## EARTHQUAKE MAPS FOR DEVELOPING AREAS SAN FRANCISCO BAY AREA

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#### INTRODUCTION

In this project, ABAG extended the computer-based earthquake hazard mapping capability developed in an earlier contract (which focused on the San Mateo County area) to selected areas of significant development pressure. Specific applications for this mapping capability have been extended and refined. The results are being made available in forms useful to a variety of people working for and with local governments in the San Francisco Bay Area.

#### PROJECT COMPONENTS

#### 1. Target Area Selection

Although many of the basic data map files and hazard map files previously developed were for the entire nine county Bay Area, several were developed only for or only in detail for San Mateo County. The first task in this project was to choose study areas of significant development pressure. The study areas chosen were fifteen 7-1/2 minute quadranges in Petaluma and its vicinity and the ridgelands areas of the East Bay hills.

#### 2. File Development

Three basic data map files have been extended to or refined in those fifteen quadrangles either by digitizing maps or by obtaining existing machine readable data sets. These files include:

- o geologic materials
- o existing landslides
- o digital elevation models (elevation, slope and slope aspect)

#### 3. File Manipulation

These upgraded basic data map files were used to produce more refined hazard maps for those fifteen quadrangles.

- o Information needed to produce more detailed ground shaking intensity files was collected. New maximum ground shaking intensity maps and several risk of ground shaking damage maps were not produced because of the strong possibility that the shaking attenuation and damage relationships to be used will be modified by USGS researchers by mid-1981. Such a change would have made these maps obsolete shortly after they were produced. These maps will be produced by mid-1981.
- o The geology, landslide, and topography information, as well as information on vegetation and precipitation, was examined to create a method of extending both the rainfall-induced and earthquake-induced landslide susceptibility mapping beyond San Mateo County. Because of the decrease in the work required on the ground shaking intensity files, much effort was made in

perfecting the slope and slope aspect data used in the landslide susceptibility models.

#### 4. Application of Files

These upgraded hazard maps, as well as hazard maps of liquefaction susceptibility, fault surface rupture, and tsunami and dam failure inundation, were used in sample applications:

- o as maps for local general plans
- o to refine and extend ABAG's ability to develop an automated regional environmental assessment document to serve as a background report for local Environmental Impact Reports (EIRs)
- o to compile composite maps of earthquake hazards for the fifteen quadrangles being studied
- o to assess the vulnerability of existing and projected land uses and population to damage from a major earthquake.

#### 5. Communication of the Information

Much effort has been made to ensure that this information is effectively communicated and disseminated to a variety of professionals working for and with local governments in the San Francisco Bay Area.

- o A series of ten working papers developed previously to document the mapping capabilities was extended to include the documentation of this contract.
- o Tools were developed to aid in presentations.
- o Talks were given at professional societies.
- o Meetings were conducted with local staff.
- o Descriptions of ABAG's mapping capabilities were provided to various newsletters and magazines.
- o A procedure for producing these products were integrated into ABAG's administrative structure.
- o The working papers on ground shaking intensity mapping have been integrated into a draft report for possible publication by USGS.

#### DISCUSSION OF RESEARCH

#### 1. Target Area Selection

The urban and potentially urban 7-1/2 minute quadrangles were examined

to select those fifteen most suitable for a study focusing on earthquake mapping for developing areas. The study area selected consists of two parts:

- o Petaluma and its vicinity -- the Cotati, Glen Ellen, Petaluma and Petaluma River quadrangles
- o The East Bay ridgelands -- the Briones Valley, Las Trampas Ridge, Diablo, Hayward, Dublin, Niles, Milpitas, Calaveras Reservoir, San Jose East, Morgan Hill and Mt. Sizer quadrangles

More information on the selection process is contained in Working Paper #11 (Appendix A of this report).

#### 2. File Development

The development of the files of geology and landslides for these study areas has been completed. These two files were obtained by digitizing existing maps described in Working Paper #11 (Appendix A). All maps digitized were at a scale of 1:24,000, except for the bedrock geology of the Petaluma area, where maps at a scale of 1:62,500 were being used.

Tapes of digital elevation model (DEM) data were obtained from the National Mapping Division of USGS. Because of unforeseen commitments being placed on that Division due to the recent eruptions of Mt. St. Helens, the data were delivered late, making a one month contract extension necessary.

Problems with the DEM data for San Mateo County needed to be resolved so that they did not reoccur with the new data. These problems include data matching errors along quadrangle boundaries (due to tapes being produced on a quadrangle-by-quadrangle basis) and calculated percent slopes being too low. These problems were solved using the techniques described in Working Paper #11 (Appendix A).

#### 3. File Manipulation

Information on ground shaking intensity increments was obtained from USGS staff to enable ABAG to produce more refined ground shaking intensity maps based on the detailed bedrock geology in the study areas (see Working Paper #11). However, the likelihood of significant changes being made by mid-1981 in the attenuation formula and damage estimates to be used led to the decision to produce intensity maps as part of a subsequent contract and to concentrate on refining the landslide susceptibility hazard maps. Tabulations for San Mateo County of landslide coverage by geologic unit, existing slope, slope aspect, vegetation type, and average annual precipitation were produced to gain a better understanding of how these variables contribute to rainfall-induced landslide susceptibility within San Mateo County. was the first step in ABAG transferring the San Mateo County experience to the ridgelands and Petaluma areas. As a second step, similar tabulations were produced for the study areas to confirm and supplement the San Mateo County data. The results and hazard maps are described in

Working Paper #11. To produce the earthquake-induced landslide susceptibility maps for the study areas, discussions were held with Gerry Wieczorek of USGS to determine alternative ways of obtaining data on the relative strength of cementation of the geologic units in these areas. These data and the resulting maps of earthquake-induced landslide susceptibility also are described in Working Paper #11.

#### 4. Applications of Files

Four sample applications for the hazard map data developed previously have been greatly refined and expanded.

First, the maps have been used to show levels of various hazards in local plans. This application is discussed in more detail in Working Paper #12 (Appendix B of this report). The Working Paper also includes information that should be valuable to those ordering mapped data based on ABAG's experience with the City of Livermore Planning Department and the San Mateo County Area Disaster Office. The City of Pleasant Hill Planning Department has requested such maps to use as part of their seismic safety element.

Second, ABAG's capability to produce automated background reports for environmental impact reports has been greatly expanded and streamlined. The more limited output developed in the earlier USGS contract was tested on sites in Pleasanton and Oakland and was found to require too much computer time to run and too much explanation for potential users. The setting and impacts sections have been modified accordingly. The options to be used in the mitigation section also were found to be too incomplete for most jurisdictions and therefore this section has been greatly expanded. Finally, an option of producing computer maps for the site being examined and its vicinity has been explored in the Petaluma area. The findings and products of these tasks are described in Working Paper #13 (Appendix C of this report).

Third, the various hazard maps have been combined into several sample composite maps for the fifteen quadrangles in the study areas. Because of the interest in these maps by local officials involved in general plan development, an attempt was made to improve the accuracy of the damage estimates used to combine the hazard maps into composite maps. No better estimates could be made at this time. However, the uses of this composite mapping process as a screening mechanism for locating areas with few hazards for hypothetical public facilities and to anticipate mitigation costs were researched and the results are discussed in Working Paper #14 (Appendix D of this report).

Last, the hazard and composite maps were used to assess the vulnerability both of existing and of projected land uses and population to damage from a major earthquake. The extension of this application to assess <u>future</u> vulnerability is key to local officials being able to understand the impact of current trends in growth on future vulnerability. Information used included 1970 census tract (updated to 1975) population data, land use data compiled by the National Mapping Division of USGS, and ABAG's land use and population projections. Problems arose in obtaining adequate land use information for other than

San Mateo County. Therefore, this County was used as a demonstration area for this sample application. The land use data were used to disaggregate the population data before the population data were aggregated to areas of similar hazard level. This work is discussed in Working Paper #15 (Appendix E of this report).

#### 5. Communication of the Information

Several mechanisms have been developed and used for communicating and disseminating the products of this project.

First, the series of ten working papers previously developed to document the analysis techniques was extended to included the documentation for this project. Working Papers prepared (and referenced earlier) include:

- #11 The Method Developed to Extend Detailed Map Information Beyond San Mateo County to Selected Areas of Significant Development Pressure.
- #12 Ordering and Using Earthquake Hazard Maps in Local General Plans.
- #13 Automated Environmental Impact Assessment An Update.
- #14 Using Earthquake Hazard Maps for Site Screening and Anticipating Mitigation Benefits and Costs
- #15 Assessment of Current and Projected Property and Population at Risk An Update.

In addition, amendments and additions to the <u>Guide to ABAG's Earthquake Hazard Mapping Capability</u> were prepared and <u>distributed</u> (See Appendix F). The revised maps are being delivered to the three East Bay counties and Petaluma.

Second, tools have been developed to aide in communicating the uses of the hazard maps. A slide show was produced and a large (22 foot by 8 foot) display was developed in conjunction with ABAG's BASIS program.

Third, talks on ABAG's work have been given upon request at meetings of professional groups. To date, talks have been given at the State Conference of the Association of Environmental Professionals (Appendix G), at the American Society of Civil Engineers Speciality Conference on the Social and Economic Impact of Earthquakes on Utility Lifelines (Appendix H), at the July 1980 monthly meeting of SABER (The Society to Adapt Building to the Environment Reasonably), and at the Oakland Office of Emergency Services workshop for industrial vulnerability on October 14, 1981. Since the SABER and Oakland OES presentations were informal and no proceedings are planned, copies of the texts of those presentations are not included as appendices.

Fourth, workshops were held for local staff in various parts of the region. The first, in August, was with the county and city emergency services staff within San Mateo County. Two additional meetings were

held with planning and public works staff of cities within San Mateo County and the County. Another series of three workshops was held for various types of staff of jurisdictions in the ridgelands area of the East Bay hills. Meetings with Petaluma staff were held in conjunction with meetings held on a related program. A special workshop also was held with Petaluma and its neighboring jurisdictions of Cotati and Rohnert Park. These workshops were attended by representatives from all three cities in the Petaluma study area and from nine of the thirteen jurisdictions in the ridgelands area. Staff present included planners, engineers, building inspectors, emergency services officials, and city managers. These people expressed a need for fewer maps at more detailed scales, a request that resulted in no maps being produced for mass distribution. They preferred information in map form to data on tables and had a strong interest in the landslide susceptibility information.

Fifth, reviews were submitted to the newsletters of the Natural Hazards Information Center, the American Planning Association, and the California Division of Mines and Geology. An extensive article on BASIS and earthquake mapping is to appear in the magazine published by Polaroid.

Sixth, a policy for pricing special products has been developed and many of the legal issues surrounding the provision of various maps and other special products have been resolved. In addition, a procedure for filling various types of requests has been integrated into ABAG's administrative structure.

Finally, the first three working papers have been rewritten into the format of a USGS report on ground shaking risk maps. Publication of this report should provide the series of risk maps with more legitimacy among technical professionals.

APPENDIX A

#### EARTHQUAKE MAPPING PROJECT - WORKING PAPER #11

## THE METHOD DEVELOPED TO EXTEND DETAILED MAP INFORMATION BEYOND SAN MATEO COUNTY TO SELECTED AREAS OF SIGNIFICANT DEVELOPMENT PRESSURE

#### INTRODUCTION

One of the major objectives of the second phase of the Earthquake Mapping Project was to extend the basic data map files, the hazard map files and the composite map files that had been made available only in San Mateo County or in detail only in San Mateo County to areas of significant development pressure. This objective has been accomplished through performing the following series of tasks:

- o choosing those areas for the expansion to occur (limited to fifteen 7-1/2 minuté quadrangles);
- o upgrading the existing geology file and extending the landslide and topography files to those 15 quadrangles;
- o gathering data needed to produce more detailed ground shaking intensity maps for those 15 quadrangles;
- o examining the geology, landslide, and topography information to create a method to extend the landslide susceptibility mapping beyond San Mateo County and then producing these maps for those 15 quadrangles; and
- o combining the various hazard maps to create a series of composite maps for those quadrangles.

Throughout this work, several issues emerged including hazard boundary definition and appropriate use of hazard maps.

This working paper describes the issues. It is the eleventh in a series of working papers documenting the data used and the assumptions made in the ABAG/USGS Earthquake Mapping Project. It is also the first of those papers dealing with the second phase of the work. Working Papers #12-#15 deal with both new and expanded applications for these basic data map files and hazard map files.

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#### CHOOSING A STUDY AREA

The urban and potentially urban 7-1/2 minute quadrangles were examined to select those fifteen most suited for a study focusing on earthquake mapping for developing areas. The study area chosen (Figure 1) consists of two parts:

o Petaluma and its vicinity -- the Cotati, Glen Ellen, Petaluma and Petaluma River quadrangles; and

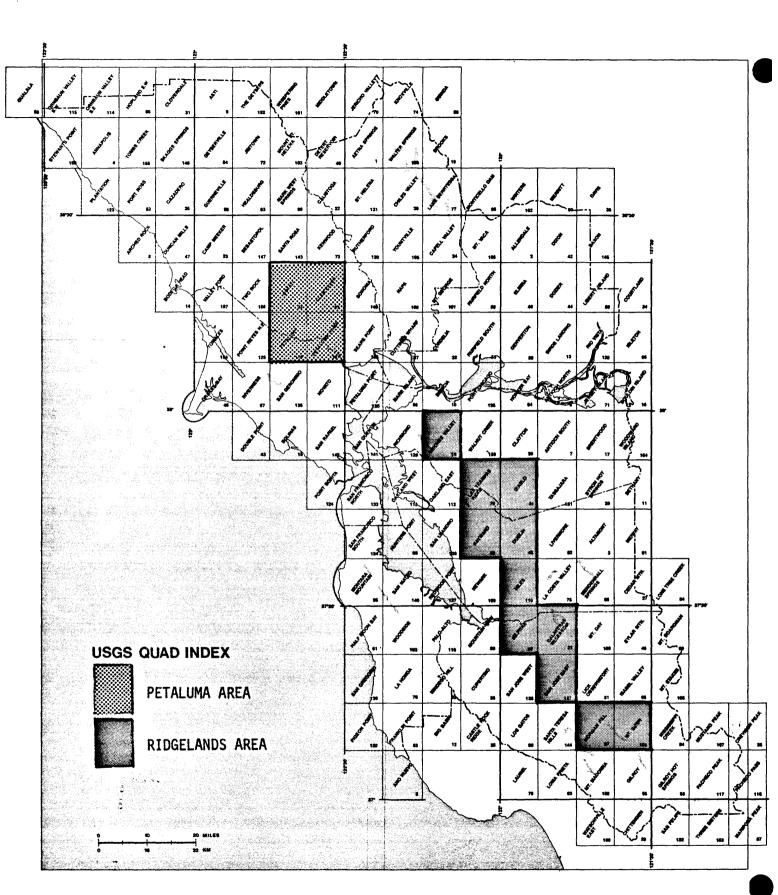


FIGURE 1: PROJECT STUDY AREAS

o the East Bay ridgelands -- the Briones Valley, Las Trampas Ridge, Diablo, Hayward, Dublin, Niles, Milpitas, Calaveras Reservoir, San Jose East, Morgan Hill and Mt. Sizer quadrangles.

The first step in the selection of a study area involved defining "urban" or "potentially urban" areas as those quadrangles that contain part of a sphere of influence or a general planning area of a city. Only 83 of the 165 quadrangles in the region met this definition. Of these 83, five were excluded because they had been examined as part of the San Mateo County study area used in the first phase of this project, leaving 78 quadrangles available for possible use.

Two types of criteria were used to select those 15 of these 78 quadrangles most suitable for study. The first set can be defined by mapped units and are:

- o the presence of significant seismic hazards within the quadrangle, as defined by maximum ground shaking intensity A-C being readily noticeable on the map produced in the first phase of this report (see Working Paper #3); and
- o the overall potential for growth in the area, as defined by quadrangles with transportation planning zones (aggregates of census tracts) growing by more than 12,000 people, with special emphasis being placed on the three fastest growing areas San Jose, Fremont, and the San Ramon Valley (Reference 1).

Forty-five quadrangles met these criteria, fourteen of which are within the planning boundaries of San Jose, Fremont, and the San Ramon Valley. The results of this selection process were reviewed using a second type of criterion that required interaction with potential users:

- o the presence of hillside development or development pressure along faults resulting in numerous geotechnical reports and environmental impact reports (to make the acquisition of topographic and detailed bedrock geology most worthwhile); and
- o the potential interest of the staff of cities and counties.

Because of the appropriateness of several quadrangles in the San Jose, Fremont, and unincorporated San Ramon Valley areas, it was tentatively decided to use this area as the main study area for the project. It was felt, however, that a smaller area in the North Bay was needed to balance the project geographically and to adequately test the transferability of many techniques. The Petaluma area, in addition to having three of the four quadrangles surrounding the City (the Cotati, Glen Ellen and Petaluma River quadrangles) meet the first pair of criteria, had a additional strength. The City of Petaluma is currently working with ABAG in another program designed to develop a detailed City data base that could be used for automated environmental assessment. The use of this related program's study area -- all four quadrangles surrounding Petaluma (including the Petaluma quadrangles) would ensure

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that the earthquake mapping work would be used in day-to-day development decisions. In addition, the availability of other types of environmental and social data for this related Petaluma project could enable this earthquake mapping project to use some experimental data access and manipulation techniques.

The use of four quadrangles in the Petaluma area resulted in eleven quadrangles remaining for the East Bay ridgelands study area. The local government geologists who review the geotechnical reports in this area (those for the City of San Jose and the counties of Santa Clara, Alameda and Contra Costa) were contacted. The eleven quadrangles chosen by this group for a study area are Briones Valley, Las Trampas Ridge, Diablo, Hayward, Dublin, Niles, Milpitas, Calaveras Reservoir, San Jose East, Morgan Hill and Mt. Sizer.

After the study areas were chosen, staff at the U.S. Geological Survey were contacted to confirm that adequate geologic and landslide information was available for these areas.

#### UPGRADING AND EXTENDING BASIC DATA MAP FILES

Three basic data map files required modification in the Petaluma and ridgelands area in order to extend the detailed map information beyond San Mateo County: geology; landslides; and topography. The process used to improve these files involved two different methods for integrating new data into existing map files. In the case of geology, the new information focuses only on the hillside portions of the study area since the flatlands materials had been upgraded as part of the first phase of this project. Existing map units, consisting of aggregations of bedrock units, were replaced by the full range of units present on existing geologic maps. Integrating the landslide and topographic information involved the addition, rather than the replacement, of mapped information in the study areas. In both cases, however, the new data was chosen to be compatible with existing detailed data in San Mateo County.

#### Geology

The bedrock geology data for the two study areas came from three different authors (References 2-9). All work for the U.S. Geological Survey and therefore the criteria used for mapping geology are similar. However, two issues arose that had to be resolved before the data could be integrated into ABAG's data base.

First, essentially identical map units were represented by different symbols on different maps (even those by the same author published at different times) and the same symbol could represent different map units on different maps. Tables 1 and 2 describe the units used in this project and note the symbol typically used on these maps. Table 1 applies to the ridgelands area, while Table 2 applies to the Petaluma area.

TABLE 1: GEOLOGIC UNITS IN THE RIDGELANDS AREA

Typical Map Symbol	Geologic Unit
Qhac	Coarse-grained Holocene alluvium
Qham	Medium-grained Holocene alluvium
Qhs	Holocene sand deposits
Qhbm	Holocene Bay mud
Qhsc	Holocene stream channel deposits
Qhaf	Fine-grained Holocene alluvium
Qhafs	Fine-grained Holocene alluvium (salt-affected)
Qpmt	Pleistocene marine terrace deposits
Qpa	Late Pleistocene alluvium
Qpea	Early Pleistocene alluvium
Qaf	Artificial fill
Qc1	Colluvium
Qu	Undivided Quaternary deposits (largely in urban areas)
Qg	Stream channel gravel, sand and clay
QTs	Santa Clara Formation gravel sand, and clay
Qsb	Gravel with basalt detritus of QTs
Qsp	Conglomerate or breccia of serpentine detritus of QTs
Qsa	Clay of QTs
Qsc(a)	Areas of "a" within Qsc, andesite of QTs
Qsc(b)	Areas of "b" within Qsc, basalt of QTs Livermore Gravel
QT1 QTt	Tassajara Formation
QТЬ	Unnamed olivine basalt lava
rh	Rhyolite that is Tertiary (Pliocene) in age (includes the Alum Rock Rhyolite)
Tps	(also Tsc and Tor), Pliocene nonmarine sedimentary rocks (includes the Orinda Formation)
ТЬ	(Tbu), Pliocene unnamed basalt (includes basalt in Orinda Fm.)
Tbp	Pliocene Bald Peak Basalt
Tmb	Pliocene Moraga Formation, basalt
Tmt	Pliocene Moraga Formation, tuff breccia
<u>T</u> p1	Pliocene lacustrine limestone
<u>T</u> pt	Pliocene tuff and sandstone
Tn Taxaa	Miocene Neroly Sandstone
Tmss	Miocene sandstone (includes the Briones, Cierbo and sometimes the Neroly sandstones)
Tms1	Miocene siltstone with minor sandstone
Tmsh -	Miocene silty to silicous gray-white shale (includes upper part of Claremont Shale from Mt. Sizer quadrangle)
Tmsc	Miocene brittle cherty and silicious tan-white shale (includes Claremont Shale and lower part of Claremont on Mt. Sizer quadrangle)
Tms	Miocene basal sandstone (includes the Sobrante and Temblor sandstones)
Tmsr	Oligocene San Ramon Formation of siltstone and basal sandstone
Tt	Eocene Tolman Formation of marine sandstone and siltstone
Tk	Eocene Kreyenhagen Formation of claystone with thin sandstone beds

### TABLE 1. GEOLOGIC UNITS IN THE RIDGELANDS AREA (Cont.)

Typical Map Symbol	Geologic Unit
Tkm	Eocene Markley Sandstone Member of Kreyenhagan Formation
Tds	Eocene Domengine Sandstone that is tan and arkosic
Tmg	Eocene Meganos Formation of claystone and sandstone with thin
Tmgs	sandstone lenses Sandstone that is locally pebbly at base within the Eocene Meganos Formation
Tmz	Paleocene Martinez Formation of claystone and siltstone with thin sandstone lenses
KTsh	Cretaceous and/or Paleocene unnamed micaceous clay shale and siltstone
KTs	Sandstone within KTsh (can be locally pebbly on Morgan Hill quadrangle)
KTsh	with circles, conglomerate within KTsh
KTsh	with lines, limestone within KTsh
Km	Cretaceous micaceous claystone of the Moreno Shale
Kmi	Cretaceous semi-siliceous shale of the Moreno Shale
Кp	Cretaceous Panoche Formation of clay shale
Kps	Sandstone within Panoche Formation
Крс	Conglomerate within Panoche Formation
Ksh	Cretaceous marine micaceous shale, undivided
cg	Cretaceous conglomerate younger than Kcg
Kshu	Cretaceous Berryessa Formation, undivided
Kshb	Shale within the Cretaceous Berryessa Formation
Ksg	Sandstone and conglomerate within the Cretateous Berryessa Formation
Kss	Sandstone within the Cretaceous Berryessa Formation
Kcg	(also Kcgo), Cretaceous Oakland Conglomerate
JKk	Jurassic and/or Cretaceous Knoxville Formation, dark micaseous shale with minor thin sandstone
JKc	Conglomerate and sandstone within the Knoxville Formation
db	Diabase
an	Andesite
sp	Serpentine, serpentinite
spr	Serpentine rubble
gb	Gabbro-diabase
S C	Silica-carbonate rocks
br	Fault? breccia
tr	Travertine
fs	Franciscan assemblage graywacke (sandstone) and shale
fc	Franciscan assemblage chert
fl	Franciscan assemblage limestone
fg	Franciscan assemblage greenstone
fsr	Franciscan assemblage pervasively sheared (shale and graywacke, largely)
gl f	Franciscan assemblage glaucophane schist
1	Franciscan assemblage hard monolithic fragments

#### TABLE 2: GEOLOGIC UNITS IN THE PETALUMA AREA

Typical Map Symbol	Geologic Unit
Qhac	Coarse-grained Holocene alluvium
Qham	Medium-grained Holocene alluvium
Qhs	Holocene sand deposits
Qhbm	Holocene Bay mud
Qhsc	Holocene stream channel deposits
Qhaf	Fine-grained Holocene alluvium
Qhafs	Fine-grained Holocene alluvium (salt-affected)
Qpmt	Pleistocene marine terrace deposits
Qpa	Late Pleistocene alluvium
Qpea	Early Pleistocene alluvium
Qaf	Artificial fill
Qc1	Colluvium
Qu	Undivided Quaternary deposits (largely in urban areas)
Qr	Rhyolite gravel
Qmi	Millerton Formation
Qc	Colma Formation
Qg	Gravel
Qc1t	Clear Lake area tuff
Qob	Olivine basalt in Clear Lake area
QThg	Huichica and Glen Ellen Formations
QTc	Cache Formation
QTm	Merced Formation
<u>T</u> p	Undifferentiated Petaluma Formation
Трс	Unbedded gray claystone of the Petaluma Formation
Tps	Claystone and siltstone of the Petaluma Formation
Tsv	Sonoma Volcanics, undifferentiated
Tsr Tsri	Sonoma Volcanics rhyolite lava flows Sonoma Volcanics rhyolite plugs and dikes
Tsa	Sonoma Volcanics injurite plugs and dikes  Sonoma Volcanics andesitic to basaltic lava flows
Tsfd	Sonoma Volcanics andesitic to basaltic lava flows thinly underlain
1314	by diatomite
Tst	Sonoma Volcanics pumicitic ash flow tuff
Ts	Miocene sandstone including the San Ramon Formation
KJfs	Franciscan sheared shale and sandstone
KJfss	Franciscan sandstone and interbedded shale
KJfg	Franciscan greenstone
KJfm	Franciscan metamorphic rocks
ch	Chert
////	Hydrothermally altered rocks
gs	Greenstone
mgs	Greenstone and schistose rocks
ch&gs	Chert and greenstone
gwy	Graywacke
mch	Metachert
cg	Conglomerate
sp	Serpentinite
m	High grade metamorphic rocks
SC V 1	Silica-carbonate rock
KJ gv	Great Valley sequence
KJgvc	Great Valley sequence - Novato Conglomerate

Second, landslides are shown as separate units on these maps and therefore obsure the geologic unit information. The landslide areas have been assigned to the bedrock units adjacent to them. In those cases where the appropriate assignment was not immediately evident, the map author or Earl Brabb of USGS was consulted before the final assignment was made.

After these two issues were resolved, the bedrock information on the maps was digitized. The resulting file was used to upgrade the existing data in the hillside portion of the study area. However, the flatlands data entered into the system in the first phase of this work remains for the flatlands portions.

#### Landslides

Several issues also had to be resolved before the landslide information for the Petaluma and ridgelands areas could be integrated with the San Mateo County landslide mapping.

The new landslide information, much like the geology data, came from three different authors (References 10-12). Although the maps were to have been produced using the same techniques, authors judgements made the data much more incompatible. In addition, slightly different, though similar, landslide classification systems were used by the three authors (see Table 3). Consequently landslides in the southern Petaluma area often did not continue into the northern portion and the landslide classification changed. Third, data from local government files and consultants reports, together with some field reconnaissance work, were integrated into the landslide mapping for San Mateo County (Reference 13). This type of information was not available for the study areas being used in this phase of the project. Last, all of these issues increased in importance because of the probability of the landslide maps being used directly as hazard maps and the tendency of potential users to view the landslide maps as black-and-white indications of problem areas.

The main decision made to alleviate these potential problems was to strongly recommend to all potential users that the landslide maps only be used as a basis for the landslide susceptibility maps and that these landslide susceptibility maps be used as a gradational, not black-and-white, means of depicting hazard level. This decision greatly increased the importance of the landslide susceptibility modeling and increased the complexity of that work, as discussed later in this working paper.

Second, the decision was made to greatly reduce the number of landslide categories entered into the computer data base. The relationship of the categories used to those mapped is illustrated in Table 3, below.

