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Engineering Geology at the Local Government Level: Planning, Review, and Enforcement

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ABSTRACT

City and county governments are increasingly using geologic data and interpretation in land-use decisions. Local governments in at least five states have hired City or County Geologists to supplement State Geological Survey support for land-use planning, development review, and ordinance enforcement. Geologic input to long range land-use planning occurs within local Master Plans and Policy Plans. Agency review of pre-development geotechnical reports is becoming more common and more crucial, as local governments require more detailed data, and as projects involving marginal lands become more expensive. Ordinances regulating land-use activity in geologic hazard or mineral resource areas, typically written by non-geologists, often mandate special geologic investigations or restrict development options. Consultants should become more aware of the planning, review, and ordinance enforcement processes within local governments. The author draws upon his experience as County Geologist of metropolitan Jefferson County, Colorado, to describe the internal processing of geologic data within a local government.

INTRODUCTION

Geologic data have traditionally been applied to local land-use planning during the development phase, addressing such concerns as unfavorable geologic conditions at particular sites. A newer trend in some regions is application of geologic data earlier in the planning process, so that geologic conditions over large areas can form part of the basis for future land-use decisions. Lands containing unusually favorable or unfavorable geologic conditions can be identified and thereafter managed differently from other areas. Land uses compatible with the particular constraints on the land are encouraged by various administrative actions, and inappropriate uses are likewise discouraged.

At the local government level geology is applied to land-use controls in three stages. First, review of the geologic and hydrologic setting of proposed developments is typically required whenever rezoning or land subdivision is involved. Potential geotechnical problems are identified at this stage and the feasibility of mitigating measures is assessed. Secondly, geologic data are applied to long range planning via technical inputs to the local Master Plan and various Policy Plans. Thirdly, geologically-related portions of the Zoning Ordinance are drafted and interpreted by either in-house or contracted geological experts.

FRAMEWORK OF GEOLOGIC INPUT IN LOCAL GOVERNMENT

Land-Use Controls of the Local Government

Local governments exercise all land-use controls which are not specifically pre-empted by the state. The most common technique for land-use control is a dual system, involving a Master Plan or Comprehensive Plan to set out desired policy, and a Zoning Ordinance to assure that Master Plan goals are met. State law may charge local governments to develop and implement long range plans for critical areas within their jurisdictions, such as those containing geologic hazards. For example, in Colorado a bill charges counties to identify and regulate areas that contain certain geologic hazards or mineral deposits (House Bill 1041; Colorado Revised Statutes, 1973, Sec. 34-1-101 et seq.). In the foregoing example, the State Geological Survey was also charged to assist local governments in delineating which areas in their jurisdiction contained such hazards or deposits.

The overriding importance of applying geology intelligently to local land-use decisions lies in the immediate impact of those decisions. If platting of a tract is approved one day, earthmoving equipment may be modifying the earth's surface the next day. The local level is the interface where geologic theory is applied to real-world land-use decisions. The cumulative effect of each of these day-to-day decisions results in the physical and cultural environment in which most of us live and work. With geologic information applied judiciously, we can improve that environment, or at least minimize its degradation in the face of inevitable development.

The Geologist's Role Within Local Government

In areas where geologic problems are common some local governments have hired their own full- or part-time geologists. States with local government geologists have several things in common: 1) active geologic processes or unstable geologic conditions, 2) rapid land development, and 3) a relatively sophisticated level of planning. In at least two states a further factor is state legislation delegating responsibility to local governments to identify and manage areas of geologic/hydrologic hazards or mineral resources. Land development regulations which require geologic, soils, and drainage reports on all new subdivisions add to the review workload. If some counties generate a disproportionate number of required reports, the State Geological Survey may encourage a geology position in local government.

A recent poll conducted by the writer confirms that the State Geological Surveys are still the main source of geologic input to local governments (Table 1). Forty-nine percent of responding State Geologists specifically mentioned the active state role in providing local governments with geologic expertise. Such aid comes in the form of technical reviews, workshops for local employees, and availability of publications aimed at solving local geologic problems. Even in states where local government geologists exist, interaction with the State Survey is still important due to the greater depth of geologic expertise at the state level. Twenty percent of responding states described people in local government with geology degrees, but who performed only limited geologic work (e.g., septic site evaluations) for agencies such as the County Health Department or Engineering Department. Counties in five states employ, or have employed, individuals titled County Geologist; although in two of the states (Illinois and Washington) the positions were temporary. Finally, fifteen percent of respondents indicated an active interest in developing formal local geologist positions within their states. One State Geologist stated "it is my professional opinion that each county should have its own geologist who can deal with local environmental, geohydrologic, and other geologically related problems . . . in the future, we may see the employment of county geologists because of the many geohydrologic and related waste disposal problems." (Markewicz, 1982).

