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POSSIBLE COSTS ASSOCIATED WITH INVESTIGATING AND MITIGATING SOME GEOLOGIC HAZARDS IN RURAL PARTS OF SAN MATEO COUNTY, CALIFORNIA

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With a section on

USING THE USGS WEBSITE TO DETERMINE THE POSSIBLE COST OF INVESTIGATING LANDSLIDE HAZARDS IN RURAL PARTS OF SAN MATEO COUNTY, CALIFORNIA

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POSSIBLE COSTS ASSOCIATED WITH INVESTIGATING AND MITIGATING SOME GEOLOGIC HAZARDS IN RURAL AREAS OF WESTERN SAN MATEO COUNTY, CALIFORNIA

By
Earl Brabb, Sebastian Roberts, William Cotton, Alan Kropp, Robert Wright, and Erik Zinn

INTRODUCTION

This digital publication consists of three parts: 1) A database with ARC/INFO files containing information about the distribution of landslides, landslide susceptibility and slope; and 2) A Web site **http://kaibab.wr.usgs.gov/geohazweb/intro.htm** having interactive landslide hazard maps and tools for estimating the cost of investigating potential landslide hazards for landowners; and 3) Plot files for landslide and landslide susceptibility maps, digital orthophoto quadrangles, digital raster graphic quadrangles, geologic maps, and slope maps. By superimposing these landslide hazard map layers on property lines either interactively at the website or by using paper plots of the map layers, an owner can determine which hazards might impact the property and estimate costs that might be involved in investigating the effects of these hazards. Coastal erosion, earthquake shaking, liquefaction, and swelling clays are not included, but might be added later when digital maps are available.

Large parts of rural San Mateo County have been zoned “Resource Management” (RM) by San Mateo County (1973), meaning that areas with landslides and other geologic hazards are restricted to one dwelling unit per 40 acres. Plans for a proposed one-dwelling-unit must include a geologic report indicating that a safe and suitable site is available. Decision-makers in coastal parts of the County have asked the U.S. Geological Survey to indicate how much the investigation and mitigation of these geologic hazards might cost. Accordingly, a panel of consulting geologists was convened to determine these costs, and their deliberations were summarized in a short report sent to approximately 200 consultants in the San Francisco Bay region. The consultant responses and the short report form the basis for this publication.

The decision-makers also wanted a way to make this information readily available to the public. Accordingly, a Web site has been designed to allow a property owner to determine which landslide hazards might impact her site and the related investigation and mitigation costs. This publication also provides a way for the public to obtain copies of the landslide hazard maps for the Half Moon Bay and Montara Mountain Quadrangles and the Pescadero/Butano Creeks drainage areas from the Web site.

The cost of a geotechnical investigation depends on a large number of complex factors, including: (1) The thoroughness of the geologic consultant and whether or not the consultant is practicing the so-called “standard of care”; (2) The extent of the geologic review, and whether or not additional work is required or recommended by the reviewer; (3) The availability of large-scale, topographic base maps at the scale needed for the project; (4) Access to the site by heavy equipment (for example, add another $1000 to $2000 if grading is needed); (5) The amount of liability insurance needed by some clients; and (6) The wetness of the ground if subsurface investigations, such as trenches and large diameter borings, are needed. The wetter the ground, the higher the costs.

Because of this complexity, some consultants have stopped offering a fixed price contract and now provide a client with a worst-case estimate and then charge for time and material. Only a few consultants provided cost information, so whether or not these costs are representative is not known. As such, they are intended to be used as general guidelines. Moreover, the costs generally reflect the conservatism of consultants who fear unanticipated problems -- prospective builders may be able to negotiate lower investigation and mitigation costs if anticipated problems are minimal.

COST ASSUMPTIONS

The complexity of factors involved in estimating the cost of investigating and mitigating geologic hazards in a rural part of western San Mateo County forced us to make certain simplifying assumptions. Property and developments that differ from those described below may have very different costs. Assumptions:

A. The development is a single house in a rural part of western San Mateo County.
B. The lot size is one or 40 acres.
C. A geotechnical or geologic report is required.
D. The cost of reviewing the geotechnical and geologic report is not included, but that amount is typically about $1200 (Jay Mazetta, oral comm. 12/20/99).

THE COST OF INVESTIGATING AND MITIGATING LANDSLIDE HAZARDS

There are several kinds of landslide hazards in western San Mateo County, each with different investigation and mitigation requirements. The main landslide hazards and their associated costs are discussed below.

1. **Debris flows** - Debris flows are fast-moving shallow landslides that can destroy property and are a threat to life because they move quickly with great force. During an intense winter storm in 1982, for example, 25 people were killed and more than $65,000,000 in damages was recorded. More than 4,000 of these debris flows occurred in San Mateo County during that storm. To evaluate site vulnerability, a certified engineering geologist or soils engineer should examine steep slopes where debris flows may be triggered in the future. Debris flows are normally included in any investigation of deep-seated landslides. If a separate **investigation** is needed, costs may range from $1000 to $5000 for this specific investigation. If **mitigation** measures are required, such as drainage ditches, diversion structures, or piers, the costs might be in the range of $10,000 to $100,000.

2. Deep-seated landslides - Deep-seated landslides are estimated to cause $25,000,000 to $50,000,000 in damages in the San Francisco Bay region in a normal winter, and to exceed $200,000,000 in very wet winters like 1997-1998. Hundreds of these landslides have been recognized in San Mateo County. Some of them may never move again, but others, such as the landslides in La Honda and on Polhemus Road, have gained notoriety by high mitigation costs (at least $5,000,000 for the Polhemus Road slide). The cost of **investigating** these landslides might be on the order of $5,000 to $10,000 if the landslide is small and seems to be inactive, or $10,000 to $100,000 or greater if it is larger and seems to have had recent movement. The cost of **mitigating** these landslides is likely to range from $10,000 to $100,000 for small slides and may range into the millions of dollars for larger slides.