#### TABLE 3: A COMPARISON OF LANDSLIDE CLASSIFICATION SYSTEMS

Used By						
Classification Unit	Nilsen in Ridgelands Area	Wentworth and Others in Southern Petaluma Area	Dwyer & Others in Northern Petaluma Area	Brabb & Pampeyan in San Mateo County	Used in This project	
Landslide Deposits Mapped by Photo- interpretation						
Distinction based on quality of data						
D, definite land- slide deposit	No*	No*	Yes***	Yes	Yes**	
DA, landslide may be active	No	Yes	Yes***	Yes	Yes**	
P, probable land- slide deposit	Yes*	Yes*	Yes***	Yes	Yes	
?, questionable landslide deposit	Yes	Yes	Yes***	Yes	Yes	
Distinction based on type of movement (landslide, block slide, creep, flow, glide)	No	Yes	Yes (for creep only)	No ·	No	
Landslide Deposits Mapped in the field						
F, mapped in the field (and by as-sumption definitely there)	No	No	No	Yes	Yes**	
FA, active	No	-No	No	Yes	Yes**	
Landslide Information from Public Sources						
- Subsidence of road or ground	No	No	No	Yes	Yes**	
- Active landslide	No	No :-	No	Yes	Yes**	
Landslide Information from Private Consulting Firms						
- Landslide	No****	No	No	Yes	Yes**	

<sup>\*</sup>The distinction used between landslides and questionable landslides was assumed to be equivalent to that used by Brabb and Pampeyan between probable and questionable landslides, although many could have been classified by the authors as definite.

<sup>\*\*</sup>The classification category was used only when the information was available.

<sup>\*\*\*</sup> Areas shown as zones of many small landslides are treated as single large landslides by ABAG in this project.

<sup>\*\*\*\*</sup> Data from consulting firms tended to confirm photointerpretation mapping (see text).

Third, two additional categories of landslides were added in the cell conversion process since the cell conversion program normally assigns landslides to only those cells where landslides cover more than 50% of the area of the cell. The two new categories are cells with 10-30% landslide coverage and cells with 30-50% landslide coverage.

Lastly, a geology graduate student was used to collect data in the Alameda County portion of the study area and test the importance of data contained in consultant's geotechnical reports prepared in accordance with local requirements. The test indicated that very little usable data can be gathered from these reports. The work also indicated the importance of adequate report cataloging and retrieval systems. (The system used by Alameda County proved more usable than those for Contra Costa or Santa Clara Counties.) In addition, the work showed that reports cannot be used to indicate existing landslides because often the geologists recommend removal of the slide area as the appropriate means to mitigate the hazard (Reference 14).

#### Topography

ABAG obtained digital elevation model (DEM) tapes with a resolution of 30 meters on the ground (aggregated to 100 meters) and an elevation accuracy of +7 meters rms error for San Mateo County from the National Mapping Division of the U.S. Geological Survey. This Division also was the source of topographic information used in the Petaluma and ridgelands areas.

In using these DEM tapes in the earlier San Mateo County work, two problems were discovered. First, if one generalized the elevation data to hectare cells and then calculated percent slope, the area of high slope was underestimated. Secondly, the elevation data tended to be inaccurate enough along quadrangle boundaries to create artificially steep slopes in these areas. The first problem was alleviated by calculating the percent slope for the 30m by 30m cell nearest the center of the 100m by 100m (hectare) cell and assigning that value to the entire hectare cell. This technique produced steeper slopes in those areas thought to be steep based on a comparison with a slope map produced photographically from contour line information in San Mateo County. (The comparison was made by Earl Brabb, Evelyn Neuman and Bob Mark of the U.S. Geological Survey in Menlo Park.) To help mitigate data problems along quadrangle boundaries in the ridgelands and Petaluma areas, the National Mapping Division used more control points to register the raw elevation data.

#### PRODUCING DETAILED GROUND SHAKING INTENSITY MAPS

Those U.S. Geological Survey scientists instrumental in assigning the geology units to several seismically distinct units in the first phase of this project (Reference 15 and Working Paper #2) were contacted and consented to assign the new geology units to the appropriate seismically distinct units. Their work is summarized in Table 4, below.

These seismic units can then be transferred into appropriate intensity increments using the technique described in Working Paper #3. New intensity maps could be generated based on these revised intensity increments. However, new maps have not been generated because the other two main variables used in producing the intensity maps (an attenuation formula for the reduction of intensity with distance from the fault sources and damage estimates for various intensities) are currently being re-evaluated and may be changed by mid-1981.

The maximum ground shaking intensity map and three risk of ground shaking damage maps will be regenerated for the entire region as part of the third phase of the project when the new information is available. This reduction of work made possible the increase of work related to the topography files and the landslide susceptibility map files described in the preceding and following sections.

## TABLE 4A: AVERAGE PREDICTED INTENSITY INCREMENTS FOR THE GEOLOGIC UNITS IN THE RIDGELANDS AREA

Typical Map		Seismic Unit	Range of Predicted Intensity	Average Predicted Intensity
Symbol	Geologic Unit	Range	Increments	Increments
Qhac	Coarse-grained Holocene alluvium	٧	.9	.9
Qham	Medium-grained Holocene alluvium	III	1.7	1.7
Qhs	Holocene sand deposits	III, V	.9-1.7	1.3
Qhbm	Holocene Bay mud	I	2.9	2.9
Qhsc	Holocene stream channel deposits	III, V	.9-1.7	1.3
Qhaf	Fine-grained Holocene alluvium	II	1.8	1.8
Qhafs	Fine-grained Holocene alluvium (salt-affected)	II	1.8	1.8
Qpmt	Pleistocene marine terrace deposits	٧	.9	.9
Qpa	Late Pleistocene alluvium	V, VI	.49	.6
Qpea	Early Pleistocene alluvium	V, VI	.49	.6
Qaf	Artificial fill	II, III, V	.9-1.8	1.5
Qc1	Colluvium	III, V	.9-1.7	1.3
Qu	Undivided Quaternary deposits (largely in urban areas)	II-VI	.4-1.8	1.2
Qg	Stream channel gravel, sand and clay	III, V	.9-1.7	1.3
QTs	Santa Clara Formation gravel sand, and clay	IV, Y	.45	1
Qsb	Gravel with basalt detritus of QTs	V, VI	.49	.6
Qsp	Conglomerate or breccia of serpentine detritus of QTs	VΙ	.4	.4
Qsa	Clay of QTs	III	1.7	1.7
Qsc(a)	Areas of "a" within Qsc, andesite of QTs	VII	- 1.1	- 1.1
Qsc(b)	Areas of "b" within Qsc, basalt of QTs	<u>VII</u>	- 1.1	- 1.1
QTI	Livermore Gravel	III-VI	.4-1.7	1.1
QTt	Tassajara Formation	IV-V	.9-1.7	1.3
QТЬ	Unnamed olivine basalt lava	VII	-1.1	-1.1
rh	Rhyolite that is Tertiary (Pliocene) in age (includes the Alum Rock Rhyolite)	<u> </u>	11.1	6
Tps	<pre>(also Tsc and Tor), Pliocene nonmarine sedimentary rocks (includes the Orinda Formation)</pre>	<u>I-¥</u>	.75	0
Tb	(Tbu), Pliocene unnamed basalt (includes basalt in Orinda Fm.)	<u>II</u> , <u>VI</u>	.38	3
Tbp	Pliocene Bald Peak Basalt	II, VII	.31.1	4
Tmb	Pliocene Moraga Formation, basalt	<u>VI, VII</u>	81.1	9
Tmt	Pliocene Moraga Formation, tuff breccia	II, III	.3-0	.1
Tp1	Pliocene lacustrine limestone	VI —	8	8
Tpt	Pliocene tuff and sandstone	III, VI	18	4
Tn	Miocene Neroly Sandstone	<u>I, 11</u>	.37	.5
Tmss	Miocene sandstone (includes the Briones, Cierbo and sometimes the Neroly sandstones	<u>Tv, Vi</u>	38	5
Tmsl	Miocene siltstone with minor sandstone	111, 1V 11, 111	13	2
Tmsh	Miocene silty to silicous gray-white shale (includes upper part of Claremont Shale from Mt. Sizer quadrangle)	11, 111	.3-0	.1

TABLE 4A: GEOLOGIC UNITS IN THE RIDGELANDS AREA (Cont.)

Typical Map Symbol	Geologic Unit	Seismic Unit	Range of Predicted Intensity Increments	Average Predicted Intensity Increments
Tmsc	Miocene brittle cherty and silicious tan-white shale (includes Claremont Shale and lower part of Claremont on	II-IV	.33	0
Tms	Mt. Sizer quadrangle) Miocene basal sandstone (includes the Sobrante and Temblor sandstones)	IV-VI	.38	5
Tmsr	Oligocene San Ramon Formation of siltstone and basal sandstone	<u>III</u> , <u>IV</u>	03	2
Tt	Eocene Tolman Formation of marine sandstone and siltstone	IV, V	35	4
Tk	Eocene Kreyenhagen Formation of claystone with thin sandstone beds	<u>111</u> , <u>1V</u>	03	2
Tkm	Eocene Markley Sandstone Member of Kreyenhagan Formation	<u>I</u> , <u>II</u>	.73	.5
Tds	Eocene Domengine Sandstone that is tan and arkosic	<u>I</u> , <u>V</u>	.75	•1
Tmg	Eocene Meganos Formation of claystone and sandstone with thin sandstone lenses	<u>11</u> , <u>111</u>	.3-0	.1
Tmgs	Sandstone that is locally pebbly at base within the Eocene Meganos Formation	<u>I</u> , <u>II</u>	.73	.5
Ţmz	Paleocene Martinez Formation of claystone and siltstone with thin sandstone lenses	<u>II</u> , <u>III</u>	.3-0	.1
KTsh	Cretaceous and/or Paleocene unnamed micaceous clay shale and siltstone	<u>11</u> , <u>111</u>	.3-0	.1
KTs	Sandstone within KTsh (can be locally pebbly on Morgan Hill quadrangle)	<u> 111-Y</u>	05	3
KTsh	with circles, conglomerate within KTsh	<u>v</u>	5	5
KTsh	with lines, limestone within KTsh	<u>VI</u>	8	8
Km	Cretaceous micaceous claystone of the	<u>II, 111</u>	.3-0	.1
Kmi	Cretaceous semi-siliceous shale of the Moreno Shale	п, ш	.3-0	.1
Kp	Cretaceous Panoche Formation of clay shale	<u>II, III</u>	.3-0	.1
Kps	Sandstone within Panoche Formation	<u>111-VI</u>	08	4
Kpc	Conglomerate within Panoche Formation	<u>V, vi</u>	58	6
Ksh	Cretaceous marine micaceous shale, undivided		.38	3
cg	Cretaceous conglomerate younger than Kcg	<u>V</u>	5	5
Kshu	Cretaceous Berryessa Formation, undivided	<u>TII- VI</u>	08	4
Kshb	Shale within the Cretaceous Berryessa Formation	$\overline{\Pi}$ , $\overline{\Pi}$	03	2
Ksg	Sandstone and conglomerate within the Cretateous Berryessa Formation	<u>vi</u>	8	8
Kss	Sandstone within the Cretaceous Berryessa Formation	<u>v</u> , <u>vi</u>	58	6

TABLE 4A: GEOLOGIC UNITS IN THE RIDGELANDS AREA (Cont.)

Typical Map Symbol	Geologic Unit	Seismic Unit Range	Range of Predicted Intensity Increments	Average Predicted Intensity Increments
Kcg	(also Kcgo), Cretaceous Oakland Conglomerate	IV, V	35	4
JKK	Jurassic and/or Cretaceous Knoxville Formation, dark micaseous shale with minor thin sandstone	<u>TT-17</u>	35 .33	0
JKc	Conglomerate and sandstone within the Knoxville Formation	III, IV	03	2
db	Diabase	VII	-1.1	-1.1
an	Andesi te	VII	-1.1	-1.1
sp	Serpentine, serpentinite	TI-VI	.38	3
spr	Serpentine rubble	TI-VI	.38	3
gb	Gabbro-diabase	<u>VI 1</u>	-1.1	-1.1
sc	Silica-carbonate rocks	TII-VII	01.1	6
br	Fault? breccia	N/A		
tr	Travertine	N/A		
fs	Franciscan assemblage graywacke (sandstone) and shale	111, <u>VI</u>	·· 08	4
fc	Franciscan assemblage chert	III	0	0
fl	Franciscan assemblage limestone	IV-VII	31.1	7
fg	Franciscan assemblage greenstone	<u>VI 1</u>	-1.1	-1.1
fsr	Franciscan assemblage pervasively sheared (shale and graywacke, largely)	<u>II-VI</u>	.38	3
gl	Franciscan assemblage glaucophane schist	III-VII	01.1	6
gl f	Franciscan assemblage hard monolithic fragments	VII -	-1.1	-1.1

 $<sup>\</sup>mbox{N/A}$  Not available due to lack of physical descriptions; they appear only on the Morgan Hill quadrangle as 2-3 small slivers

TABLE 4B: AVERAGE PREDICTED INTENSITY INCREMENTS FOR THE GEOLOGIC UNITS IN THE PETALUMA AREA

Typical Map		Seismic Unit	Range of Predicted Intensity	Average Predicted Intensity
Symbol	Geologic Unit	Range	Increments	Increments
Qhac	Coarse-grained Holocene alluvium	Y	.9	.9
Qham	Medium-grained Holocene alluvium	III	1.7	1.7
Qhs	Holocene sand deposits	III, V	.9-1.7	1.3
Ohbm	Holocene Bay mud	I	2.9	2.9
Ohsc	Holocene stream channel deposits	III, V	.9-1.7	1.3
Qhaf	Fine-grained Holocene alluvium	11	1.8	1.8
Qhafs	Fine-grained Holocene alluvium (salt-affected)	II	1.8	1.8
Qpmt	Pleistocene marine terrace deposits	Y	.9	.9
Qpa	Late Pleistocene alluvium	V,VI	.49	•6
Qpea	Early Pleistocene alluvium	V,VI	.49	.6
Qaf	Artificial fill	II,III,V	.9-1.8	1.5
Qc1	Colluvium	V, III	.9-1.7	1.3
Qu	Undivided Quaternary deposits (largely in urban areas)	II-ŸI	.4-1.8	1.2
Qr	Rhyolite gravel	Y,VI	.49	.6
Qmi	Millerton Formation	III,VI	.4-1.7	1.0
. Qc	Colma Formation	V	.9	.9
Qg	Gravel	V,VI	.49	.6
Qc1t	Clear Lake area tuff	<u>I,II</u>	.37	.5
Qob	Olivine basalt in Clear Lake area	II, VII	.31.1	4
QThg	Huichica and Glen Ellen Formations	<u>T,11</u>	.37	.5
QTc	Cache Formation	I	.7	.7
QTm	Merced Formation	V	.9	.9
Tp	Undifferentiated Petaluma Formation	<u>1,11</u>	.37	.5
Трс	Unbedded gray claystone of the Petaluma Formation	<u>I,II</u>	.37	.5
Tps	Claystone and siltstone of the Petaluma Formation	<u>I,II</u>	.37	.5
Tsv	Sonoma Volcanics, undifferentiated	<u>I-III,VII</u>	.71.1	1
Tsr	Sonoma Volcanics rhyolite lava flows	IV-VII	31.1	<b></b> 7
Tsri	Sonoma Volcanics rhyolite plugs and dikes	<u>11,111,v11</u>	.31.1	3
Tsa	Sonoma Volcanics andesitic to basaltic lava flows	Tri,Vii	01.1	6
Tsfd	Sonoma Volcanics andesitic to basaltic lava flows thinly underlain by diatomite	<u>I</u> , <u>VII</u>	.71.1	2
Tst	Sonoma Volcanics pumicitic ash flow tuff	<u> 1,11,VII</u>	.71.1	0
Ts	Miocene sandstone including the San Ramon Formation	TV-VI	38	5
KJfs	Franciscan sheared shale and sandstone	11-11	.38	3
KJfss	Franciscan sandstone and interbedded shale	<u>III, vi</u>	08	4
KJfg	Franciscan greenstone	AII —	-1.1	-1.1
KJfm	Franciscan metamorphic rocks	<u>VII</u>	-1.1	-1.1
ch	Chert	$\overline{\Pi}$	0	1
////	Hydrothermally altered rocks	TII-VI	08	4
gs	Greenstone	111	0	1
mgs	Greenstone and schistose rocks	11,111,V11	.31.1	7
chågs	Chert and greenstone	<u>111,V11</u>	01.1	6

## TABLE 4B: AVERAGE PRE SITY INCREMENTS FOR THE GEOLOGIC UNITS SHA AREA (Cont.)

Typical Map Symbol	Geologic Unit	Seismic Unit Range	Range of Predicted Interesty Incresents	er Fredi and antino accrement -
gwy	Graywacke	<u>111,<b>34</b>-</u> .8	98	-, P
mch	Metachert	III D	0	0
Cg	Conglomerate	<u> </u>	Ø8	* ,. Fi
Sp ·	Serpentinite	11-V! 8	.3 ·.?	. 3
m	High grade metamorphic root	TV, VII.	81.1	:
SC	Silica-carbonate rock	31. <b>-VI</b> 8	08	- 3
Kiga -	Great Valley sequence	TIT-VI	<b>-0-</b> 8	•
Stave 1	Great Fallay sequence	E	•	

## EXTENDING RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY MAPPING BEYOND SAN MATEO COUNTY

Rainfall-induced landslide susceptibility maps were produced in the study area using a two-step process. First, data were collected on the interrelationship of geology, slope, slope aspect, vegetation, average annual precipitation, and existing landslides within San Mateo County. This information served as background for examining the relationships among these same variables outside of that County in the Petaluma and ridgelands areas, the second step in the process. A model describing these relationships then was used to produce a rainfall-induced landslide susceptibility map for these new areas.

#### San Mateo County Information

To obtain these data for San Mateo County, tabulations were obtained (using ABAG's computer-based geographic information system) of the surface extent of coverage by existing landslides for various categories of geology and slope, as well as slope aspect, vegetation type, and average annual precipitation. The results for geology and computer-derived slope (Tables 5A and B) can be used to assign a landslide susceptibility category to any given hectare using a method similar to that developed by Brabb and Pampeyan (Reference 13) and used in the first phase of this project (in Working Paper #5). The resulting map would not be identical to that developed in the first phase work, however, because the calculation of the surface extent of failure for each of the geologic units is not necessarily the same when performed automatically as when performed manually. Because of these different results, those groupings, or categories, that are based on the automated calculations (A-F in Table 5) are not identical to those based on manual calculations (I-VI in Table 2 of Working Paper #5) even though the percent ranges used to define the two sets of categories are identical.

Geology, slope, and existing landslides are not the only variables that can be used to predict landslide susceptibility, however. Slope aspect, vegetation, and average annual precipitation also appear to be related to landslide occurrence. In the case of slope aspect, for example, the percentage ocurrence of failure ranges from 15.6 to 25.5 for the eight categories, with 18.9 the main percentage failure of all hectares able to be examined (Table 5C). Even though the highest failure rate is two-thirds higher than the lowest failure rate, the difference is not nearly as great as for the other four variables and therefore has been ignored in the modeling for this project. The effects of vegetation and precipitation appear to be more pronounced (based on Tables 5D and E). However, these effects also could be due to slope, since steeper slopes also tend to receive greater rainfall and have different types of Therefore, four additional tabulations were generated. first two, Tables 5F and G, relate percent failure to vegetation type for only those areas of 5-15% slope and of greater than 15% slope, respectively. The last two, Tables 5H and I, relate percent failures to average annual precipitation for those same areas of 5-15% slope and of greater than 15% slope, respectively. The tendency for the vegetation types of coniferous forest, conifer/brush, and hardwood/conifer forest to have greater coverage by landslides was confirmed when the effects of slope were reduced. The average failure coverage of 6.5% in 5-15% slope was increased to 43.1, 29.4 and 32.0%, or by factors of 6.6, 4.5, and 4.9, respectively. Although the average failure coverage of 22.6% in greater than 15% slope was increased to 28.5, 25.3, and 29.8%, respectively, this increase was not nearly as pronounced. The tendency for areas of greater than 30 inches of rainfall annually to show markedly higher landslide coverage was quite obvious when calculated for those areas of 5-15% to slope. The effects of precipitation were not particularly significant when tabulated for only slopes of greater than 15%.

Based on these results, one can create a table relating rainfall susceptibility in San Mateo County to slope, geology, and existing landslides, and then modify that table to take some account of vegetation type and average annual precipitation. Table 6A, below, is a preliminary table based only on the first three variables. Note that this table uses fewer categories of percent slope than used by Brabb and others (Reference 13) and modified for use in the first phase of this work due to no significant increase in failures occurring once the criteria of greater than 15% slope was reached.

TABLE 6A: PRELIMINARY ASSIGNMENT OF RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY CATEGORIES FOR SAN MATEO COUNTY BASED ON GEOLOGY, SLOPE, AND EXISTING LANDSLIDE OCCURRENCE

Geology Unit Susceptibility	Surface Extent of the Geology Unit that Has	Landslide Susceptibility Category by Percent Slope Range		
Category (See Table 5A for names)	Failed Through Landsliding (from Table 5A) (in percent)	0-5%	5-15%	15%
	0.1	•	•	
Α	0-1	I	Ī	I
В	2-8	I	I	ΙΙ
С	<b>9-2</b> 5	I	ΙΙ	III
D	26-42	I	II	ΙV
E	43-53	I	111	٧
F	54-90	Ī	ĪĪĪ	٧I
G(Existing Landslides)	100	VII	VII	VII

All units, except the last, are assigned the lowest landslide susceptibility category when on 0-5% slopes due to the relatively rare (<1%) occurrence of landslides on slopes that low. On slopes of greater than 15%, categories are assigned from I through VII to account for the relatively higher occurrence of landslides fairly uniformly once slopes reach 15%. Since failure rates in areas of 15+% slope are approximately 3.5 times that in areas of 5-15% slope, the stability categories for 5-15% slope were obtained by dividing each surface extent of failure percent range by 3.5 and assigning the category corresponding to areas of 15+% slope for the resulting extent of failure range. For example, for geologic unit category C, the percent failure of 9-25%, when divided by 3.5, yields 2.6-7.1, a range within that for the geologic unit category B, which has been assigned a landslide susceptibility category of II for 15+% slope. Therefore, the susceptibility category II has been assigned to geologic unit category C for areas of 5-15% slope.

Because areas of greater than 30 inches of rainfall and of major conifers and broadleaf vegetation are approximately four times more susceptible to landslides in areas of 5-15% slope, and because the factor of four also is the difference between the susceptibility of areas of 5-15% slope as opposed to 15+% slope, one should adjust the preliminary susceptibility categories assigned in Table 6A. Thus, areas meeting either of these two criteria in areas of 5-15% slope should be assigned the same category as those units in 15+% slope. These adjustments are shown in Table 6B, below.

TABLE 6B: ASSIGNMENT OF RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY CATEGORIES FOR SAN MATEO COUNTY BASED ON GEOLOGY, SLOPE, EXISTING LANDSLIDE OCCURENCE, VEGETATION, AND ANNUAL PRECIPITATION

Geology Surface Extent Landslide Susceptibility Category				
Unit Susceptibility Category (See Table 5A for names)	of the Geology Unit that Has Failed Through Landsliding (from Table 5A) (in percent)	If 0-5% Slope Regardless of Vegetation Type or Annual Precipitation	If 5-15% Slope, Most Vegetation Types and <30" Annual Precipitation	If 15+% Slope or 5-15% Slope with either 1) Coniferous Forest, Conifer/ Brush or Hard- wood/Conifer Forest or 2) >30" Annual Precipitation
A B C D E F G(Existing Landslides	0-1 2-8 9-25 26-42 43-53 54-90 100	I I I I VII	AII III II II I	AII A A IA III II

TABLE 5A: LANDSLIDE FAILURE RECORD FOR GEOLOGIC UNITS IN SAN MATEO COUNTY

Geologic	Surface Extent of the	Approximate	Approximate
Unit	Geologic Unit that	Area in	Area that
Map	Has Failed by Land-	County	Has Failed
Symbol*	sliding (percent)	(hectares)	(hectares)
CATEGORY A**	0-1%		
(Qhac) Quf (Qham) Qyf (Qhaf) Qb (Qhbm) Qym Qaf Qob (Qpmc) Qc	0 1.5 .17	3328 2901 1201 2521 7205 149 2908	39 44 2 0 9 0 7
Tuv	0.	4	0
Tus	.94	530	5
Tpm	0.	5	0
Ksh	0.	1	0
KJv	0.	8	0
KJf	.94	534	5
fl	.97	104	1
fm	0.	7	0
fcg	0.	10	0
KJs	1.3	1243	16
m	0.	2	0
CATEGORY B**	2-8%		
(Qhs)Qs	3.0	564	17
Qof	3.0	4773	142
(Qpmt)Qmt	1.8	3739	67
Qal	4.4	227	10
QTm	8.2	2268	187
Tlo	7.6	105	8
Tb?	1.6	2349	38
Kpp -	8.5	1537	130
Kgr	2.3	6030	139
fs	1.9	5693	108
fg	2.9	2910	84
fc	2.8	392	11
fsr	4.2	2813	119
sp	1.9	1335	25

TABLE 5A (Cont.)

Geologic Unit Map Symbol*	Surface Extent of the Geologic Unit that Has Failed by Land- sliding (percent)	Approximate Area in County (hectares)	Approximate Area that Has Failed (hectares)
CATEGORY C**	9-25%		
Qc1 QTs	13 17	2635 2493	332 420
Tla Tvq Tsl Tss Tb (North c	25 23 11 10 of La Honda) 15	5641 2036 136 1063 7029	1428 468 15 109 1048
CATEGORY D**	26-42%		
Tp Tpp Tpt Tsc Tsm Tm Tmb Tsr Tb (South o	31 37 40 37 29 32 38 38 38 38	5918 2908 8969 5120 290 1352 3261 375 5310	1811 1062 3596 1898 85 434 1232 143
CATEGORY E**	43-53%		
Tptu Tpsg Tst	52 45 45	697 651 224	364 291 100
CATERGORY F**	54-90%		
Tpl Tls Tbs	57 63 90	1070 1710 40	608 1082 36
TOTAL	16.7 (ave)	116324	19411

<sup>\*</sup> Symbol in parentheses is that used in tables describing Quaternary geology of Petaluma and ridgeland areas if different than that used on San Mateo County map.

<sup>\*\*</sup> Categories are labeled A-F instead of I-VI to distinguish these categories of geologic materials based on computer derived-failure rates from those based on the manually-derived failure rates of Brabb and Pampeyan (Reference 13).

## TABLE 5B: LANDSLIDE FAILURE RECORD FOR PERCENT SLOPE CATEGORIES IN SAN MATEO COUNTY

Percent Slope Category	Surface Extent of the Slope Category that Is the Result of Failure by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that Is the Result of Failure (hectares)
0- 5	.4	19498	79
5- 15	6.5	15875	1032
15- 30	21.4	27953	5978
30- 50	24.4	30560	7461
50- 70	21.8	16614	3916
70-100	20.9	5268	1100
100+	23.3	551	145
TOTAL	16.7 (ave.)	116319*	19411*

<sup>\*</sup> A total of 5 hectares in San Mateo County have not been assigned a vegetation unit due to differences in the land-water boundary.

## TABLE 5C: LANDSLIDE FAILURE RECORD FOR SLOPE ASPECT CATEGORIES IN SAN MATEO COUNTY

TOTAL	16.8 (ave)	116315*	19508*
North-West	25.5	12217	3116
West	21.8	10445	2281
South-West	18.0	14113	2536
South	15.6	12478	1947
South-East	17.2	10817	1859
East	16.9	9445	1593
North-East	17.8	13483	2402
North	18.4	13966	2576
Multiple Aspec	cts 6.2	19351	1198
Slope Aspect Category	Surface Extent of the Aspect Category that Is the Result of Failure by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that is the Result of Failure (hectares)

<sup>\*</sup> A total of 9 hectares in San Mateo County have been eliminated from consideration because of processing difficulties and differences in the land-water boundary. In addition, 97 hectares of landslides have been counted twice. Neither error should effect these results significantly.

