the Bluebird Canyon subdivision of Laguna Beach in southern California. Twenty-four homes were destroyed by the slide.

To stabilize the slide mass from the 1978 Bluebird Canyon landslide, the Federal Emergency Management Agency funded construction of this buttress, which is shown here under construction in 1979.

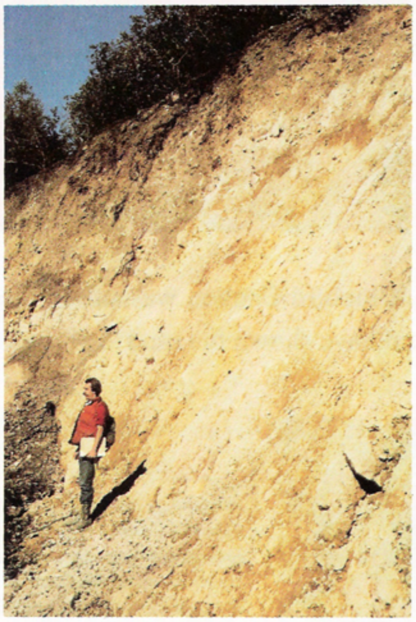
Part of the Bluebird Canyon subdivision as it looked in 1984; this area was rebuilt after many homes were destroyed by a 1978 landslide.

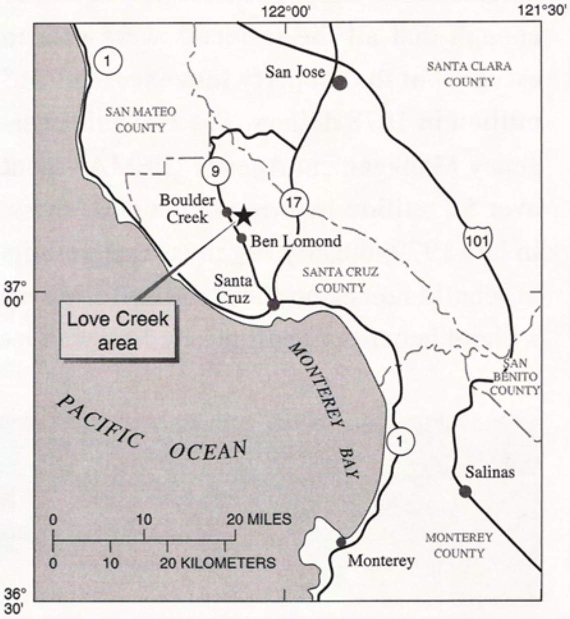
Debris Flow—Love Creek, Santa Cruz County, California

During winter storms of 1982, a huge debris flow roared down the Love Creek canyon in Santa Cruz County, burying 10 people and destroying 9 homes. Post-disaster studies showed that an adjacent area was also unstable, and the county forced the evacuation and eventual removal of an additional 25 homes because of possible future slope failure. The Love Creek community was developed mostly in cabin-style second homes long before geologic studies were required. Over the years, the cabins were improved and converted to permanent homes. However, this transition in land use occurred without the benefit of geologic studies.

(left) Geologist standing at the toe of the Love Creek landslide. Photographer unknown.

(right) Index map showing location of Love Creek canyon near Santa Cruz, California.





Subsidence—Baytown, Texas

Before 1983, the Brownwood subdivision in Baytown near Houston, Texas, had been gradually sinking into Galveston Bay as a result of ground-water withdrawal. By 1979, residents were moving to the second stories of their homes several times a year because high tides routinely flooded the ground floors. Several plans by various Federal, state, and local agencies to buy out the owners were rejected by them. FEMA finally refused to write flood-insurance policies in the area or offer any disaster assistance. In 1983, Hurricane Alicia removed virtually all traces of the subdivision. Subsidence from fluid withdrawal is a predictable and controllable problem. Unfortunately, most homes in the Brownwood subdivision were built in the 1940's before the subsidence hazard was identified.

Home in the Brownwood subdivision near Baytown, Texas, which is near Houston. The entire subdivision was gradually sinking into Galveston Bay as a result of ground-water withdrawal; high tides from Galveston Bay routinely flooded the homes in this subdivision. The entire subdivision was destroyed by Hurricane Alicia in 1983.

Sinkhole—Winter Park, Florida

In 1981, support for the roof of a cave gave way in Winter Park, Florida, north of Orlando; this process formed a huge sinkhole. Within three days it engulfed part of a community swimming pool, parts of two businesses, a home, and several automobiles. Damages exceeded $2 million (in 1981 dollars). Such collapses are prevalent in areas underlain by limestone rock. Limestone can dissolve in water and thus create underground voids or caves. When water tables fall, as happens during droughts, the roofs of these voids are left with inadequate support and they may collapse. Geologic studies can identify areas of limestone rock susceptible to such failures.

House in sinkhole that formed near Winter Park, Florida, near Orlando, in 1981. Sinkhole is approximately 100 feet deep. Photograph by John G. Newton.

HEEDING GEOLOGIC ADVICE

In all of the disasters described thus far, deaths, injuries, and property damage might have been prevented or certainly reduced if geologic information had been available and heeded before building. Although some of these disasters preceded widespread recognition of their underlying geologic causes, today, all of them could be prevented. With adequate geologic information prior to development, public agencies and property owners can make informed decisions about risk. They can take actions to either avoid or reduce the risks. Several examples from the San Francisco Bay Area and elsewhere show that safe development can take place in areas with geologic hazards, if geologic information is used in project planning.

Regulation of Density—San Mateo County

Since the early 1970's, the U.S. Geological Survey has used San Mateo County in northern California as a study area for mapping hazards. The resulting maps are specifically designed for land-use planning, and the county has used these maps to regulate residential density in parts of the Santa Cruz Mountains. For example, the county adopted a zoning district, applied to steep and forested hillsides, which establishes a minimum lot size of 5 acres. However, if a parcel

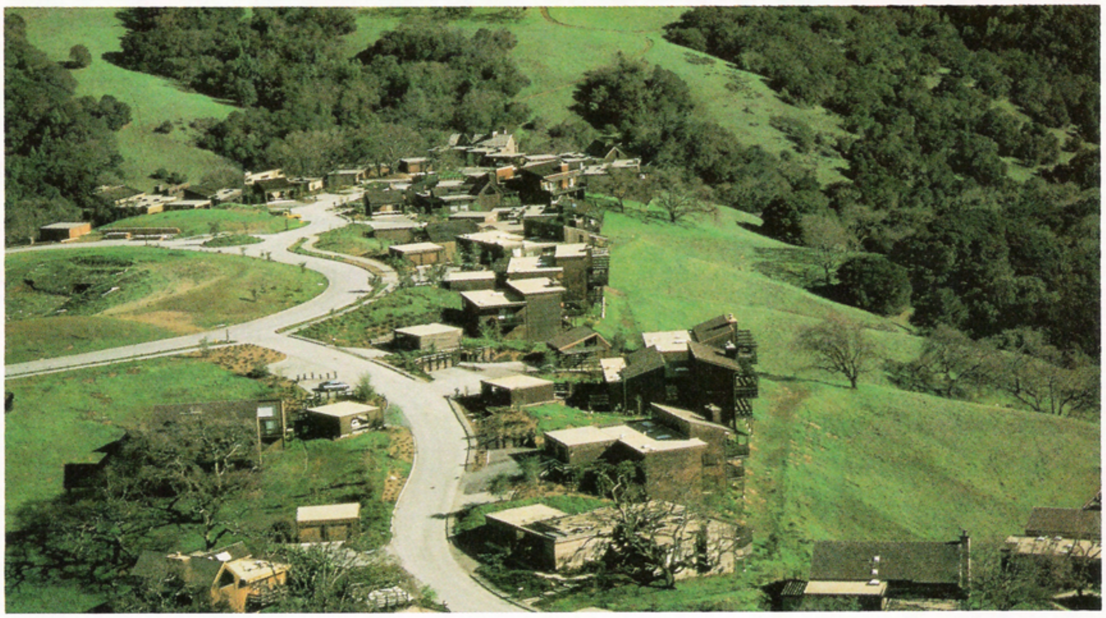
With adequate geologic information prior to development, public agencies and property owners can make informed decisions about risk.

is in one of three categories of unstable slopes as shown on a landslide-susceptibility map, the minimum lot size must then be increased to 40 acres. This minimum lot size may be decreased if the proposed development is designed to mitigate possible hazards, retain vegetation, and limit grading.

Typical hillside area in San Mateo County, California. Since the early 1970's, the U.S. Geological Survey has been mapping geologic hazards in San Mateo County to compile hazards maps for land-use planning.

Cluster Development to Avoid Risks—Portola Valley, California

When hazardous areas have been identified before development, they can simply be avoided by clustering the development. Portola Valley, California, faced an application to subdivide a parcel crossed by the San Andreas Fault and flanked on one side by unstable hillsides. Portola Valley required the subdivider to submit detailed geologic studies and design the subdivision to avoid the fault and unstable hillsides. Under planned unit development provisions, he was allowed to create lots smaller than normally permitted under the zoning ordinance. The lots were clustered in the least vulnerable areas to keep the most unstable hillsides and the fault zone in permanent open space. The result is a successful subdivision from the developer's point of view and a responsible development from the town's point of view.

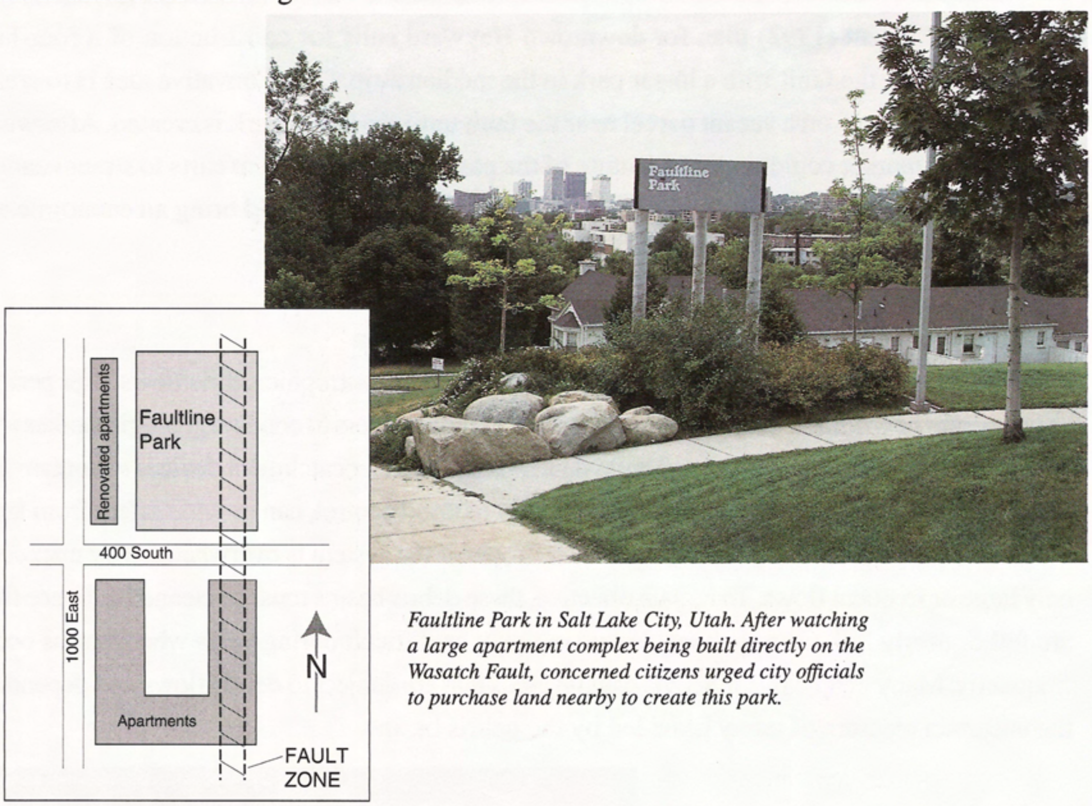


Development in Portola Valley, California, that was clustered to avoid faults and unstable slopes nearby. Photograph courtesy of Ron Sanford Photo, Gridley, California.