3. Other landslides – Earth falls, rock falls, topples, translational slides and other ground failures may damage or destroy residences. Most geotechnical studies for deep-seated landslides or debris flows will generally address these other landslide processes.

THE COST OF INVESTIGATING AND MITIGATING EARTHQUAKE HAZARDS

There are several kinds of earthquake hazards in western San Mateo County, each with different investigation and mitigation requirements. The main earthquake hazards and their associated costs are discussed below.

A. **Fault rupture –** (Digital maps not available. See the report by Brabb and Olson, 1986, and "Fault-rupture Hazard Zones" published by the California Division of Mines and Geology). Ground rupture along faults during major earthquakes can damage or destroy buildings. The State Geologist has identified the San Andreas and San Gregorio faults in the area of this report as active faults requiring special geologic studies. However, most geologists will investigate all linear features on a site that appear to indicate recent faulting. Special studies usually mean that the consultant will dig one or more trenches to investigate the fault and to determine the location of the active traces. Structures for human occupancy should not be put on active fault traces. **Investigation** costs for special studies generally range from $10,000 to $15,000. **Mitigation**, in addition to possible relocation of structures, might include foundation strengthening and additional support of other structural members to provide strength during earthquake shaking and ground deformation. Specially designed utility crossings may also be required. These costs might be on the order of $10,000 to $50,000.

B. **Liquefaction and ground failure –** (Digital maps not available. See the reports by Youd and Perkins, 1987, and Wieczorek and others, 1985) Water-saturated sand and silt as deep as 50 feet from the surface may liquefy during earthquakes. The land next to creeks, lakes and reservoirs may move laterally causing damage to buildings. Areas with steep slopes and weak soil or bedrock may fail by landsliding during earthquakes. Geotechnical studies **investigating** these processes may cost less than $5,000 to $10,000 or more. **Mitigation measures**, such as the installation of concrete columns, removing weak materials, or water pumping are likely to range from $10,000 to in excess of $100,000. San Mateo County has not previously had requirements for single family residences to mitigate liquefaction or earthquake-induced ground failure, and few if any houses in the western part of the county have been built to resist these processes. However, the State of California is preparing maps of areas susceptible to liquefaction and earthquake-induced landsliding, and the new California Building Code essentially requires that liquefaction be assessed.

C. **Ground shaking –**(Digital maps not available. See Perkins, 1987) Shaking generated by an earthquake may be so violent that buildings and other structures collapse. Ridge tops may also shatter and crack where earthquake energy is concentrated. In general, post-1955 single family residences have held up quite well in earthquakes in the San Francisco Bay region. Because new houses have the benefits of upgraded building codes, San Mateo County does not impose additional restrictions on single-family houses to deal with earthquake shaking.

THE COST OF INVESTIGATING AND MITIGATING COASTAL EROSION HAZARDS

The coast at Moss Beach has eroded 165 feet in the past 105 years, according to a Guidebook published in 1972 by the Friends of the Pleistocene. During 1998, media attention focused on houses in Pacifica falling into the sea. Coastal erosion is a recurring problem that is difficult and expensive. Geotechnical and engineering **investigations** to determine the extent of the hazard and mitigation measures needed will probably cost $10,000 to $100,000. **Mitigation** measures are generally in excess of $100,000 if permission from County and Coastal Commission authorities can be obtained.

USING THE USGS WEBSITE
(http://kaibab.wr.usgs.gov/geohazweb/intro.htm)
TO DETERMINE THE POSSIBLE COST OF INVESTIGATING LANDSLIDES IN RURAL PARTS OF SAN MATEO COUNTY, CALIFORNIA

By

Sebastian Roberts and Earl E. Brabb

INTRODUCTION

This website contains an interactive link to geological hazard maps of the Pescadero and Butano Creeks watershed and the Half Moon Bay and Montara Mountain USGS quadrangles. To assist in planning safe construction, the website also provides a technique to estimate costs required to investigate potential deep-seated landslide hazards. Users can import and overlay maps showing deep-seated landslides, deep-seated landslide susceptibility, debris-flow susceptibility, land-use zoning, shaded relief, and topography.

The website is organized in four principal parts: 1) The main map showing the area of interest; 2) An index map showing the location of the area selected; 3) Buttons at the top of the main map that control the positions of the map window and permit the map to be queried and redrawn; and 4) A legend that explains what is shown on the map, allows changes to what is shown on the map, provides a link to explanatory text, and provides another link to explain the zoning symbols.

The website was prepared by using Map Objects software developed by Environmental Systems Research Institute, Redlands, California. This software provides ways to link maps with other information, such as the cost of investigating landslides and whether or not deep-seated landslides are located on the property.

HOW TO USE THE INTERACTIVE MAPS

A. Map page layout

1. Main map – selected from possible areas of interest.
2. Index map – has no interactive functions. Shows where the selected main map area is located relative to the rest of San Mateo County and San Francisco.
3. Buttons at the top of the main map – control position of the map window, allow querying the map, and allow the map to be redrawn at a different scale or with additional information.
4. Legend and legend buttons at the right side of the map – control changes in the map content, explain what is on the map, provide a link to text explaining the map, and provide a link to zoning categories on the map.