## TABLE 5D: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN SAN MATEO COUNTY

Vegetation Ha	Surface Extent of the Vegetation Unit that as Failed by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	N/A	0	0
Hardwood/Brush	21.8	7546	1647
Coniferous Forest	28.5	3307	943
Conifer/Brush	25.3	8285	2095
Hardwood/Conifer	Forest 29.8	9316	<b>277</b> (
Conifer/Hardwood	Forest N/A	0	0
Grassland	21.5	15842	3409
Open Shrub	20.1	5355	1123
Brush	21.1	29174	6369
Mixed Agricultura	l Land 0	1	0
Commercial, Servi	ces .7	1475	10
Mixed Urban	.3	3128	9
Low Vegetation Residential	1.4	14229	193
Moderate Vegetati Residential	on 11.1	2546	282
High Vegetation Residential	3.9	3235	127
Urban Open Space	.1	960	1
Non-Forested Wetl	ands 0	3012	0
Water	2.3	131	3
Shallow or Turbid	Water .2	1284	2
Salt Evaporation	Ponds 0	556	0
Mixed Barren	2.1	1459	30
Clouds	7.1	5478	390
TOTAL	16.7 (ave.)	116319*	19411*

<sup>\*</sup> A total of 5 hectares in San Mateo County have not been assigned a vegetation unit due to differences in the land-water boundary. 11-24

TABLE 5E: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN SAN MATEO COUNTY

Average Annual Precipitation (inches)	Surface Extent of the Precipitation Unit that Has Failed by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that Has Failed (hectares)
6- 8	N/A	0	0
8-10	N/A	0	0
10-12	N/A	0	0
12-14	0	945	0
14-16	.01	6715	1
16-18	3.9	4000	155
18-20	10	8348	845
20-22	9.6	13977	1341
22-24	6.8	13807	934
24-26	11	9493	955
26-28	20	7622	1526
28-30	20	6568	1321
30-32	29	7425	2183
32-34	32	8590	2782
34-36	26	8295	2120
36-38	22	4629	1004
38-40	18	5232	916
40-44	32	5385	1717
44-48	32	4864	1564
48-52	6.7	114	8
TOTAL	16.7 (ave)	116009*	19372*

<sup>\*</sup> A total of 315 hectares in San Mateo County have not been assigned a precipitation unit due to differences between the land-water boundary.

# TABLE 5F: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN AREAS OF 5-15% SLOPE WITHIN SAN MATEO COUNTY

Vegetation Ha	Surface Extent of the Vegetation Unit that as Failed by Landsliding	Approximate Area in County	Approximate Area that Has Failed
Unit	(percent)	(hectares)	(hectares)
Hardwood Forest	N/A	0	0
Hardwood/Brush	11.5	253	29
Coniferous Forest	43.1	72	31
Conifer/Brush	29.4	245	, 4
Hardwood/Conifer l	Forest 32.0	250	80
Conifer/Hardwood I	Forest N/A	0	0
Grassland	9.4	2963	280
Open Shrub	13.5	741	100
Brush	14.4	1981	286
Mixed Agricultura	l Land 0	0	0
Commercial, Servio	ces 1.7	294	5
Mixed Urban	.3	796	2
Low Vegetation Residential	1.1	4046	45
Moderate Vegetation Residential	on 3.0	765	23
High Vegetation Residential	.7	710	5
Urban Open Space	.2	423	1 :
Non-Forested Wetl	ands 0	132	0
Water	12.5	16	2
Shallow or Turbid	Water 4.9	41	2
Salt Evaporation	Ponds 0	0	0
Mixed Barren	14.9	347	7
Clouds	3,4	1798	62
TOTAL	6.5 (ave.)	15875	1032
		•	

# TABLE 5G: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN AREAS OF MORE THAN 15% SLOPE WITHIN SAN MATEO COUNTY.

V	urface Extent of the egetation Unit that Failed by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	N/A	0	0
Hardwood/Brush	22.5	7180	1618
Coniferous Forest	28.5	3199	912
Conifer/Brush	25.3	7986	2019
Hardwood/Conifer Fo	rest 29.8	9048	2695
Conifer/Hardwood Fo	rest N/A	0	0
Grassland	27.0	11505	3104
Open Shrub	23.3	4372	1017
Brush	1.2	26593	6063
Mixed Agricultural	Land 0	0	0
Commercial, Service and Industrial	es 3.3	152	5
Mixed Urban	1.3	445	6
Low Vegetation Residential	3.2	4429	142
Moderate Vegetation Residential	19.2	1332	256
High Vegetation Residential	8.9	1356	121
Urban Open Space	0	283	0
Non-Forested Wetlar	ods 0	8	0
Water	1.9	52	1
Shallow or Turbid k	ater 0	18	0
Salt Evaporation Po	onds 0	0	0
Mixed Barren	6.4	358	<b>2</b> 3
Clouds	12,2	2610	318
TOTAL	22.6 (ave.)	80946	18300

# TABLE 5H: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN AREAS OF 5 - 15% SLOPE WITHIN SAN MATEO COUNTY

Average Annual Precipitation (inches)	Surface Extent of the Precipitation Unit that Has Failed by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that Has Failed (hectares)
6- 8	N/A	0	0
8-10	N/A	0	0 ,
10-12	N/A	0	0
12-14	N/A	0	0
14-16	0	207	0
<b>16-1</b> 8	4.8	516	25
18-20	5.0	2087	105
20-22	3.9	3722	145
22-24	2.2	3817	85
24-26	3.9	1886	73
26-28	9.5	1139	108
28-30	8.5	824	70
30-32	21.1	454	96
32-34	28.6	371	106
34-36	24.8	302	75
36-38	27.3	117	32
38-40	18.6	113	21
40-44	29.0	162	47
44-48	55.1	78	43
48-52	0	1	0
TOTAL	6.5 (ave)	15797	1032

# TABLE 51: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN AREAS OF MORE THAN 15% SLOPE WITHIN SAN MATEO COUNTY

Average Annual Precipitation (inches)	Surface Extent of the Precipitation Unit that Has Failed by Landsliding (percent)	Approximate Area in County (hectares)	Approximate Area that Has Failed (hectares)
6- 8	N/A	0	0
8-10	N/A	0	0
10-12	N/A	0	0
12-14	N/A	0	0
14-16	0	13	0
16-18	21.0	609	128
18-20	27.9	2647	739
20-22	15.5	7570	1175
22-24	9.9	8394	831
24-26	12.5	6933	870
26-28	22.8	6207	1413
28-30	22.3	5595	1247
30-32	30.1	6913	2080
32-34	32.6	81 93	2673
34-36	25.6	7966	2041
36-38	21.6	4508	972
38-40	17.5	5118	895
40-44	32.0	5222	1670
44-48	18.9	8050	1520
48-52	7.1	113	8
TOTAL	22.6 (ave)	18293	1032

TABLE 7A: LANDSLIDE FAILURE RECORD FOR GEOLOGIC UNITS IN THE RIDGELANDS AREA

Geologic Unit MapSymbol*	Surface Extent of the Geologic Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
CATEGORY A** 0-1%			
Qhac	.3	15819	53
Qham	.4	16548	65
Qhbm	0.	4188	0
Qhaf	0.	6353	?
Ohafs	0	702	. *.
Qg	.5	863	4
Qaf	0.	216	0
Qpa	1.1	17231	185
Qsp	0.	18	0
Qsc(a)	0.	7	0
Qsc(b)	0.	<b>2</b> 3	0
Tpt Tmsr	0. 0.	20	0 0
	0.	20 5	0
KTsh w/ circles fl	0.	10	0
cg	0.	10	Ŏ
br	<b>0.</b>	i	ő
f	0.	10	Ŏ
<b>s</b> pr	o.	5	Ŏ
CATEGORY B** 2-8%			
Qhsc	1.7	58	1
QTs	7.1	4682	1334
Qsb	7.1	14	1
QTt	4.7	1185	56
<u>rh</u>	5.0	301	15
<u>T</u> b	3.1	162	5
Tn	4.1	639	26
Tds	1.9	619	12
Kps	5.1	2855 81	145 2
Ksg	2.5 6.1	81 1287	79
JKk ·	5.0	60	3
sc db	4.3	231	10
an	7.7	13	1
gb	2.0	645	13
<del>2-</del>	2.0	U T J	•0

TABLE 7A (Continued)

Geologic Unit Map	Surface Extent of the Geologic Unit that Has Failed by Landsliding	Approximate Area in Area	Approximate Area that Has Failed
Symbol*	(percent)	(hectares)	(hectares)
CATEGORY C** 9-25%			
Qc1	9	8671	800
Qsa	17	6	1
Ťbp	21	114	24
Tmb	19	561	109
Tmss	14	12400	1745
Tmsl	16	7075	126
Tmsh	19	1644	313
Tmsc	14	2100	297
Tms	10	541	55
Tt	18	127	23
Tkm	10	21	2
Tmg	10	228	22
Tmgs	16	43	7
Tmz	17	254	44
KTsh	15	3366	498
KTs	14	251	35
Km	25	4	1
Kp	10	15451	1524
Kpc	10	878	84
Kss	23	139	32
Kcg	16	464	76
JKc	24	42	10
fg	17	1510	250
sp	9	3744	322
CATEGORY D** 26-42%			
QT1	42	673	285
Tps	26	11946	5136
fs	32	11428	3687
fc	35	345	995
fsr	33	849	2545
Ksh	32	41	13
Kshb	34	3518	1197
- 1-			

TABLE 7A (Continued)

Geologic Unit Map Symbol*	Surface Extent of the Geologic Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
CATEGORY E** 43-53%			•
QTb Tmt Kshu	47 50 52	426 48 307	199 24 161
CATEGORY F** 54-90%			
Tk g1	54 54	<b>497</b> 13	· 3 7
TOTAL***	12.3 (ave)	174905	21583

<sup>\*</sup>Symbol in parentheses is that used in tables describing Quaternary geology of the ridgelands. Some units listed on those tables are not listed here because they do not appear within the eleven quadrangle area.

<sup>\*\*</sup>Categories are labeled A-F instead of I-VI to distinguish these categories of geologic materials based on computer derived-failure rates from those based on the manually-derived failure rates of Brabb and Pampeyan (Reference 13).

<sup>\*\*\*</sup>The totals are smaller than on the tables that follow because the area defined by the eleven quadrangles is smaller than the area defined by a UTM even kilometer window used in the other tables.

## TABLE 7B: LANDSLIDE FAILURE RECORD FOR PERCENT SLOPE CATEGORIES IN THE RIDGELANDS AREA

Percent Slope Category	Surface Extent of the Slope Category that Is the Result of Failure by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Is the Result of Failure (hectares)
0- 5	1.1	55811	599
5- 15	5.1	29762	1507
15- 30	17.2	46438	7967
30- 50	21.0	39581	8297
50- 70	20.1	13664	2746
70-100	19.8	3055	604
100+	12.7	921	117
TOTAL	11.5 (ave)	189232	21837

## TABLE 7C: LANDSLIDE FAILURE RECORD FOR SLOPE ASPECT CATEGORIES IN THE RIDGELANDS AREA

Slope Aspect Category	Surface Extent of the Aspect Category that Is the Result of Failure by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Is the Result of Failure (hectares)
Multiple Aspects	5.2	50182	2602
North	8.7	16522	1435
North-East	18.4	17880	3291
East	16.2	13553	2191
South-East	15.6	13414	2086
South	9.2	18089	1673
South-West	15.7	25668	4021
West	13.8	18598	2572
North-West	12.8	15326	1966
TOTAL	11.5 (ave)	189232	21837

### TABLE 7D: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN THE RIDGELANDS AREA

Vegetation Unit	Surface Extent of the Vegetation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	N/A	0	0
Hardwood/Brush	20.0	22272	4456
Coniferous Forest	N/A	0	0
Conifer/P 'sh	8.9	760	68
Hardwood/Lfer Forest	0	4	0
Conifer/Hardwood Forest	N/A	0	0
Grassland	10.5	62205	6519
Open Shrub	17.9	36681	6582
Brush	15.6	20030	3133
Mixed Agricultural Land	3.9	1789	69
Commercial, Services and Industrial	.1	1206	1
Mixed Urban	.3	3723	10
Low Vegetation Residential	2.3	28082	641
Moderate Vegetation Residential	5.1	1380	71
High Vegetation Residential	7.4	2680	198
Urban Open Space	.5	1811	9
Non-Forested Wetlands	0	1866	0
Water	18.3*	387	71
Shallow or Turbid Water	.1	760	1
Salt Evaporation Ponds	0	1531	0
Mixed Barren	.4	2064	8
Clouds	N/A	0	0
TOTAL	11.5 (ave)	189231	21837

<sup>\*</sup>This high value probably is due to the presence of landslides along the shores of reservoirs and the inability to register the LANDSAT data (on which the vegetation file is based) to precisely define a land/water boundary. (The only hectares examined in this category are those defined as land on a 7-1/2 minute quadrangle, but as water on the vegetation file. Thus, there are many more than 387 hectares of water in this area.)

TABLE 7E: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN THE RIDGELANDS AREA

Average Annual Precipitation (inches)	Surface Extent of the Precipitation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
6- 8	N/A	0	0
8-10	N/A	0	0
10-12	0	1765	0
12-14	1.2	16173	196
14-16	1.0	14552	140
16-18	6.8	29415	2006
18-20	11.4	30492	3470
20-22	16.1	32262	5192
22-24	11.0	28995	3185
24-26	17.6	20227	3570
26-28	27.0	14676	3969
28-30	20.8	525	109
30-32	0	150	0
32-34	N/A	0	0
34-36	N/A	0	0
36-38	N/A	0	0
38-40	N/A	0	0
40-44	N/A	0	0
44-48	N/A	0	0
48-52	N/A	0	0
TOTAL	11.5 (ave)	189232	21837

## TABLE 7F: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN AREAS OF 5-15% SLOPE WITHIN THE RIDGELANDS AREA

Vegetation Unit	Surface Extent of the Vegetation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	N/A	0	0
Hardwood/Brush	20.6	884	182
Coniferous Forest	N/A	0	0
Conifer/Brus	2.2	93	2
Hardwood/Conifer Forest	N/A	0	0
Conifer/Hardwood Forest	N/A	0	0
Grassland	5.3	12024	633
Open Shrub	10.7	3172	339
Brush	10.9	1620	177
Mixed Agricultural Land	3.3	448	15
Commercial, Services and Industrial	0	254	0
Mixed Urban	.4	747	3
Low Vegetation Residential	1.7	7945	132
Moderate Vegetation Residential	2.5	279	7
High Vegetation Residential	2.3	436	10
Urban Open Space	.2	438	1
Non-Forested Wetlands	- 0	390	0
Water	11.4	35	4
Shallow or Turbid Water	0	110	0
Salt Evaporation Ponds	0	383	0
Mixed Barren	4.0	504	2
Clouds	N/A	0	0
TOTAL	5.1 (ave)	29762	1507

### TABLE 7G: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN AREAS OF MORE THAN 15% SLOPE WITHIN THE RIDGELANDS AREA

Vegetation Unit	Surface Extent of the Vegetation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	. N/A	0	0
Hardwood/Brush	21.9	18553	4065
Coniferous Forest	N/A	0	0
Conifer/Brush	16.1	409	66
Hardwood/Conifer Forest	0	1	0
Conifer/Hardwood Forest	N/A	0	0
Grassland	17.6	32783	5774
Open Shrub	21.8	27989	6100
Brush	18.6	15354	2856
Mixed Agricultural Land	12.6	429	54
Commercial, Services and Industrial	0	76	0
Mixed Urban	2.8	249	7
Low Vegetation Residential	9.5	5091	485
Moderate Vegetation Residential	9.3	654	61
High Vegetation Residential	12.5	1502	188
Urban Open Space	7.0	114	8
Non-Forested Wetlands	0	2	0
Water	21.3	282	60
Shallow or Turbid Water	5.0	20	1
Salt Evaporation Ponds	0	3	0
Mixed Barren	4.1	148	6
Clouds	N/A	0	0
TOTAL	19.0 (ave)	103659	19731

TABLE 7H: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN AREAS OF 5-15% SLOPE WITHIN THE RIDGELANDS AREA

16-18	<b>4.4 5.6</b>	6526	288
18-20		5168	291
20-22	9.3	4177	387
	5.6	3434	195
24-26	11.3	1455	164
26-28	10.2	1069	109
28-30	26.3	19	5
30-32 32-34	O N/A	4	0
34-36	N/A	0	0
36-38	N/A	0	
38-40	N/A	0	0
40-44	N/A	0	0
<b>44-4</b> 8 <b>48-52</b>	N/A N/A	0	0
TOTAL	5.1 (ave)	29762	1507

TABLE 71: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN AREAS OF MORE THAN 15% SLOPE WITHIN THE RIDGELANDS AREA

TOTAL	19.0 (ave)	103659	19731	
48-52	N/A	0	0	
44-48	N/A	0	0	
40-44	N/A	0	0	
38-40	N/A	0	0	
36-38	N/A	0	0	
34-36	N/A	0	0	
32-34	N/A	0	0	
30-32	0	21	0	
28-30	25.2	262	66	
26-28	32.0	11862	3793	
24-26	20.3	16387	3332	
22-24	13.6	21659	2938	
20-22	22.0	20836	4577	
18-20	17.9	17287	3091	
16-18	13.8	12196	1688	
14-16	7.8	1356	105	
12-14	7.9	1792	141	
10-12	0	1	0	
8-10	N/A	0	0	
6- 8	N/A	0	0	
Average Annual Precipitation (inches)	itation Failed by Landsliding		Approximate Area that Has Failed (hectares)	

## TABLE 8A: LANDSLIDE FAILURE RECORD FOR GEOLOGIC UNITS IN THE PETALUMA AREA

Geologic Unit Map Symbol*	Surface Extent of the Geologic Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
CATEGORY A** 0-1%			
Qhac	1.0	1809	18
Qham	.4	5134	22
Qhbm	.1 .1	4658 1982	<b>4</b> 2
Qhaf Qg	0.	13	0
1111	0.	8	0
n	0.	ĺ	Ō
CATEGORY B** 2-8%			· · · · · · · · · · · · · · · · · · ·
Qpa	3.4	6486	222
QThg	4.4	274	12
Tst	9.4	887	83
KJgvc	2.8	72 	2 
CATEGORY C** 9-25%			
Qc1	14	2025	295
Qr	25	32	8
QTm To	12 14	4165 6419	<b>49</b> 0 867
Tp KJfa	13	15	2
KJfss	14	595	83
ch	14	7	1
CATEGORY D** 26-42%			
Tsri	40	106 -	42
Tsa	34	9950	3410
KJfs	41	6995	2886
mgs	39	802	311

TABLE 8A (Continued)

Geologic Unit Map Symbol*	Surface Extent of the Geologic Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
CATEGORY E** 43-53%			
Tps	44	2435	1082
Tpc	50	108	54
Tsv	49	1156	572
Tsr	49	140	69
SC	50	2	1
CATEGORY F** 54-90%			
Tsfd	87	119	103
Ts	82	77	63
mch	83	6	5
<b>S</b> p	57	378	217
KŪgv	91	<b>726</b>	658
TOTAL***	22.3 (ave)	61970	13833

<sup>\*</sup>Symbol in parentheses is that used in tables describing Quaternary geology of Petaluma. Some units listed on those tables are not listed here because they do not appear within the four quadrangle area.

<sup>\*\*</sup>Categories are labeled A-F instead of I-VI to distinguish these categories of geologic materials based on computer derived-failure rates from those based on the manually-derived failure rates of Brabb and Pampeyan (Reference 13).

<sup>\*\*\*</sup>The totals are smaller than on the tables that follow because the area defined by the four quadrangles is smaller than the area defined by a UTM even kilometer window used in the other tables.

### TABLE 88: LANDSLIDE FAILURE RECORD FOR PERCENT SLOPE CATEGORIES IN THE PETALUMA AREA

Percent Slope Category	Surface Extent of the Slope Category that Is the Result of Failure by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Is the Result of Failure (hectares)
0- 5	.9	20361	191
5- 15	15.3	17837	2735
15- 30	38.9	17984	6999
30- 50	41.9	8080	3387
50- 70	29.2	1637	479
70-100	17.1	263	45
100+	11.4	210	24
TOTAL	20.9 (ave)	66372	18859

## TABLE 8C: LANDSLIDE FAILURE RECORD FOR SLOPE ASPECT CATEGORIES IN THE PETALUMA AREA

Slope Aspect Category	Surface Extent of the Aspect Category that Is the Result of Failure by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Is the Result of Failure (hectares)
Multiple Aspects	9.4	17428	1635
North	13.3	5321	709
North-East	23.2	6501	1508
East	24.3	6538	1591
South-East	28.8	5217	1500
South	18.2	6070	1103
South-West	33.0	7417	2448
West	30.0	6695	2007
North-West	26.2	5185	1358
TOTAL	20.9 (ave)	66372	13859

### TABLE 8D: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN THE PETALUMA AREA

Vegetation Unit	Surface Extent of the Vegetation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	21.1	1269	268
Hardwood/Brush	24.3	2072	504
Coniferous Forest	N/A	0	0
Conifer/Brush	N/A	0	0
Hardwood/Conifer Forest	27.8	1048	291
Conifer/Hardwood Forest	20.8	615	128
Grassland	21.0	37445	7849
Open Shrub	28.2	8479	2392
Brush	21.0	4569	958
Mixed Agricultural Land	20.7	6070	1257
Commercial, Services and Industrial	.6	158	1
Mixed Urban	.6	158	1
Low Vegetation Residential	4.9	3415	167
Moderate Vegetation Residential	4.7	401	19
High Vegetation Residential	11.8	51	6
Urban Open Space	N/A	0	0
Non-Forested Wetlands	N/A	0	0
Water	N/A	0	0
Shallow or Turbid Water	2.0	344	7
Salt Evaporation Ponds	0	1	0
Mixed Barren	5.0	280	14
Clouds	N/A	0	0
TOTAL	20.9 (ave)	66372	13859

TABLE 8E: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN THE PETALUMA AREA

Average Annual Precipitation (inches)	Surface Extent of the Precipitation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
6- 8	N/A	0	0
8-10	N/A	0	0
10-12	N/A	0	0
12-14	N/A	0	0
14-16	N/A	0	0
16-18	N/A	0	0
18-20	12.0	1210	145
20-22	22.2	10839	2404
22-24	24.2	16867	4074
24-26	16.0	14725	2353
26-28	12.3	9100	1120
28-30	42.7	7975	3402
30-32	9.3	3246	301
32-34	2.5	1785	45
34-36	2.4	625	15
36-38	N/A	0	0
38-40	N/A	0	0
40-44	N/A	0	0
44-48	N/A	0	0
48-52	N/A	0	0
TOTAL	20.9 (ave)	66372	13859

### TABLE 8F: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN AREAS OF 5-15% SLOPE WITHIN THE PETALUMA AREA

Vegetation Unit	Surface Extent of the Vegetation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	21.8	124	27
Hardwood/Brush	20.8	216	45
Coniferous Forest	N/A	0	0
Conifer/Brush	N/A	0	0
Hardwood/Conifer Forest	`4.0	53	18
Conifer/Hardwood Forest	20.5	39	8
Grassland	15.5	11171	1728
Open Shrub	23.0	1875	431
Brush	15.1	1134	171
Mixed Agricultural Land	11.4	1871	214
Commercial, Services and Industrial	2.9	35	1
Mixed Urban	.0	37	0
Low Vegetation Residential	7.1	1021	73
Moderate Vegetation Residential	7.4	108	8
High Vegetation Residential	5.6	18	1
Urban Open Space	N/A	0	0
Non-Forested Wetlands	N/A	0	0
Water	N/A	0	0
Shallow or Turbid Water	6.2	81	5
Salt Evaporation Ponds	0	0	0
Mixed Barren	9.3	54	5
Clouds	N/A	0	0
TOTAL	15.3 (ave)	17837	2735

### TABLE 8G: LANDSLIDE FAILURE RECORD FOR VEGETATION UNITS IN AREAS OF MORE THAN 15% SLOPE WITHIN THE PETALUMA AREA

Vegetation Unit	Surface Extent of the Vegetation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)
Hardwood Forest	22.4	1072	240
Hardwood/Brush	26.9	1701	458
Coniferous Forest	N/A	0	0
Conifer/Brush	N/A	0	0
Hardwood/Conifer Forest	32.4	839	<b>2</b> 72
Conifer/Hardwood Forest	23.5	507	119
Grassland	41.7	14400	6010
Open Shrub	41.5	4626	1922
Brush	32.1	2392	769
Mixed Agricultural Land	46.6	2219	1034
Commercial, Services and Industrial	.0	3	0
Mixed Urban	7.7	13	1
Low Vegetation Residential	31.3	268	84
Moderate Vegetation Residential	21.7	46	10
High Vegetation Residential	18.5	27	5
Urban Open Space	N/A	0	0
Non-Forested Wetlands	N/A	0	0
Water	N/A	0	0
Shallow or Turbid Water	8.3	12	1
Salt Evaporation Ponds	0	0	0
Mixed Barren	16.3	49	8
Clouds	N/A	0	0
TOTAL	38.8 (ave)	28174	10933

TABLE 8H: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN AREAS OF 5-15% SLOPE WITHIN THE PETALUMA AREA

Average Annual Precipitation (inches)	ation Failed by Landsliding Area in Area		Approximate Area that Has Failed (hectares)	
6- 8	N/A	0	0	
8-10	N/A	0	0	
10-12	N/A	0	0	
12-14	N/A	0	0	
14-16	N/A	0	0	
16-18	N/A	0	0	
18-20	8.8	57	5	
20-22	14.9	2505	374	
<b>2</b> 2-2 <b>4</b>	16.4	6214	1017	
24-26	11.6	3734	435	
26-28	7.4	2873	214	
28-30	46.3	1394	645	
30-32	6.1	522	32	
32-34	2.8	431	12	
34-36	.9	107	1	
36-38	N/A	0	0	
38-40	N/A	0	0	
40-44	N/A	0	0	
44-48	N/A	0	0	
48-52	N/A 0		0	
TOTAL	15.3 (ave)	17837	2735	

TABLE 81: LANDSLIDE FAILURE RECORD FOR PRECIPITATION UNITS IN AREAS OF MORE THAN 15% SLOPE WITHIN THE PETALUMA AREA

Average Annual Precipitation (inches)	Surface Extent of the Precipitation Unit that Has Failed by Landsliding (percent)	Approximate Area in Area (hectares)	Approximate Area that Has Failed (hectares)	
6- 8	N/A	0	. 0	
8-10	N/A	0	0	
10-12	N/A	0	0	
12-14	N/A	0	0	
14-16	N/A	0	0	
16-18	N/A	0	0	
18-20	67.8	223	140	
20-22	49.7	4019	1997	
22-24	49.9	5986	2990	
24-26	36.0	<b>5</b> 245	1888	
26-28	23.8	3754	892	
28-30	48.5	5598	2714	
30-32	11.6	2294	265	
32-34	3.7	893	33	
34-36	8.6	162	14	
36-38	N/A	0	0	
38-40	N/A	0	0	
40-44	N/A	0	0	
44-48	N/A	0	0	
48-52	N/A	0	0	
TOTAL	38.8 (ave)	28174	10933	

#### Ridgelands and Petaluma Information

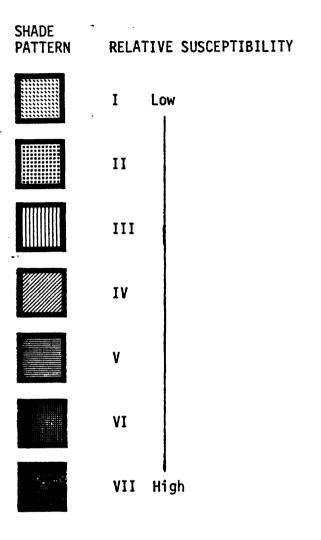
The same series of tabulation of landslide coverage were generated for the ridgelands and Petaluma areas as appear in Tables 5A-I for San Mateo County. The results appear in Tables 7A-I for the ridgelands and in Tables 8A-I for Petaluma.