Beneficial Use of Hazardous Lands—Salt Lake City, Utah

Geologists have long identified the Wasatch Fault as a hazard along the western front of the Wasatch Range in Utah. The fault slices through Salt Lake City and, although geologic evidence that it has moved recently is abundant, that evidence has had little effect on the city's development pattern until recently. In the 1970's and 80's, geologic studies highlighted the potential for a damaging earthquake on the Wasatch Fault, and the public began to express concern.

A group of citizens watched a large apartment complex being built directly on the fault and began lobbying the city to purchase the parcel to the north for a park. The park and the apartments together, they argued, would illustrate good and bad uses of the land along the fault. The parcel to the north contained a rundown apartment complex that was located at least 50 feet from the fault. The city acquired this parcel, renovated the apartments, and created Faultline Park directly on the fault. A plaque explains the fault and the hazard it presents. Faultline Park is a creative addition to the urban scene and answers the question, "What do we do with land that is unsafe for building?"



Faultline Park in Salt Lake City, Utah. After watching a large apartment complex being built directly on the Wasatch Fault, concerned citizens urged city officials to purchase land nearby to create this park.

Relocation to Reduce Risk and Beneficial Use of Hazardous Lands—Hayward, California

The Hayward Fault crosses downtown Hayward, and at one place it passes directly under Hayward's original city hall. Slow movement along the fault, called *creep*, has damaged city hall, other buildings, streets, and curbs. In the 1970's, the city initiated geologic studies that led to a decision to build a new civic center complex on a site set back from the fault. The fire and police departments and emergency operations center were transferred from the original city hall to the new complex. The city first reduced occupancy of the old building and has now vacated it completely. Some citizens are hoping the facade of the old city hall can be saved as a monument either at its present site or perhaps in another area.

(left) Aerial view of downtown Hayward, California, showing Hayward Fault Zone and location of original city hall.

(right) Original city hall in Hayward, California. This building was constructed directly over the fault. Geologic studies conducted during the 1970's prompted city officials to begin moving their operations out of the building. The building is now completely vacated.

The most recent (1992) plan for downtown Hayward calls for construction of a four-lane boulevard along the fault with a linear park in the median strip. One innovative idea is to create a "pushcart market" on a vacant parcel near the fault until the linear park is created. Afterward, the pushcart market could remain a feature of the park. The city will rent carts to street vendors and designate areas where they may set up. The pushcart market could bring an economic use to parcels on the fault without adding permanent structures.

Controlling the Hazard—Los Angeles County, California

Hillsides in Los Angeles County can spawn sudden and catastrophic debris flows after periods of heavy rain or wildfires. The county requires hillside subdividers to conduct geologic studies and, based on the information, design and build debris basins or other catchment devices to contain and direct debris flows. The solution, similar in concept to flood control, can provide safety from large volumes of material, but it can also lead to catastrophe if the system is overwhelmed by unexpectedly large or frequent flows. To remain effective, these debris basins must be cleaned out once they are full or nearly full. Getting them cleaned out may be difficult during years when storms occur frequently. Many people live in scenic canyon areas that are subject to debris flows and depend on the uncertain measure of safety provided by the debris basins.

One of a series of small debris basins designed to contain and direct debris flows. This structure is located in an unnamed canyon near Pasadena in Los Angeles County, California. It could contain a flow of approximately 100 cubic yards in volume. Photograph by John Tinsley.

Designing for the Risk—Dumbarton Bridge

Geologic studies as a part of an engineering review process are routinely required by the San Francisco Bay Conservation and Development Commission (BCDC) for any construction in San Francisco Bay and along its margins. All projects are reviewed by an Engineering Criteria Review Board for conformance with state-of-the-art engineering practice. The Dumbarton Bridge was the only bridge across San Francisco Bay subjected to such review; the others were all built before BCDC was formed. The Dumbarton Bridge, closest of all the Bay bridges to the epicenter of the 1989 Loma Prieta earthquake, was also the only bridge spanning San Francisco Bay that was not damaged. The BCDC staff credits the careful review process with this success.

Dumbarton Bridge, which spans San Francisco Bay between Fremont and Menlo Park, California. This was the only bridge spanning the San Francisco Bay that was not damaged during the 1989 Loma Prieta earthquake. It is also the only bridge in this area to be built after the San Francisco Bay Conservation and Development Commission (BCDC) was formed. The BCDC reviews all projects requiring dredging or fill of the San Francisco Bay or its margins. Photograph by David McCallen, Lawrence Livermore Laboratory, Livermore, California.

BENEFITS AND COSTS OF GEOLOGIC STUDIES

One inherent impediment to effective use of geologic information in project review is that the costs of such procedures are immediate and measurable, whereas the benefits are long term and uncertain. Geologic disasters in any given location are infrequent. Decades may pass between damaging earthquakes, landslides, and other ground failures. But the costs of preventing damage are here and now. In economists' terms, the value of the benefits should be discounted because they are future and uncertain.

Geologic studies alone yield only the benefit of improved knowledge of site conditions. Unless the knowledge is used to determine where and how to build, safety is not increased at all. However, once a site hazard has been identified it cannot, in good conscience, be ignored.

Costs of geologic studies vary greatly depending on the complexity of the project and the types of hazards at the building site. A reconnaissance hazard assessment can cost several hundred dollars; full investigations including subsurface exploration can cost thousands of dollars. In most cases, the costs are small compared to the actual costs of development and are a small percentage of the total cost to develop a piece of land. However, the costs come at a time when everything is outgo and nothing is income. Also the costs do not necessarily end with a geologic study. If the study uncovers site hazards, they need to be addressed. The developer may have to redesign the project or add mitigation measures, such as retaining walls, buttresses, and drainage systems.

A home sited carefully on the basis of geologic studies will not necessarily command a higher price than one sited on an unacknowledged landslide.

Given the current general level of information about geologic hazards, the market does not usually reflect differences in siting, foundation design, or other measures to reduce losses from ground failures. A home sited carefully on the basis of geologic studies will not necessarily command a higher price than one sited on an unacknowledged landslide. This means that the developer simply makes less profit when he or she has the expense of geologic studies. This situation could change as the public becomes more informed about geologic hazards and expects that geologic hazards have been addressed in the design and construction of projects.

The people paying the costs are not necessarily the people who will reap the benefits. Usually those subdividing or developing a property are not going to be living or working there. The risk of inadequate attention to geologic hazards is born by buyers or renters who may not be aware of the risk they are taking. Public disclosures of geologic hazards can help, but people often have little choice about occupying a building even if they are aware of the risks.

Those who reap the benefits of attention to geologic hazards are the owners and occupants of the building at the time disaster strikes. These people may be many times removed from the people who made the original decision to build. The public also benefits in the long run. Geologic hazards threaten the public facilities and infrastructure needed to serve private development. Recovery from disasters is a large public burden—not just the repair and rebuilding of public facilities, but managing the entire process of community response and recovery.

Buildings last a long time. Cost and risk analyses often assume an average building lifespan of 40 years, but a recent study by Barclay Jones of Cornell University shows that most buildings last much longer—often over 100 years. In earthquake-prone regions of the country, it is reasonable to assume that a damaging earthquake will strike within the lifetime of most buildings.

Analyzing the cost and benefits highlights why the issue of geologic review of development applications is a public responsibility. Developers who respond to the market have little motivation to consider geology. Purchasers, to the extent they are well-informed, legitimately consider the risk in terms of how long they expect to occupy a structure. Considering future generations in decisions about land development is a public responsibility.

WHO IS LIABLE FOR DAMAGE?

Liability is an uncertain motivation for using geologic information, but the issue is never far below the surface when geologic hazards are discussed. In the event of damage to a structure from geologic hazards, owners usually look first to insurance for help. However, many owners have not purchased earthquake insurance and most policies exclude landslide damage. Owners may then turn to the subdivider and (or) developer of the property, the project engineer, designer, or the general contractor. These people may be hard to locate and (or) out of business. If sued, they can often claim successfully that they followed standard practice at the time the work was done. As a last resort, those suffering damage may sue the public agency issuing the development approvals and permits for grading and construction.

Individuals have had mixed results in attempting to recover damages from public agencies. Some agencies have settled claims against them, some have won lawsuits, and some have lost lawsuits and been forced to pay claims. One property owner in Santa Clara County successfully pleaded for relief from the geologic report requirement, then suffered damage in the Loma Prieta earthquake, and finally sued the county (unsuccessfully) for failing to require the report!

"Standard practice" is changing, and that could affect liability determinations in future cases. When most of the cities and counties in an area, such as in the San Francisco Bay Area, routinely use geologic information in project review and environmental assessment, that use becomes viewed as part of standard practice. Once that happens, public agencies and private developers are more likely to be held liable for failing to acquire and use geologic information.

In earthquake-prone regions of the country, it is reasonable to assume that a damaging earthquake will strike within the lifetime of most buildings.

Using Geologic Information in Project Review

Local governments have adopted a variety of procedures to use geologic information in their project reviews. Some of the procedures respond to special characteristics of the local natural or built environment; others reflect variations in the community's willingness to regulate on the basis of geology. Successful programs have features in common. This section describes these common features along with selected examples of their use in the San Francisco Bay Area.

To use geologic information in project review requires the expertise of geologists—geologists representing public agencies and geologists working for developers. Geologists representing public agencies advise on appropriate studies and the adequacy of reports submitted by developers' geologists; developers' geologists conduct the required studies. Attention to geologic hazards is needed from project conception to completion and throughout the life of structures. The ideal process consists of several phases:

Pre-design Meeting

The developer's geologist reviews available geologic information before any design work is done. In the early stages of project conception, he or she should confer with the public agency to learn about the agency's requirements for geologic study.

Reconnaissance

If the local agency has only general geologic information and hazards maps, it makes sense to require the developer's geologic advisor to undertake a reconnaissance study of a site to define the scope of additional geologic studies that may be needed. Local agencies with geologic hazards maps at a scale of 1:7,200 or larger often skip this step.

Geologic Studies

The developer's geologist (and geotechnical engineer, depending on the type of study) then conducts the required studies of the site.

Peer Review of Geologic Studies

The public agency's geologist reviews the studies for completeness, accuracy, and appropriateness of the recommendations. The developer may be asked to redesign the project or incorporate mitigation measures to reduce the impact of geologic hazards. At this point, the public agency reviews the project and approves or disapproves it.

Monitoring and Inspection

If the project is approved, the work of the developer's geologist and geotechnical engineer continues. They must inspect site grading, foundations, and any required mitigation structures to be sure they are done according to the approved plans. The prior work is of no value if the grading and construction do not conform to the plans. Usually, local governments require an "as-built" report from the developer's geologist or geotechnical engineer certifying that the project was built as approved.

Maintenance

Failure to maintain mitigation structures, such as retaining walls or drainage systems, can nullify the careful attention paid to geologic hazards during project review, approval, and construction. Maintenance is usually a private responsibility, however, public agencies sometimes have a role. In residential developments, homeowners' associations often assume responsibility for maintenance. In other kinds of development, maintenance may be a condition of use permits, which must be renewed periodically. Local governments can rescind the use permit if maintenance is not done satisfactorily. Local governments can seek an easement, or limited right of access, to private land to maintain drainage systems or other site improvements in which there is a public interest. Local governments may also approve the formation of a special district encompassing a development. Special districts can assess property owners within the district for funds to maintain drainage channels or other site improvements. In any case, it is always important to educate property owners about the importance of maintenance and how to do it.

Review of Project Modifications

Project additions and modifications over the years can also cause unsafe conditions. The cumulative effect of multiple small modifications can undermine adequate protection built into the original project. Applications to enlarge or modify structures in areas with geologic hazards need to be supported by geologic data and evaluated by the public agency's geologist for their impact on the safety of the entire structure.