B. How to use each part of the map

1. **Main map**
   a. Displays information.
   b. Clicking the mouse provides new information depending on top buttons and legend buttons (see below).
2. **Index map**
   a. Not interactive.
   b. Changes to show location of area selected relative to the rest of San Mateo County and San Francisco.
3. **Buttons at top of map**
   a. **Zoom in –** Selected by default, or by clicking on the map after the zoom out button has been used. Enlarges map when mouse arrow is moved to an area on the map and the mouse is clicked.

c. **Zoom out –** Changes the map to a smaller scale to show a larger area.
d. **Recenter –** Changes position of center of map to a point clicked.
e. **Full extent –** Clicking on this button causes the map to revert to the original view of the entire area.
f. **Identify zoning –** When zoning boundaries have been selected in the legend (see below), clicking the "identify zoning" button and then clicking a point on the map will show the zoning designation by a symbol, the zoning boundary with a green line and the zoned area with hachured yellow lines. For an explanation of the zoning designation, click the phrase "zoning boundaries" at the lower right corner of the screen.
g. **Identify investigation costs**, one or forty acres – These buttons only work when the landslide susceptibility box has been checked in the legend (see below), and an area has been selected by clicking on the map. The map will be redrawn with a yellow square centered at the point clicked. The estimated cost for investigating landslides in this area will appear opposite a yellow box with red hachures in the lower part of the explanation.

4. **Legend and legend changes** - The legend explains what is on the map. The legend changes are accomplished by clicking in gray boxes or on phrases colored blue:
   a. **Zoning boundaries –**Selected by clicking in the gray box and then clicking "Legend Changes". The map will be redrawn with green lines. By clicking "Identify zoning" and then "Legend Changes", the map will be redrawn with the zoning boundaries shown by green lines, the zoned area with yellow hachured lines, and a zoning designation provided.
   b. **Zoning categories –** By clicking on "Zoning Categories" at the bottom of the explanation, a link opens a box with an explanation for each code. "PAD", for example, is a planned agricultural district.
   c. **Debris flow susceptibility –** When the gray box is checked, and then "Legend Changes" is clicked, the map will be redrawn to show areas susceptible to debris flow in pink. Black dots on the map show the origin points of debris flows in 1982. This map cannot be redrawn at the same time as the map for deep-seated landslide susceptibility.
   d. **Deep-seated landslide susceptibility –** Clicking in the gray box and then clicking "Legend Changes" will cause the map to be redrawn with the landslide categories shown by colors in the legend. To determine the cost for a particular parcel, click on the one or forty-acre size for the top buttons, and then click on the map in the center of the parcel to be examined. The map will be redrawn with a yellow square and red hachures showing the one or forty-acre parcel, and an estimate of the cost of investigating deep-seated landslides in this parcel in the lower part of the legend.
   e. **Shaded relief –** Selecting this box and then selecting "Legend Changes" will provide an illusion of mountains and valleys. The impression is particularly helpful when the debris-flow susceptibility or deep-seated landslide susceptibility box is also selected.
   f. **Map explanation** - When this phrase near the bottom of the explanation is clicked, the screen is redrawn to the introduction for the map so that a new area can be selected or text explaining the map is available.

EXAMPLE

Let’s assume you have a one-acre parcel near the town of Montara and you want to determine how much an investigation for landslides would cost. On the first image with the title page, click on the phrase “Half Moon Bay Map” below the phrase “Geologic Hazard Maps.” On the next map image, click three times near the town of Montara (the button to zoom or enlarge is automatically selected). A digital version of the USGS topographic map appears on the screen. Click in the area closest to your property. The largest-scale version of the topographic map now appears on the screen. Click on the little shaded box for “Landslide susceptibility.” Now click on the words “Legend Changes” above the map, and a layer with landslide hazards, from highest (red) to lowest (green) is displayed on the screen overlying the topographic map. Now click the button with the area closest to your property size (in this case, one-acre) in the space above the map. A yellow square of about one-acre is now on the map. If the yellow square depicting your property touches a highly susceptible landslide area colored red, the investigation cost might exceed $100,000, as shown in lower part of the legend. If your property is entirely in the green area, with moderate and low landslide susceptibility, the cost might range from $0 to 10,000, depending on the geologic hazards that may exist but are not shown on the map. Additional hazards, such earthquakes, floods, coastal erosion, and swelling clays are not currently a part of this presentation.

If you wish, you can zoom out to get an overview of a larger area, recenter the map image, or return to the original map by clicking on the words “Full extent”. To recenter, click the recenter button and then click on the map in the area of interest. You can turn on any of the layers that appear in the legend with a checkbox to the left of their symbol. Click in the checkbox for those layers that you would like to have displayed and then click on the "Legend Changes" button to submit your request. Please note that the debris flow susceptibility, topography, and landslide maps cannot be displayed at the same time. Activating the shaded relief button with the landslide susceptibility layer active will give the map a three-dimensional appearance at intermediate scales.

If you want to examine another area, review the explanation for the map, or begin again in the same area, click on “Map Explanation” in the lower right-hand corner of the map. The computer will then show the introduction to the web site where you can select the area or text wanted.

SOURCE MATERIALS FOR THE GEOHAZARDS DIGITAL DATABASE

All data layers described below are in Universal Transverse Mercator (UTM) projection, zone 10. The Half Moon Bay study area encompasses the Half Moon Bay 7.5' quadrangle, and the Montara Mountain study area encompasses the Montara Mountain 7.5' quadrangle. On the website these two quadrangles are treated as one map on the interactive geologic hazards map page, but in the open file report they are two separate map products. The Pescadero/Butano Creeks Watershed Study Area spans parts of the following six 7-5' quadrangles; San Gregorio, Pigeon Point, La Honda, Franklin Point, Mindego Hill, and Big Basin.