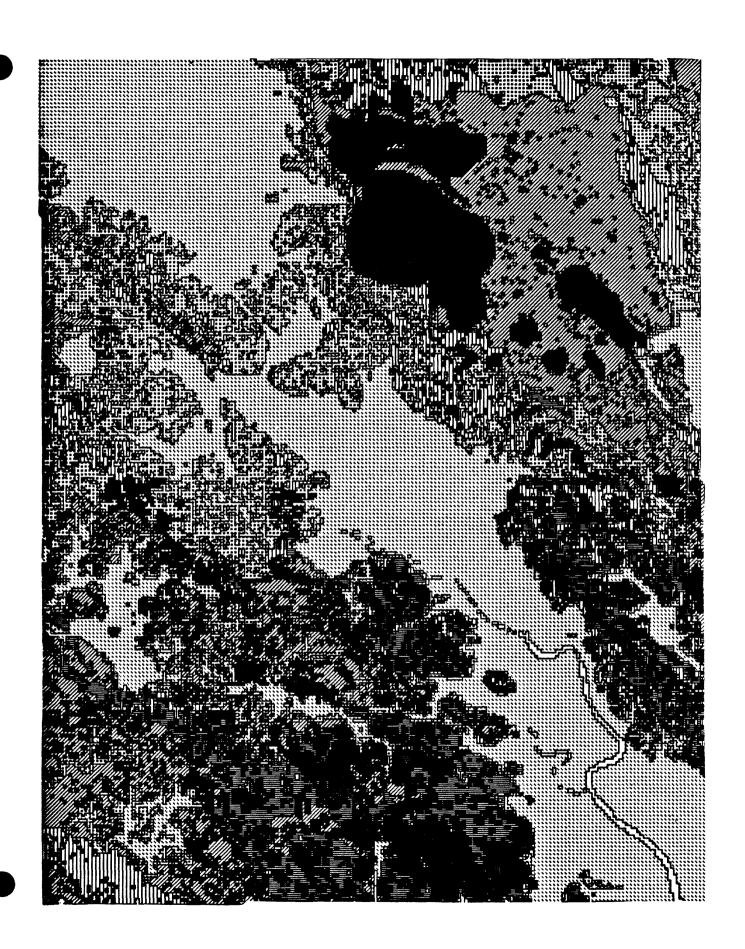
Again, the results for the geology and slope tabulation in these areas can be used to assign rainfall-induced landslide susceptibility categories. As in San Mateo County, the overall average landslide coverage for all fifteen quadrangles for slopes of 5-15% is 3.5 times less than for slopes of 15+%. Again, the results for slopes aspect are mixed, making it difficult to incorporate this factor into any modeling However, the results for vegetation type and average annual precipitation lend themselves into incorporation into such a model. Areas of 5-15% slope and of hardwood/brush in the ridgelands or of hardwood/conifer forest in the Petaluma area had almost the same landslide coverage as areas of greater than 15% slope. Similarly, areas of 5-15% slope and of greater the 28 inches of annual rainfall had a slightly greater likelihood of landsliding than the average for areas of greater than 15% slope in both areas. Therefore, vegetation and precipitation were both incorporated into the landslide susceptibility model, as shown in Table 10, below. The resulting map for the Petaluma area is reproduced as Figure 1.

#### TABLE 10: ASSIGNMENT OF RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY CATEGORIES FOR THE RIDGELANDS AND PETALUMA AREAS

		Landsi	ide Susceptibility	Category
Geology Unit Susceptibility Category (See Table 7A and 8A for names)	Surface Extent of the Geology Unit that has Failed Through Landsliding (in percent)	If 0-5% Slope Regardless of Vegetation Type or Annual Precipitation	If 5-15% Slope, Most Vegetation Types and <28" Annual Precipitation	If 15+% Slope or 5-15% Slope with either 1) Hardwood/ Brush (in Ridge- lands) and Hard- wood/Conifer (in Petaluma) or 2) >28" Annual Precipitation
A B C D E F G(Existing Landslides	0-1 2-8 9-25 26-42 43-53 54-90 100	AII I I I I	A11 111 111 11 11	A11 A1 A 1A 111 11

# RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY





## EXTENDING DETAINED EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY MAPPING BEYOND SAN MATEO COUNTY

The key requirement to extend the work in San Mateo County on earthquake-induced landslide susceptibility to the new study areas is to group the new geologic units into three susceptibility categories - A, B The distinction between the units A and B used in San Mateo County and the unit C is largely lithologic, with most sandstones, methamorphic and volcanic rocks falling in category A or B and with clay-rich rocks (shade, mudstone, Bay mud, sheared rocks, serpentine, alluvium and chert) falling in category C. The distinction between A and B is based on the strength of cementation of the rocks, with those in A being strongly cemented and those in B relatively cohesionless. The rocks in San Mateo County were assigned to either A or B based on the results of tests on 50 samples of each unit using a point load tester. Since performing additional point load tests is beyond the scope of this project, and since USGS staff have no plans to perform additional tests (Reference 17), another way to assign geologic units to the three susceptibility units had to be developed. The new geologic units have been assigned to A, B, or C as indicated in Table 11, below, by ABAG staff based on similarities to formations occurring in San Mateo County and the relative susceptibility of each combination of geology and percent slope assigned as illustrated in Table 12. This table is identical to that used in San Mateo County (in Working Paper #5). These relationships have been reviewed by the author of the method in San Mateo County (Reference 17). The resulting map for the Petaluma area is reproduced as Figure 2.

TABLE 12: RELATIVE SUSCEPTIBILITY OF ROCK UNITS TO SEISMICALLY-INDUCED LANDSLIDES

Stability <u>Category</u>	0-5%	5-15%	15-30%	30-50%	50-70%	70-100%	100+%
Α	1	1	1	1	2	3	4
В	1	1	2	3	4	4	4
С	1	2	3	4	4	4	4

Category 1: Stable all year

2: Stable in summer; of intermediate stability in winter

3: Of intermediate stability in summer; unstable in winter

4: Unstable all year

## TABLE 11A: EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY UNITS FOR GEOLOGIC UNITS IN THE RIDGELANDS AREA

Typical Map		Susceptibility
Symbol	<u>Geologic Unit</u>	Unit
Qhac	Coarse-grained Holocene alluvium	В
Qham	Medium-grained Holocene alluvium	Č
Qhs	Holocene sand deposits	
Qhbm	Holocene Bay mud	B C C C C C C C
Qhsc	Holocene stream channel deposits	Č
Qhaf	Fine-grained Holocene alluvium	Č
Qhafs	Fine-grained Holocene alluvium (salt-affected)	Č
Qpmt	Pleistocene marine terrace deposits	Ř
Qpa	Late Pleistocene alluvium	Č
Qpea	Early Pleistocene alluvium	ŗ
Qaf	Artificial fill	Ç
Qcl	Colluvium	Č
Qu	Undivided Quaternary deposits (largely in	C
Qu	urban areas)	U
Qg	Stream channel gravel, sand and clay	С
QTs	Santa Clara Formation gravel sand, and clay	Č
Qsb	Gravel with basalt detritus of QTs	C C B C
Qsp	Conglomerate or breccia of serpentine	Ċ
Q3P	detritus of QTs	J
Qsa	Clay of QTs	С
Qsc(a)	Areas of "a" within Qsc, andesite of QTs	Ä
Qsc(b)	Areas of "b" within Qsc, basalt of QTs	Ä
QTI	Livermore Gravel	В
QTt	Tassajara Formation	Č
QTb	Unnamed olivine basalt lava	Ă
rh	Rhyolite that is Tertiary (Pliocene) in age	Ä
1 11	(includes the Alum Rock Rhyolite)	~
Tps	(also Tsc and Tor), Pliocene nonmarine sedimentary	С
. 53	rocks (includes the Orinda Formation)	· ·
Tb	(Tbu), Pliocene unnamed basalt (includes basalt in	Α
	Orinda Fm.)	
Tbp	Pliocene Bald Peak Basalt	Α
Tmb	Pliocene Moraga Formation, basalt	Ä
Tmt	Pliocene Moraga Formation, tuff breccia	В
Tpl	Pliocene lacustrine limestone	Ä
Tpt	Pliocene tuff and sandstone	В
Tn	Miocene Neroly Sandstone	Ä
Tmss	Miocene sandstone (includes the Briones, Cierbo and	Ä
111133	sometimes the Neroly sandstones)	~
Tmsl	Miocene siltstone with minor sandstone	В
Tmsh	Miocene silty to silicous gray-white shale (includes	C
1111311	upper part of Claremont Shale from Mt. Sizer	· ·
•	quadrangle)	`
	quantumgic/	

## TABLE 11A: EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY UNITS FOR GEOLOGIC UNITS IN THE RIDGELANDS AREA (Cont.)

Typical		6
Map Symbol	Geologic Unit	SusceptibilityUnit
Tmsc	Miocene brittle cherty and silicious tan-white shale (includes Claremont Shale and lower part of Claremont on Mt. Sizer quadrangle)	С
Tms	Miocene basal sandstone (includes the Sobrante and Temblor sandstones)	Α
Tmsr	Oligocene San Ramon Formation of siltstone and basal sandstone	В
Tt	Eocene Tolman Formation of marine sandstone and siltstone	В
Tk	Eocene Kreyenhagen Formation of claystone with thin sandstone beds	С
Tkm	Eocene Markley Sandstone Member of Kreyenhagan Formation	Α
Tds	Eocene Domengine Sandstone that is tan and arkosic	Α
Tmg	Eocene Meganos Formation of claystone and sandstone with thin sandstone lenses	С
Tmgs	Sandstone that is locally pebbly at base within the Eocene Meganos Formation	В
Tmz	Paleocene Martinez Formation of claystone and siltstone with thin sandstone lenses	С
KTsh	Cretaceous and/or Paleocene unnamed micaceous clay shale and siltstone	С
KTs	Sandstone within KTsh (can be locally pebbly on Morgan Hill quadrangle)	Α
KTsh	with circles, conglomerate within KTsh	Α
KTsh	with lines, limestone within KTsh	Α
Km	Cretaceous micaceous claystone of the Moreno Shale	С
Kmi	Cretaceous semi-siliceous shale of the Moreno Shale	С
Кр	Cretaceous Panoche Formation of clay shale	С
Kps	Sandstone within Panoche Formation	Α
Крс	Conglomerate within Panoche Formation	Α
Ksh	Cretaceous marine micaceous shale, undivided	C
cg	Cretaceous conglomerate younger than Kcg	Ā
Kshu	Cretaceous Berryessa Formation, undivided	В
Kshb	Shale within the Cretaceous Berryessa	Č
	Formation	-
Ksg	Sandstone and conglomerate within the Cretateous Berryessa Formation	Α
Kss	Sandstone within the Cretaceous Berryessa Formation	Α

## TABLE 11A: EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY UNITS FOR GEOLOGIC UNITS IN THE RIDGELANDS AREA (Cont.)

Typical Map Symbol	Geologic Unit	Susceptibility Unit
Kcg	(also Kcgo), Cretaceous Oakland Conglomerate	Α
JKŘ	Jurassic and/or Cretaceous Knoxville Formation, dark micaseous shale with minor thin sandstone	С
JKc	Conglomerate and sandstone within the Knoxville Formation	A
db	Diabase	Α
an	Andesite	Α
sp	Serpentine, serpentinite	С
spr	Serpentine rubble	C
gb	Gabbro-diabase	A
sc	Silica-carbonate rocks	
br	Fault? breccia	A C
tr	Travertine	A
fs	Franciscan assemblage graywacke (sandstone) and shale	С
fc	Franciscan assemblage chert	С
fl	Franciscan assemblage limestone	Α
fg	Franciscan assemblage greenstone	A
fsr	Franciscan assemblage pervasively sheared (shale and graywacke, largely)	С
gl f	Franciscan assemblage glaucophane schist	A
Ť	Franciscan assemblage hard monolithic fragments	Α

## TABLE 11B: EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY UNITS FOR GEOLOGIC UNITS IN THE PETALUMA AREA

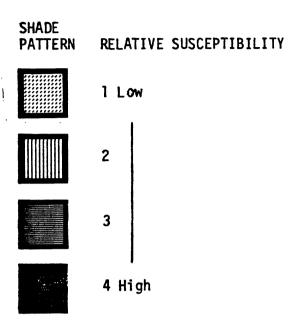
Typical Map Symbol	Geologic Unit	Susceptibility Unit
Qhac	Coarse-grained Holocene alluvium	В
Qham	Medium-grained Holocene alluvium	С
Qhs	Holocene sand deposits	В
Qhbm	Holocene Bay mud	C C C C C C C C
Qhsc	Holocene stream channel deposits	C
Qhaf	Fine-grained Holocene alluvium	C
Qhafs	Fine-grained Holocene alluvium (salt-affected)	C
Qpmt	Pleistocene marine terrace deposits	В
Qpa	Late Pleistocene alluvium	С
Qpea	Early Pleistocene alluvium	C
Qaf	Artificial fill	C
Qc1	Colluvium	C
Qu	Undivided Quaternary deposits (largely in urban areas)	-
Qr	Rhyolite gravel	В
Qmi	Millerton Formation	В
Qc	Colma Formation	В
Qg	Gravel	В
Qc1t	Clear Lake area tuff	В
Qob	Olivine basalt in Clear Lake area	A
QThg	Huichica and Glen Ellen Formations	В
QTc	Cache Formation	В
QTm	Merced Formation	C
Tp To a	Undifferentiated Petaluma Formation	C C
Tpc	Unbedded gray claystone of the Petaluma Formation	C
Tps	Claystone and siltstone of the Petaluma Formation	C
Tsv	Sonoma Volcanics, undifferentiated	В
Tsr	Sonoma Volcanics rhyolite lava flows	A
Tsri Tsa	Sonoma Volcanics rhyolite plugs and dikes Sonoma Volcanics andesitic to basaltic lava flows	A A
Tsfd	Sonoma Volcanics andesitic to basaltic lava flows	B
1514	thinly underlain by diatomite	_
Tst	Sonoma Volcanics pumicitic ash flow tuff	В
Ts	Miocene sandstone including the San Ramon Formation	В
KJfs	Franciscan sheared shale and sandstone	C
KJfss	Franciscan sandstone and interbedded shale	C
KJfg	Franciscan greenstone	A
KJfm	Franciscan metamorphic rocks	A
ch	Chert	C
////	Hydrothermally altered rocks	В
gs	Greenstone	A
mgs	Greenstone and schistose rocks	A
ch&gs	Chert and greenstone	С

## TABLE 11B: EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY UNITS FOR GEOLOGIC UNITS IN THE PETALUMA AREA (Cont.)

Typical Map Symbol	Geologic Unit	Susceptibility Unit
gwy	Graywacke	Α
mch	Metachert	С
cg	Conglomerate	Α
sp	Serpentinite	С
m	High grade metamorphic rocks	Α
sc	Silica-carbonate rock	Α
KJgv	Great Valley sequence	В
KJgvc	Great Valley sequence - Novato Conglomerate	Α

Figure 2.

# EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY

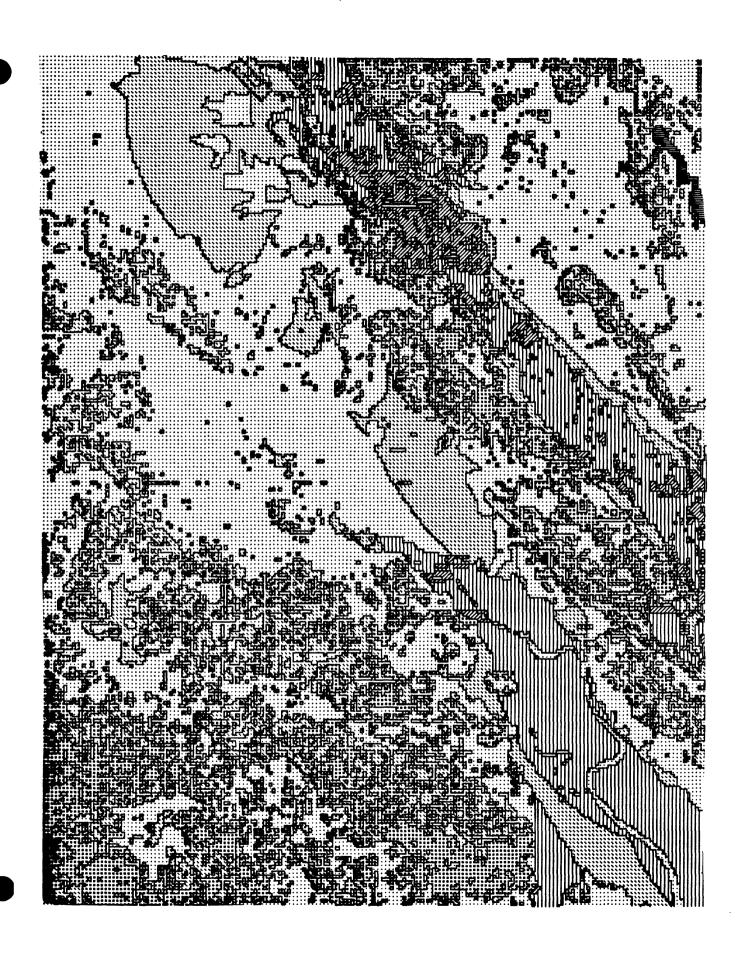




## COMPOSITE MAXIMUM EARTHQUAKE DAMAGE — WOOD FRAME DWELLINGS

**SHADE PATTERN** AVERAGE DAMAGE PER EVENT\* 0 - 2 % 3 - 5 % 6 - 10% 11 - 15% 16 - 20% 21 - 25% 26 - 30% 31 - 35% 36 - 40% 41 - 45% 46 + %

<sup>\*</sup>Estimate based on statistical procedures



## PREPARING COMPOSITE MAPS FOR THE PETALUMA AND RIDGELANDS AREAS

A method to use cost information to weight the importance of the various hazard maps and then to overlay them has been described in Working Paper #9. It had been hoped that better cost information had become available since the preparation of that working paper. However, this has not been the case. Therefore, maps using a method identical to that described in that working paper have been prepared. Please refer to Working Paper #9 for a description of the technique. A sample map for the Petaluma area appears as Figure 3.

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# APPENDIX B

#### EARTHQUAKE MAPPING PROJECT-WORKING PAPER #12

# ORDERING AND USING EARTHQUAKE HAZARD MAPS IN LOCAL GENERAL PLANS

#### INTRODUCTION

One of the major ways for local governments to use the earthquake hazard maps available in BASIS is to incorporate them into the General Plan required by California Government Code.

Because of the flexibility available to a potential user in ordering maps available through BASIS, some general guidelines are essential to ensure that a wise choice is made. Questions that need to be answered include:

- o Are maps or some other type of data form more useful?
- o Which of the approximately twenty hazard and basic data maps should be ordered?
- o What is the geographic area of interest?
- o What are the patterns that should appear on the map(s)?
- o At what scale should the maps be produced?

This working paper provides guidelines for answering these questions, as well as information on using the maps in local general plans. It is the twelfth in a series of working papers being prepared on the ABAG/USGS earthquake mapping project and the second of those dealing with the second phase of that work.

#### USING MAPPED INFORMATION IN A GENERAL PLAN

One of the appropriate ways to use the mapped information is for identifying hazardous areas in a safety or seismic safety element of a local general plan. The latest <u>General Plan Guidelines</u> for these elements recommend having several maps, most of which are available through ABAG's earthquake hazard mapping work. Table 1, below, lists those maps available through ABAG that are recommended in the State Office of Planning and Research Guidelines.

#### MAPS vs. OTHER FORMS OF DATA FROM BASIS

Before ordering maps, it is essential that a potential user review the reasons for requiring copies of many maps. If they are to be combined with other maps for general or long-term planning purposes, they are probably appropriate. However, if they will be used mainly in subdivision or other project assessment and review where specific sites will be examined, ABAG's automated regional environmental assessment tool (providing a simple printout for specific sites listing the data on

## TABLE 1: SELECTED MAPS RECOMMENDED IN STATE GENERAL PLAN GUIDELINES

(adapted from Reference 1 page 110)

Hazard

Surface Rupture Identification and assessment of

potential for displacement along active and potentially active faults

Map

in the planning area.

Location of Special Studies Zones in

the planning area.

Ground Shaking Identification of active and

potentially active faults in the

region.

Geotechnical evaluation of potential for groundshaking based on maximum

credible earthquake.

Ground Failure Geotechnical evaluation of potential

for seismically induced landslide,

mudslide, and liquefaction.

Tsunami Evaluation of potential "run-up".

Inundation from a Identification of areas potentially

Dam Failure subject to inundation after a dam

failure.

Slope Stability Geotechnical evaluation of potential

for landslides and mudslides.

Il twenty maps) may be much more valuable. In addition to not having to bother with rummaging through a stack of twenty maps, the user can be certain that the data used is the most accurate and detailed available. Hard copies of the maps can become outdated and ABAG has no obligation to provide a user with each new edition unless a specific request is made and the new maps are purchased.

# THE TYPES OF MAPS

Seven basic data maps, ten hazard maps, and three composite maps are currently available that have been compiled or substantially modified as part of at least one of the ABAG contracts with USGS on earthquake hazard mapping (Table 2). It is most unlikely that a potential user would need a copy of any of the basic data maps because they either are, or (in the case of geology in San Mateo County) shortly will be, available in published form. Possible exceptions to this rule occur when the scale that a particular user needs is an overriding factor.

The ten hazard maps are potentially very valuable, with one possible exception. The sample map of risk of ground shaking damage to wood frame dwellings that used the assumption that long-term slip was released through only small earthquakes is probably valuable only as an exercise to test the sensitivity of the assumption of distribution of large and small earthquakes. Because of the predominance of ground shaking damage over liquefaction or landsliding damage, users able to order only a very few maps should consider ground shaking maps first. The maximum ground shaking intensity map is more valuable to those interested in the worst case than the three risk maps, while the risk maps are more valuable to those analyzing the benefit of mitigation measures. The liquefaction potential map contains more information than the liquefaction susceptibility map, but it also contains more possible sources of error. The two landslide susceptibility maps depict two different hazards -- rainfall-induced landslide susceptibility and earthquake-induced landslide susceptibility. Many users could find uses for both. The fault surface rupture, dam failure inundation, and tsunami inundation maps are most valuable to potential users requiring a complete set of hazard maps of compatible scale and interest. Very few areas are susceptible to tsunami inundation, however.

The composite maps are useful in depicting a large amount of information on individual maps. Their main disadvantage is the large possibility of error in one or more of the assumptions used in creating the maps. The composite maximum damage maps are most useful to those same individuals who find the maximum ground shaking intensity map more useful than the three maps depicting risk of ground shaking damage. The composite maps of risk of damage are more useful to those preferring the maps depicting risk of ground shaking damage. Whether users would prefer a maximum composite map that includes or eliminates dam failure inundation areas depends on their view on the possibility of dam failure in their area and the value of planning for such failures.

TABLE 2: EARTHQUAKE MAPS AVAILABLE THROUGH BASIS

## Basic Data Maps

Geology
Fault study zones and traces
Percent slope\*\*
Existing landslides\*\*
Tsunami inundation areas
Dam failure inundation areas
1975-6 Land use\*\*

## Hazard Maps

Maximum ground shaking intensity
Risk of ground shaking damage o wood frame dwellings o concrete/steel bldgs. o tilt-up concrete bldgs. o wood frame dwellings--sample for all small

earthquakes

# Composite Maps

(all for wood from
 dwellings only)
Composite maximum
 earthquake damage\*\*
o with dam
 failure
o without dam
 failure
Composite risk of
 earthquake damage\*\*

Liquefaction susceptibility Liquefaction potential

Rainfall-induced landslide susceptibility\*\* Earthquake-induced landslide susceptibility\*\* Fault surface rupture (Tsunami inundation areas)\* (Dam failure inundation areas)\*

<sup>\*</sup> Same as basic data maps

<sup>\*\*</sup> Available only for San Mateo County; will be available for the Petaluma River, Petaluma, Cotati, Glen Ellen, Briones Valley, Las Trampas Ridge, Diablo, Hayward, Dublin, Niles, Milpitas Calaveras Reservoir, San Jose East, Morgan Hill and Mt. Sizer 7-1/2 minute quadrangles in February 1981.

# LIQUEFACTION POTENTIAL

RELATIVE LIQUEFACTION POTENTIAL*		
0009 %		.161185 %
.010025 %		.186205 %
.026045 %		.206230 %
.046070 %		.231250 %
.071094 %		.251275 %
.095114 %		.276299 %
.115140 %	= <del>1</del> = 1	.300 + %
.141160 %		

<sup>\*</sup> Liquefaction potential is the product of liquefaction susceptibility and liquefaction opportunity. Numbers indicate more accurate relationships to each other than to absolute values.

<sup>\*\*</sup>Black is the sixteenth pattern.

#### THE AREA

After the user defines the area of interest, the user must specify a rectangular window that includes the area that is defined by north-south and east-west UTM lines rounded to the nearest 1 km value because of the way in which the mapping program in BASIS operates. Although most users will only require detailed maps of their jurisdiction or area of interest, maps covering an entire county or even the region at less detailed scales are valuable to gain an understanding of the hazard level of the entire jurisdiction relative to that of the county in which it lies or of the Bay Area.

# THE PATTERNS ON THE MAPS

At the present time, only sixteen <u>standard</u> patterns are available for maps. The shades are shown in Figure 1, below. Shades can be chosen by a user. However, standard explanations have been developed for the twenty maps.

Any changes needed in the explanation due to changes in the shades by the user are the responsibility of the user. Two sets of shades (and explanations) are available for the land use map. One set was chosen to show the detail of the map and the second set was chosen to group similiar (especially rural) land use types together.

# THE MAP SCALE

The ultimate resolution of the earthquake-related information is one hectare or a 100 meter square (approximately 2 1/2 acres). Maps of this data at any scale more detailed than 1:24,000 (1 inch = 2,000 feet) are of marginal use. There is no change in the resolution of the data from 1:62,500 or 1:60,000 to 1:24,000 because at both scales the hectare grid cell is visible. The only reason to order maps as large as 1:24,000would be to overlay them on a commonly used base. There are potentially many disadvantages. The paper on which the maps are plotted is 22 inches wide. Splicing together large maps is tedious and can lead to inaccuracies. In addition, the computer time used to produce maps, and therefore the cost of producing these maps, increases with the scale of the map. A typical 100 square kilometer area (10 kilometers by 10 kilometers) plot of a typical map file at 1:24,000 takes 4 1/4 times as much computer time as at 1:62,500 and  $9 \frac{1}{2}$  times as much computer time as at 1:125,000. Using a computer charge rate of \$100/hour, the times involved mean a cost of \$40.35 for the 1:24,000 plot, \$9.45 for the 1:62,500 plot and \$4.25 for the 1:125,000 plot. Time (and therefore cost) for running a plot of an area that is elongated in an east-west direction is greater than for a plot elongated in the north-south The density of shades on the maps also increases cost direction. slightly. Staff costs and overhead are added to these computer costs.

## BASE MAPS

The maps produced by the computer are on translucent paper and show the grid cells in the area of concern. They do not show street patterns or topography. However they are reproducible using a standard blueprint machine, and when overlaid with a transparent (photo positive) base map can be run through the blueprint machine to produce a copy with base map features. A second more costly method is to print the computer map on an existing base map (with streets and topography) using standard printing practices.

#### REFERENCES

1. California State Office of Planning and Research, January 1980, Review Draft -- 'General 'Plan' Guidelines, Sacramento, 241 pp.

APPENDIX C

# EARTHQUAKE MAPPING PROJECT - WORKING PAPER #13 AUTOMATED ENVIRONMENTAL IMPACT ASSESSMENT - AN UPDATE

#### INTRODUCTION

Since Working Paper #8 on computer production of background reports for environmental impact reports was prepared, the production capability has been greatly expanded and streamlined. The output developed as part of the first phase of the ABAG/USGS Earthquake Mapping Project was tested on sites in Pleasanton and Oakland and was found to require too much computer time and explanation for potential users. The setting and impacts sections have been modified accordingly. The mitigation section also was found to be incomplete for most prisdictions and, therefore, has been greatly expanded. Finally, an option of producing computer maps for both the project site and its vicinity has been initiated in conjunction with the city of Petaluma. The findings and products of all of this work are described in this paper, the thirteenth in a series of working papers documenting the data used, the assumptions made, and applications foreseen in the ABAG/USGS Earthquake Mapping Project.