Indeed, building safely in areas with geologic hazards requires vigilance that starts at project inception and continues for as long as structures remain standing. Effective programs to provide this vigilance have common features. The following examples are drawn from interviews conducted with staff members of public agencies in the San Francisco Bay Area.

Attention to geologic hazards is needed from project conception to completion and throughout the life of structures.

LOCAL POLICIES AND ORDINANCES

The authority for local governments to require geologic reports stems from police power—the power to regulate in the interest of public health, safety, and welfare. Policies and ordinances establish the need for geologic studies and define the circumstances under which studies will be required.

In California, all cities and counties are required by the State to adopt a safety element as part of their general plans; this element sets forth how the community will be protected from geologic, seismic, and other hazards. In most California localities, the safety element of the general plan establishes the policy framework for requiring geologic studies. Usually policies are quite general, simply stating that the jurisdiction may or will require geologic studies in areas with suspected hazards. Sometimes, policies are detailed and specify the exact circumstances that call for a geologic study and the types of studies needed.

CALIFORNIA SAFETY ELEMENTS OF LOCAL GENERAL PLANS

California Government Code Section 65302(g) requires that local general plans include safety elements . . . "for the protection of the community from any unreasonable risks associated with the effects of seismically induced surface rupture, ground shaking, ground failure, tsunami, seiche, and dam failure; slope instability leading to mudslides and landslides, subsidence, and other geologic hazards known to the legislative body; flooding; and wildland and urban fires. The safety element shall include mapping of known seismic and other geologic hazards. . ." California's Division of Mines and Geology is authorized to review elements to be sure all available seismic and geologic information has been used.

Regardless of the specificity of policies, they are typically implemented with regulations stating, in legal terms, the obligations of applicants to provide geologic information for various development permits. The regulations may be in any of several parts of local codes:

- zoning, if requirements apply to a zoning district or districts
- subdivision, if they apply to land divisions
- grading or site development, if they pertain to cuts and fills or other aspects of preparing a site for construction
- building regulations, if they apply to certain types of structures

A jurisdiction may establish a zoning district and mandate that any development within the district be preceded by a geologic study. Some cities simply require geologic studies with all applications for development. Requirements may also vary with the type of application or land use.

San Francisco's Community Safety Element recommends special geologic and soils engineering studies before building in "special geologic study areas" with potential for ground failure and flood hazards. These special geologic study areas were defined and mapped in the early 1970's during a city-wide evaluation of geologic hazards conducted by a consultant as background for the city's safety element. The Bureau of Building Inspection carries out the policy by requiring geologic studies before issuing building permits in the special geologic study areas. Geologic reports are also required, when appropriate, as part of the environmental assessment of a project.

Santa Clara County requires geologic reports for single building sites, mobile homes, subdivisions, grading, zoning district changes, and use permits depending on project location. The county geologist prepared a map showing relative seismic stability for the seismic safety element. This map depicts areas of high, moderate, and low hazard potential in red, yellow, and green, respectively. Requirements for site investigations are keyed to this map as shown in the table.

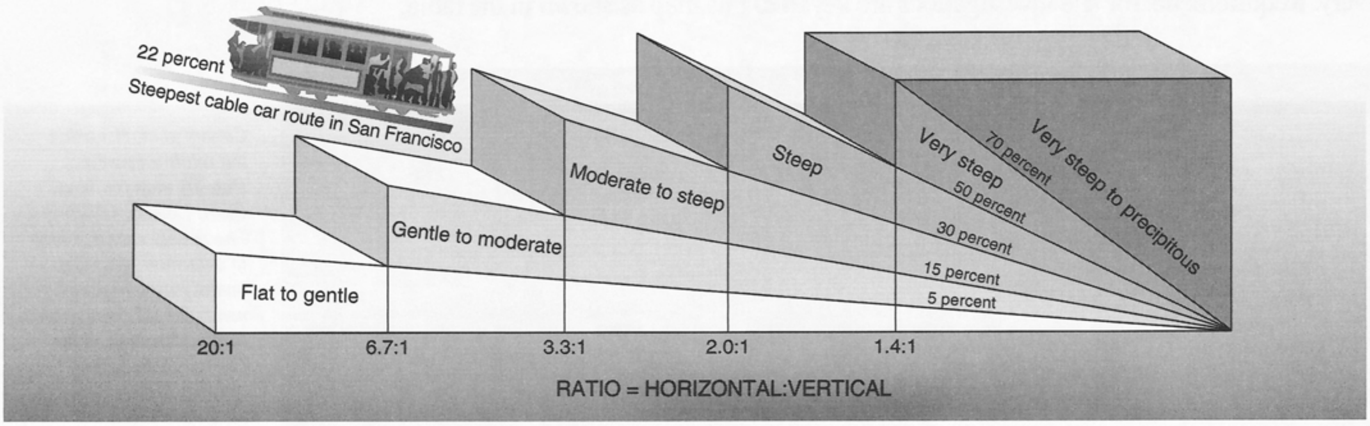
County geologist using the relative seismic stability map for Santa Clara County, California. The county uses this map to determine geologic investigation requirements for all changes in current land use in the county. Table below outlines how requirements are keyed to hazards.

HAZARD ZONES AND INVESTIGATION REQUIREMENTS
summarized from
Santa Clara County Relative Seismic Stability Map

	Hazards	Investigation Requirements
Red	Areas of high potential for liquefaction, lateral spreading, differential settlement, fault rupture, earthquake-induced landslides, tsunamis, and flooding.	Site investigations mandatory unless detailed information permits waiver.
Yellow	Areas of moderate potential for liquefaction, lateral spreading, and earthquake-induced landslides.	Site investigations required unless waived by county.
Green	Area with low potential for liquefaction, lateral spreading, and earthquake-induced landslides.	Site investigation not automatically required; may be required by county on the basis of detailed information.

Sometimes slope is the key factor. Some jurisdictions require geologic studies with applications to develop sites having average slopes steeper than 15 percent, 20 percent, 30 percent, or any percentage chosen by the jurisdiction. For example, Pacifica, California, requires soils and geologic studies of all sites with slopes steeper than 15 percent. The decision is made by the local legislative body and needs to be supported by either experience of failures in slopes above a certain percentage or geologic information indicating potential instability.

Land slope expressed as percentages and ratios.



GEOLOGIC HAZARDS MAPS

Local governments need some knowledge of a potential hazard in order to require a geologic study. For this, they use the best available geologic maps and hazards maps derived from the geologic maps. Ideally, the maps are adopted by the city or county as part of an ordinance or resolution requiring geologic studies.

Geologic hazards maps combine basic geology with other information to show areas subject to specific hazards. They show where the hazard exists, its relative severity at

Small-scale maps can give misleading information about individual sites, particularly if the site is a single lot or small parcel not subdivided. A site may be shown in a generally hazardous zone, but in fact may be free of hazards. . .

each location, and sometimes, the probability of occurrence. Landslide-susceptibility maps and liquefaction-potential maps are examples.

Large-scale hazards maps are best, but small-scale maps can be used effectively, especially at the county level. Sonoma County uses maps at a scale of 1:62,500 (1 inch = 5,208 feet) prepared by California's Division of Mines and Geology. Napa County has geologic hazards map overlays as part of a 26-map overlay system at the scale of 1:24,000 designed to fit over U.S. Geological Survey 7 1/2-minute topographic quadrangles. Several cities in the San Francisco Bay Area and Santa Clara County use maps at a scale of 1:12,000 (1 inch = 1,000 feet). Ideally, cities should have geologic hazards maps at scales ranging from 1:2,400 (1 inch = 200 feet) to 1:7,200 (1 inch = 600 feet), but most cities have not acquired mapping at these large scales.

Small-scale maps can give misleading information about individual sites, particularly if the site is a single lot or small parcel not subdivided. A site may be shown in a generally hazardous zone, but in fact may be free of hazards. Conversely, it may be shown on a small-scale map as hazard-free when, in fact, it contains significant hazards. The purpose of geologic studies is to provide the site-specific detail missing in small-scale hazards maps of large areas. If available hazards maps contain more information, the studies need to provide less.

A few communities in the San Francisco Bay Area have retained consultants to prepare detailed geologic hazards maps of all or part of their jurisdictions. Such maps identify more accurately than small-scale maps where further geologic information is needed prior to development. Morgan Hill has both geologic and landslide-potential maps covering the entire city at a scale of 1:2,400 (1 inch = 200 feet). The maps are used to regulate land-use as well as determine the need for pre-development geologic studies. Belmont obtained geology and landslide-potential maps at the same scale for the San Juan Hills neighborhood. The city uses the maps to determine land uses, road standards, and geologic study requirements.

. . .Conversely, it may be shown on a small-scale map as hazard-free when, in fact, it contains significant hazards.

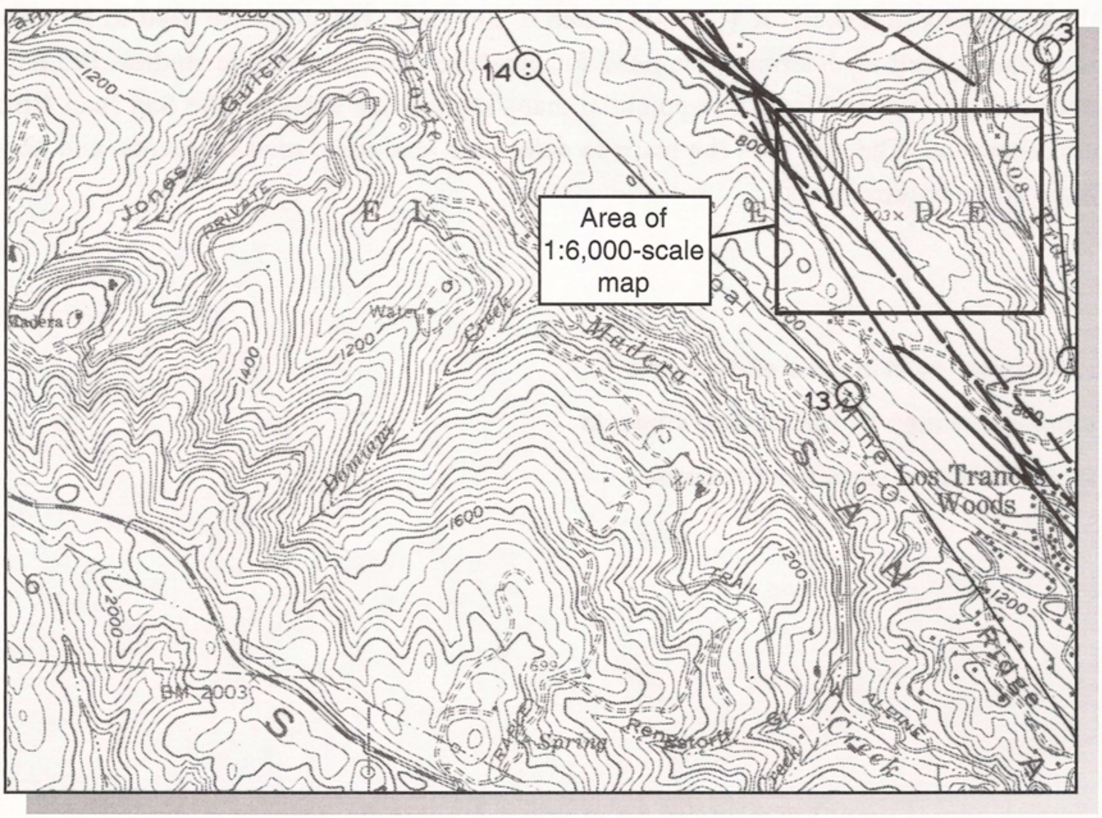
MAP SCALES

Map scales may be shown on a map graphically and expressed as a fraction (1/24,000) or ratio that implies a fraction (1:24,000). The larger the denominator, the smaller the scale, and the larger the area depicted by a map of a given size. For example, a 1:24,000 scale map (1 inch = 24,000 inches or 2,000 feet) is much smaller scale than one at 1:2,400 (1 inch = 2,400 inches or 200 feet).