Several of the digital source data layers have already been released in other publications by the USGS and are available for downloading on the Internet. Those source layers are not included in this digital database, but a reference is given indicating where the data can be found. Map plots for the areas of this report are on the publications web site, http://geopubs.wr.usgs.gov.

TOPOGRAPHIC BASE MAPS

The digital topographic base maps are USGS Digital Raster Graphic (DRG) base maps at a scale of 1:24,000. These are raster versions of the familiar USGS topographic paper maps. Each raster cell has dimensions of 2 meters on a side. The DRGs are not included in the database, but DRGs for the entire San Francisco Bay Area can be downloaded from the USGS website, http://bard.wr.usgs.gov, and the DRGs for the areas of this report can be plotted from files on the publication web site, http://geopubs.wr.usgs.gov/. The citation for a DRG of any quadrangle in the United States is, Digital Raster Graphic Topographic Base Map, U.S. Geological Survey, Reston, Virginia, 1991.

SHADED RELIEF BASE MAPS

On the geohazard web site, a shaded relief base is always used on the debris flow susceptibility map, may or may not be used on the deep-seated landslide susceptibility map, or may be displayed by itself. Shading the hillsides from a sun angle of 315 degrees clockwise from north, at an azimuth of 45 degrees creates an illusion of three-dimensional topography. The shaded relief is derived from a 10 meter USGS Digital Elevation Model (DEM). This is a raster data set with cells 10 meters on a side and an elevation value interpolated from the orthophotos described below. A shaded relief grid can be made from a DEM using the ARC/INFO GRID *hillshade* command. The shaded relief is combined on the map with the other data layers, such as the pink debris-flow susceptibility map, by using the ARC/INFO *gridcomposite* command. The shaded relief maps and the DEM from which they were derived are not included in the database, but USGS DEMs for the Bay Area can be downloaded from the USGS website, http://bard.wr.usgs.gov, and the shaded relief maps for the areas in this report can be plotted from the publications web site, http://geopubs.wr.usgs.gov. The complete citation for a DEM is, quadrangle name, 10 meter Digital Elevation Model, U.S. Geological Survey, Reston, Virginia, 1998.

SLOPE MAPS

The slope maps are derived from USGS 10-meter Digital Elevation Models (DEMs) and are created using the ARC/INFO GRID *slope* command. For each 10-meter cell, the slope is calculated from an average of the slope in each of 8 cells surrounding the 10-meter cell. This slope is expressed as percent rise. The slope grid is included as part of the digital database, and can also be plotted from the publications web site, http://geopubs.wr.usgs.gov.

DIGITAL ORTHOPHOTO QUADRANGLE MAPS

A Digital Orthophoto Quadrangle (DOQ) is a computer-generated image made from aerial photographs in which the images are digitally rectified to remove distortions caused by relief and camera angle. Buildings and other objects shown on the quadrangle are positioned to reflect their true distances from each other.

Four DOQs are needed for each 7.5’ quadrangle. The Pescadero watershed DOQ map includes parts of 11 separate DOQs spanning 6 quadrangles. The Half Moon Bay quadrangle map includes 4 DOQs in their entirety. The Montara Mountain quadrangle includes 6 DOQs because it is slightly larger than a standard USGS quadrangle. All the DOQs were derived from airphotos taken on October 30, 1991. The DOQs are not included in the database, but DOQs can be downloaded from the USGS website, http://bard.wr.usgs.gov, and for the areas of this report they can be plotted from the publications web site, http://geopubs.wr.usgs.gov. The complete citation for the DOQs is, Digital Orthophoto Quadrangles, 1991, US Geological Survey, Reston, VA.

GEOLOGIC MAPS

The geologic map of the Pescadero watershed is from the digital geologic map of the Palo Alto 30’ x 60’ Quadrangle by Brabb and others (1998). The geologic maps of the Half Moon Bay and Montara Mountain Quadrangles are from the geologic map of San Mateo County by Brabb and others (1998). These maps show the general distribution of bedrock and surficial deposits that can influence the distribution of landslide deposits and affect construction costs. The description of the geologic units represented on the geologic maps can be found on the accompanying unit description sheet. The geologic maps themselves are not included in the database but they can be downloaded and plotted from the following web sites http://geopubs.wr.usgs.gov/open-file/of98-348, for the Pescadero/Butano Creeks watershed, and http://geopubs.wr.usgs.gov/open-file/of98-137 for the Half Moon Bay and Montara Mountain quadrangles.

DEEP-SEATED LANDSLIDE INVENTORY MAPS

The deep-seated landslide inventories for the Pescadero/Butano watershed and the Half Moon Bay quadrangle were digitized from the inventory prepared by Brabb and Pampeyan (1972). The authors identified landslides according to their certainty about the existence of a landslide. Most landslides were identified as ‘definite’, ‘probable’, and ‘questionable’, but several were ‘unattributed’. In contrast, Pampeyan (1994), whose landslide inventory was used for the Montara Mountain Quadrangle, mapped young Quaternary landslides (Qyl), old Quaternary landslides (Qol), questionable young Quaternary landslides (Qyl?), and questionable old Quaternary landslides (Qol?). All landslide map layers are included as part of the digital database. The landslide inventories for the areas of this report can de downloaded and plotted from the publications web site, http://geopubs.wr.usgs.gov.

At the time the original landslide maps were made, debris flows were not recognized as a landslide problem. In 1982, more than 4,000 debris flows occurred in San Mateo County, and a new inventory was made by Wieczorek and others (1988) to show these landslides. In order to distinguish their map from the one made by Brabb and others, the catchall term “deep-seated landslide inventory” is used realizing that some shallow landslides are included.