# THE REVISED OUTPUT

The setting and impact sections of the environmental assessment tool have been revised to decrease their cost and increase their usefulness. The revised format is shown in Table 1, below, for the proposed Sweeney Ridge development in Pacifica.

After the output was obtained, it was compared with the data produced in the actual Environmental Impact Report for the Sweeney Ridge development (Reference 1). In general, the computer information in the setting section was virtually identical to that in the EIR, although many names are very abbreviated. This annoyance will be corrected when time becomes available. The EIR indicated that one portion of the site was underlain by Montara-Climara Soils association while the computer output indicated that it was Los Gatos-Sobrante-Gaviota. A check of the source map indicated the computer output was correct; the preparers of the EIR had misread the soil association map. In spite of this error in this one EIR making the soils section appear acceptable, the computer output in this section has the potential to be inferior. Soil information currently is available only for general soils associations (except for the Petaluma Study area, where more detailed information on soil type is available). In addition, the more general soil association information has a resolution (grid cell size) of 25 hectares (1/4 sq. km.), rather than the hectare resolution provided for the remainder of the data. Since improving soils data is beyond the scope of this earthquake hazard mapping project, no attempt has been made to improve the quality of that data.

The data in the impacts section, was, in general, more interpretive in the computer output. For example, the data on magnitude and recurrence

interval of earthquakes provided in the EIR are part of the basis of the earthquake intensity and risk of damage data provided in the computer printout. These background data are provided in earlier ABAG reports (References 2-4). The EIR states that there is a low probability of seismically-induced ground failure occurring by landsliding. The computer output states a different conclusion.

Another problem with the output may be significant with very mall sites that is not significant with the Sweeney Ridge example due to its size. Because the programs that convert polygons, such as inundation areas or fault study zones, to grid cells currently assign a cell to the hazard area only if more than 50% of the cell is within that area, small corners of hazard areas on the edges of sites may not be flagged. Since smaller sites have a proportionately greater percentage of their cells defining the border of the site, this disadvantage may become significant.

#### TABLE 1:

\*\*\*\*\*\*\*\*\*\* SWEENEY RIDGE: AUTOMATED ENVIRONMENTAL IMPACT ASSESSMENT \*\*\*\*\*\*\*\*\*\*\*\*

# GEOLOGY AND SOILS - HAZARDS AND RESOURCES

SETTING

TOPOGRAPHY ELEVATION (METERS) MUMIKAN 388. MINIMIM 41. AVERAGE 268. PERCENT SLOPE MUNIXAM 77. MINIVIN AREA (HECTARES) RANGE 0 - 5%

0. 10. 5- 15% 90. 15- 30% 50- 50% 219. 50- 70% 117. 5. 70-100%

>100%

FAULT STUDY ZONES

AREA (HECTARES) TYPF

DUTSIDE STUDY ZONE

442.

0.

LANDSLIDES

AREA (HECTARES) IDENTIFIER ON AIR PHOTOS 10. FROM FIELD 4. 0. FROM LOCAL FILES TOTAL OF ABOVE 14.

GEOLOGIC MATERIALS

TYPE AREA (HECTARES) 4. RYF (QHAC) HOLO. ALL.C. 5. DYFO(QHAM)HOLO.AL.F. 34. DCL & DSR-COLLUVIUM FS-FRAN. GRAYNACKE 249. FG-FRAN. GREENSTONE 151. 2. FC-FRAN.CHERT

SOIL ASSOCIATIONS

TYPE	AREA (HECTARES)	SHRINK/ Swell	PERMEA- BILITY	ERDSION POTENTIAL	PRIME AG LAND
F11TUNITAS-LOCKWOOD	6.	M	L	L	Y
L14SWEENEY-MINDEGO	318.	M	L	Н	NO
N7LS GTS SBANTE-GAV	118.	L	L	Н	NO

# TABLE 1 (cont.):

GEOLOGY AND SOILS - HAZARDS AND RESOURCES

IMPACTS

MAXIANA EARTHQUAKE INTENSITY

#### AREA (HECTARES)

Δ	(4)-VERY VIOLENT	0.
3	(3) = VIOLENT	36.
C	(2) = VERY STRONG	63.
Ð	(1) =STRONG	242.
Ε	(n)-WEAK	101.
	NEGLIGIBLE	0.

# RISK OF DAMAGE

EXPECTED RISK OF GROUND-SHAKING DAMAGE FOR BUILDING TYPES PROPOSED FOR SITE (ESTIMATE BASED ON STATISTICAL PROCEDURES USING MAJOR FAULT EARTHQUAKE RECURRENCE INTERVALS AND AVERAGE BUILDING DAMAGE) AREA (HECTARES)

PRESENT VA	LUE OF MO	DD FRAME	CONCRETE/STEFL	TILT-UP
PERCENT DA	MAGE DWI	ELLINGS	BUILDINGS	CONCRETE
0.0-1.0%	MODFRATE	442.	406.	343.
1.1-2.0%	*	n.	34.	63.
2.1-3.0%	*	0.	2.	21.
3.1-4.0%	HIGH	0.	0 •	13.
4.1-5.0%	*	0.	0 •	≥.
5.1-6.0%	*	0.	0.	0.
>6.0%	VERY HIGH	0.	0 -	U .

#### LIQUEFACTION POTENTIAL

#### AREA(HECTARES)

VERY LOW	442.
*	0.
*	0.
LON	0 .
*	0.
*	0.
MODERATE	0 -

('IMPACT' SECTION CONTINUED NEXT PAGE)

# TABLE 1 (cont.):

# GEOLOGY AND SOILS - HAZARDS AND RESOURCES

IMPACTS

SLOPE STABILITY

RAINFALL-INDUCED

LANDSLIDE SUSCEPTIBILITY

AREA (HECTARES)

STABLE 112.

\* 316.

\* 0.

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EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY

AREA (HECTARES)

\$TABLE 294. + 95. \* 21. UNSTABLE 31.

TSUNAMI INUNDATION AREAS

AREA (HECTARES)

INSIDE 0.

DAM FAILURE INUNDATION AREAS

AREA (HECTARES)

OUT OF DAM THUNDATE 442.

#### MITIGATION MEASURES

The automated environmental impact assessment program also can be adapted to print out any number of mitigation measures that a local government may recommend should any threshold criteria be exceeded in the setting and impact sections. The list of measures that follow (on ground shaking, surface rupture, liquefaction, landslide susceptibility, inundation, expansive soils and erosion) is intended to illustrate the range of possibilities available. The symbol "----" identifies local options.

Producing mitigation measures for erosion is beyond the scope of this project. The section on erosion therefore has been compiled using ABAG work from the surface runoff program (Reference 5). The remaining mitigation measures have been compiled from ABAG's Regional Plan (Reference 6) and selected environmental impact reports (Reference 1, 7 and 8).

# Ground Shaking

For those areas of the site where ground shaking intensity is greater than ---, a local government may choose to require one or more of the following:

- 1. Additional structural considerations, greater than those provided in the latest edition of the Uniform Building Code, may be warranted. Therefore, a structural engineer familiar with earthquake resistant design should be consulted to ensure maximum earthquake resistance for the proposed structures. Since the acceptable cost of any specific engineering mitigation is related to the anticipated risk of damage, that engineer should be encouraged to examine the risk of damage information for the geographic location and the type of building proposed or to develop similar information from site-specific geologic data. The engineer then may choose to recommend conservative design features, such as:
  - o structures of more than one (or ----) stories should have exceptional shear wall and lateral bracing
  - o upper stories either should be constructed over a garage with extra heavy bracing, or should not be constructed
  - o wood frame construction should be used for all buildings
  - o all planned structures should be firmly attached to their foundations
  - o the use of heavy tile roofing materials should be

avoided or roof tiles should be designed so that they will remain in place during a major seismic event

- 2. Special utility lifeline precautions that may be warranted include:
  - o flexible conduit materials should be used for buried utility lines
  - o flexible joints or details that allow flexibility should be provided where utility lines enter structures
  - o automatic shut-off valves should be installed in gas lines
  - o utility lines within structures should be braced and flexible joints should be provided at corners so that such lines will move with the structure
  - o one or more manual shut-off valves should be installed on the main on-site gas line
  - o on-site utility systems should have several inter-connections with existing systems so that damaged pieces can be easily isolated and service rerouted to unaffected areas
  - o water heaters and furnaces should be fastened securely to structural frames
  - o all suspended and attached light fixtures and decorations should be securely fastened to the structure
- New residents should be provided with instructions on earthquake preparedness, including:
  - o what to do during an earthquake
  - o the location of shut-off valves for utility lifelines and how to close them

1 1

- o basic emergency supplies that may be needed
- o the value of a plan to reunite a family
- o checking for injuries, safety and food supplies after an earthquake
- 4. The local fire, police, and emergency services staff should review the site and proposed building locations for the project to ensure adequate access and egress are provided for emergency situations.

## Surface Rupture

If the proposed development (if it includes structures intended for human occupancy) falls within a Special Studies Zone designated by the State Geologist or by the local government itself, the local government will require the developer to hire a geologist/engineering geologist to perform an investigation to determine if the fault trace(s) are in the vicinity of the proposed structures. The ground within 50 feet of the fault is assumed to be underlain by traces of that fault unless the geologist can prove otherwise. Since, by law, no structure intended for human occupancy can be placed across the trace of an active fault, the structures may be required to be set back 50 feet from the fault, or conditions may warrant a set back of less or more than that amount. The amount may vary from one side of the fault to the other. In general, residential developments of less than five units are exempt from this requirement, although the local government may require special studies in all or part of the zone within its jurisdiction. The State also recommends (and local governments often require) that a study be performed if the structures will be placed within 100 feet of the active trace regardless of the size of the development.

If all or part of the proposed development falls within a Special Studies Zone, the local government also may require one or more of the following:

- Roads passing over the fault traces should not be the sole access/egress to more than ---- houses or serve a population greater than ----. Similarly, utility lifelines, such as sewers, water supply, gas and electricity, should not serve more than ---- houses or ---- people unless more than one lifeline serves the same area.
- 2. Specially designed materials or special designs should be used for utility lines where they cross the fault traces. Extra shut-off valves also should be installed on the lines on each side of the potential rupture zone.
- 3. The local fire, police, and emergency services staff should review the site and proposed building locations for the project to ensure adequate access and egress are provided for emergency situations.

## Liquefaction

For the following combinations of liquefaction susceptibility (or potential), the local government may require that an engineering geologist or soils engineer be hired by the developer to determine the possibility of liquefaction:

---- people/houses/use ---- susceptibility/potential

Several of the specific recommendations for category landslide susceptibility may also apply, including 2, 3, 6, and 10, especially along creeks.

# Landslide Susceptibility

For those areas of the site where the rainfall-induced landslide susceptibility is greater than ---, or the earthquake induced landslide susceptibility is greater than ---, a local government may choose to require one or more of the following:

- 1. The developer is required to hire a geologist/engineering geologist to perform a geotechnical investigation as part of the EIR.
- Project grading should be held to a minimum and should not exceed ---/residence or ---/mile of road.
- 3. Cut slopes in that portion of the site that has a landslide susceptibility of greater than --- should be constructed no steeper than 2:1 (horizontal to vertical). Cut slopes in that portion of the site that have a landslide susceptibility of greater than --- should be constructed no steeper than 3:1.
- 4. All fill placed at the site should be keyed and benched into stable materials and should be nonexpansive and compacted, as well as supervised by a registered civil engineer specializing in soil engineering. All fill slopes should be no steeper than 2:1 (or 3:1). All unstable materials, consisting of uncompacted fill materials as well as landslides (the highest category on the rainfall-induced landslide susceptibility map or those landslides identified in a special investigation required by #1, above) should be removed before any fill is placed or any structures built. Adequate subdrainage for all fill should be provided. Details and specifications of fill placement, drainage, and grading operations should be contained in the geotechnical report prepared for the owner that is required by #1, above.
- 5. Subdrainage should be provided: 1) in the bottom of swale fills, 2) for any springs or seepages encountered during grading, and 3) as conditions dictate for corrective grading.
- 6. An engineering geologist or soils engineer should supervise the grading required because additional stabilization measures such as use of buttress fills, slope reconstruction, or reduction of cut slope gradients may be required for cut slopes where adverse bedding, joints, or other zones of geologic weakness are encountered.
- 7. Structures should be set back from the base and top of all cut and fill slopes to provide a buffer zone against any small

landslides which may affect these slopes. A set-back of 10 feet (or more) is recommended for this purpose.

- 8. Due to possible negative impacts on slope stability, certain facilities that might serve to increase the amount of water in the ground are not recommended. These uses include, but are not limited to, permanent sediment detention ponds, leach fields for septic tank sewage disposal systems, recreational lakes, and livestock watering ponds.
- 9. Plants utilized for landscaping should not be of varieties that require excessive or frequent watering.
- 10. Roads passing through unstable areas should not be the sole access/egress to more than ---- houses or serve a population greater than ----. Similarly, utility lifelines, such as sewers, water supply, and gas and electricity, should not serve more than ---- houses or ---- people unless more than one line serves the same area.

Because, in general, the steepest slopes, cuts and fills, and existing landslides are especially unstable in an earthquake, measures 1, 2, 3, 5, 6, 8, and 10 are some of the most effective mitigation measures for earthquake induced-induced landslides.

## Inundation

If all or part of the proposed development falls within a tsunami inundation area or a dam failure inundation area, the local government may choose to require the local fire, police, and emergency services staff to review the site and proposed building locations to ensure adequate access and egress are provided for emergency situations. In addition, those staff may be required to update their emergency evacuation plans if the proposed development exceeds ---- houses or ---- people, or if the development is in an area that has grown by ---- houses or ---- people. (Areas will need to be defined separately.)

# **Expansive Soils**

For those areas of the site of ---- (very highly/highly/moderately) expansive soils, the local government may choose to require that those soils be treated with lime, removed and replaced with nonexpansive material, or special foundations be utilized (such as pier and grade beam) to resist expansion or soil creep. The project soils engineer usually should decide which measures are suitable for each particular application.

# Erosion

Some erosion control measures should be required for all projects involving removal of vegetation. For those areas of the site of the highest erosion category for soils, the local government may choose to require most of the following:

- Development should fit the existing topography, soils and vegetation as much as possible, thereby retaining the natural vegetation.
- 2. Soil exposure during the rainy season should be minimized by the proper timing of grading and construction. Denuded areas should be replanted v 'mulched to protect them from winter rains.
- 3. Runoff should be diverted away from steep denuded slopes or other critical areas with barriers or ditches. The length and steepness of slopes should be minimized by benching, terracing, or constructing diversion structures. Techniques for accomplishing these objectives include:
  - o installation of a temporary diversion dike or perimeter dike
  - o construction of a permanent diversion
  - o installation of a temporary perimeter swale
  - o installation of a temporary interceptor swale
  - o in small unprotected areas, installation of a temporary straw bale dike or a temporary silt fence
  - o installation of a temporary grade stabilization structure where diversion is not feasible.
- 4. During construction, sediment-laden runoff should be trapped in temporary traps or basins to allow soil particles to settle out before flows are released to receiving waters.
- 5. A stabilized construction entrance should be installed to reduce the tracking or flowing of sediment onto public rights-of-way.
- 6. Drainage ways should be prepared to handle concentrated or increased runoff from disturbed areas permanently by using rock riprap, concrete or other lining materials. A permanent grassed waterway may be acceptable if flow is expected to be wide and shallow. In addition, permanent storm drain outlet protection should be constructed.

- 7. Construction sites should be inspected frequently to ensure control measures are working properly and to correct problems as needed.
- 8. An erosion control plan should be developed for the project which should include: a) a narrative containing a project description, a schedule for grading and stabilization, phasing of land-disturbing activities, a description of erosion and sediment control measures, and a maintenance program, b) a map showing the site, topography, identifiable landmarks, acreage, limits of clearing and grading, critical environmental areas, existing vegetation, soils and their relative erodibility, location and types of both temporary and permanent control measures, and dimensional details of these facilities, and c) construction drawings or sketches and supporting data.

#### THE OPTION OF MAPS

The City of Petaluma, in conjunction with ABAG, currently is developing the ability to report environmental assessment impacts covering a full range of environmental and social concerns. As part of that project, ABAG has developed the capability to produce maps of the project site and its vicinity. This option greatly increases the cost of the geology and soils background report, but may be of value for relatively large developments, such as Sweeney Ridge. Therefore, a series of maps has been produced for that development for illustration purposes and is included in this report on the following pages.

#### INFORMATION ON ORDERING SITE DATA

There is a charge for obtaining the computer printout only (with no maps) for sites of 1 to 2,500 acres (1 to 1000 hectares) of approximately \$80.00. When requesting this service, the client must furnish ABAG a map of the area on an U.S. Geological Survey 7-1/2 minute quadrangle or on an overlay of such a map with the latitude and longitude corner points clearly marked. (Failure to provide such a map will result in an additional charge to cover the costs of map compilation.) The user will then be mailed a BASIS Request Control Form containing the actual cost estimate which he must sign and return. Additional information on delivery and payment is contained on that form.

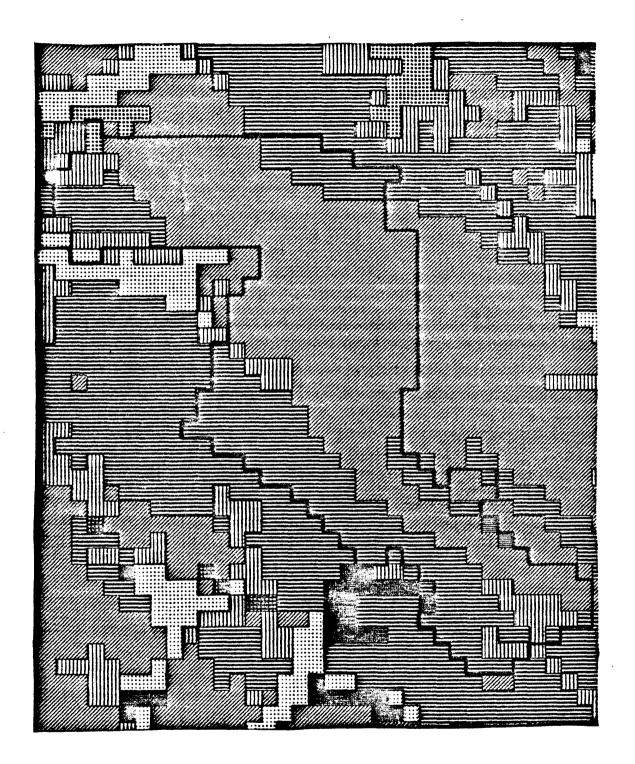
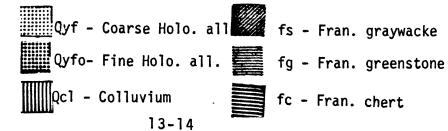


FIGURE 1: GEOLOGIC MATERIALS

scale - 1:24,000

EXPLANATION



!!

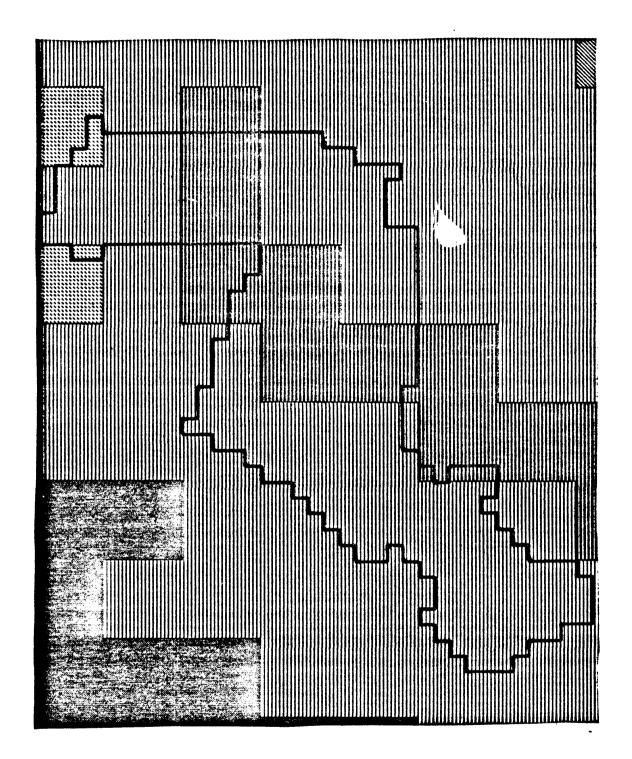


FIGURE 2: SOIL ASSOCIATIONS

scale - 1:24,000

**EXPLANATION** 



13-15

# **MAXIMUM GROUND SHAKING INTENSITY**

# SHADE PATTERN SAN FRANCISCO INTENSITY



A - Very Violent



B - Violent



C - Very Strong



D - Strong



E - Weak



<E - Negligible

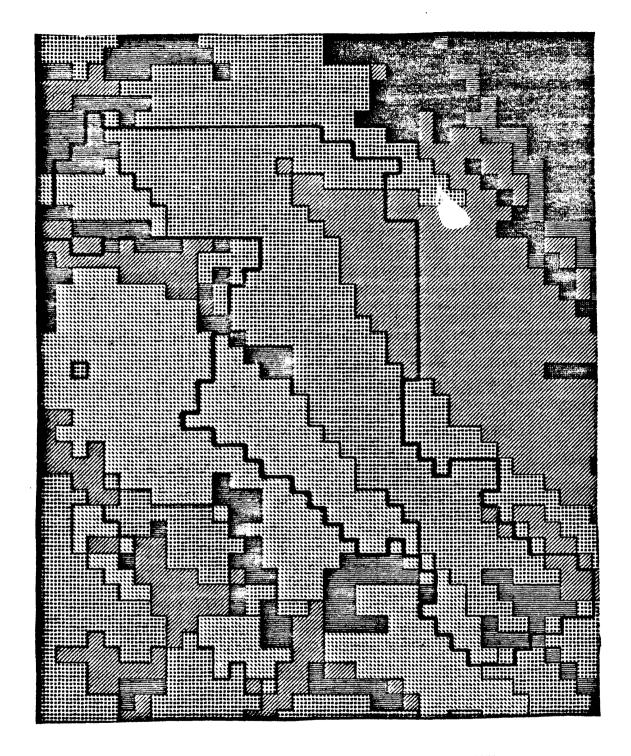
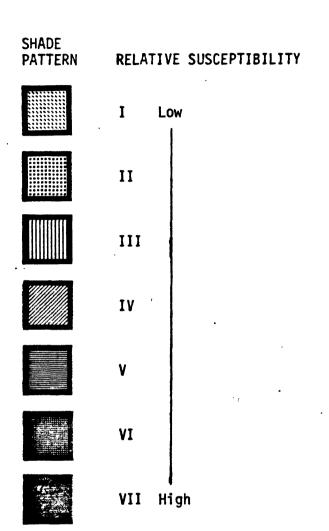


FIGURE 3: MAXIMUM GROUND SHAKING INTENSITY

scale - 1:24,000

# RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY



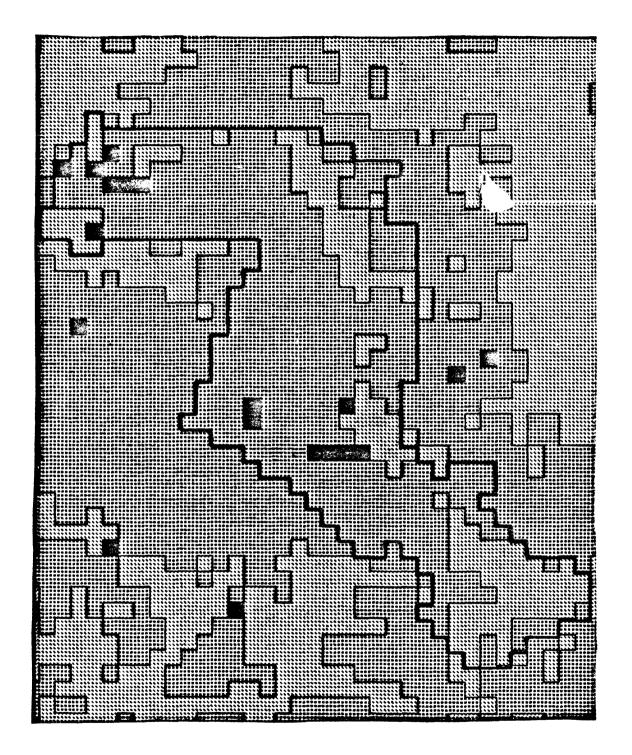
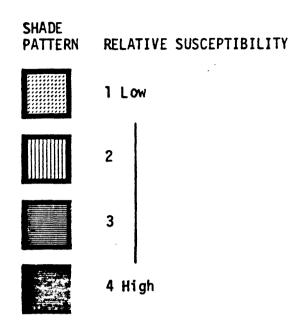


FIGURE 4: RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY

scale - 1:24,000

# EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY



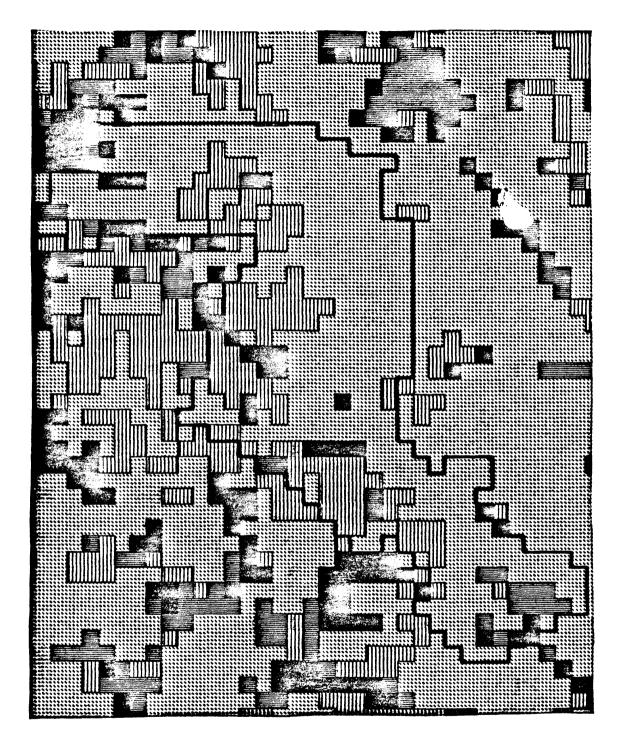


FIGURE 5: EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY

scale - 1:24,000

#### REFERENCES

- 1. HKS Associates, 1980 <u>Draft Environmental Impact Report for a Planned Unit Development on Sweeney Ridge in Pacifica</u>, prepared for the City of Pacifica, 239 pp.
- 2. ABAG, 1980, A Guide to ABAG's Earthquake Hazard Mapping Capability, prepared by J.B. Perkins, D.A. Olmstead, and P.M. Wilson, 50 pp.
- 3. ABAG, 1980, Earthquake Map Applications for Automated Environmental Impact Assessment, Earthquake Mapping Project-Working Paper #8, 15 pp.
- 4. ABAG, 1981, The Method Developed to Extend Detailed Map Information Beyond San Mateo County to Selected Areas of Significant Development Pressure, Earthquake Mapping Project Working Paper #11, 66 pp.
- 5. ABAG, 1980 Manual of Standards for Surface Runoff Control Measures, Appendix I San Francisco Bay Area Environmental Management Plan, 176 pp. + appendices.
- 6. ABAG, 1980, Regional Plan 1980 San Francisco Bay Area, 224 pp.
- 7. Ecumene Associates, 1980, <u>Draft Supplemental EIR for the Hilltop</u> Property in Richmond, prepared for the City of Richmond, 106 pp.
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# APPENDIX D

#### EARTHQUAKE MAPPING PROJECT - WORKING PAPER #14

# USING EARTHQUAKE HAZARD MAPS FOR SITE SCREENING AND ANTICIPATING MITIGATION BENEFITS AND COSTS

#### INTRODUCTION

Local governments, as well as private groups, are often faced with deciding where to locate extensive new development or major new facilities. This decision takes on additional importance when the functioning of the proposed facility maybe of critical importance after an emergency are when its destruction could have a significant effect on the safety of large number of people. Earthquake hazard maps can be helpful in this process by pointing to areas that should be easier to develop in a safe manner. In addition, these maps can warn decision-makers early in the siting process that a site has one or more hazards and that the costs associated with both potential damage and necessary hazard mitigation may be significant. This working paper describes these considerations. It is the thirteenth in a series that document the preparation and application of the hazard maps generated in the ABAG/USGS Earthquake Mapping Project. It is the third document concerning the second phase of that work.