Map scale, however, is less critical than the information the map conveys; large-scale maps show small areas in detail, small-scale maps provide overviews of large areas. Enlarging a map may make it more legible or easier to use, but it does not change its information content. In fact, enlarging small-scale maps can give the illusion that the map contains more information than it actually does and thus lead to inappropriate use.

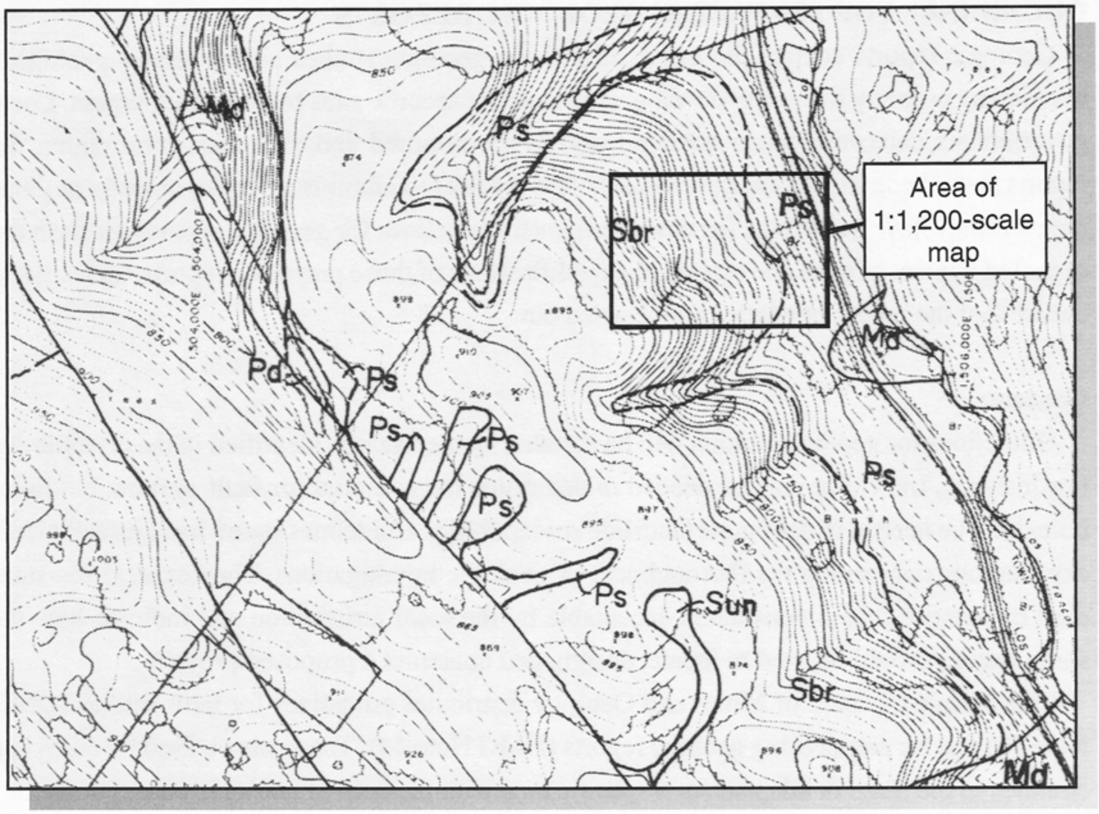
VARIOUS SCALE MAPS OF PART OF PORTOLA VALLEY, CALIFORNIA

1:24,000



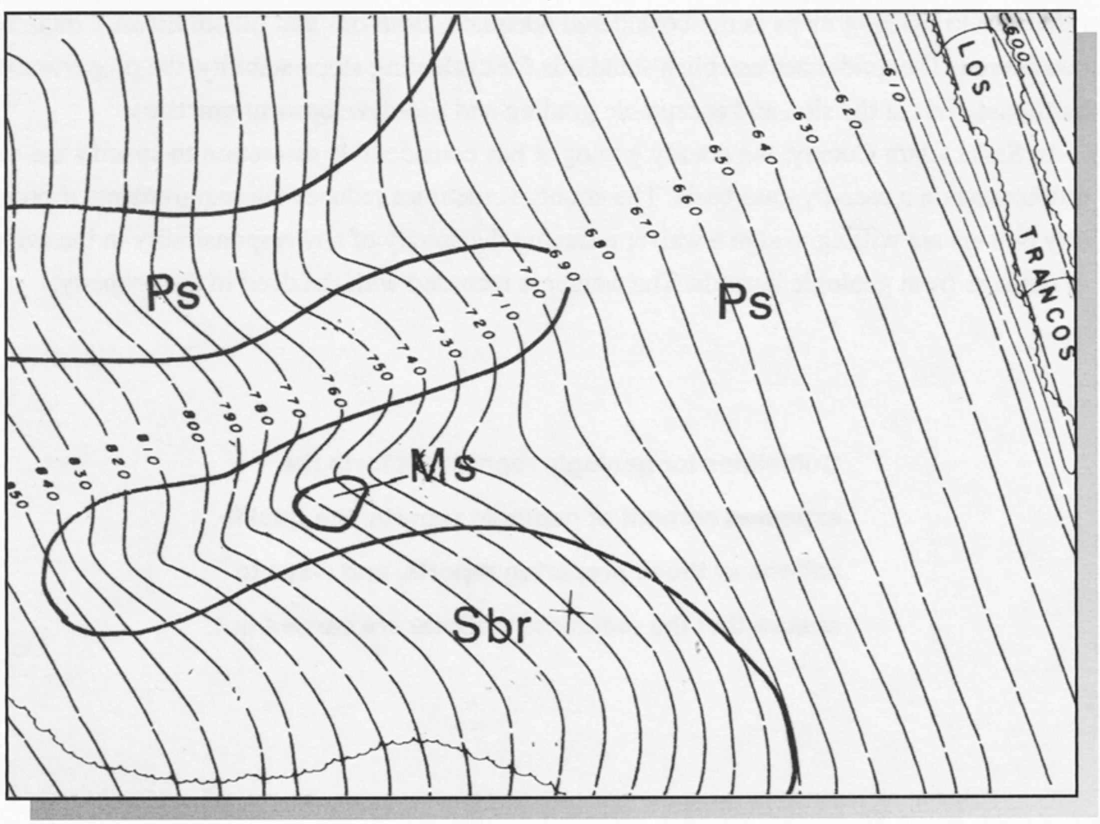
1:24,000-scale map 1 inch equals 2,000 feet. This map is used to determine the need for fault studies prior to development. Box outlines area of 1:6,000-scale map. From Special-Studies Zone Map published by California Division of Mines and Geology. Contours in feet; heavy lines indicate faults. Used with permission.

1:6,000



1:6,000-scale map 1 inch equals 500 feet. This map is the basis for land-use regulations adopted by Portola Valley. Box outlines area of 1:1,200-scale map. From a map showing movement potential of undisturbed ground in Portola Valley. Contours in feet; heavy lines indicate faults; geologic outlines are outlined.

1:1,200



1:1,200-scale map 1 inch equals 100 feet From a map showing movement potential of ground in the Blue Oaks subdivision near Portola Valley. This map refines information in the 1:6,000-scale map and is detailed enough to guide subdivision design. Prepared by Harlan-Tait Associates, San Francisco, California. Contours in feet; geologic units are outlined. Used with permission.

GUIDELINES FOR PREPARING GEOLOGIC REPORTS

Geologic reports contain the information from geologic studies performed by geologists retained by property owners or developers to evaluate specific sites before development. Local governments determine when geologic studies are required and also what information the reports should contain. Local governments find it easier to administer geologic study requirements if they have guidelines for report contents. Guidelines for geologic reports set forth the expected content of geologic reports, the qualifications of those preparing reports, and ways to ensure that the recommendations are carried out.

Contents

Guidelines for geologic reports will be dictated by the hazards identified in the community. For instance, trenching may be needed to determine the potential for fault rupture, but boreholes may be needed to determine landslide susceptibility. Guidelines state a local jurisdiction's expectations concerning the thoroughness of geologic investigations. They express the standard of practice that is considered acceptable by the local jurisdiction and indicate how the study results should be used to locate, design, and construct a proposed project.

California's Division of Mines and Geology distributes guidelines for fault studies (DMG Note 49) and for engineering geology reports (DMG Note 44). These can be used by cities and counties in the State or adapted for a specific area with the help of geologic consultants.

Pacifica provides detailed guidelines for geotechnical reports. Applicants' geologists must submit their own geologic maps, including geologic cross sections, of proposed building sites; reference to existing maps is not considered adequate. Both on- and offsite hazards must be considered. The guidelines establish standards for evaluating slope stability, the properties of earth materials at the site, and acceptable grading and site-development practices.

In Santa Clara County, the county geologist has considerable discretion to specify the requirements on a case-by-case basis. The county sometimes reduces the requirements if property owners are willing to sign a waiver relieving the county of any responsibility in the event of damage from geologic hazards. The waiver is recorded with the deed to the property.

Guidelines for geologic reports set forth the expected content of geologic reports, the qualifications of those preparing reports, and ways to ensure that the recommendations are carried out.

GUIDELINES FOR PREPARING ENGINEERING GEOLOGIC REPORTS
Outlined from DMG Note 44

I. Geologic Mapping. The reports should include maps with the following information:

- Independent, large-scale, geologic maps on a detailed topographic base at appropriate scale, extending to adjacent areas, if necessary.
- Physical character, structural elements, and three-dimensional distribution of the earth materials—usually both bedrock and surficial deposits.
- Distinction between observed and inferred features and relationships.
- Structural cross sections, as needed.
- Locations of test holes or other sources of subsurface data.

II. General Information. The report should include:

- Location and size of area and its geographic and geologic setting.
- Date of mapping and who did it.
- Descriptions of investigations conducted.
- Topography and drainage.
- Abundance, distribution, and general nature of exposed earth materials.
- Nature and source of available subsurface information.

III. Geologic Descriptions. The report should contain descriptions of all natural materials and structural features including, but not limited to, the following:

- Bedrock—igneous, sedimentary, and metamorphic.
- Structural features.
- Surficial deposits.
- Drainage.
- Features of special significance.

IV. Bearing of Geologic Factors Upon Intended Land Use. The report should discuss the effects of geologic features on grading, construction, and land use and the effects of the proposed project on geologic processes. Topics normally include:

- Compatibility of the project with geologic conditions.
- Proposed cuts.
- Proposed fills.
- Recommendations for subsurface testing and exploration.
- Special recommendations.

Qualifications of Preparers

Guidelines typically specify the qualifications of those who can conduct geologic investigations and review the resulting reports. The most common professional designations are "geologist," "engineering geologist," and "geotechnical engineer." The terms are often confused. Geologists and engineering geologists both have degrees in geology. An engineering geologist has additional training in engineering. A geotechnical engineer has a degree in civil engineering with additional training in geology. The definitions used in this circular are shown in the box below.

PROFESSIONALS WHO PREPARE GEOLOGIC REPORTS

A *geologist* is a scientist who studies the dynamics and physical history of the earth, the rocks of which it is composed, and the physical, chemical, and biological changes that the earth has undergone or is undergoing. The State of California registers geologists.

An *engineering geologist* is a geologist versed in the application of geologic knowledge and principles in the investigation and evaluation of naturally occurring rock and soil for use in the design of civil works (adapted from Uniform Building Code, 1991, Chapter 70, Sec. 7005). The State of California certifies engineering geologists who pass an examination given by the State.

A *geotechnical engineer* (also called a soils engineer) is a civil engineer versed in the application of the principles of soils mechanics in the investigation, evaluation, and design of civil works involving the use of earth materials and the inspection or testing of the construction thereof (adapted from Uniform Building Code, 1991, Chapter 70, Sec. 7005). The State of California licenses geotechnical engineers.