Within local government a County Geologist can have major responsibilities in either case review or planning, depending on local priorities. Technical review of geologic, hydrologic, and soils reports usually occurs in two stages. First, a generalized review of the proposed development site occurs during application for rezoning. Secondly, if the rezoning is approved, a more detailed review will cover the actual site plan during the platting process.

Geologic Input to Case Review

Much of the effort of the geotechnical industry today consists of preparing reports which are required, and then reviewed by some level of government. Whether good or ill, this situation is expected to persist. In the past, the mere submittal of such geotechnical reports was often enough to insure project approval. In the writer's opinion this was a result of three factors: 1) the reviewing agency had little time for an in-depth review, 2) the personnel in the reviewing agency were often less technically proficient in some areas than their counterparts in industry, and 3) if the report was not perfectly accurate, the economic or social consequences were not likely to be severe. Within the last ten years these three factors have changed. More time is now

Table 1. *Status of geologic expertise within local governments in the United States.*[1]

State Geological Survey Provides All or Most of Expertise[2]	Have County Geologists	Have City Geologists	Have Planners with Geology Background
CO, FL, GA, IL, IA, KS, KY, ME, MO, MT, NV, NJ, ND, OR, PA, SD, TX, UT, WI	CA (15+)[3] CO (2) IL (2−)[4] WA (1−) UT (3−)[5]	CO (1) MO (1)	FL, MT, ND

Have Geologists Performing Limited Geological Duties	Have Geologists in Regional Planning Commissions	Express Interest in Developing Local Government Geology Positions
CO (3), IL (1), KS (1), MO (1), NV (1), NC (1), WA (1), HI (3)	ME (1), VT (1−)	DE, IA, KY, NJ, WA, WI

[1] Based on responses from 41 State Geological Surveys, April–June 1982.
[2] State names are abbreviated.
[3] Fifteen counties have geologists; total number employed is not available.
[4] ( ) Estimated number of persons occupying position. Minus (−) indicates a temporary position.
[5] Positions authorized January, 1985.

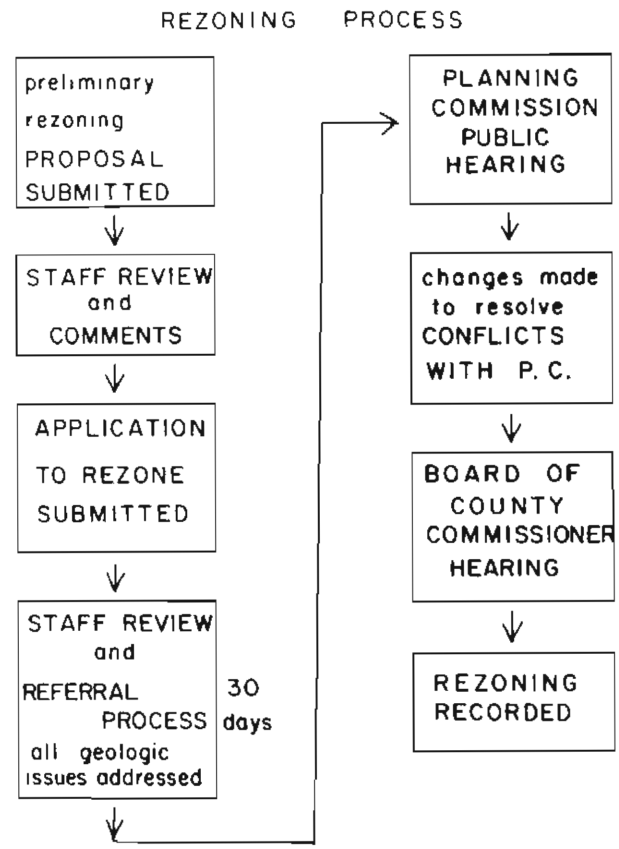

Figure 1. Diagram of a typical rezoning process. Adapted from the Jefferson County Planning Department.

devoted to report review. State and local government agencies have enlarged their staffs, attracting highly skilled personnel. The expensive development projects presently being designed for marginal land situations often rely heavily on engineering mitigation techniques. Inaccuracies in geotechnical data collection and interpretation can often lead to expensive correction measures, or worse, to even more expensive litigation. With this framework in mind it is of interest to describe in detail the technical review process within local governments. The process has two stages: review of a rezoning action, and review of a platting (subdivision) action.