#### THE SITE SCREENING PROCESS

The location of a large development or a new facility is determined by examining many criteria, yet often none of these involves potential site hazards. Only after the site is chosen are the potential hazards are identified and the necessary geologists and engineers are found to design around the problems. Although the extent of earthquake hazards is clearly not the only--or even the most important--criterion to be used in most siting decisions, the existence of such hazards should be a consideration.

A composite map of risk of earthquake damage, as a <u>single</u> map expressing the sum of all of the many earthquake hazards in the study areas, is often the most appropriate map to be used in this site screening process. The sample composite maps produced and described in Working Papers #9 and #11 are for wood-frame dwellings and are therefore most appropriate for residential subdivision decisions. Composite maps for other types of buildings or facilities would appear quite different because the potential for damage associated with different severities of hazards vary from one type of structure to another. Different composite maps can be generated by using different criteria for overlaying the individual maps.

the use of earthquake hazard maps for site screening is not meant to suggest that areas identified as having the greatest potential for damage are <u>not</u> suitable for these facilities. Rather, the maps show areas that, by virtue of their relatively low levels of damage risk, should be easier, and therefore cheaper, to make acceptably safe.

The hazard maps can warn decision-makers early in the siting process that the costs associated with both potential damage and necessary hazard mitigation may be significant in a hazardous site chosen for a variety of other overriding considerations. In addition, the composite maps based on anticipated costs of damage may be more valuable than individual maps for warning purposes because an overall estimate of the magnitude of the potential costs associated with that damage can be compared with the anticipated costs of mitigation.

## INFORMATION ON ORDERING SCREENING DATA AND MAPS

The types of maps and screening data that can be obtained are very flexible. Consequently, the cost of obtaining these maps and data can vary greatly. It is not simply wants a map of a map file already in BASIS, the costs can be decermined from the information in Working Paper #12. If the application requires a special model or overlaying process, the computer costs will be roughly double those for the map alone, varying with the complexity of the model. Models involving distance calculations are much more expensive. In addition, the cost of staff time, other than that for basic advise, will be added to the computer change. For any specific application, ABAG staff should be contacted for a cost estimate. The user should remember that if he wants all of the hazards data for a specific site, an AREA printout, described in Working Paper #13, maybe more applicable.

APPENDIX E

# EARTHQUAKE MAPPING PROJECT - WORKING PAPER #15

# ASSESSMENT OF CURRENT AND PROJECTED PROPERTY AND POPULATION AT RISK - AN UPDATE

# INTRODUCTION

The hazard and composite maps can be used to assess the vulnerability both of existing and of projected land uses and population to earthquake—"elated damage. Very general information on property and population es sure was generated as part of the first phase of this project. S. le tabulations of the amount of land located in the various levels of hazards were generated for many of the hazard maps by county for the entire Bay Area and by city and land use for San Mateo County only. These techniques are described in Working Paper #10.

This paper describes additional information for risk assessment that has been developed using the hazard maps as part of the second phase of this project. This information includes:

- o tabulations of population at risk, rather than land area
- o the issues surrounding the development of a risk map based on existing building types
- o comparisons of various methods of estimating earthquake losses
- o comparisons of existing and projected risk

This working paper is the fifteenth in a series of working papers being prepared on the ABAG/USGS earthquake mapping project and the fifth working paper focusing on the second phase of that work.

# A NOTE ON THE STUDY AREA

All of these data were developed using San Mateo County rather than the Petaluma and Ridgelands areas for three main reasons. First, because the Petaluma and Ridgeland areas were defined by U.S. Geological Survey 7-1/2 minute quadrangles, rather than by political boundaries, few cities and no counties are entirely included. Jurisdiction based data is key to generating most of these new types of information. Second, adequate land use data is not available in BASIS for the Petaluma and Ridgelands areas. The land use data that was expected to be digitized by USGS for all nine Bay Area counties at no cost to ABAG will not become available for many months. In order to change this schedule so that this information would be of use to this project would require \$10,000 to be spent by ABAG in a cooperative project with the Survey (Reference 1). In addition, the level of detail of the USGS data is not adequate for many local uses. Only level one and two land use

categories would be available (or the categories labeled with one and two digit numbers on Table 1). The maps do not distinguish among the densities of residential development, for example. Third, the late delivery of the topographic data by USGS and the ABAG decision to postpone the generation of new intensity maps (described in Working Paper #11) meant that detailed hazard map data would not be available for the Petaluma and Ridgelands areas in sufficient time to allow for additional analysis work to be performed.

# A NOTE ON THE USER GROUP

The sample tabulations produced for San Mateo County as part of Working Paper #10 proved to be the least popular with local staff of all of those applications attempted for San Mateo County as part of the first phase of this project. One reason for this cool reception appears to be that local staff and officials believe that they know more about where people and land uses are located than other levels of government. In addition, these data are most often useful for making administrative decisions on budgets or the allocation of staff resources. In contract, the main users of the mapped data are more involved in day to day decisions. Thus, these map users are not those who decide whether to purchase additional heavy rescue equipment, to allocate additional money to survey buildings or for earthquake research, but are rather those who want to know precisely where to place their limited resources or where to require additional geotechnical studies within their own jurisdiction for maximum benefit in saving lives and property.

Local administrative, planning, public works and building inspection staff in the San Mateo County area were asked the relative usefulness of the five types of assessment information—the one developed in Working Paper #10 and the four discussed in this paper so that future assessment work could be made of maximum use. Conversations confirmed that all are in fact most interested in the mapped data and least interested in the tabular or statistical data.

# TABULATIONS OF POPULATION AT RISK

As discussed in Working Paper #10, census and land use data can be used to obtain information on the approximate population exposed to various levels of hazards. Briefly, the figures have been obtained by disaggregating census population data based on land use to individual hectare cells and then reaggregating that population for specific hazard areas. Specifically, the disaggregation process was developed using the following procedure.

1. Tapes of 1975 population data projected from 1970 census data by ABAG's Projections Program (Reference 2) were obtained for San Mateo County for transportation planning zones that are aggregation of census tracts.

2. The total <u>nighttime population</u> (NP) was defined as the residential population (RP) <u>plus</u> the group quarters population (GQP). Total <u>daytime population</u> (DP) was defined as this nighttime population (NP) <u>minus</u> the employed residents (ER) <u>plus</u> the basic employment (BE) plus the local serving employment (LSE). Or,

$$NP = RP + GQP$$

$$DP = NP-ER+BE+LSE = RP+GOP-ER+BE+LSE$$
(1)

3. These various population categories (RP, GQP, ER, BE, and LSE) then were assigned to the land use categories.\*

Residential population (RP) was divided among the three density levels of residential population assuming five times the dwelling units per hectare in category 112 as in category 111, and fifteen times the dwelling units per hectare in category 113 as in category 111. By assuming no change in household size among the three density categories, the dwelling unit ratios can be applied to population. A value for residential population/hectare in each category unique to each planning zone can be derived so that the total residential population in the planning zone is consistent with the zone data. Thus,

where RP/hectare of C.112 = 5 (RP/hectare of C.111) and RP/hectare of C.113 = 15 (RP/hectare of C.111)

The residential land use map data can thereby be converted to a map file of residential population.

The group quarters population (GQP) was divided equally among the hectares of land use categories 1232, 124, and 125. When none of these land uses occurred, but the census data showed a group quarters population, that population was placed in category 113, high density residential.

The employed residents (ER) were divided among the three densities of residential land use (categories 111, 112, and 113) based on the ratio of employed residents to total residential population. Note that no employed residents were assumed to have originated from the group quarters population.

<sup>\*</sup>See Table 1 for definitions of land use categories.

The basic employment (BE) was assigned equally to the total hectares of the various manufacturing and industrial uses, including categories 124, 125, 13, 131, 132, 143, 144, and 15. Similarly, the local serving employment (LSE) was assigned equally to the total hectares of the various commercial and services uses, including catgories 12, 121, 122, 123, 1231, 1232, 126, 127, and 16. If the census data included basic employment, but the land use map did not have any manufacturing or industrial uses, that population was assigned to the same areas as the local serving employment. The opposite occurred for local serving employment.

Note that the population associated with several categories of transportation and utilities (141, 142, 145, and 146) as well as other urban or built-up land (17 and its subdivisions) and all non-urban land (categories 2-7 and their subdivisions) was ignored in this experimental work.

4. This hectare data on daytime and nighttime population can then be reaggregated according to hazard areas.

Tables 2-4, below, illustrate the results for three different hazards of concern: Alquist-Priolo Special Studies Zones for surface rupture, maximum ground shaking intensity, and dam failure inundation areas, by jurisdictions in San Mateo County.

These tables reconfirm that a large number of people are located in hazardous areas in San Mateo County. These tables should be especially useful in estimating general emergency response needs. However, because of the many assumptions used (and specified in this paper), population estimates for specific neighborhoods at specific times would not be accurate.

# TABLE 1: DEFINITIONS OF LAND USE CATEGORIES IN SAN MATEO COUNTY

(Adapted from Reference 3)

```
1
    URBAN OR BUILT-UP LAND
         Residential
         111 One or less dwelling units (DU) per hectare
         112 Two to eight DU/hectare
         113 Nine or more DU/hectare
     12
         Commercial and Services
         121 Retail and wholesale
         122 Commercial outdoor recreation
         123 Education
              1231 Elementary and secondary schools
              1232 Colleges and universities
          124 Hospitals, rehabilitation centers and other public
                 facilities
          125 Military installations
         126 Other public institutions and facilities
          127 Research centers
      13 Industrial
         131 Heavy industry
         132 Light industry
         Transportation, Communication and Utilities
          141 Highway rights-of-way
         142 Railway rights-of-way
         143 Airports
         144 Port facilities
         145 Power transmission lines
         146 Sewage treatment plants
     15 Commercial and Industrial Complexes
      16 Mixed Urban or Built-Up Land
      17 Other Urban or Built-Up Land
         171 Extensive recreation
              1711 Golf courses
              1712 Racetracks
         172 Cemeteries
173 Parks
          174 Open space-urban
2
     AGRICULTURAL LAND
     21 Cropland and Pasture
         211 Cropland
               2111 Irrigated
               2112 Nonirrigated
         212 Pasture
         Orchards, Groves, Vineyards, Nurseries and Ornamental
           Horticultural Areas
          221 Orchards or groves
         222 Vineyards or kiwi fruit
         223 Floriculture-greenhouses
     23 Confined Feeding Operations
      24 Other Agricultural Operations
```

# TABLE 1 (Continued)

```
3
      RANGELAND
      31 Herbaceous Rangeland
         Shrub and Brush Rangeland
          321 Chaparral
          322 Coastal shrub
      33 Mixed Rangeland
      FOREST LAND
4
      41 Deciduous Forest Land
      42 Evergreen Forest Land
          421 Redwood
          422 Pine
          423 Evergreen mix
      43 Mixed Forest Land
5
      WATER
      51 Streams and Canals
      52 Lakes
      53 Reservoirs
      54 Bays and Estuaries
      WETLAND
6
      61 Forested Wetland
      62 Nonforested Wetland
7
      BARREN LAND
      71 Dry Salt Flats
      72 Beaches
      73 Sandy Areas Other
                             an Beaches
      74 Bare Exposed Rock
      75 Strip Mines, Quarries, and Gravel Pits76 Transitional Areas
          761 Sanitary landfills
          762 Other transitional
      77 Mixed Barren Land
```

TABLE 2A: ESTIMATED DAYTIME POPULATION WITHIN ALQUIST-PRIOLO SPECIAL STUDIES ZONES IN SAN MATEO COUNTY

JURISDICTION	Within Zones for San Andreas and Related Faults	Within Zones for San Gregorio and Related Faults	Outside Zones
ATHERTON	0	0	7,716
BELMONT	0	0	20,509
BRISBANE	0	0	4,168
BURLINGAME	1,845	0	28,798
COLMA	0	0	963
DALY CITY	1,416	0	55,444
FOSTER CITY	0	0	14,185
HALF MOON BAY	0	2,101	10,382
HILLSBOROUGH	0	0	8,049
MENLO PARK	0	0	31,259
MILLBRAE	4,677	0	13,032
PACIFICA	1,812	0	23,918
PORTOLA VALLEY	922	0	2,557
REDWOOD CITY	0	0	67,014
SAN BRUNO	7,586	0	31,609
SAN CARLOS	0	0	28,942
SAN MATEO	0	0	71,203
SOUTH SAN FRANCISCO	1,441	0	49,008
WOODSIDE	1,164	0	4,278
OTHER AREAS	228	91	55,661
TOTAL	21,092	2,292	528,697

TABLE 2B: ESTIMATED NIGHTTIME POPULATION WITHIN ALQUIST-PRIOLO SPECIAL STUDIES ZONES IN SAN MATEO COUNTY

JURISDICTION	Within Zones for San Andreas and Related Faults	Within Zones for San Gregorio and Related Faults	Outside Zones
ATHERTON	0	0	10,217
BELMONT	0	0	27,358
BRISBANE	0	0	4,796
BURLI ( 'ME	3,551	0	21,099
COLMA	0	0	183
DALY CITY	2,020	0	80,183
FOSTER CITY	0	0	23,240
HALF MOON BAY	0	2,598	11,853
HILLSBOROUGH	0	0	9,678
MENLO PARK	0	0	30,174
MILLBRAE	8,598	0	13,575
PACIFICA	2,974	0	35,094
PORTOLA VALLEY	661	0	4,182
REDWOOD CITY	0	0	73,555
SAN BRUNO	12,525	0	28,501
SAN CARLOS	0	0	24,318
SAN MATEO	0	0	81,680
SOUTH SAN FRANCISCO	2,319	0	46,893
WOODSIDE	1,875	0	4,060
OTHER AREAS	171	42	32,502
TOTAL	34,694	2,640	563,141

TABLE 3A: ESTIMATED DAYTIME POPULATION IN EACH INTENSITY CATEGORY IN SAN MATEO COUNTY

<b>J</b> URISDICTI <b>ON</b>	Negligible ∠E		N FRANCISCO 1 Strong D	NTENSITY Very Strong C	Violent B	Very Violent A
ATHERTON	0	0	4,261	3,359	79	0
BELMONT	0	2,296	11,310	6,403	501	0
BRISBANE	Q	1,601	0	2,566	0	0
BURLINGAME	0	0	2,421	9,358	16,487	2,377
COLMA	0	0	0	433	530	0
DALY CITY	0	2,577	1,211	22,627	18,484	11,961
FOSTER CITY	0	0	0	14,090	95	0
HALF MOON BAY	176	1,574	4,190	4,296	2,248	0
HILLSB <b>O</b> ROUGH	. 0	0	4,640	3,010	326	72
MENLO PARK	0	53	10,192	17,768	3,246	0
MILLBRAE	0	0	0	1,443	12,623	3,643
PACIFICA	0	2,198	3,867	7,915	5,891	5,859
PORTOLA VALLEY	0	13	119	1,543	303	1,502
REDWOOD CITY	0	454	17,357	47,060	1,645	466
SAN BRUNO	0	0	130	12,786	14,479	11,800
SAN CARLOS	0	1,728	12,855	14,359	0	0
SAN MATEO	0	463	20,494	43,342	6,880	23
SOUTH SAN FRANCISC	0 0	792	2,839	28,410	14,361	4,048
WOODSIDE	0	0	1,979	1,409	828	1,227
OTHER AREAS	0	655	11,401	24,532	18,844	548
TOTAL	176	14,404	109,267	266,711	117,850	43,526

TABLE 3B: ESTIMATED NIGHTTIME POPULATION IN EACH INTENSITY CATEGORY IN SAN MATEO COUNTY

SAN FRANCISCO INTENSITY Verv									
JURISDICTION	Negligible ≪E	Meak E	Strong D	Very Strong	Violent B	Very Violent A			
ATHERTON	0	0	4,751	5,379	58	0			
BELMONT	0	3,717	17,608	5,568	464	0			
BRTSBANE	0	2,595	0	2,200	0	0			
BUI GAME	0	0	4,504	7,621	10,495	2,030			
COLMA	0	0	0	183	0	0			
DALY CITY	0	3,676	1,128	30,483	26,727	20,188			
FOSTER CITY	0	0	0	23,120	119	0			
HALF MOON BAY	233	2,085	5,125	4,801	2,207	0			
HILLSBOROUGH	.0	Q	5,035	3,987	534	121			
MENLO PARK	0	102	14,616	15,203	254	0			
MILLBRAE	0	0	0	2,235	14,187	5,750			
PACIFICA	0	3,445	6,053	11,554	8,353	8,663			
PORTOLA VALLEY	0	32	340	2,017	928	1,526			
REDWOOD CITY	0	537	26,000	45,144	1,822	0			
SAN BRUNO	0	0	170	9,715	12,540	18,600			
SAN CARLOS	0	2,470	16,172	5,676	0	0			
SAN MATEO	0	352	23,647	52,859	4,771	52			
SOUTH SAN FRANCISC	0 0	37	4,005	21,289	17,185	6,697			
WOODSIDE	0	0	1,038	1,638	1,272	1,987			
OTHER AREAS	0	425	11,297	20,385	445	164			
TOTAL	233	19,473	141,488	271,059	102,362	65,779			

TABLE 4A: ESTIMATED DAYTIME POPULATION WITHIN DAM FAILURE INUNDATION AREAS IN SAN MATEO COUNTY

JURISDICTION	Within Inundation Areas	Outside Inundation Areas
ATHERTON	567	7,149
BELMONT	1,588	18,922
BRISBANE	0	4,168
BURLINGAME	3,519	27,124
COLMA	0	963
DALY CITY	0	56,860
FOSTER CITY	14,185	0
HALF MOON BAY	356	12,127
HILLSBOROUGH	1,102	6,947
MENLO PARK	2,135	29,123
MILLBRAE	0	17,709
PACIFICA	0	25,731
PORTOLA VALLEY	60	3,420
REDWOOD CITY	6,018	60,996
SAN BRUNO	0	39,195
SAN CARLOS	0	28,942
SAN MATEO	39,881	31,322
SOUTH SAN FRANCISCO	0	50,449
WOODSIDE	16	5,427
OTHER AREAS	621	55,360
TOTAL	70,049	481,932

TABLE 4B: ESTIMATED NIGHTTIME POPULATION WITHIN DAM FAILURE INUNDATION AREAS IN SAN MATEO COUNTY

JURISDICTION	Within Inundation Areas	Outside Inundation Areas
ATHERTON	824	9,394
BELMONT	1,754	25,603
BRISBANE	0	4,796
BURLINGAME	2,863	<b>21,7</b> c
COLMA	0	183
DALY CITY	0	82,203
FOSTER CITY	23,240	0
HALF MOON BAY	356	14,095
HILLSBOROUGH	1,278	8,401
MENLO PARK	3,520	26,654
MILLBRAE	0	22,172
PACIFICA	0	38,068
PORTOLA VALLEY	24	4,818
REDWOOD CITY	7,130	66,425
SAN BRUNO	0	41,026
SAN CARLOS	0	24,318
SAN MATEO	48,161	33,520
SOUTH SAN FRANCISCO	0	49,212
WOODSIDE	29	5,907
OTHER AREAS	598	32,117
TOTAL	89,775	510,700

# COMBINING THE RISK MAPS PRODUCED FOR INDIVIDUAL BUILDING TYPES INTO A SINGLE MAP BASED ON EXISTING LOCATIONS OF EACH BUILDING TYPE - THE ISSUES

Only one map that has not been produced as part of the first phase of this mapping project has been requested. That map is of risk of damage from earthquake ground shaking to those building types currently in particular locations. From a computer programming standpoint, combining the risk map produced for individual building types into such a map is relatively simple. The major problem with this task is that the resulting risk map would be used for building-by-building analysis, rather than for general policy development and planning. These risk maps are not appropriate for such specific purposes since they are based on general statistical data. A second problem comes from the need to have a survey of current building locations since neither the land use data nor census data can be used. The land use data is based on building use, rather than building type; the census data deals with building age and occupancy, not type. To obtain such a survey is not a small task. For example, the building officials for the City of Petaluma estimate that it would take 3-6 months for that city alone (Reference 4).

# A COMPARISON OF DOLLAR LOSS ESTIMATES

One of the pieces of information that government officials at the regional, state and federal level often request is an estimate of total losses likely to occur from a specified earthquake. This estimate, much like the tabulations of land and people at risk, is much more useful in administrative decisions on how much to allocate to earthquake safety, rather than what to do with that allocation—a task of most local level staff.

Recently, two sources of such estimates have been generated. One is the result of work by Algermissen and Steinbrugge (Reference 5). The second was prepared by Evernden (Reference 6). The tabulations generated in Working Paper #10 can be analyzed to provide a third source. comparison of these three sources and their results indicates that they are remarkably in agreement. All three would predict losses of 5-7% for residential buildings in San Mateo County should a 1906-type earthquake The only major difference was in the estimate of long-term annual losses. Algermissen and Steinbrugge estimate these annual losses at 0.1 to 1.6 percent. The estimates for San Mateo County (from Working Paper #10, Table 14) indicate that the present value of most expected damage ranges from 0 to 1.5 percent with only 8 hectares exceeding 1.5 percent. These percentages are equivalent to estimates of long-term annual losses of 0 to .15 percent. The discrepancy is probably the result of different methods of estimating the frequency of occurrence of various magnitudes of earthquakes.

# A COMPARISON OF EXISTING AND PROJECTED RISK

In theory, the hazard and composite maps could be used to assess the vulnerability of projected, as well as existing, land uses and population to damage from a major earthquake. The extension of this application to assess future vulnerability is key to local officials being able to understand the impact of current trends in growth on future risk. Again, tapes of land use and population projection data for the Bay Area (Reference 2) were used. Since the land use data required is only available in BASIS at the present time for San Mateo County, only this county can be used for sample analyses. Unfortunately. San Mateo County is not a rapidly developing area so the usefulness of this application cannot be fully assessed. (The County population was only expected to grow by 8,606 people from 1975 to 1980, by 20,401 from 1980 to 1985, and by 14,663 from 1985 to 1990 for a total of 43,670 people. Since the 1975 County population, as projected from 1970 census data, is 601,743, this population growth of 7.26% is relatively small.)

The number of dwelling units in San Mateo County has increased more significantly, however, so this particular type of growth will be analyzed. (The occupied dwelling units increased from 216,822 in 1975 by 10,497 from 1975 to 1980, by 12,169 from 1980 to 1985, and by 13,429 from 1985 to 1990, for a total of 36,095 or 16.65% growth.) In order to more accurately estimate the location of the residential growth, the ABAG projection data for jurisdiction, rather than transportation planning zones, has been used. It has been assumed that the new residential units would be placed in areas that were not urbanized in 1975 yet are within a local jurisdiction's sphere-of-influence as defined by the San Mateo County Local Agency Formation Commission (LAFCO). If the new units are assumed to be spread equally among these hectares of land available for development, one can compare the maximum intensity of the hectares of existing residential land use with the hectares available for new development.

These calculations can be performed for each jurisdiction individually. This information is provided in Tables 5A and 5B, below.

TABLE 5A: PROBABLE NUMBER OF EXISTING DWELLING UNITS THAT WERE IN EACH CATEGORY OF INTENSITY IN 1975 IN SAN MATEO COUNTY, BY JURISDICTION

JURISDICTION	Negligible ∠E	SAI Weak E	N FRANCISCO I Strong D	NTENSITY Very Strong C	Violent B	Very Violen: A_
ATHERTON	0	92	1,310	987	40	22
BELMONT	0	1,494	3,610	4,242	60	0
BFISBANE	0	99	9	296	741	110
<b>TURLINGAME</b>	0	0	1,301	6,633	4,158	686
COLMA	0	16	5	56	59	36
DALY CITY	. 0	915	353	14,162	7,143	5,700
FOSTER CITY	1,187	1,010	1,822	3,100	636	0
HALF MOON BAY	25	219	2,130	1,604	469	18
HILLSBOR <b>O</b> UGH	. 0	0	573	1,392	916	6
MENLO PARK	0	41	5,581	4,833	2,664	529
MILLBRAE	0	1,437	2,250	1,396	1,624	761
PACIFICA	0	291	1,167	4,245	2,962	3,746
PORTOLA VALLEY	0	2	115	960	696	77
REDWOOD CITY	0	147	8,392	12,397	4,095	3,971
SAN BRUNO	0	137	3,626	4,823	2,147	3,258
SAN CARLOS	0	403	4,366	5,154	640	40
SAN MATEO	0	108	7,308	15,825	9,663	24
SOUTH SAN FRANCIS	s <b>co</b> 0	0	2,914	7,083	3,510	2,953
WOODSIDE	0	0	323	503	428	
TOTAL*	1,212	6,411	47,154	89,691	42,651	22,605

<sup>\*</sup> These totals do not add up to the total number of projected new units in the County because a relatively small number of units would be built outside of these nineteen jurisdictions.

TABLE 5B: NUMBER OF NEW DWELLING UNITS THAT MIGHT BE GUILT IN EACH CATEGORY OF INTENSITY FROM ]975-]990 IN SAN MATEO COUNTY, BY JURISDICTION\*

JURISDICTION	Negligible ∠ E	SAN Weak E	FRANCISCO 1 Strong D	INTENSITY Very Strong C	Violent B	Very Violent A
ATHERTON	0	0	87	108	2	0
BELMONT	0	171	818	350	21	0
BRISBANE	0	12	0	48	0	0
BURLINGAME	0	0	ויי	188	335	56
COLMA	0	0	0	115	29	0
DALY CITY	0	122	84	1,120	1,186	<b>74</b> 8
FOSTER CITY	0	0	0	3,495	131	0
HALF MOON BAY	81	309	1,245	1,554	1,001	0
HILLSBOROUGH	0	0	536	403	69	15
MENLO PARK	0	2	310	471	209	0
MILLBRAE	0	0	0	52	499	176
PACIFICA	0	181	274	619	542	384
PORTOLA VALLEY	0	1	31	128	99	138
REDWOOD CITY	0	19	1,140	2,877	1,097	25
SAN BRUNO	0	a	3	133	277	274
SAN CARLOS	0	124	1,053	646	0	1
SAN MATEO	0	21	1,339	2,762	380	3
SOUTH SAN FRANCISC	0 0	82	177	1,935	1,447	492
WOODSIDE	0	0	109	162	125	290
TOTAL**	81	1,044	7 <b>,27</b> 7	17,166	7,449	2,502

<sup>\*</sup> Assuming the units are built randomly on the available land within each jurisdiction as defined in the text.

<sup>\*\*</sup> These totals do not add up to the total number of projected new units in the County because a relatively small number of units would be built outside of these nineteen jurisdictions.

These results then can be weighted based on the percentage share of existing and future dwelling units held by each jurisdiction to obtain a weighted County average, shown in Table 6.

TABLE 6: CENTAGE OF DWELLING UNITS LOCATED

# PERCENTAGE OF DWELLING UNITS LOCATED IN VARIOUS CATEGORIES OF MAXIMUM GROUND SHAKING INTENSITY IN SAN MATEO COUNTY AS A WHOLE

#### SAN FRANCISCO INTENSITY SCALE

	_ <e< th=""><th>E</th><th>D</th><th>С</th><th>В</th><th>Α</th></e<>	E	D	С	В	Α
FOR DWELLING UNITS EXISTING IN 1975	.58%	3.06	22.48	42.77	20.34	10.78
FOR DWELLING UNITS TO BE ADDED FROM 1975 TO 1990	.23%	2.94	20.49	48.33	20.97	7.04

Since the growth in employment is also significant (20.73%) a similar analysis might be performed on these data. Since that growth will occur in a much smaller area, however, the location of that development is much more critical. ABAG did perform a survey of vacant industrial lands in the region in 1977, however (Reference 7). It is possible to compare the hazards associated with the land on which industry was located in 1975 with this vacant industrial land. These characteristics are described in Table 7, below.