A deep-seated landslide deposit consists of debris composed of fresh and weathered rock fragments, sediment, colluvial material, and artificial fill, or any combinations thereof, that has been transported downslope by falling, sliding, or rotational slumping. Landslide deposits smaller than approximately 200 feet in longest dimension are not shown on these maps. Complex landslide deposits, which result from combinations of different types of downslope movement, are probably the most common type of landslide deposit included on these maps. The deposits vary in appearance from clearly discernible, largely unweathered and uneroded topographic features to indistinct, highly weathered and eroded features recognizable only by their characteristic shape. The time of formation of the mapped landslides is largely unknown, but may range from as much as a few hundred thousand years ago to as recent as 1963, the date of the latest photography used for the interpretation. No landslide deposits that formed since 1963 are shown. The thickness of the landslide deposits may vary from about 10 feet to several hundred feet. The larger deposits are generally thickest; many small deposits may be very thin and may involve only surficial materials.

DEEP-SEATED LANDSLIDE SUSCEPTIBILITY MAPS

The deep-seated landslide susceptibility maps were produced using a procedure developed by Brabb and others (1972). The maps are constructed using three source maps: a geologic map, a slope map, and an inventory of earlier landslides. The geologic, slope, and landslide inventory maps are described above.

To develop the 1972 susceptibility map, Brabb and others superimposed the landslide inventory map onto a geologic map and arranged the geologic units by increasing percentage of area that had failed due to landsliding. The units were then given an overall susceptibility ranging from I (low) to VII (high). The highest susceptibility class (L) was assigned to the landslide deposits themselves, because they were believed to be more susceptible to future landsliding than the rock units from which they are derived. The slope map was then superimposed onto the combined geologic map and landslide inventory map to determine the incidence of landsliding in each geologic unit in each slope category. The overall susceptibility rating for the geologic unit was adjusted downward where no landslides had formed on low slopes.

The primary differences between the 1972 map and the susceptibility maps provided here are the use of new slope maps and the use of polygons around just the landslide deposits. On the 1972 map, areas between the deposits and the scarps were also included as a landslide polygon. The matrix table used by Brabb and others (1972) for the entire county is the same one used here. Susceptibility numbers are assigned for each 30-meter cell depending on the unit-slope combination defined in the table. The deep-seated landslide susceptibility maps are included as part of the digital database, and are available for downloading and plotting from the publications web site at: http://geopubs.wr.usgs.gov . Only the three highest hazard zones, including the landslide deposits (L), are used to determine costs on the web site because these zones are the same ones used by San Mateo County (1973) to restrict development.

DEBRIS FLOW INVENTORY AND SUSCEPTIBILITY MAPS

Debris flow points of origin recorded by Wieczorek and others (1988) for the January 1982 storm are shown as black dots on these maps. The shaded pink areas indicate places where debris flows might occur in the future. The shading originates from a statement by Nilsen and others (1979, p. 36) that most of the landslides in the San Francisco Bay area occur on slopes steeper than 15%. Accordingly, the pink shading shows slopes steeper than 15% derived from the slope map described above. This shaded area contains 97% of the 900 debris flow origin points in the Pescadero/Butano drainage area and 98% of the 1597 debris flows mapped in the Half Moon Bay and Montara Mountains quadrangles mapped after the 1982 storm. Some of the debris flows in 1982 extended beyond the pink shading and into the flat valleys below—future hazard should be determined by qualified experts on a site-by-site basis. The 1982 debris flow origin points are not included in the database, but they can be downloaded from the USGS website, http://geopubs.wr.usgs.gov/open-file/of97-745e.html. The debris flow susceptibility grid is included as part of the database.

THE DIGITAL PUBLICATION

INTRODUCTION

This publication consists of a digital map database on a geohazards web site, http://kaibab.wr.usgs.gov/geohazweb/intro.htm, this text, and 43 digital map images on another web site, http://geopubs.wr.usgs.gov. The report is stored as several digital files, in ARC export (uncompressed) format for the database, and Postscript and PDF formats for the map images. Several of the source data layers for the images have already been released in other publications by the USGS and are available for downloading on the Internet. These source layers are not included in this digital database, but rather a reference is given for the web site where the data can be found in digital format.

The exported ARC coverages and grids lie in UTM zone 10 projection. This pamphlet, which only describes the content and character of the digital map database, is included as Postscript, PDF, and ASCII text files and is also available on paper as USGS Open-File Report 00-127. Any or all of the digital files can be obtained over the Internet or by magnetic tape copy, as described at the end of this section.

The full versatility of the spatial database is realized by importing the ARC export files into ARC/INFO or an equivalent GIS. Other GIS packages, including MapInfo and ARCVIEW, can also use the ARC export files. The Postscript map image can be used for viewing or plotting in computer systems with sufficient capacity, and the considerably smaller PDF image files can be viewed or plotted in full or in part from Adobe ACROBAT software running on Macintosh, PC, or UNIX platforms.

SPATIAL RESOLUTION

Users of this digital map should not violate the spatial resolution of the data. Although the digital form of the data removes the physical constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. Because this database was compiled from maps at a scale of 1:24,000, higher-resolution information is not present. Enlargement of the database to scales larger than 1:24,000 will not yield greater real detail, although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of this data.