Generally speaking, a geologist or an engineering geologist can assess a site for geologic hazards. A geotechnical engineer or an engineering geologist with a strong engineering background is needed to recommend and approve mitigation measures such as special foundation designs, retaining walls, or drainage systems. California registers geologists, licenses geotechnical engineers, and certifies engineering geologists and, in many cases, local guidelines require that report preparers have such verification of minimum competency.

It is important that geologic studies be prepared by the appropriate professional. Practice in the San Francisco Bay Area varies considerably. In Santa Cruz County, geology reports must be prepared by an engineering geologist. The county geologist would like to see more reports done jointly by geotechnical engineers and engineering geologists with more emphasis on the design of mitigation measures. In Pacifica, the reports may be prepared by a registered geologist or a certified engineering geologist along with a geotechnical engineer, if needed. Healdsburg requires an initial review by an engineering geologist. The as-built construction report submitted at the completion of the project may be signed by either an engineering geologist or a geotechnical engineer.

Carrying out Recommendations

A thorough geologic report with well-supported recommendations accomplishes little if the recommendations are not followed when the project is constructed. Guidelines often contain a schedule for inspections by the applicant's geologist or geotechnical engineer and makes him or her responsible for seeing that the work is done as approved.

Healdsburg requires an as-built construction report certifying that the work was performed in accordance with recommendations of the engineering geologist and (or) geotechnical engineer and signed by an engineering geologist certified by the State of California and (or) a geotechnical engineer registered in the State of California. The as-built report must include the building plans, explanation of any deviations from the approved grading plan, location and results of field tests, results of laboratory tests, and a statement that the work was performed under the supervision of a certified engineering geologist and (or) geotechnical engineer.

A thorough geologic report with well-supported recommendations accomplishes little if the recommendations are not followed when the project is constructed.

GETTING GEOLOGIC ASSISTANCE

One barrier to effective use of geology, particularly in smaller jurisdictions, can be the lack of geologists and engineers with appropriate training to conduct site investigations and review geologic reports. Adopting regulations generates a demand for geologists and geotechnical engineers, and economic theory assures us they will come. Yet, there is usually a time gap between creating the need and filling it. For example, after adopting requirements for geologic reports, Salt Lake County (Utah) found that developers initially had problems finding qualified professionals to prepare geologic reports.

Public agencies can encourage local universities and community colleges to develop education programs for geologists and geotechnical engineers. They can contact the professional engineering and geology associations for lists of members and advice about how to meet their needs. Sometimes state geological surveys can help. The Utah Geological Survey will conduct geologic investigations for essential public facilities and tax-supported projects in the State.

Requirements for geologic studies can be phased in, perhaps starting with large infrastructure projects or subdivisions on very steep slopes, and as need is demonstrated, extended to other projects or areas within the jurisdiction. A lack of geologists in an area need not be a reason to defer adopting requirements for geologic studies.

INDEPENDENT REVIEW OF GEOLOGIC REPORTS

Without independent, professional review of geologic reports submitted by applicants' geologists, a geologic review program cannot be considered adequate. It is difficult to assess risk from geologic conditions, and qualified geologists often disagree. The final decision rests with the political body having approval authority over the proposed action. This body needs the knowledge and advice of an experienced and objective professional geologist who speaks for the public interest in safe development.

The development review process is inherently adversarial. The public agency by law must give preeminence to public health, welfare, and safety. The property owner may be more interested in economic return or achieving a desired development pattern. Some applicants wish to downplay any potential hazards and may hire a geologist with similar inclinations. Often the applicant will not be living on the property and is not assuming any personal risk. The public agency is needed to protect the safety of those who will be exposed to potential hazards in the long term.

The professional reviewing geologic reports for a public agency must be free of real or apparent conflicts of interest. This usually means someone who does not accept work for private clients in the jurisdiction. Because a good geologist with knowledge of local geology is valuable to both sectors, finding a geologist without any conflict of interest is not as easy as it may seem. He or she may be faced with a difficult career choice—to do public work and sacrifice private work or to accept private clients and forfeit the chance to do work for a public agency. From the perspective of the public agency, the need is to provide professional, impartial review of geologic reports.

The depth of review can vary considerably. In some jurisdictions, geologic review is a simple check to be sure a geologic report covers all the subjects listed in the jurisdiction's guidelines. The function of this type of review is basically to shift liability to the applicant's consultants. The qualifications of the reviewer are not as important for this kind of review. However, a more critical kind of review is needed to ensure responsible site development. The reviewer visits the site, studies aerial photographs, and generally draws on available information and his or her professional judgment to determine if the conclusions in the geologic report are well supported.

Most San Francisco Bay Area cities and counties use consultants to review geologic reports, but specific arrangements vary. Healdsburg keeps an engineering geologist on retainer to review geologic reports. San Rafael has a Geologic Review Board consisting of three geotechnical consulting firms that take turns reviewing geologic reports. Pacifica contracts directly for peer review with one of two approved consultants.

In jurisdictions with a staff geologist, a major function of that person is to review geologic reports. In Santa Cruz County, the county geologist, a certified engineering geologist, is responsible for reviewing geologic reports. Until his retirement in 1993, the Santa Clara County geologist, a certified engineering geologist, reviewed all geologic reports for the county; he reviewed an average of 140 reports a year.

County geologist in Utah explaining site hazards to planners.

GEOLOGISTS ON STAFF

Ideally, each county would have a geologist on staff to develop and administer geologic report requirements and review geologic reports. When city and county relationships are generally cooperative, a county geologist could also contract with small- and medium-sized cities to provide geologic services. In some cases, a geologist from a state geological survey might fill this role. A staff geologist can fill many roles.

• A staff geologist can encourage the incorporation of geologic information at all stages of the planning-development process—general planning, subdividing, zoning, reviewing site plans, assessing environmental impacts, and monitoring construction. Communities relying on consultants often use them only to review geology reports submitted in support of development applications.

• He or she can be an influential educator increasing awareness of staff and legislators of the importance of geology in land-use decisions. A staff geologist is accessible to other staff members, and this presence alone encourages the interchange of information and ideas.

• A staff geologist can also be a powerful force favoring the institutionalization of geologic study requirements. Such requirements, once in place, can survive even the loss of the geologist position. Both Contra Costa and Alameda Counties lost staff geologists through retirement and decided not to replace them because of tight budgets. Both counties continue to require geologic reports, and they now use consultants to review them. However, the planners in these counties would prefer to have a permanent geologist on staff to help with geologic issues that arise.

• He or she can lower the cost of geologic review for applicants, particularly if part of the geologist's salary is paid out of general funds rather than fees. With a geologist on staff, the jurisdiction does not have the costs of establishing and administering contracts with consulting geologists or the costs of liability insurance. A staff geologist is immune from liability in California. Also, because of increasing familiarity with local geology, a staff geologist may need less time to review reports than a consultant.

• He or she exercises discretionary professional judgment in administering regulations, which can result in a more efficient and equitable system drawing on the experience of the geologist to make determinations about the needs for specific kinds of investigations. Local jurisdictions may be more willing to grant discretion to a staff member than to a consultant serving as geologic reviewer.

• He or she maintains files of geologic reports and makes sure that the information is retained and used to update geologic maps and influence requirements on nearby properties.

• Finally, a staff geologist prepares and updates hazards maps for the jurisdiction or particular areas of concern.

Santa Clara County was one of the first San Francisco Bay Area counties to create a position for a staff geologist. The geologist who served most of the last 20 years established geologic report procedures that are well respected, particularly among geotechnical professionals. The county's fee of $405 for review of a geologic report is one of the lowest in the San Francisco

Bay Area. As a result of the continuous presence of a geologist on staff for so long, county officials now routinely consider geologic information in all aspects of planning and regulating land development.

WAYS TO RESOLVE DISPUTES

Geology is not an exact science, and well-qualified professionals can disagree on geologic interpretation and what needs to be done. Such disagreements can trouble public officials who may be uncomfortable using geologic information already. The first need in such situations is often more intensive site studies. More detailed information can eliminate or greatly reduce professional differences. If significant differences remain, it helps to have a policy or procedure for making decisions. Some options are a presumption in favor of the public agency geologist, third-party peer review, and mediation.

Presumption in Favor of Public Agency Geologist

In both the City of Saratoga and Contra Costa County, the governing board agrees to back the geologist working for the jurisdiction in the event of scientific disagreement. The public agency geologist usually recommends accepting less risk from geologic hazards than the developer's geologist. Accordingly, this approach typically means resolving disputes in favor of safety.

Third-Party Peer Review

Sometimes a jurisdiction may bring in a third geologist to advise about a dispute. This is appropriate when, for whatever reason, the issue has become polarized. Portola Valley established a geologic review committee to resolve a dispute over the adequacy of a geologic report for a proposed subdivision. The committee supported the town geologist (a consultant) and, as a result, the applicant decided to retain a new geologist to complete the investigation and submit a revised report. The town geologist accepted the revised report as adequate.

Mediation

Pacifica has an informal procedure for mediating disputes. When an applicant's geologist objects to the recommendations in a review, he or she may request a meeting to resolve the issue. Both geologists and appropriate city staff attend. City staff explains why studies are needed and helps the parties to reach agreement. So far, agreement has been reached at such meetings without the necessity for further action.

FEES

Project applicants pay for geologic studies and reports. Public agencies incur costs to administer the requirements and provide independent peer review of geologic reports submitted with project applications. Increasingly, these costs are paid by the applicants. A good program clearly states all fees and deposits and provides applicants with general information about typical costs for geologic studies. Fees and deposits for geologic review are normally collected along with other fees for handling project applications.

Some jurisdictions establish fixed fees to cover these costs; others require deposits that are drawn down as work proceeds. Jurisdictions typically adjust fees and deposits to reflect their experience so that the charges are generally close to actual costs.

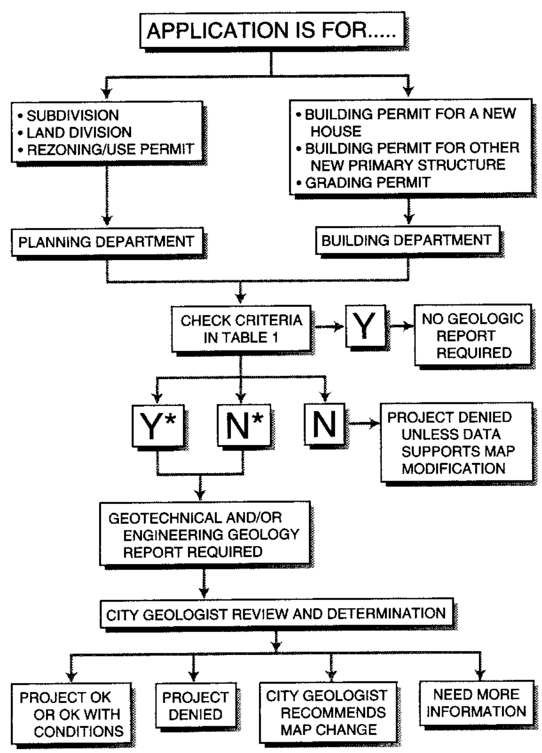
In most San Francisco Bay Area jurisdictions, geologic review is done by consultants and the full cost is paid by project applicants. In 1991, San Rafael collected a $1,500 deposit for geologic review. Santa Cruz County staff spends an average of 14 hours to complete a preliminary hazard assessment. For this, the county collected a fee of $530 in 1991, which then covered about 83 percent of the cost of staff time. This fee is likely to be raised so that it covers closer to 100 percent of the cost. If the preliminary hazard assessment indicates the need for a full geologic study, the applicant retains a consultant to conduct a study and prepare a report. In 1991, the county charged a deposit of $750 to review the report. The applicant receives a refund of any unused amount. The actual costs of review can vary significantly depending on site conditions and the adequacy of the report submitted by the applicant's consultant.