TABLE 7:

PERCENTAGE OF EXISTING AND VACANT INDUSTRIAL LAND LOCATED IN VARIOUS CATEGORIES OF MAXIMUM

GROUND SHAKING INTENSITY IN SAN MATEO COUNTY

# SAN FRANCISCO INTENSITY SCALE

	<Ε	E	D	С	В	A
FOR EXISTING (1975) INDUSTRIAL LAND	0%	1.3	2.3	48.6	47.4	0
FOR VACANT (1977) INDUSTRIAL LAND	0%	3.5	1.2	58.2	37.1	0

The results indicate that the non-urbanized areas of San Mateo County within city spheres-of-influence are subject to slightly less intense ground shaking than existing residential areas. This decrease, if expressed in terms of possible damage, is on the order of a 3% improvement—a level almost insignificant. On the other hand, the improvement in new over existing industrial lands is greater, perhaps on the order of 10%. Both of these improvements, when augmented with probable improvements in construction practices, mean that new development is probably less susceptible to ground shaking damage than existing development in San Mateo County.

#### REFERENCES

- 1. Hallam, Cheryl, personal conversation in November 1980 regarding the cost of a cooperative project to obtain land use data.
- 2. 1980, ABAG, Projections 79.
- 3. U.S. Geological Survey, 1978, 1975-6 Land Use and Land Cover-Woodside Quandrangle, USGS Open File Map 78-745.
- 4. Tupa, Mary, personal conversation in October 1980 regarding her conversation with a chief building official of Petaluma.
- 5. Algermissen, S.T., and Steinbrugge, K.V., 1978, Earthquake Losses to Buildings in the San Francisco Bay Area, in Proceedings of the Second International Conference for Safer Construction Research and Application: NSF, UNESCO, ASCE, EERI, SSA, UCEER, San Francisco, California, pp. 291-302.
- 6. Evernden, Jack, unpublished materials prepared for a report to the President in the summer of 1980.
- 7. ABAG, 1977, Industrial Siting Pilot Project, 69 pp. + appendices.

# APPENDIX F

# Information For Updating the <u>Guide To ABAG's</u> <u>Earthquake Hazard Mapping Capability</u>

# This appendix includes:

- o a new cover sheet
- o a one page sheet of revisions to the basic data map files (to be included in the yellow section of the Guide)
- o a one page sheet of revisions to the hazard map files (to be included in the goldenrod section of the Guide)
- o an entirely new green section on map file applications (to replace the earlier green section)
- o a revised list of working papers (to replace the earlier list)

# A GUIDE TO

# ABAG'S

# EARTHQUAKE HAZARD MAPPING

CAPABILITY

**MARCH 1980** 

REVISED MARCH 1981

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# **ACKNOWLEDGEMENTS:**

We would like to thank those many people at USGS and working for cities and counties in the Bay Area who took the time to review the many papers that form the basis for this guide.

# TABLE OF CONTENTS

Introduction
Basic Data Map Files
Hazard Map Files
Map File Applications
Working Papers (Not automatically included)

White Yellow Goldenrod Green White

graphics: Pat Yoshitsu Merrilee Ollendick

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# REVISIONS TO BASIC DATA MAP FILES (through March 1981)

#### **GEOLOGY**

Coverage has been increased for fifteen 7-1/2 minute quadrangles in the Petaluma and East Bay ridgelands areas, including the Cotati, Glen Ellen, Petaluma, Petaluma River, Briones Valley, Las Trampas Ridge, Diablo, Hayward, Dublin, Niles, Milpitas, Calaveras Reservoir, San Jose East, Morgan Hill, and Mt. Sizer quadrangles. The four bedrock categories are broken into 65 categories in the Ridgelands area and into 35 categories in the Petaluma area.

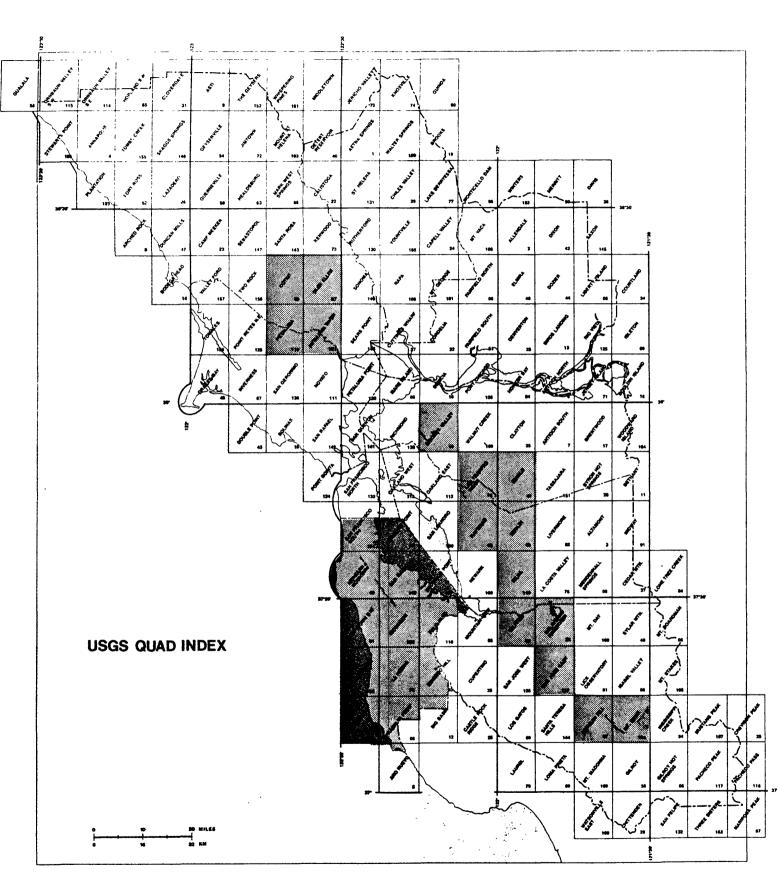
#### **TOPOGRAPHY**

The coverage has been increased to include the fifteen 7-1/2 minute quadrangles listed above. The scale has been improved since calculations are performed using 30 meter squares rather than hectares. Hectare files of slope and slope aspect (eight directions of slope) are now available.

#### **LANDSLIDES**

The coverage has been increased to include the fifteen 7-1/2 minute quadrangles listed above.

More information on all of these files is contained in Working Paper #11. Coverage should increase for all three of these files for fifteen additional quadrangles in the central urban portion of the Bay Area by January 1982.



AREAS FOR WHICH DETAILED BASIC DATA MAPS AND HAZARD MAPS ARE AVAILABLE

# REVISIONS TO HAZARD MAP FILES (through March 1981)

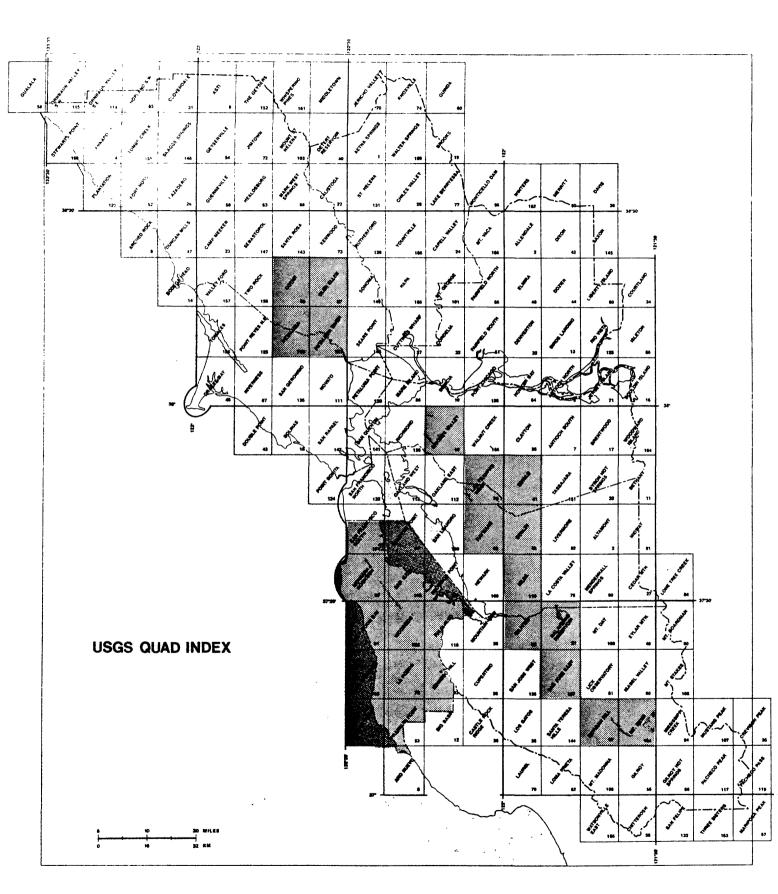
#### RAINFALL-INDUCED LANDSLIDE SUSCEPTIBILITY

The coverage of this map file has been increased to include fifteen quadrangles in the Petaluma and East Bay ridgelands areas. In addition, the factors contributing to the susceptibility model have been increased to include slope aspect, average annual precipitation, and vegetation.

# EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY

The coverage of this map file has been increased to include fifteen quadrangles in the Petaluma and East Bay ridgelands areas.

More information on both of these files is contained in Working Paper #11. Coverage should increase for both of these files for fifteen additional quadrangles in the central urban portion of the Bay Area by January 1982. The maximum ground shaking intensity and risk of ground shaking intensity maps are scheduled for revision in June 1981.



AREAS FOR WHICH DETAILED BASIC DATA MAPS AND HAZARD MAPS ARE AVAILABLE

# MAP FILE APPLICATIONS (revised March 1981)

As of March 1981, these map files can be manipulated for four different types of applications:

- o local general plans
- o computer assisted environmental assessment
- o production of composite hazard maps and site screening
- o assessment of current projected property and population at risk

Each of the following sheets consists of five major sections describing various aspects of the applications on the front and a sample of an application product on the back. The five sections include:

- o Coverage the area of the region covered (including a map) and the resolution of the data
- o Source files a list of the basic data map files and the hazard map files used
- o Description of product
- o Further information on this file is contained in a list of the working papers further describing the map application
- o Limitations and future plans limitations in coverage or accuracy are described, together with future plans to improve ABAG's ability to produce the products described



#### LOCAL GENERAL PLANS

#### MAP FILE APPLICATION

COVERAGE: All nine Bay Area counties with San Mateo County, Petaluma, and the East Bay ridgelands in more detail

SOURCE FILES: Geology; Faults; Topography; Lándslides; Tsunami Inundation Areas; Dam Failure Inundation Areas; Maximum Ground Shaking Intensity; Risk of Ground Shaking Damage; Liquefaction Susceptibility; Liquefaction Potential; Rainfall and Earthquake-Induced Landslide Susceptibility; Fault Surface Rupture



# DESCRIPTION OF PRODUCT:

One of the appropriate ways to use the mapped information is for identifying hazardous areas in a safety or seismic safety element of a local general plan. The latest State General Plan Guidelines for these elements recommend having several maps, most of which are available through ABAG's earthquake hazard mapping work. The table on the back of this page lists those maps available through ABAG that are recommended in the State Office of Planning and Research Guidelines. The cost of these maps depends on the quantity ordered and the map scale specified.

# FURTHER INFORMATION ON THIS FILE IS CONTAINED IN:

o Working Paper #12: Ordering and Using Earthquake Hazard Maps in Local General Plans

# LIMITATIONS AND FUTURE PLANS:

Most maps are available for the entire region. However, the slope, slope aspect, landslide, landslide susceptibility and composite maps are only available for San Mateo County, the Petaluma area and the East Bay ridgelands at this time.

# COMPUTER ASSISTED ENVIRONMENTAL ASSESSMENT



# MAP FILE APPLICATION

COVERAGE: All nine Bay Area counties with San Mateo County, Petaluma, and the East Bay Ridgelands in more detail

SOURCE FILES: Geology: Faults: Topography: Landslides: Tsunami Inundation Areas; Dam Failure Inundation Areas; Maximum Ground Shaking Intensity: Risk of Ground Shaking Damage: Liquefaction Susceptibility: Liquefaction Potential; Rainfall and Earthquake-Induced Landslide Susceptibility; Fault Surface Rupture



March 1981 Hectare resolution

# DESCRIPTION OF PRODUCT:

This application will produce a background document for development proposals that can be incorporated into the Environmental Impact Report (EIR). This document currently has eleven parts, each focusing on a different social or environmental concern. The part dealing with earthquake hazards is "Geology and Soils--Hazards and Resources". Each section, including the one on geology and soils. contains three parts--setting, impacts, and mitigation. The setting section contains information on five data items: topography, faults, landslides, geologic materials, and soil associations. The impacts section contains information on: rainfall-induced landslide susceptibility, earthquake-induced landslide susceptibility, liquefaction potential, tsunami inundation areas, dam failure inundation areas, maximum earthquake intensities, and earthquake intensity damage and risk. The mitigation section would include those items to be required of the developer by the city or county, including requirements for further study. An extensive list of possibilities is contained in Working Paper #13. The information for each section is presented on a single page. A copy of the impacts section for a hypothetical development is reproduced on the back of this sheet.

#### FURTHER INFORMATION ON THIS FILE IS CONTAINED IN:

o Working Paper #8: Earthquake Map Applications for Automated Environmental Impact Assessment

o Working Paper #13: Automated Environmental Impact Assessment An Update

#### LIMITATIONS AND FUTURE PLANS:

At the present time, because of the limited coverage of the topography, landslide, and landslide susceptibility files, a complete report can be produced only for San Mateo County, Petaluma and its vicinity, and the East Bay ridgelands. The coverage will be expanded to include fifteen urban 7-1/2 minute guadrangles of high development potential in 1981 and early 1982. The file also could be expanded should a city or county request the service and provide funds for file development.

```
* SWEENEY RIDGE: AUTOMATED ENVIRONMENTAL IMPACT ASSESSMENT *
          GEOLOGY AND SOILS - HAZARDS AND RESOURCES
                           -----
                           IMPACTS
MAXIMUM EARTHQUAKE INTENSITY
                          AREA (HECTARES)
    A (4) - VERY VIOLENT
                                  0.
    3 (3)-VIOLENT
                                  35.
                                 63.
    C (2)-VERY STRONG
    D (1)-STRONG
                                 242.
    E (n)-WEAK
                                 101.
        NEGLIGIBLE
                                  0.
RISK OF DAMAGE
    EXPECTED RISK OF GROUND-SHAKING DAMAGE
     FOR BUILDING TYPES PROPOSED FOR SITE
   CESTIMATE BASED ON STATISTICAL PROCEDURES
    USING MAJOR FAULT EARTHQUAKE RECURRENCE
    INTERVALS AND AVERAGE BUILDING DAMAGE)
                           AREA (HECTARES)
                    HOOD FRAME
                                                      TILT-UP
 PRESENT VALUE OF
                                   CONCRETE/STEEL
 PERCENT DAMAGE
                                     BUILDINGS
                                                      CONCRETE
                    DWELLINGS
                                                      343.
  0.0-1.0% MODERATE
                         442.
                                       406.
                          0.
                                        34.
  1.1-2.0%
                                                       63.
                                         2.
                                                       21.
  2.1-3.01
                           0.
  3.1-4.0%
                           0.
                                         0.
              HIGH
                                                       13.
  4.1-5.0%
               .
                           0.
                                          0.
                                                        2.
                                                        0.
  5.1-6.0%
                           0.
                                         0.
     >5.0% VERY HIGH
                                                        U.
                           0.
LIQUEFACTION POTENTIAL
                          AREA (HECTARES)
        VERY LON
                          442.
                            0.
                            0.
                            0.
          LON
                           0.
                            0.
        MODERATE
SLOPE STABILITY
   RAINFALL-INDUCED
   LANDSLIDE SUSCEPTIBILITY
                         AREA (HECTARES)
         STABLE
                          112.
                          316.
                            0.
                            0.
                            0.
                           0.
        UNSTABLE
                           14.
   EARTHQUAKE-INDUCED
   LANDSLIDE SUSCEPTIBILITY
                          AREA (HECTARES)
         STABLE
                          294.
                           95.
                           21.
           ٠
        JNSTABLE
TS INAMI INUNDATION AREAS
                          AREA (HECTARES)
         INSIDE
                           ο.
        JUTSIDE
                         447.
DAM FAILURE INUNDATION AREAS
```

AREA (MECTARES)

442.

DUT OF DAM THUNDATE



#### COMPOSITE HAZARD MAPS AND SITE SCREENING

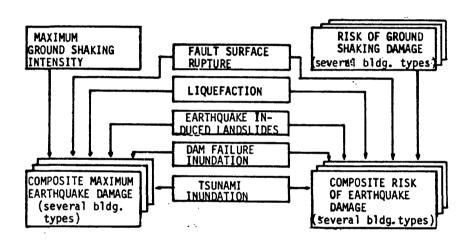
# MAP FILE APPLICATION

COVERAGE: All nine Bay Area counties with San Mateo County, Petaluma, and the East Bay ridgelands in more detail

SOURCE FILES: Maximum Ground Shaking Intensity; Risk of Ground Shaking Damage; Fault Surface Rupture; Liquefaction Susceptibility and Potential; Earthquake-Induced Landslide Susceptibility (and Potential when available); Tsunami Hazard Areas; and Dam Failure Hazard Areas



#### DESCRIPTION OF PRODUCT:



An example of a composite map appears on the reverse of this sheet. Uses for these maps are described in Working Paper #14.

# FURTHER INFORMATION ON THIS FILE IS CONTAINED IN:

o Working Paper #9: Earthquake Map Applications for Composite

Earthquake Hazard Mapping

o Working Paper #11: The Method Developed to Extend Detailed Map

Information Beyond San Mateo County to Selected

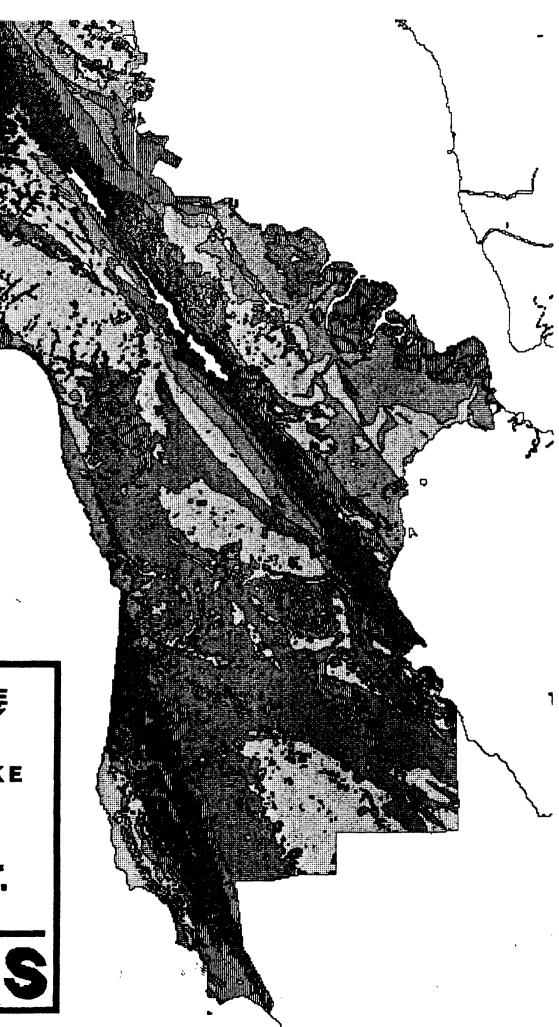
Areas of Significant Development Pressure

o Working Paper #14: Using Earthquake Hazard Maps for Site Screening

and Anticipating Mitigation Benefits and Costs

# LIMITATIONS AND FUTURE PLANS:

Any composite maps that are produced at this time have two limitations. First, the landslide susceptibility file is only available for part of the region. Second, the lack of information on landslide opportunity in earthquakes makes the production of a landslide potential map impractical. The current data on damage associated with both landslides and liquefaction make composite maps only a rough estimate of areas that are relatively safe.



COMPOSITĘ MAXIMUM EARTHQUAKE DAMAGE

WITHOUT DAM FAILURE

BASIS



# ASSESSMENT OF CURRENT AND PROJECTED PROPERTY AND POPULATION AT RISK

#### MAP FILE APPLICATION

COVERAGE: All nine Bay Area counties with San Mateo County more detail

**SOURCE FILES:** This application can use any of the basic data map files or hazard map files together with the land use jurisdiction and census tract files.



March 1981 Hectare resolution

# **DESCRIPTION OF PRODUCT:**

This application can produce tables of the amount of land in each hazard category on each hazard map file by:

- o Census tract
- o City sphere of influence
- o County
- o Land use

An example of one of these types of tables is reproduced on the back of this sheet. Census tract data has been disaggregated by using the land use data to produce statistics on population at risk. Comparisons of existing and projected risk in San Mateo County have been made and indicate that areas of high potential for development are less hazardous than existing developed areas.

#### FURTHER INFORMATION ON THIS FILE IS CONTAINED IN:

o Working Paper #10: Earthquake Map Applications for

Automated Assessment of Property and

Population at Risk

o Working Paper #15: Assessment of Current and Projected

Property and Population at Risk - An

Update

# LIMITATIONS AND FUTURE PLANS:

At the present time, the land use file is available only for San Mateo County so some of the more sophisticated applications only can be performed for that area. In addition, the extent of coverage of the data files may limit those areas where tables can be produced.

# AREA (IN HECTARES) FOR CATEGORIES OF MAXIMUM GROUND SHAKING INTENSITY BY JURISDICTION

# SAN FRANCISCO INTENSITY SCALE

MOTOTOTION		3/11/ 11	01101300 1		UNLL	
JURISDIĘTION	∢F	E	<u>D</u>	<u>c</u>	<u>B</u>	<u>A</u>
Cities		-	<u>~</u>	<u> </u>	=	<u> </u>
ATHERTON	0.	0.	573.	711.	10.	0.
BELMONT	0.		785.	711. 283. 427.	21.	9.
BRISBANE	0.	130.	7.	427.	0.	0.
BURLINGAME	0.	0.	123.	342.	638.	114.
COLMA	0.	0.			86.	0.
DALY CITY	0.	161.		677.	746.	572.
FOSTER CITY	0,	0.	0.		72.	6.
HALF MOON BAY	871.		1531.	5055.	548.	0.
HILLSBOROUGH	0.	0.	866.	675.	122.	
MENLO PARK	0.	4.	806.	1494.	698.	0.
MILLBRAE	0.	0.	0.		579.	208.
PACIFICA	0.		0. 1078. 244.	804.	525.	331.
PORTOLA VALLEY	0.	4.	244.	1120.	831.	1108.
REDWOOD CITY	0.	16.	1077.	3137.	1606.	43. 708.
SAN BRUNO	0.	0.	8.	267.	543. 20. 263.	708.
SAN CARLOS	0.	95.	1061.	581.	20.	3.
SAN MATEO	0.	21.	1060.	2203.	263.	10.
SOUTH SAN FRANCISCO	- •	122.	157.	1155.	752.	307.
WOODSIDE	0.	0.	1060.	2107.	1058.	1249.
Counties						
ALAMEDA	39296.	50523.	42469.	25213.	33543.	0.
CONTRA COSTA	54370.	69843.	33027,	13644.		0.
MARIN	8125.	57824.	40531,		9295.	4383.
	141612.	33736.	10281.	9430.	388.	0.
SAN FRANCISCO	21.	1216.	1090.	7643.	388. 2091. 18267.	0.
SAN MATEO	1308.	21422.	36739.	32231.	18267.	6356.
SANTA CLARA	100607,	44197.	87339.	60875.	37206.	4340.
	72112.	93703.	16815.	21528.	11245.	0.
SONOMA	94519.	147883.	88234.	38634.	35104.	6005.
Regional						. :
Total						
BAY AREA	511970.	520347.	356525.	223806.	163667.	21084.

# WORKING PAPERS (revised March 1981)

The working papers referenced in this guide are not automatically included in this document. They can be ordered from ABAG's offices at a small change. This user's guide, complete with all Working Papers, has automatically been forwarded to the planning director in each city and county in the Bay Area.

The available working papers include:

- #1 Faults and Ground Shaking Intensity -- a description of those faults from which significant ground shaking could originate, including source of mapping, length, character of motion, maximum magnitude, maximum intensity, relative slip rate and recurrence intervals for various earthquakes
- #2 Attenuation, Geologic Materials and Ground Shaking -- a description of an attenuation relationship between intensity and distance from faults for a standard geologic material, a method of combining geologic materials into groups with similar responses to earthquake ground shaking, and intensity increments to be added to the standard intensity for each of the seismically distinct groups of geologic materials
- #3 Damage and Ground Shaking Intensity -- a description of how experience from past earthquakes can be used to estimate the damage different types of buildings would experience when subjected to various intensities of ground shaking; also a description of how damage data, the intensity maps, and recurrence interval information can be used to produced maps of risk of ground shaking damage for various building types
- #4 Liquefaction Potential Mapping -- a description of the likelihood of finding cohesionless sediments within a geologic map unit, the likelihood that those sediments (when saturated) would be susceptible to liquefaction, the likelihood of finding those sediments saturated, and liquefaction opportunity (based on recurrence intervals of earthquakes and the distance from various faults at which liquefaction can occur)
- #5 Slope Stability Mapping -- a description of how slope, geology and existing landslides can be used to estimate landslide susceptibility in an earthquake and under more normal circumstances
- #6 Tsunami Inundation Areas -- a description of the data used to develop a tsunami hazard map and of the relative risk associated with tsunamis
- #7 Dam Inundation Areas -- a description of dam inundation mapping and of the relative risk associated with dam failure

- #8 Earthquake Map Applications for Automated Environmental Impact Assessment -- a description of how hazard map files can be used to produce a background document for development proposals that can be incorporated into an Environmental Impact Report
- #9 Earthquake Map Applications for Composite Earthquake Hazard Mapping -- a description of how the various hazard maps can be combined to yield two types of hazard maps of total earthquake-associated damage
- #10 Earthquake Map Applications for Automated Assessment of Property and Population at Risk -- a description of how tables of area in cities, counties, census tracts and land use can be created for each hazard map category, as well as some sample tables with a discussion of the conclusions that can be formed. In addition, the feasibility of disaggregating census tract data on population using land use to create data on population at risk in various hazard categories is discussed.
- #11 The Method Developed to Extend Detailed Map Information Beyond San Mateo County to Selected Areas of Significant Development Pressure -- a description of the process used to select the areas of development pressure, the refinements and extensions of the geology, landslide, and topography files, and the extensions of the intensity maps, landslides susceptibility maps, and composite maps
- #12 Ordering and Using Earthquake Hazard Maps in Local General Plans -- a description of the types of maps available, their relationship to maps recommended for inclusion in local plans by the State Office of Planning and Research General Plan Guidelines, and the scale and form in which those maps are available
- #13 Automated Environmental Impact Assessment An Update -- a description of the revised setting and impacts section and an extensive description of possible mitigation measures
- #14 Using Earthquake Hazard Maps for Site Screening and Anticipating Mitigation Benefits and Costs -- a description of the use of these maps for pointing to areas that should be easier to develop in a safe manner, as well as for warning of the costs associated both with potential damage and with necessary hazard mitigation
- #15 Assessment of Current and Projected Property and Population at Risk An Update -- a description of tabulations of population at risk, rather than land area, the issues surrounding the development of a risk map based on existing building types, comparisons of various methods of estimating earthquake losses, and comparisons of existing and projected risk. San Mateo County is used as a study area.