PUBLICATION CONTENTS

The 60 digital files included in the publication are encoded in more than one format. The names of the files are unique designators based on the report identifier, of00-127, followed by part numbers (i.e. 1 through 14 below) and an extension indicating file type. Some of the files have been bundled using the tar (UNIX Tape Archive) utility (.tar extension). All of the larger files have been compressed with the gzip utility, indicated by the .gz extension. The files and their identities are as follows:

1. **Revision List**; A list of the parts of the report and at what version number of the report each was last revised (if at all) followed by a chronological list that describes any revisions (see REVISIONS, below):

of00-127revs_1.txt   ASCII file

2. **Open File Text**; The open-file pamphlet (this text), which describes the database and how to obtain it:

of00-127_2.txt	ASCII file (no formatting)
of00-127_2.ps	Postscript file
of00-127_2.pdf	PDF file

3. **Database for debris flow susceptibility**; ARC export grid containing a 10-meter raster grid:

of00-127_3a.e00.gz	Arc export grid for Pescadero/Butano watershed
of00-127_3b.e00.gz	Arc export grid for Half Moon Bay quadrangle
of00-127_3c.e00.gz	Arc export grid for Montara Mountain quadrangle

4. **Database for deep-seated landslide inventory**; ARC export coverage containing both lines and polygons:

of00-127_4a.e00.gz	Arc export coverage for Pescadero/Butano watershed
of00-127_4b.e00.gz	Arc export coverage for Half Moon Bay quadrangle
of00-127_4c.e00.gz	Arc export coverage for Montara Mountain quadrangle

5. **Database for deep-seated landslide susceptibility**; ARC export grid containing a 30-meter raster grid:

of00-127_5a.tar.gz	Arc export grid for Pescadero/Butano watershed
of00-127_5b.tar.gz	Arc export grid for Half Moon Bay quadrangle
of00-127_5c.tar.gz	Arc export grid for Montara Mountain quadrangle

6. **Database for slope**; ARC export grid containing a 10-meter raster grid:

of00-127_6a.tar.gz	Arc export grid for Pescadero/Butano watershed
of00-127_6b.tar.gz	Arc export grid for Half Moon Bay quadrangle
0f00-127_6c.tar.gz	Arc export grid for Montara Mountain quadrangle

7-14. **Plot Files for the Maps**: The map images are provided as both Postscript and PDF format files. The map layer is listed in the left-hand column. The location and file type are listed in the top row. Half Moon Bay quadrangle is abbreviated as HMB and Montara Mountain quadrangle is abbreviated as MM below. File size is rounded up to the closest megabyte.

	Pescadero watershed Postscript	Pescadero watershed PDF	HMB quadrangle Postscript	HMB quadrangle PDF	MM quadrangle Postscript	MM quadrangle PDF
Debris flow susceptibility	of00-127 _7a.ps.gz (32 MB compr to 4 MB)	of00-127 _7a.pdf (2 MB)	of00-127 7b.ps.gz (15 MB compressed to 2 MB)	of00-127 _7b.pdf (1 MB)	of00-127 _7c.ps.gz (20 MB compressed to 2 MB)	of00-127 _7c.pdf (2 MB)
Digital ortho–photo quads (DOQ)	of00-127 _8a.ps.gz (231 MB compressed to 107 MB)	of00-127 _8a.pdf (2 MB)	of00-127 _8b.ps.gz (96 MB compressed to 41 MB)	of00-127 _8b.pdf (1 MB)	of00-127 _8c.ps.gz (123 MB compressed to 58 MB)	of00-127 _8c.pdf (2 MB)
Digital raster graphic (DRG)	of00-127 _9a.ps.gz (638 MB compressed to 22 MB)	of00-127 _9a.pdf (2 MB)	of00-127 _9b.ps.gz (285 MB compressed to 6 MB)	of00-127 _9b.pdf (3 MB)	of00-127 _9c.ps.gz (300 MB compressed to 13 MB)	of00-127 _9c.pdf (7 MB)
Geology	of00-127 _10a.ps.gz (640 MB compressed to 25 MB)	of00-127 _10a.pdf (2 MB)	of00-127 _10b.ps.gz (286 MB compressed to 7 MB)	of00-127 _10b.pdf (1 MB)	of00-127 _10c.ps.gz (303 MB compressed to 15 MB)	of00-127 _10c.pdf (9 MB)
Deep-seated landslide inventory	of00-127 _11a.ps.gz (523 MB compressed to 15 MB)	of00-127 _11a.pdf (2 MB)	of00-127 _11b.ps.gz (286 MB compressed to 6 MB)	of00-127 _11b.pdf (3 MB)	of00-127 _11c.ps.gz (300 MB compressed to 13 MB)	of00-127 _11c.pdf (8 MB)
Deep-seated landslide susceptibility	of00-127 _12a.ps.gz (521 MB compressed to 16 MB)	of00-127 _12a.pdf (2 MB)	of00-127 _12b.ps.gz (286 MB compressed to 7 MB)	of00-127 _12b.pdf (4 MB)	of00-127 _12c.ps.gz (357 MB compressed to 14 MB)	of00-127 _12c.pdf (8 MB)
Slope	of00-127 _13a.ps.gz (52 MB compr to 18 MB)	of00-127 _13a.pdf (1 MB)	of00-127 _13b.ps.gz (285 MB compressed to 8 MB)	of00-127 _13b.pdf (4 MB)	of00-127 _13c.ps.gz (300 MB compressed to 16 MB)	of00-127 _13c.pdf (9 MB)
Geologic unit description	The unit description sheet is comprehensive and describes the units found on all three maps. Therefore there are only two image files. The postscript file is named of00-127_14.ps.gz (4 MB compressed to 1 MB). The PDF file is named of00-127_14.pdf (1 MB).					