The Rezoning Process

All land that is to be developed must attain the appropriate zoning before development to a higher use-intensity can proceed. A typical rezoning process is diagrammed in Figure 1. The applicant for rezoning must essentially prove that the proposed new land use is compatible with: 1) the physical limitations of the site, 2) with the present surrounding land uses, and 3) with the future orderly development of the region, as set forth in the local Master Plan. Geologic input at this stage mainly concerns the first item, although geologic concerns are also present within the Master Plan.

The rezoning decision is based on whether the *type* of proposed land use is compatible with the parcel, and does not pass judgement on a particular site plan, for none is usually offered at this stage. Consequently, site-specific geologic information may not be available and local review can only be based on existing information sources. Published reports and unpublished data within the local government's own files are scanned to determine if there is any overwhelming geologic impediment to the proposed use. Such an impediment might be defined as a geologic condition or process so adverse that it could not be reliably or economically overcome with existing engineering methods. Active fault zones or large landslide complexes might present such a hazard for a residential subdivision, for example.

Different land uses have varying sensitivities to geologic constraints. What might pose a serious threat to a high-density residential neighborhood may pose little risk to an industrial district. Figure 2 shows a qualititative rating matrix of a type commonly used by planners to assess compatibility of

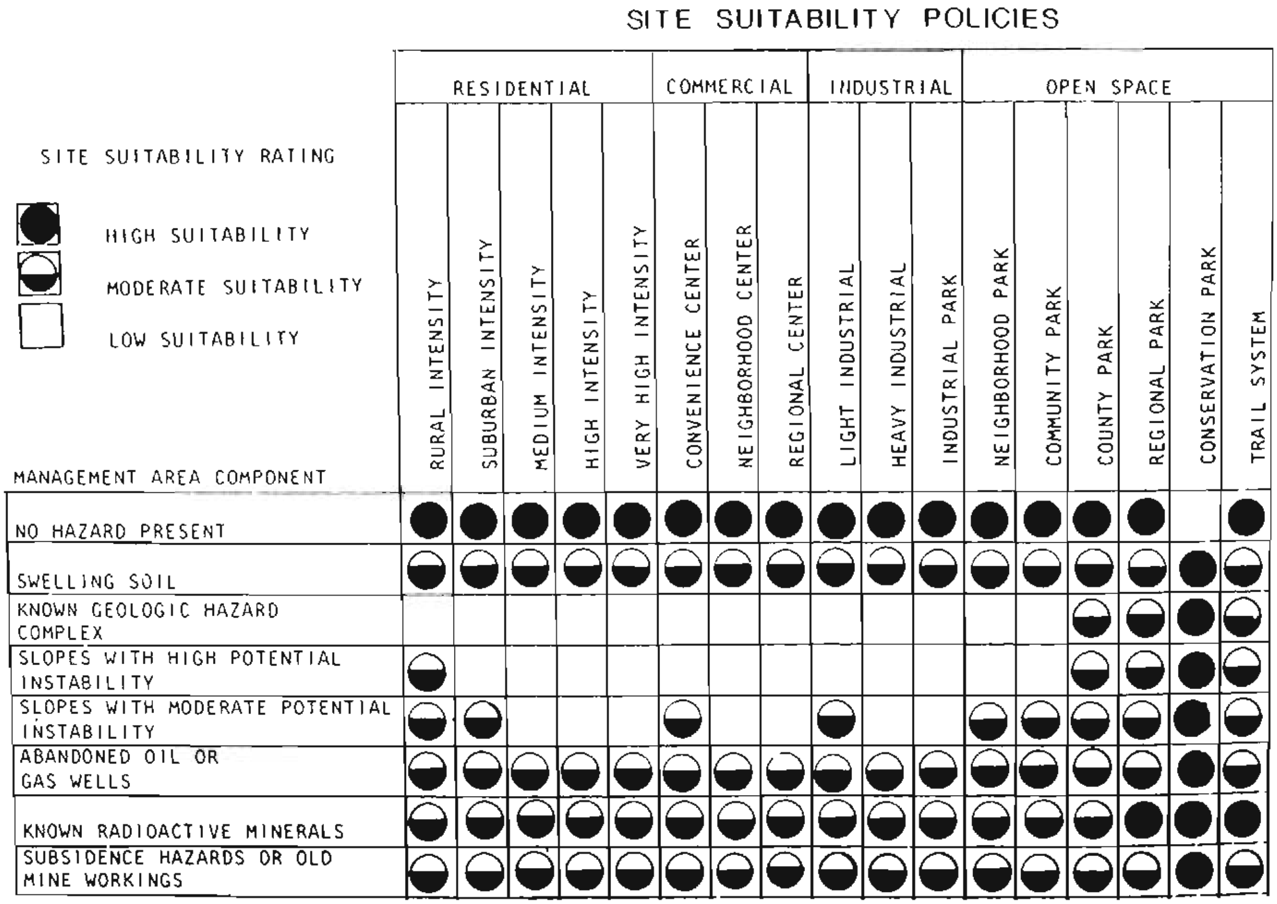

Figure 2. Qualitative matrix system for rating the sensitivity of various land uses (vertical columns) to various geologic constraints (horizontal rows). The moderate suitability category obviously covers a wide range of site-specific situations. Source: Jefferson County Land Use Policy Plan, Phase One-Summary (Jefferson County, Colorado, 1980), p. E4.