INSTRUCTIONS FOR APPLICANTS

Most project applicants undertaking geologic investigations will be facing the process for the first time. It helps if the jurisdiction has prepared a pamphlet with a clear, nontechnical description of the requirements. A flow diagram can be particularly helpful. The instructions should contain a step-by-step description of the process, noting time limits, decision points, and what person or body makes decisions.

Belmont requires geologic reports for new construction or substantial modifications of existing structures in the San Juan Hills area of the city. The city has developed a flow diagram for applicants showing the procedures for new construction.

The instructions should contain a step-by-step description of the process, noting time limits, decision points, and what person or body makes decisions.



Y — Yes, the land use is permitted.

Y* — The land use would be permitted, provided geologic data indicates geologic conditions and(or) engineering solutions are favorable.

N* — The land use would not be permitted unless geologic data indicates geologic conditions are more favorable than mapped or engineering solutions will reduce the risk to acceptable levels.

N — No, the land use is not permitted. The map must be changed to show that this hazard does not exist before development will be allowed. The map change must be based on geologic data showing that the map was in error or that improvements have been undertaken which remove the hazard.

Flow diagram used by Belmont, California, to help guide builders, developers, and property owners through the city's requirements for geologic studies.

KEEPING GEOLOGIC REPORTS AVAILABLE

What happens to geologic reports submitted to a local government? Some communities have systems for indexing and filing the reports for later use and others do not. A rich information resource is hard to use if the reports are not kept accessible to other geologists preparing reports in the jurisdiction and to geologists who may be mapping in the area. Sometimes, investigations on adjacent parcels may be complete enough to eliminate the need for a study of a site.

Methods of keeping reports accessible include maintaining index maps showing properties for which reports have been prepared, filing all reports with applications as well as creating and maintaining a data base that can be accessed using county assessor's parcel numbers and (or) street addresses.

In Santa Clara County, when the county geologist arrived in 1973, the county had about 70 geologic reports on file. Now there are more than 2,800. The location of each investigation is recorded on a set of the geologic hazards maps called the "geologic activities maps." A file is kept of the geographic coordinates of all the investigation sites. The county geologist recommended entering the index into the county's geographic information system (GIS) and cross-referencing entries to county assessor's parcel numbers and street addresses.

In Healdsburg, all geologic reports are kept on file in the planning department and indexed on a map. City staff and prospective developers use the index map to identify geologic reports prepared for sites near a proposed development.

A rich information resource is hard to use if the reports are not kept accessible to other geologists preparing reports in the jurisdiction and to geologists who may be mapping in the area. Sometimes, investigations on adjacent parcels may be complete enough to eliminate the need for a study of a site.

Examples of Using Geology for Project Review

Descriptions of how two cities and three counties in the San Francisco Bay Area apply procedures for using geologic information during project review give some sense of possible ways to use such procedures. All are different and all work effectively for the jurisdiction given its geologic hazards, staff capabilities, and political philosophy.

HEALDSBURG—GEOLOGIC STUDIES FOR SPECIFIC PLANS

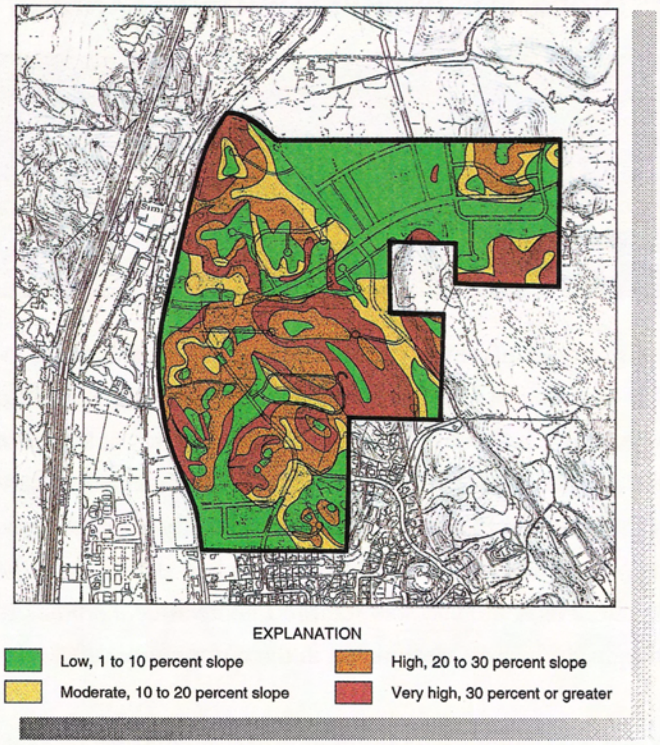
Healdsburg	
1990 population:	**9,900**
Geologic services:	**one consulting firm**
Land-use issues:	**hillside development and annexations**

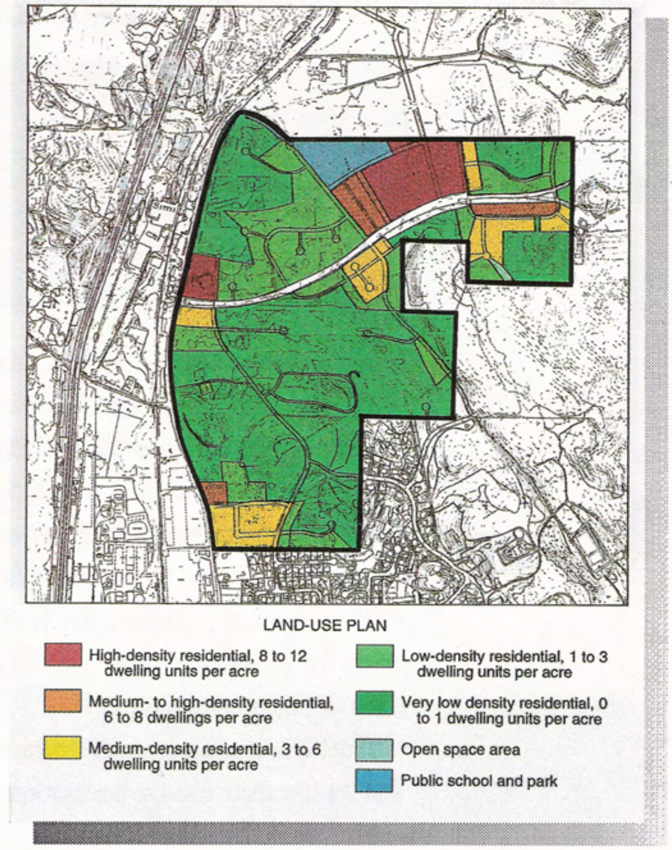
Healdsburg requires that specific plans be prepared for a parcel of land or group of parcels prior to annexation to the city. In California, a specific plan is a detailed land-use and infrastructure plan containing all the regulations, programs, public works projects, and financing mechanisms to ensure that development occurs according to the plan (California Government Code, Article 8, Section 65451). Healdsburg requires geologic maps and evaluation of geologic hazards as part of specific plans.

Under current plans, Healdsburg could annex up to 800 acres north of the present city limits. A specific plan is being prepared for 233 acres of this area consisting of several large and many small parcels. The specific plan is being done as a cooperative venture by two developers, property owners, and the city.

As required by the city, geologic hazards were mapped and evaluated during an early phase of the planning process. Consultants compiled a geologic map and a slope map. Using these maps, land-use alternatives were drawn and evaluated as part of the environmental assessment. The recommended land use shows residential development at a maximum density of one unit per acre in most of the areas having slopes of 20 percent or more. At this density, buildings can be located to avoid steep slopes, and it may be possible to cluster development on the relatively flat areas of parcels.

Because Healdsburg was a party to this plan, the city's consulting geologist did the geologic study. The city and prospective developers helped pay for the geologic work. Geology and slope were mapped at a scale of 1:2,400—detailed enough for land-use planning, but not for project review. In areas with identified hazards, the city will require additional studies prior to approving





Maps that are part of a specific land-use plan required by the city of Healdsburg, California, before annexation of a 233-acre area north of its present boounday.

(left) Slope map of area to be annexed.

(right) Land-use plan for area to be annexed. Low-density residential uses are proposed for most of the areas with steep slopes.

development. These site investigations will be used to establish design parameters for foundations, drainage structures, retaining walls, cuts and fills, and other site modifications and construction details. Healdsburg also uses deed restrictions and disclosure requirements to enforce long-term maintenance of mitigation structures, particularly drainage systems on potentially unstable hillside lots.

Healdsburg's requirement for specific plans with geologic information prior to annexation provides a useful bridge between California's Division of Mines and Geology 1:24,000-scale maps that the city uses for general planning and geologic maps of individual parcels done prior to development. The map, completed by an engineering geologist, at a scale of 1:2,400 is detailed enough to establish land uses for areas several hundred acres in size. The information pinpoints where additional information will be needed prior to actual development and what hazards need to be studied further.

Specific plans are being used more frequently in California because they provide coordinated planning of contiguous parcels with different owners. State planning law allows a city or county to charge the eventual developer of the site for the costs of preparing a specific plan. The State considers shifting these costs to be reasonable because a specific plan accomplishes much of the site planning a developer would normally be expected to do. The procedure gives local governments a means to obtain detailed geologic information for areas slated for development before a project is presented for approval. Information at this early stage in the development process allows full consideration of options to avoid or otherwise mitigate identified geologic hazards. Sometimes, when the information is obtained after a development scheme has already been worked out, mitigation is the only option seriously considered.

SAN FRANCISCO—GEOLOGIC STUDIES FOR REDEVELOPMENT PLANNING

San Francisco

1990 population:	**740,000**
Geologic services:	**consultants as needed**
Land-use issues:	**redevelopment of filled land**

In San Francisco, the greatest need for geologic information is in evaluating proposals for redevelopment of several large tracts on the east side of the city where liquefaction and amplified ground shaking are potential hazards. An example is the development proposal for the tracts known as Mission Bay. Mission Bay is 315 acres situated about a mile southeast of San Francisco's financial district. The site was long owned by the Southern Pacific Railroad and currently contains some old warehouses and industrial plants. Bay mud and unengineered fill, including debris from the 1906 earthquake, underlie much of the site. Here, the city has required geotechnical studies to refine the boundaries of the special geologic study areas designated in the community safety element of the general plan.

Geologic studies of the Mission Bay site were completed during the 10-year approval process. The studies were used as background for a specific plan for the site and as part of the environmental impact report on the proposed development. In 1982, consultants conducted a general soils study of about 80 percent of the Mission Bay site. This was followed in 1986 by another soils survey to address three basic questions:

- What soil conditions affect the development potential of the site?
- Do any soil conditions constrain the location or scale of residential development and (or) the types of residential buildings on the site?
- How is the cost of construction affected by soil conditions?

The study concluded that with proper engineering and foundation design, and flexible utility connections, the site could be safely developed. Additional investigations would be needed prior to development of each parcel. The study also concluded that on about half of the proposed residential sites, extra costs for foundations would be too high to permit construction of housing affordable to households with lower-than-average incomes. A separate preliminary seismic risk assessment by another consultant came to similar conclusions.