REVISIONS

Changes to any parts of the report (the numbered items described above and listed in the revision list, of00-127revs_1.txt) may be made in the future if needed. These could involve, for example, fixing files that don't work, correcting or adding landslide details, or adding new file formats or other components. Major revision of the basic landslide information would result in a new report.

The report begins at version 1.00. Any revisions will be noted in the revision list and will result in the recording of a new version number for the report. Decimal increments will indicate small changes and integer increments larger changes in the version number. Revisions will be announced and maintained on the Web page for this report on the Western Region Geologic Information Server (see next section).

OBTAINING THE DATA FILES

The digital files may be obtained in three ways.

1. The simplest way to obtain the digital files is to download them over the World Wide Web from the USGS Western Region Geologic Information Server: http://geopubs.wr.usgs.gov. From the main page, click on "Geologic map databases" under the heading "Data On-line;" next click on "California." Scroll down to the listing for this database (Open-File Report 00-127) and click on the "Open-File" button, which takes you to the page for this publication. You can also go directly to that final page at: http://geopubs.wr.usgs.gov/open-file/of00-127. On this page, the several parts of the report in their different file types are separately available. Set your Web browser to save to a local disk and click on the appropriate links to download the desired files.

2. To download the files from the Internet via anonymous ftp:

ftp geopubs.wr.usgs.gov	- make ftp connection with the USGS computer wrgis.
Name: anonymous	- enter "anonymous" as your user name.
Password: [your address]	- enter your own email address as password.
pub/open-file/of00-127	-the subdirectory in which the files from this report are stored

3. To obtain files from the database on magnetic tape, send a blank tape with a request specifying the desired files and your return address to:

Western San Mateo County Landslide Hazard
c/o Database Coordinator
U.S. Geological Survey
345 Middlefield Road MS 975
Menlo Park, CA 94025

The specified files bundled in a compressed tar file will be returned to you on the tape. The acceptable tape types are: 2.3 or 5.0 GB, 8 mm Exabyte tape.

OPENING THE DATABASE FILES

Some of the files are packaged as tar files, and the larger files containing the databases and images have been compressed with gzip. Thus gzip is required to uncompress the files, and a tar utility is required to open the tar files. The necessary utilities are available on-line:

Compressed Gzip Files

Files compressed with gzip (those with a .gz extension) can be uncompressed with gzip. The gzip utility converts the compressed file name.gz to its uncompressed equivalent name. The compressed file is replaced by the uncompressed file. This utility is free of charge over the Internet at: **http://w3.teaser.fr/*jlgailly/gzip**

Tar Files (UNIX Tape Archive)

To extract the contents of a tar file, first uncompress it with gzip if the extension is .tar.gz. Once the tar extension is exposed, extract the contents with a tar utility. This utility is included in most UNIX systems. Tar utilities for PC and Macintosh can be obtained free of charge via the Internet from Internet Literacy's Common Internet File Formats Web Page:
http://www.matisse.net/files/formats.htm

WinZip

This commercial package runs on PCs and can deal with both gzip and tar files. An evaluation copy of WinZip for Windows 3.1, 95 and NT can be downloaded from:
http://www.winzip.com/winzip/:

IMPORTING THE ARC EXPORT FILES

The ARC export files (.e00 extension) can be converted to ARC/INFO vector maps (coverages) or GRID raster files and INFO files by using the import command in ARC. Be sure to uncompress the gzip or tar files before trying to import the files.

DIGITAL COMPILATION

INTRODUCTION

The digital database was compiled using version 7.2.1 of ARC/INFO, a commercial geographic information system, or GIS (Environmental Systems Research Institute [ESRI], Redlands, California) on a UNIX computer using the menu interface ALACARTE (versions 1 through 3.1: Fitzgibbon and Wentworth, 1991; Fitzgibbon, 1991; Wentworth and Fitzgibbon, 1991).

The contents of the map databases are described in terms of the lines and/or areas that compose it. For integer ARC/INFO grids the database records are stored in a value attribute table (.VAT) and for ARC/INFO coverages the records are stored in polygon attribute tables (.PAT) and arc attribute tables (.AAT). The terms in Table 1 describe the database fields of these attribute tables.

Table 1. Field Definition Terms

ITEM NAME	Name of the database field (item)
WIDTH	Maximum number of digits or characters stored
OUTPUT	Output width
TYPE	B, binary integer; F, binary floating point Number; N, ASCII floating point number; I, ASCII integer; C, ASCII character string
NDEC	N.DEC, number of decimal places maintained for floating point numbers

DEBRIS FLOW SUSCEPTIBILITY

The debris flow susceptibility map for each of the three study areas is an ARC/INFO grid that was derived from the slope grid described in the source materials section. The grid consists of cells measuring 10 meters on a side. Using the GRID function *conditional*, the debris flow susceptibility grid was calculated to give all cells with a slope of 15% or higher a value of 15 and set all the remaining cells to null. These values are stored as integers in the VALUE database field of the value attribute table (VAT) of the grid. Note that cells having a value of null are not recorded as part of the VAT.

Table 2. Content of the value attribute table

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION
VALUE	4	10	B	-	"15" for slopes >= to 15%
COUNT	4	10	B	-	Number of cells with this value

LANDSLIDE INVENTORY

The digital compilation of the landslide inventory for the Pescadero watershed and the Half Moon Bay quadrangle was derived from linework inked directly by the authors on USGS mylar greenline

7.5-minute (1:24,000-scale) quadrangle maps. The inked linework for each source map was scanned (400 dots per inch), converted from raster to vector form, imported into ARC/INFO, and hand edited and combined into a single digital file. Adjustments were made to fit lines across quadrangle boundaries. The digital compilation for the Montara Mountain quadrangle was derived from the geologic map by Pampeyan (1994). Likewise, the original greenline was scanned, converted to vector form, and hand edited to extract just the landslide information from the geologic map.