APPENDIX G

### EARTHQUAKE HAZARDS AND RISK IN THE SAN FRANCISCO BAY AREA\*

by
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## HISTORY OF ABAG'S INVOLVEMENT IN EARTHQUAKE RISK

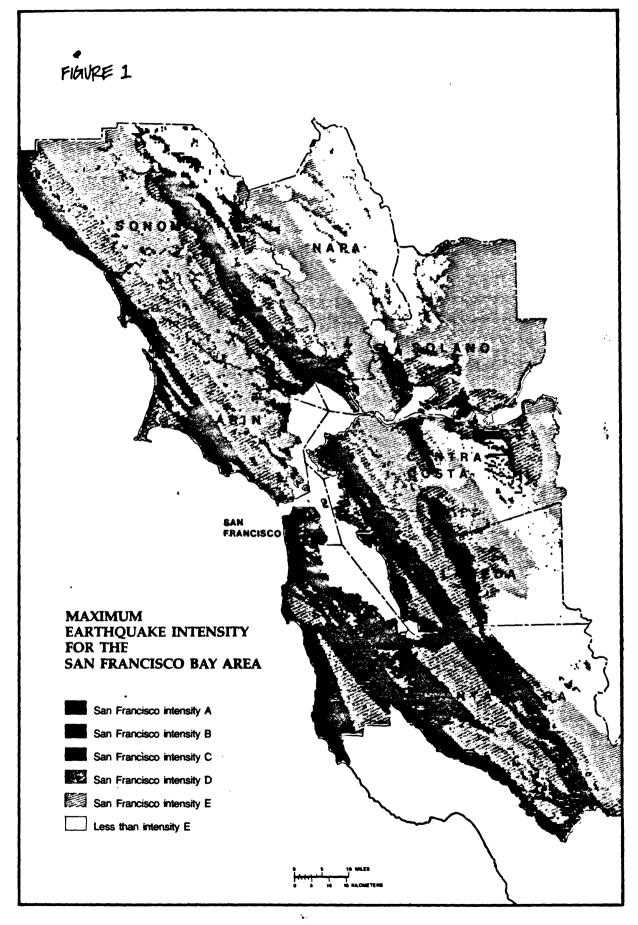
ABAG is the regional comprehensive planning agency for the San Francisco Bay Area. ABAG's involvement in mapping earthquake risk has extended from 1975 when we prepared a report, Quantitative Land Capability Analysis (Laird, et al., 1979) for the U.S. Geological Survey for a study area in Santa Clara County. In attempting to prepare a composite map of all earth science constraints and resources, several ways of comparing what amounts to apples and oranges were examined. We decided to quantify the differences in the categories on the maps as well as the differences between maps using many of the economic techniques used in benefit-cost analyses. The method required that we examine risk from earthquakes both in terms of magnitude of possible damage and in terms of the frequency of damaging events. Also, in the process of identifying statistical damages, we determined that it was important to examine the differences between various building types and land use development types.

<sup>\*</sup> A paper presented at the State Conference of the Association of Environmental Professionals, Asilomar, March 1980.

Several follow-up projects grew out of this work, including one to map earthquake intensity and associated risk for all nine Bay Area counties, resulting in a packet of sample maps, Earthquake Intensity and Expected Cost in the San Francisco Bay Area (Perkins, 1978). This project produced two separate types of earthquake intensity\* maps. A series of intensity maps were produced for twelve faults based on the distance from that fault and corrections for site geology (generalized to six categories). These maps were combined in two ways. First, a maximum intensity map was created by picking the highest intensity for each area from any of the series of individual intensity maps, as shown in Figure 1. This type of map can be used with information on existing buildings to forecast locations of maximum damage for use in planning emergency response measures and for designating areas of critical concern.

Second, a set of four sample, cumulative a somic risk maps were created using data on expected damage for particular types of buildings over time and discounting these cost to their present value. These maps relied on intensity information as well as on information on the amount of damage that can be expected for each intensity and general type of

<sup>\*</sup> Intensity is a measure of effects of earthquakes at a particular place as contrasted with magnitude which is a measure of energy. An earthquake has one magnitude, but several intensities depending on one's location.



building and information on how often a particular earthquake is likely to occur. Figures 2A-D are a portion of each of these risk maps. They indicate the total expected percent damage due to earthquakes in part of the Bay Area for two types of small buildings: wood-frame (Figures 2A and C) and other types more susceptible to damage (Figures 2B and D). The graphic appearance of these risk map is very dependent on how often earthquakes are assumed to occur on each fault. Figures 2A and B use a different set of recurrence intervals than Figures 2C and D. These risk maps may be used in evaluating the relative costs due to earthquakes for new buildings in various locations throughout the region and for designating areas where special precautions may be needed. However, the intensity-cost information is not a sufficient basis for engineering decisions at a specific site, for these require specific knowledge of the process causing damage.

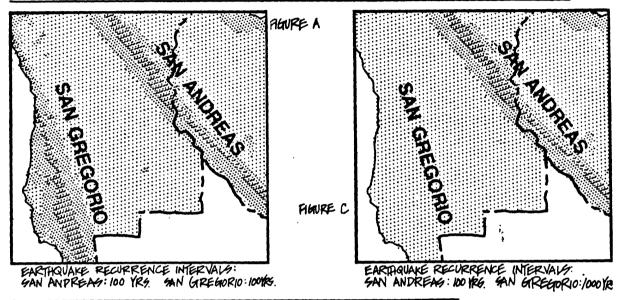
ABAG is now completing a project to refine and update these intensity maps in several important ways by:

- o increasing the resolution of the computer produced maps from a cell that is a quarter square kilometer (500 meters square) to a hectare (100 meters square)
- o increasing the numbers of faults built into the analysis from twelve to thirty
- o refining the effects of geology and increasing the number of geologic units from six to 67

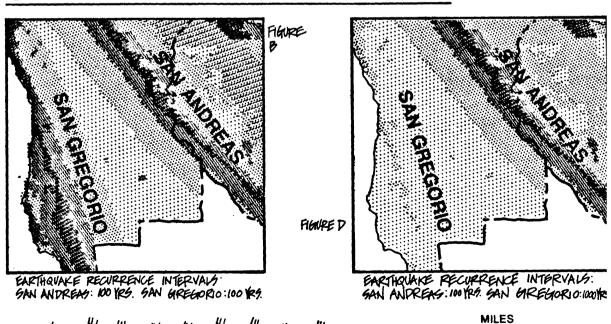
FIGURE 2:

# SAMPLE CUMULATIVE ECONOMIC RISK MAPS FOR EARTHQUAKE DAMAGE

# SMALL WOOD-FRAME BUILDINGS



# OTHER SMALL BUILDINGS



10

KILOMETERS

- or refining the estimates of recurrence intervals using long term rates of slip (determined from the geologic record of tens of thousands of years rather than from the historic record of 200 years
- o examining how the distribution of large and small earthquakes could affect the total risk

In addition, we are expanding the work beyond intensity mapping, which focuses mainly on ground shaking damage, to include other earthquake effects:

- o fault surface rupture
- o earthquake-induced landslides
- o liquefaction
- o earthquake-induced flooding from tsunamis and dam failure

Ways of combining these hazard maps into composite maps of all earthquke hazards are also being examined.

## ISSUES SURROUNDING EARTHQUAKE RISK AND RISK MAPPINNG

In the process of mapping earthquake hazards and risk, several issues surrounding this type of work have surfaced.

First, there are problems in obtaining sufficient technical data about, for example:

- o which faults are active and where they are located
- o how intensity decreases with the distance from the fault
- o how intensity is increased or decreased depending on geology and the location of various geologic units
- o recurrence intervals between damaging earthquakes and the relative numbers of large, moderate and small earthquakes
- o damages associated with different building types for different intensities
- o the relative importance of ground shaking damage and other types of damage
- o how to relate these hazards to non-geologic concerns

These problems with technical data can sometimes seem minor, however, when one has to deal with some of the other issues surrounding risk. For example, calculating the impact of hazard mitigation on risk complicates any mapping. The State law (the Alquist-Priolo Special Studies Zones Act) that is designed to prohibit most building of structures on or near active faults, or city and county requirements to have geotechnical studies done by developers to reduce landslide damage, should reduce the expected cost of damages associated with earthquakes. At the same time, however, these regulations are a cost to developers that increase the initial cost of housing (or other buildings) to consumers.

In addition, there are problems associated with communicating this information to local government staff and elected officials, the main audience for ABAG's work. After we explain intensity and damage, we still have to explain the concepts of probability and, even worse, of discounting future costs of damage to their present value.

Fortunately, most losses in earthquakes are in damage to buildings, where relatively few people are injured or killed. Although traffic engineers routinely assign a dollar value to human life, this concept is disturbing. Such a value could be assigned, or a separate map could be produced showing expected numbers of lives to be lost. Assigning of value to social disruption also is a problem.

A fifth issue is the difficulty of defining acceptable risk. Among other problems, it is viewed differently by different disciplines. As a social or political concept, it means that there is some level of risk that is somehow no longer worth the time or costs (both economic or social) of attempting to reduce further. For something like earthquake risk, the level of risk that is acceptable is different than that of other involuntary hazards. In addition, those who are saving the money by not reducing the risk further also should be those who are subjected to the damage. Traditionally, these decisions are ultimately made by elected officials. Yet the concept is quite close to the legal concept of "reasonableness", that overrides the concepts of liability and immunity for damages for action and inaction. Reasonableness is determined by the circumstances - the foreseeability of the injury, the apparent magnitude of the risk and the relative cost and benefits of action vs. inaction. The concept of acceptable risk also has technical ramifications. There are various grades of risk. But there are also various categories of facilities, for each of which a different level of hazard would be acceptable. Also there are various levels of action.

A final issue is that of the possibility of earthquake prediction. A prediction would completely alter the timing portion of risk assessment and therefore change the level of action viewed acceptable.

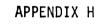
### SOME IDEAS FOR DEALING WITH THESE ISSUES

Although there can be no single way to deal with these issues, two techniques have proved useful. First, the importance of identifying an audience cannot be overestimated. As mentioned earlier, different types of people would find the maximum intensity maps useful than would find the cumulative economic risk maps useful. Also, the amount of problems with communicating information can be reduced if the level of expertise of the users can be determined. Second, the probable use of the information is important. The limitations of the technical data are less important, for example, for a subdivision than for a nuclear power plant. The use is also directly related to the level of acceptable risk.

### REFERENCES

Laird, R.T., Perkins, J.B., Bainbridge, D.A., Baker, J.B., Boyd, R.T., Huntsman, D., Staub, P.E., and Zucker, M.B., 1979, Quantitative Land-Capability Analysis, U.S. Geological Survey Professional Paper 945, 115p.

Perkins, J.P., 1978, Earthquake Intensity and Expected Cost in the San Francisco Bay Area, Association of Bay Area Governments, 12p.



### QUANTIFYING HAZARDS INFORMATION FOR LIFELINES by Jeanne B. Perkins\*

#### **ABSTRACT**

Since 1975, the Association of Bay Area Governments (ABAG) has been using cost-benefit analysis and computer mapping technology to develop quantified information on earthquake and other geologic hazards in the San Francisco Bay Area. This work has provided data for several regional planning programs, and should prove useful to cities and counties, as well. The computer map files currently available include basic maps (such as geology and topography), hazard maps (such as maximum ground shaking intensity, risk of ground shaking damage to various building types, liquefaction potential, and earthquake-induced landslide susceptibility), and composite hazard maps. These map files can be used to provide varied data on lifeline systems: simple overlays, area tabulations of hazard level by lifeline type or link, identification of points of concern on networks, a printout of hazards associated with the location of key facilities, an assessment of development patterns on utility service areas, and estimates of damage.

#### INTRODUCTION

The Association of Bay Area Governments (ABAG) is a regional comprehensive planning agency that is operated by the local governments of the San Francisco Bay Area. It was established in 1961 to meet regional problems through the cooperative action of its member cities and counties.

The Bay Area is one of the most seismically active areas in the United States. The effects of earthquakes also usually cross city and county boundaries. Consequently, earthquake safety is a major regional concern. The activities of ABAG's Earthquake Preparedness Program include developing information to help local governments, reviewing plans and projects, and advocating legislation.

Since 1975, ABAG staff have been using cost-benefit analysis and computer mapping technology to develop quantified information on earthquake and other geologic hazards in the San Francisco Bay Area (1,2,3,). The latest work has been funded in part by the Earthquake Hazards Reduction Program of the U.S. Geological Survey. The mapping and analysis makes extensive use of ABAG's Bay Area Spatial Information System (BASIS), a computer-based system for handling geographic information.

<sup>\*</sup> Regional Planner, Association of Bay Area Governments, Berkeley, CA \_\_ A paper presented at the American Society of Civil Engineers Specialty Conference on the Social and Economic Impact of Earthquakes on Utility Lifelines, San Francisco, May 1980.

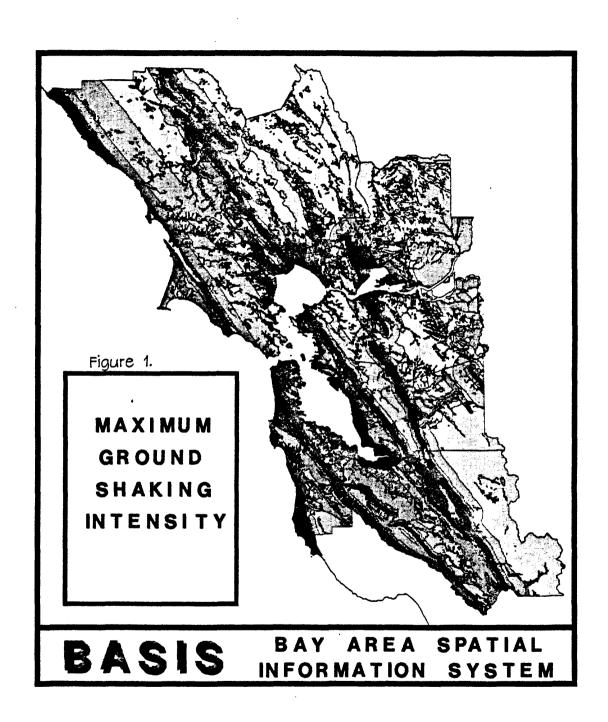
#### AVAILABLE MAPPING CAPABILITIES

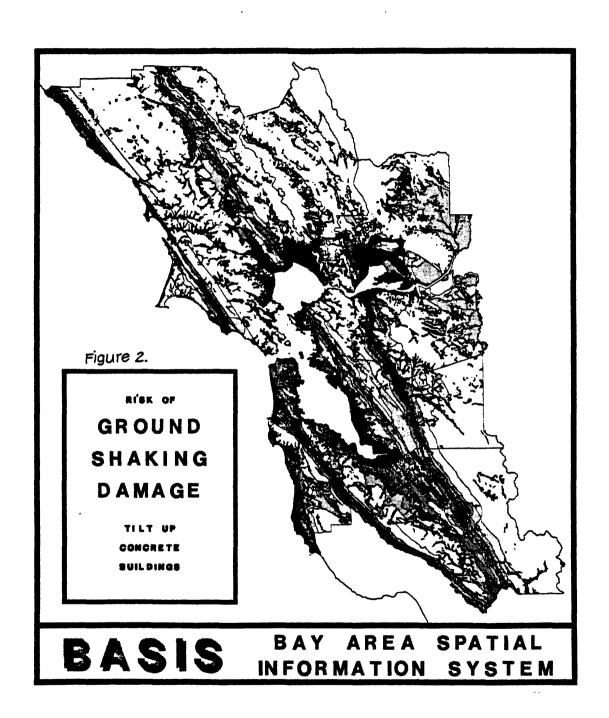
The mapping system contains three different types of map files. The simplest, basic data map files, include such maps as geology, fault traces and study zones, elevation and slope, existing landslides, and tsunami and dam failure inundation areas. These maps are based largely on work of the U.S. Geological Survey and the California Division of Mines and Geology. Map files of social and political boundaries, such as city shperes of influence, counties, census tracts, land use, and zip codes also are available. These files are entered into the system directly, either by digitizing maps or by obtaining existing, machine-readable data sets.

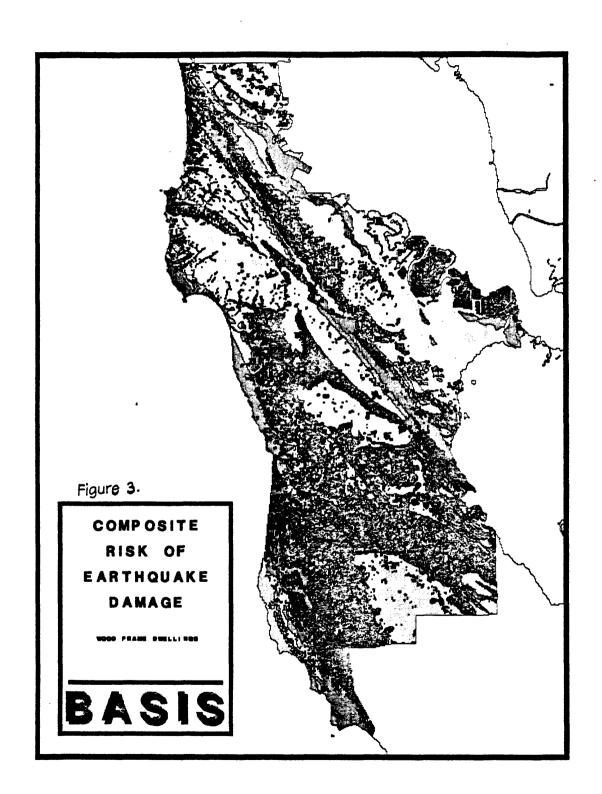
These basic maps can occasionally be converted directly into a second type of map file. Examples are surface rupture and inundation hazards. Usually, however, the maps must be combined using some criteria. The map files of earthquake and related hazards that have been derived to date include maximum ground shaking intensity, risk of ground shaking damage to various building types, liquefaction susceptibility, liquefaction potential, rainfall-induced landslide susceptibility, and earthquake-induced landslide susceptibility. These hazard maps can be combined in turn to create various composite maps, the third type of map file.

The hazard maps themselves can be categorized by type of hazard as well as by means of expressing that hazard. Thus, there are two types of ground shaking intensity maps, maximum ground shaking intensity (Figure 1) and risk of ground shaking damage (Figure 2). (Darker shades indicate greater hazard.) Both types of maps are based on a series of intensity maps derived from information on geology and distance from each fault. However, different criteria are used to combine these intensity maps for individual faults. The highest intensity for each geographic location is used for the maximum intensity map. This type of map can be used with information on existing building types, land use and patterns, and lifelines to forecast locations of maximum damage for use in planning emergency response measures and for designating area of critical concern.

The maps illustrating risk of damage can relate the expected damage to particular types of buildings over time. For these maps, the categories on the intensity maps for individual faults are assigned values based on the anticipated damage in a major event. These values can then be multiplied by the probable frequency that such an event will occur to determine the average annual damage. That value can be discounted to obtain the present value for the damage. Since the series of individual intensity maps now consists of an array of numbers, these values can be summed for all the maps to create an overall map of risk of ground shaking damage. Because damage is related to building type, a separate risk map needs to be produced for each building type of interest. To date. ABAG has produced such maps for three building types: tilt-up concrete buildings (Figure 2), concrete and steel frame buildings, and wood-frame dwellings. The maps present risk information inherent in a geogrpanic location; they are in no way based on the existing buildings located there. Risk maps may be used in evaluating the relative costs due to earthquakes for new developments in various locations throughout







tne region and for designating areas where special design precautions may be needed. However, the intensity-cost information is not a sufficient basis for engineering decisions at a specific site, for these require specific knowledge of the process causing damage.

Similarly, one can produce two types of composite maps of earthquake nazards, one which is the sum of the damage from the most destructive earthquake (Figure 3 for San Mateo County), and a second type which builds in the concept of recurrence interval.

Assigning numerical values to the categories on the various map files based on cost therefore allows the maps to be combined in a variety of meaningful ways. It has a second important use. Any microzonation map, though a representation for the earthquake problem, cannot by itself represent the problems due to all geologic constraints, let alone all environmental social or economic constraints. By relating each of these concerns to some common denominator, such as cost, one can effectively compare the concerns and devise cost effective mitigation measures.

### USING MAPPED INFORMATION TO ASSSESS LIFELINE SYSTEMS

These maps are useful in assessing the earthquake hazards associated with various lifeline systems: the networks, key facilities, and service areas. The simplest technique for using the hazard maps would be to overlay them with maps showing the location of lifeline networks. Given the number of lifelines and hazards, as well as the size of the Bay Area, such a process can become cumbersome. Other methods to use the maps become available if geographic information on each of the lifeline systems is entered into a computer-based system as separate basic data map files.

One technique is to produce area tabulations of hazard level by type of lifeline networks for particular areas of interest or by lifeline link. Although ABAG has not produced such tabulations for all utility networks, the tabulations have been produced for various land use types in San Mateo County. One such land use category consists of transportation, communication, and utilities. Tables 1 through 4, below, are the result of performing these area tabulations for four hazards and six types of lifelines or related systems: highway rights-of-way, railway rights-of-way, airports, port facilities, sewage treatment facilities, and power transmission lines. Although not all of these are utility lifelines, all six can be treated similarly. information has at least two limitations. Because these facilities are part of a general land use map file, only utilities with relatively wide area requirements are shown. Pipeline systems, because they are narrower than the resolution of the system, cannot be shown. addition, the tables can only provide general data within a broad area for each lifeline type. To point out the hazard location more comletley, the lifelines must be subdivided into segments, or links, from one major junction to another. Although ABAG has not performed such detailed analysis to date, it hopes to investigate the analysis of links, at least for the highway network, within the next one to two years.

# TABLE 1 - AREA (IN HECTARES) FOR CATEGORIES OF MAXIMUM GROUND SHAKING INTENSITY BY LAND USE TYPE

TRANSPORTATION	SAN FRANCISCO INTENSITY SCALI				ALE	
AND UTILITY TYPE	ΚE	E	D	. С	В	Α
HIGHWAY	· 5	33	112	<b>5</b> 65	394	123
RAILWAY	0	3	12	170	27	1
AIRPORTS	0	0	4	147	784	1
PORT FACILITIES	0	0	0	8	0	0
POWER TRANSMISSION	0	4	1	80	<b>68</b>	6
SEWAGE TREATMENT	0	0	0	22	7	3

# TABLE 2 - AREA (IN HECTARES) FOR CATEGORIES OF LIQUEFACTION SUSCEPTIBILITY BY LAND USE TYPE

TRANSPORTATION AND UTILITY TYPE	VERY LOW	LOW	MOD.	HIGH	VERY HIGH
HIGHWAY	489	99	631	13	0
RAILWAY	24	5	184	0	0
AIRPORTS	5	127	803	1	0
PORT FACILITIES	0	0	8	0	0
POWER TRANSMISSION	10	2	82	65	0
SEWAGE TREATMENT	5	0	26	1	0

# TABLE 3 - AREA (IN HECTARES) FOR CATEGORIES OF EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY BY LAND USE TYPE

TRANSPORTATION AND UTILITY TYPE	LOW	MOD. Low	MOD. HIGH	HIGH
HIGHWAY	785	230	173	35
RAILWAY	198	11	0	0
AIRPORTS	931	5	0	0
PORT FACILITIES	8	0	0	0
POWER TRANSMISSION	155	4	0	Ō
SEWAGE TREATMENT	26	3	3	0

# TABLE 4 - AREA (IN HECTARES) FOR CATEGORIES OF DAM FAILURE INUNDATION BY LAND USE TYPE

TRANSPORTATION AND UTILIITY TYPE	WITHIN	OUTSIDE
HIGHWAY	102	1124
RAILWAY	15	194
AIRPORTS	0	936
PORT FACILITIES	0	8
POWER TRANSMISSION	50	109
SEWAGE TREATMENT	3	29

A second technique for providing hazard data for lifeline networks is to produce a new map highlighting only those portions of the utility net located in areas exceeding some hazard level set by the user. Again ABAG hopes to investigate his method of identifying points of key concern in the future. The data may be appropriate, for example, in highlighting key areas for utility retrofitting projects.

A third technique involves the presentation of the hazard data for certain critical facilities in the lifeline system. Examples include solid waste disposal sites, sewage treatment plants, airports, and seaports. ABAG has been involved in three projects that required the development of such a site file for hazard as well as other concerns: one for vacant industrial lands, a second for potential seaports, and a third for existing solid waste disposal sites. In addition to the printout of nazard level for individual sites, all three involved a screening program where those sites passing or failing specified criteria, perhaps related to hazards, could be listed in a printout. ABAG also is involved in developing an automated environmental assessment system for flagging hazards associated with new, largely residential, development. This type of analysis could be adapted to assess the hazards associated with existing or proposed critical lifeline facilities. Table 5, below, is an example of one section, "Impacts", in such a report for a solid waste disposal site. Care must be taken when using this type of data, however. As stressed earlier, much of the map data though suitable for indicating possible hazards, are not specific enough to be used for facility design or seismic review.

A fourth technique involves an analysis of the utility lifeline service areas and sub-areas. If particular portions of a network or key facilities are located in hazardous areas, the characteristics of their service areas can be examined to indicate, for example, the residential population affected. Census tract data must be a key part of this type of analysis.

Finally, with information on average extent of damage for various parts of the lifeline systems for the different levels of hazard, one can make some educated estimates of total damage.

#### SOME CONCLUSIONS

Cost-benefit analysis and computer mapping technology can be used to develop quantified information on earthquake hazards that is useful in assessing the impact of major earthquakes on utility lifelines. Although the major applications of this data by ABAG have focused on buildings, not utility lifeline systems, many of the techniques developed can be converted to assessing lifelines. ABAG is considering developing some specialized techniques for lifeline analysis.

### TABLE 5

#### GEOLOGY AND SOILS - HAZARDS AND RESOURCES ---**IMPACTS** LIQUEFACTION POTENTIAL SLOPE STABILITY RAINFALL-INDUCED AREA (IN HECTARES) LANDSLIDE SUSCEPTIBILITY LOW 0 AREA (IN HECTARES) ٠ 0 STABLE TO 61 37 0 \* 0 0 24 0 HIGH ٥ • 0 DAM FAILURE INUNDATION AREAS UNSTABLE DAM ٥ AREA NONE EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY AREA (IN HECTARES) STABLE 61 \* ٥ 0 MAXIMUM EARTHQUAKE INTENSITY UNSTABLE 0 AREA (IN HECTARES) (4)-VERY VIOLENT TSUNAMI INUNDATION AREAS (3)-VIOLENT 24 AREA (IN HECTARES C (2)-VERY STRONG 37 INSIDE (1)-STRONG 0 E (D)-WEAK DUTSIDE 61 Ð NEGLIGIBLE \*\*\*EARTHQUAKE INTENSITY -- DAMAGE AND RISK\*\*\* FAULT MAXIMUM RECURRENCE AVE. INTENSITY MAGNITUDE (IN YEARS) FOR AVE. ROCK SAN ANDREAS 8.4(7.2) 1000(100) E 300(100) CALAVERAS 7.3(6.7) E SAN GREGORIO 7.1 500 Ε HAYWARD 6.9 200 Ε CONCORD/GRN. VAL. 7.0 200 E HEALDSBURG/ROD. CR. 6.8 E 200 MAACAMA 7.1 300 +++INTENSITY INCREASES (OR DECREASES) FOR GEOLOGIC MATERIALS ON SITE+++ BAY MUD 2.9 ARTIFICIAL FILL 1.5

\*\*\*\*EXPECTED DAMAGE (PER EVENT) AT VARIOUS INTENSITIES FOR \*\*\*\*

\*\*\*BUILDING TYPES PROPOSED FOR SITE\*\*\*

Intensity

Building Types

• • • •	F110711	
		WOOD-FRAME
A	(4)	16 X
8	(3)	12 %
C	(2)	5 X
D	(1)	2 1
E	(0)	0.2%
	₹E	0 x

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- 1. ABAG, 1978, Maximum Intensity and Expected Cost in the San Francisco Bay Area, 12 pp. and 5 map plates.
- 2. ABAG, 1979, Quantified Land Capability Analysis, U.S. Geological Survey Professional Paper 945, 115 pp.
- 3. ABAG, 1980, A Guide to ABAG's Earthquake Hazard Mapping Capability, 50 pp.