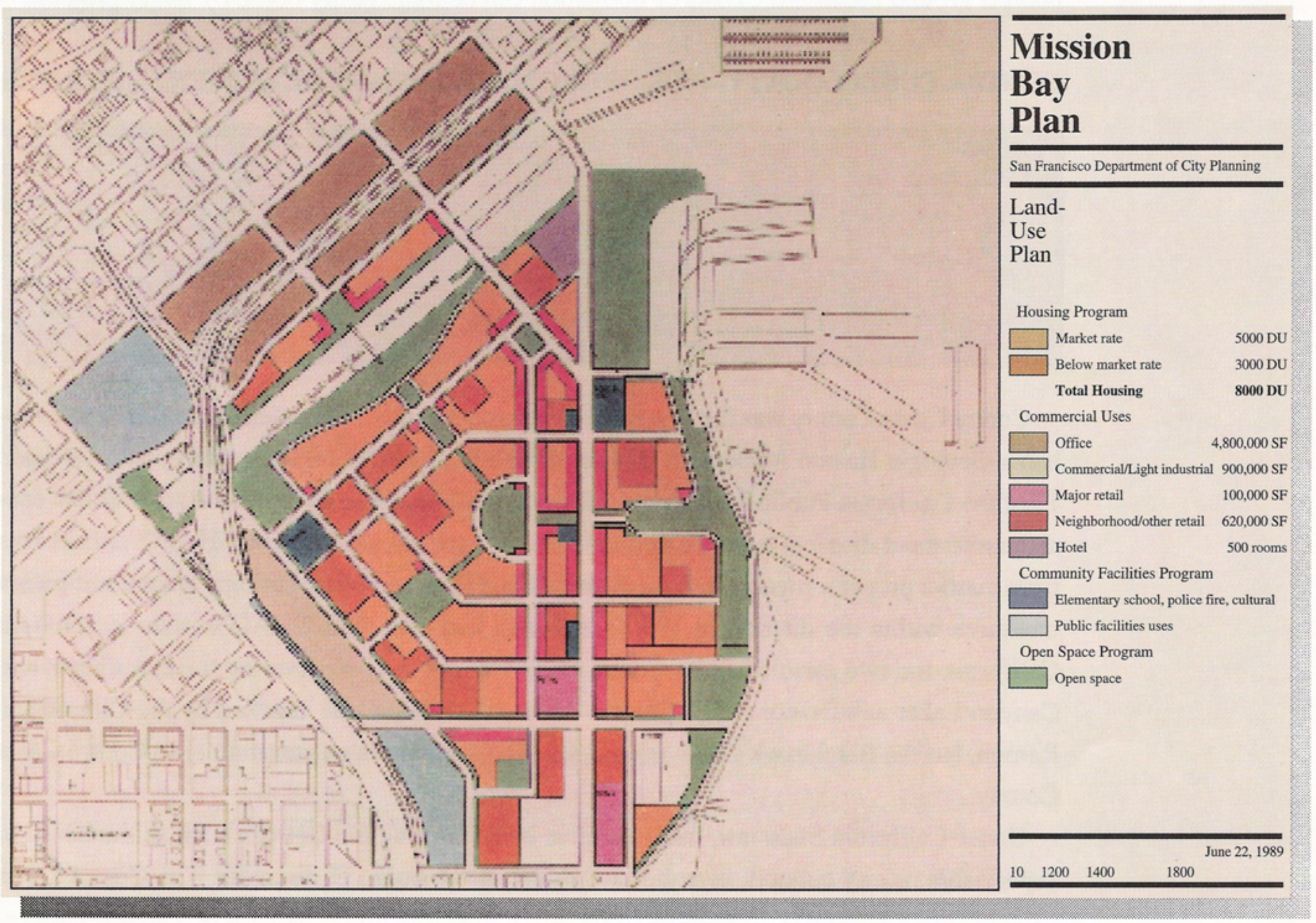
The Mission Bay Specific Plan, adopted in August 1991, incorporates the recommendations of the geotechnical studies. The plan is for a mixed-use development with the following uses:

- 8,270 residential units, of which 3,000 will be priced at below-market rates
- 4.8 million square feet of office space
- 900,000 square feet of light-industry space
- 735,000 square feet of retail space
- 500 hotel rooms
- 68 acres of open space

Developers expect the project to be home to about 16,000 people and 24,000 permanent jobs.

Aerial view of Mission Bay site. Parts of this site have been filled and may be subject to liquefaction. A mixed-use development has been approved for this site by the City of San Francisco, California. Copyrighted photograph by John K. Nakata, Sight & Sound Productions.

Approved land-use plan for Mission Bay site on the east side of San Francisco, California. DU, dwelling units; SF, square feet. Courtesy of Planning Department, City and County of San Francisco.



Because of the generally high water table, the plan calls for raising the site level. Streets will be constructed, without excavation, at the ground surface and fill brought in to raise the level of adjacent parcels to the same level as the streets. Soil conditions particularly affected the selection of sites for affordable housing. The developer offered the city 26 acres in 17 sites for affordable housing. The city negotiated to get sites with the best possible soil conditions to keep site preparation and foundation costs as low as possible. Conversely, high-cost, high-density housing is proposed for sites with poor soil conditions. The city believes that the extra costs of engineering and foundation work can be more easily absorbed by high-density projects.

The specific plan designates special geologic study areas. The life-safety section of the plan requires detailed geologic and soil-engineering investigations for each site on which new structures are to be built. When necessary, building foundations must be designed and constructed to resist damage from liquefaction, lateral spreading, or differential settlement. More stringent construction standards than usual will be applied to critical facilities such as schools, police stations, and fire stations to ensure that these facilities remain functional after an earthquake.

Redevelopment gives the opportunity to do studies that probably should have been done when the land was first developed. Obsolete land uses can be removed in the process and, just as important, safety hazards can be directly addressed. Mission Bay illustrates another interesting point—sometimes it makes economic sense to put the highest intensity uses on the poorest ground because the costs of mitigation can be more easily borne by larger projects.

CONTRA COSTA COUNTY—USE OF GEOLOGIC HAZARD ABATEMENT DISTRICTS

Contra Costa County

1990 population:	**836,900**
Geologic services:	**three consulting firms (formerly had staff geologist)**
Land-use issues:	**development of bayshore, delta, and hillsides**

Contra Costa County was the first local government in the San Francisco Bay Area to establish a Geologic Hazard Abatement District (GHAD). GHAD's are authorized under Division 17 of the California Public Resources Code, which allows local governments to establish special assessment districts in which geologic hazards are known to exist. GHAD's collect fees from district property owners to finance landslide repairs and other geologic hazard mitigation measures within the district. In 1990, California had only four GHAD's—two in southern California and two established by Contra Costa County in 1986 covering the Blackhawk and Canyon Lakes subdivisions. The Canyon Lakes subdivision was annexed by the City of San Ramon, but the Blackhawk subdivision is still an unincorporated community in Contra Costa County.

Under California State law, the legislative body forming the GHAD, such as the board of supervisors or city council, is authorized to act as the board of directors. The Contra Costa County Board of Supervisors sits as the board of directors for both districts. The law requires geologists to quantify potential hazards in the district and determine the amount of funding needed to cover a catastrophic event. The GHAD then assesses property owners in the district to create a reserve fund for mitigation and repairs. The GHAD board of directors may increase or decrease fees at any time.

Formation of a GHAD is relatively simple when there are only two parties involved—the owner

Canyon Lakes subdivision in Contra Costa County, California, which is one of Geologic Hazard Abatement Districts in the State. Photograph by Dave Rogers, Rogers-Pacific, Pleasant Hill, California.

and (or) developer and the county or city. Both the Contra Costa County GHAD's were formed by the subdivider and county prior to the sale of lots in the subdivision. They were established to deal with potential future failures rather than to finance stabilization of already failed land. A local engineering firm manages both the GHAD's; the same geologist serves both.

For much of the time since these GHAD's were established, the region has been in a drought. Therefore, these districts have not experienced the saturated conditions that can cause landslides. They have had minor problems including a slippage in a road cut, but they have not faced any major landslide repairs. The primary activities of the districts are maintaining drainage systems, controlling erosion, and diagnosing potential problems. Some reserve funds have been used to repair minor slope failures, revegetate unstable slopes on common lands, stabilize creek banks, and educate property owners.

The GHAD's do not typically apply to a single lot, but deal only with problems affecting the common land or more than one lot. Both subdivisions have soil that swells when wet and shrinks when dry. This swelling and shrinking can cause cracks in foundations and other damage to individual structures. The GHAD's do not address this problem, which affects individual lots, except by monitoring a site with a problem to be sure cracks are not caused by landsliding.

So far, large land failures have not occurred in either of the GHAD's, but these districts are proving their value in preventative maintenance. They provide a mechanism for homeowners to maintain common land in a development, monitor cracks, revegetate slopes, clean drainage channels, and repair breaks in irrigation systems. GHAD staff members work with homeowners to resolve problems without the need for litigation. The staff also advises homeowners about how watering wisely, cleaning roof gutters and pool drains, and other routine property maintenance can help prevent land failures. In the long run, this educational role may be a GHAD's greatest strength.

When GHAD's are formed before land is developed, some responsibility for the consequences of land failures within the district is shifted from local governments to developers. This shift may provide an incentive for developers to thoroughly investigate and mitigate site hazards, thus avoiding future expenses for repairs. This does not imply, however, that local governments are relieved from rigorous review of geologic reports and monitoring of construction. They retain the responsibility to ensure that patterns of development, including location and design of public improvements, are consistent with risks from geologic hazards.

SANTA CLARA COUNTY—GEOLOGIC INFORMATION IN GEOGRAPHIC INFORMATION SYSTEMS

Santa Clara County

1990 population:	**1,310,000**
Geologic services:	**staff geologist**
Land-use issues:	**development of hazardous lands**

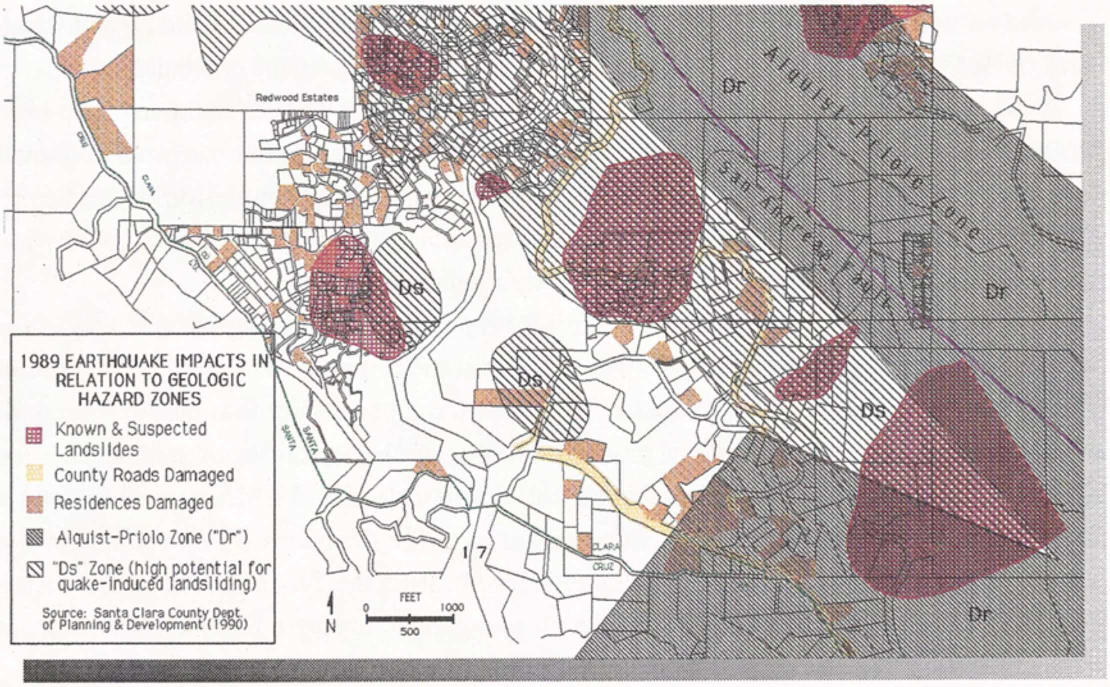
Administering requirements for geologic studies can be aided by computerized geographic information systems (GIS). These systems are used to store, combine, and manipulate digital data with a geographic base, that is, data which can be mapped. Map data can be scanned or digitized into the system and then combined with other data to create new maps. The results can be displayed at virtually any scale. GIS has many potential applications in land-use planning and is beginning to be used to combine geologic information with other map information for analysis and display.