All landslides larger than 200 feet in maximum dimension are represented in the spatial database by polygons enclosing their approximate boundaries. The primary landslide identifier is a character string in the field PTYPE (polygon type) in the polygon attribute table for the deep-seated landslide inventory database.

Because landslides in the Brabb and Pampeyan map (1972), used for the Pescadero watershed and Half Moon Bay quadrangle, were identified via analysis of aerial photographs without an opportunity to field check the resulting map, the values in the PTYPE fields reflect the degree of confidence the author had in his interpretations. The values for this field are; "definite", "probable", "questionable", and "unattributed". In both the Postscript and PDF plot files, large landslide polygons are color coded according to this classification.

Landslides derived from the Pampeyan (1994) geologic map used for the Montara Mountain quadrangle have a different designation. These landslides have been identified as "young Quaternary landslide", "old Quaternary landslide", "questionable young Quaternary landslide", and "questionable old Quaternary landslide".

The landslide-deposit spatial database for each of the three maps is stored in UTM projection (zone 10). Digital tics define a 7.5-minute grid of latitude and longitude.

Lines - Database lines (arcs) are recorded as strings of vectors with characteristics that are described in the arc attribute table (see Table 3). In the landslide inventory map layer they define the boundaries of the landslide units, topographic scarps, and the quadrangle boundaries. These distinctions are recorded in the LTYPE database field according to the line types listed in Table 4.

Table 3. Content of the Arc Attribute Table

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION
FNODE#	4	5	B	-	Starting node of arc (from node)
TNODE#	4	5	B	-	Ending node of arc (to node)
LPOLY#	4	5	B	-	Polygon to the left of the arc
RPOLY#	4	5	B	-	Polygon to the right of the arc
LENGTH	4	12	F	3	Length of arc in meters
PF-SLID#	4	5	B	-	Unique internal control number
PF-SLID-ID	4	5	B	-	Unique identification number
LTYPE	35	35	C	-	Line type

Table 4. Line Types Recorded in the LTYPE Field

LINE TYPE	DESCRIPTION
Contact, certain	Arcs delineating large landslide polygons
Topographic escarpment	Landslide scarp at head of a landslide deposit
Map boundary	Quadrangle boundary or study area

Areas - Landslide areas are recorded as vector polygons with characteristics that are described in the polygon attribute table (see Table 5). In the landslide inventory map layer they define the degree of confidence which the author had when identifying the area as a landslide deposit. These distinctions are recorded in the PTYPE database field according to the polygon types listed in Tables 6 and 7.

Table 5. Content of the Polygon Attribute Table

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION
AREA	4	12	F	3	Area of polygon in square meters
PERIMETER	4	12	F	3	Length of perimeter in meters
AL-SLID#	4	5	B	-	Unique internal control number
AL-SLID-ID	4	5	B	-	Unique identification number
PTYPE	35	35	C	-	Landslide category

Table 6. Landslide Types Recorded in the PTYPE Field
for Pescadero/Butano watershed and Half Moon Bay quadrangle maps

LANDSLIDE TYPE	DESCRIPTION
D	Definite landslide deposit
P	Probable landslide deposit
?	Questionable landslide deposit
UA	Unattributed landslide deposit

Table 7. Landslide Types Recorded in the PTYPE Field
for Montara Mountain quadrangle map

LANDSLIDE TYPE	DESCRIPTION
Qyl	Young Quaternary landslide deposit
Qyl?	Questionable young Quaternary landslide deposit
Qol	Old Quaternary landslide deposit
Qol?	Questionable old Quaternary landslide deposit

LANDSLIDE SUSCEPTIBILITY

The landslide susceptibility map for each of the three study areas is an ARC/INFO grid that was derived from the slope grid and the geologic map described in the source materials section. The grid consists of cells measuring 30 meters on a side. Each cell is assigned a relative susceptibility value between 0 and 7 as described in the source materials section. These values are stored as integers in the VALUE database field of the value attribute table (VAT) of the grid. Note that cells that have a value of null are not recorded as part of the VAT.

Table 8. Content of the Value Attribute Table

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	DESCRIPTION
VALUE	4	10	B	-	Susceptibility value 0 through 7
COUNT	4	10	B	-	Number of cells with this value

SLOPE

The slope map for each of the three study areas is an ARC/INFO grid that was derived from the Digital Elevation Model (DEM) described in the source materials section. The grid consists of cells measuring 10 meter on a side. Using the GRID function *slope*, a continuous slope is calculated using a 3 by 3 cell (30 meter by 30 meter) neighborhood to arrive at an average slope expressed as percent rise. This operation results in a grid with continuous floating-point numbers, and thus a value attribute table (VAT) is not created for the grid.

CONCLUSIONS

An interactive website for landslide hazards has been provided for rural areas in western San Mateo County. People who wish to determine if their property is impacted by these hazards can use the website to locate their property, overlay deep-seated landslide hazard maps and determine the cost to investigate them. Information is provided for investigating and mitigating several other kinds of geologic hazards, but the data are not interactive. The maps will be also useful for other purposes, such as determining where sediment from landslides might adversely affect fish in the various creeks, or where roads might be closed after heavy rainfall.

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(Maps in stock can be obtained from the Earth Sciences Information Center of the US Geological Survey, 345 Middlefield Road, Menlo Park, CA, 8am to 4pm. If the maps are out of stock, they may be examined at the USGS Library at the same address.)