Santa Clara County is one of the first counties in the San Francisco Bay Area to incorporate geologic information in a GIS. It was used in a study of the Lexington Basin area after the Loma Prieta earthquake. Lexington Basin is an area developed with single-family homes flanking a major county reservoir. According to the county's detailed geologic hazards maps, the area is subject to slope failures and severe ground shaking associated with earthquakes.

The Loma Prieta earthquake damaged 384 of the 1,243 residences in the Lexington Basin area. Water lines and storage tanks were destroyed, and many locations were left without water for nearly 6 months after the earthquake. The Santa Clara County planning department staff conducted the study to document the damage and its causes, prepare land-use plans for the area, and assemble information to help the county respond more quickly to future problems in the area.

County planning staff digitized available demographic, land-use, utility, and environmental information for the basin. They also entered the county's geologic hazards maps and data on damage patterns in the Loma Prieta earthquake. This information was combined to analyze the causes of damage in the Lexington Basin area. The analysis showed that damage to residences was most strongly related to quality of construction, but infrastructure damage correlated with mapped geologic hazards. The analysis stimulated the county to review the accuracy of its geologic hazard maps and reconsider construction requirements in light of the earthquake damage.

A major benefit of GIS is that information can be retrieved quickly and combined for analyses that would be very difficult to do without such a system. This capability is important in disaster situations, but it can also be used to streamline day to day operations. It could enable the county to determine more readily the geologic study requirements for a given parcel when approached by a prospective developer. It could also be used to identify the locations of geologic reports submitted



Area near Lexington Reservoir showing damage from the 1989 Loma Prieta earthquake with respect to previously defined hazard zones. This map was created using a geographic information system (GIS).

in the past, to update geologic hazards maps on the basis of new information, and to assist the county's geologist in determining whether geologic reports address all of the potential hazards at a site.

The biggest barrier to use and expansion of Santa Clara County's system is the cost, particularly of staff time. The staff realizes that effective application of GIS countywide would take at least one full-time person assigned to operate and maintain the system. As it is, the county is having trouble allocating staff time to update the GIS for the pilot area. New Alquist-Priolo Earthquake Fault Zones Maps have been released for the area, but they have not been entered into the GIS. In these times of tight county budgets, full use of GIS by the county remains a potential rather than a reality. The county expects to add slowly to the system as opportunities arise.

SANTA CRUZ COUNTY—REBUILDING IN HAZARDOUS AREAS

Santa Cruz County	
1990 population:	**231,600**
Geologic services:	**one registered geologist, one geotechnical specialist, and two field geologists on staff**
Land-use issues:	**pressure to develop ravines, creeksides, and steep slopes**

The Loma Prieta earthquake left broken and cracked ground in many areas of the Santa Cruz Mountains near the earthquake's epicenter. The county immediately confronted the problem of whether or not to permit repairs and rebuilding and, if so, under what conditions. On the basis of an immediate reconnaissance study of the area near the epicenter, the county defined an area called the "red zone," which encompassed the obviously deformed ground. A staff geologist visited sites with damaged buildings in this zone to determine the causes of the damage. The staff geologist thus decided on which sites owners could proceed right away with repairs and rebuilding and which sites needed further study before the county could issue permits for repairs or rebuilding.

As additional geologic studies were completed, the most severe hazards in the red zone were delineated and labeled "areas of critical concern." These areas were further narrowed to a small area with ground cracking where rebuilding was prevented pending completion of studies to determine the cause of the cracks. Repairs and rebuilding in the rest of the red zone were permitted under pre-earthquake geologic study requirements.

The question of requiring geologic studies for repairs and rebuilding became very complicated and controversial. Geologists were uncertain about the cause of some of the ground cracking observed after the earthquake. They raised the possibility that massive, ancient landslides had been reactivated by ground shaking. Geologic studies of individual sites would be inadequate to determine this potential areawide risk. FEMA agreed to fund a regional study to provide geologic information to guide decisions on rebuilding in the areas of critical concern. An interagency task force called the Technical Advisory Group (TAG) was formed to direct the study, which was carried out by a team of experts from both the public and private sectors.

The whole process was marked by bitter disputes. Property owners in the areas of critical concern simply wanted to rebuild with no further delay or expenditure on geologic studies. The county relaxed requirements several times while waiting for the TAG report, but until the study was completed, owners found it difficult to get financing and insurance to rebuild. The TAG report was released more than 2 years after the earthquake; it satisfied no one. It concluded that indeed ancient landslides had probably been reactivated, but that they did not pose a significant risk to life. The report commented generally on the risk of ground cracking in future earthquakes, but it provided no clear guidance for policies on rebuilding.

Residents in the Santa Cruz Mountains continued to attack the county's geologic requirements as needlessly restrictive. They considered them flawed because unlicensed

Large ground crack that opened up during the 1989 Loma Prieta earthquake in the Santa Cruz Mountains of California. Photograph by Howard G. Wilshire.

Areas of ground obviously deformed in Santa Cruz County, California, near the epicenter of the 1989 Loma Prieta earthquake. The maps were prepared quickly after the earthquake to guide early decisions about repairs and rebuilding.

geologists were reviewing reports. For a time, the county's pre-earthquake geologic review program was threatened, but the county hired a certified engineering geologist who helped allay people's concerns about the objectivity of the process. Individual owners are gradually rebuilding in the mountains after they complete geologic studies of their parcels, as required under pre-earthquake regulations. There are some valuable lessons to be learned from this experience.

1. If ground failure is a possibility in your jurisdiction, plan ahead for post-earthquake geologic studies. Safer rebuilding depends on getting credible geologic information quickly and using it to guide rebuilding. Support those post-earthquake geologic evaluations that have a reasonable likelihood of yielding information relevant to development decisions that local governments must make.

2. Areas defined as unsafe for rebuilding tend to become smaller as additional geologic information is obtained. Therefore, restrictions on repairs and rebuilding apply to progressively smaller areas as more information is obtained.

3. Geologic review procedures must be sensitive to political realities. People will pressure local governments to relax regulations after a disaster to make it easier for them to recover. This can result in perpetuating an avoidable hazard. Local governments need to keep the process as simple as they can while protecting public safety.

4. Regulations acceptable to the public before a disaster may not be acceptable afterward. It helps to have political consensus about rebuilding damaged structures *before* an earthquake.

5. According to the Santa Cruz County geologist, consistent enforcement of grading regulations could have reduced losses from ground failures.

The Challenge: Safer Development

Many cities and counties across the country have created programs to require geologic studies before permitting building in areas with potential hazards. The result has been to reduce deaths, injuries, and property losses from geologic hazards. The procedures to accomplish this are straightforward. Effective programs have many features in common. These have been described here along with examples of how local governments have adapted these features to meet their special needs.

Do the policies and ordinances of your city or county provide reasonable protection from geologic hazards? If not, perhaps the ideas discussed and described in this circular will trigger improvements. Community safety from geologic hazards depends on local public officials who understand the importance of geologic information in land-development decisions and know how to use geologic information to reduce risks. Successful local programs have stemmed from at least one public official who was willing to learn about geologic hazards and put that knowledge to use. Although such public officials are critical to the process, they cannot accomplish anything alone. They must have the support of informed citizens who insist that their public officials act to safeguard the community from geologic hazards.

The challenge for concerned citizens and public officials is to bring geology to the table at local commission, council, or board meetings where land-development decisions are made. The routine consideration of information about geologic hazards before approving developments, leads to safer developments and ultimately to safer communities.

A hillside area in the San Francisco Bay Area. Carefully considering and planning for geologic hazards before building in such areas leads to safer development.

SOURCES OF ADDITIONAL INFORMATION

California Department of Conservation, Division of Mines and Geology

DMG can tell you about geologic information available for locations in California and state requirements for geologic studies. For information contact:

California Division of Mines and Geology
801 K Street, 14th Floor, MS 14-33
Sacramento, CA 95814-3532
(916) 445-5716

The agency also distributes the following general guidelines:

Recommended Guidelines for Preparing Engineering Geologic Reports: DMG Note No. 44, 1975.

Guidelines for Preparing Geologic/Seismic Reports: CDMG Note No. 46, 1975.

Checklists for Review of Geologic/Seismic Reports: DMG Note No. 48, 1975.

Guidelines for Evaluating the Hazard of Surface Fault Rupture and Suggested Outline for Geologic Reports on Faults: DMG Note No. 49, 1975.

These DMG Notes may be updated, so it is wise to check with DMG before you order. They may be requested from:

California Department of Conservation
Division of Mines and Geology
PO Box 2980
Sacramento, CA 95812-2980

U.S. Geological Survey

The U.S. Geological Survey does basic topographic mapping of the United States. The USGS also produces geologic maps, hazards maps, and reports on geologic hazards and how to address them. Their products are listed monthly in *New Publications of the U.S. Geological Survey*. To be included on the free mailing list, write to:

U.S. Geological Survey
582 National Center
Reston, VA 22092

Selected USGS reports on the general topic of local use of geologic information with a focus on the San Francisco Bay Area include:

Geologic Principles for Prudent Land Use, A Decisionmaker's Guide for the San Francisco Bay Region, Professional Paper 946, 1983.

U.S. Geological Survey (cont.)

Seismic Safety and Land Use Planning—Selected Examples from the San Francisco Bay Region, California, Professional Paper 941B, 1979.

Flatlands Deposits of the San Francisco Bay Region, California—Their Geology and Engineering Properties, and their Importance to Comprehensive Planning, Professional Paper 943, 1979.

These and other reports and maps may be ordered from:

U.S. Geological Survey
P.O. Box 25286
Denver Federal Center
Denver, Colorado 80225-0046

Other Publications

Suggested Approach to Geologic Hazards Ordinances in Utah, UGMS Circular 79, 1987: Utah Geological Survey, 2363 South Foothill Drive, Salt Lake City, Utah 84109-1491.

Geology and Planning, The Portola Valley Experience, 1988: Spangle Associates, 3240 Alpine Road, Portola Valley, California 94028.

Landslide Loss Reduction: A Guide for State and Local Government Planning, 1989: Colorado Geological Survey, Department of Natural Resources, Denver, Colorado.

Selected San Francisco Bay Area Cities and Counties Using Geologic Information

Counties

CONTRA COSTA COUNTY
Department of Community Development
651 Pine Street, 4th Floor, North Wing
Martinez, CA 94553
(510) 646-2026

NAPA COUNTY
Department of Conservation
1195 Third Street, Room 210
Napa, CA 94559
(707) 253-4416

SAN MATEO COUNTY
Planning and Building Division
590 Hamilton Street, Mail Drop 5500
Redwood City, CA 94063
(415) 363-4161

SANTA CLARA COUNTY
Department of Planning and Development
County Government Center, East Wing
70 West Hedding Street
San Jose, CA 95110 • (408) 299-2521

SANTA CRUZ COUNTY
Planning Department
701 Ocean Street
Santa Cruz, CA 95060
(408) 425-2782

SONOMA COUNTY
Planning Department
575 Administration Drive, Room 105a
Santa Rosa, CA 95403
(707) 527-1900

Cities

BELMONT
Community Development Department
1365 Fifth Avenue
Belmont, CA 94002
(415) 595-7416

HEALDSBURG
Planning Department
P.O. Box 578
Healdsburg, California 95448
(707) 431-3346

MORGAN HILL
Planning Division
17555 Peak Avenue
Morgan Hill, CA 95037
(408) 779-7248

PACIFICA
Community Development
170 Santa Maria Avenue
Pacifica, CA 94044
(415) 738-7341

PORTOLA VALLEY
Planning Department
765 Portola Road
Portola Valley, CA 94028
(415) 851-1700

SAN FRANCISCO
Department of City Planning
450 McAllister Street
San Francisco, CA 94102
(415) 558-6377

SAN RAFAEL
Planning Department
P.O. Box 151560
San Rafael, CA 94915
(415) 485-3085

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