certain geologic conditions with various land uses. According to this figure, some geologic conditions (high potential for slope instability) are incompatible with high-density development, whereas others (swelling soils) have moderate to high suitability, depending on the proposed land use.

If no major impediments to rezoning exist (geologic or otherwise) the rezoning may be approved. The developer can then proceed to develop the site plan for construction and legally create lots (platting).

The Platting Process

Procedurally the platting process is more specific and detailed than the rezoning process. For a site plan to be approved, numerous issues such as number of dwelling units per acre, ingress and egress routes, public facilities, utilities, emergency services, and so on must be reviewed. The platting process is outlined in Figure 3. Detailed pre-construction engineering and geologic investigations are made concurrently with site plan preparation. Resulting reports often must be furnished to the local government with full description of the anticipated impacts of the development and any necessary mitigating measures.

A list of pertinent issues and required reports for a subdivision within Jefferson County, Colorado, is shown in Table 2. Geologic consultants are naturally active in preparing geologic, soils, drainage, water supply, and sewage disposal reports. The technical review of platting-stage reports is more detailed than in the rezoning stage, because site-specific data are now available, and because this is the last review phase before approval.

Principal geologic concerns in reviewing site plans will vary across the country due to variations in local geology and in type of development. In the Front

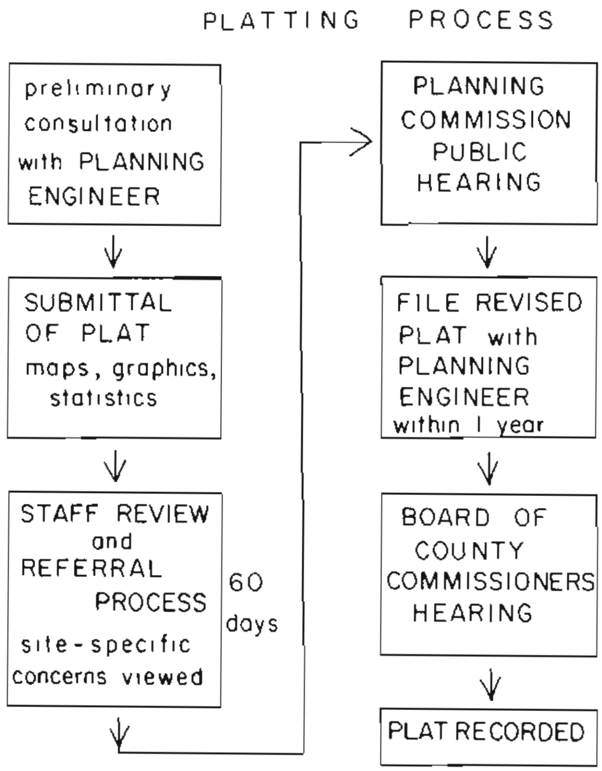

Figure 3. Diagram of a typical platting process. Adapted from the Jefferson County Planning Department.

Range area of Colorado, common geologic hazards include (in approximate order of severity): swelling soils, collapsible soils, unstable slopes, rockfall, subsidence, flash floods/debris flows, and high groundwater tables. As development surrounds and encroaches on previously undeveloped enclaves which were passed over in earlier years because of these geologic constraints, it becomes more likely that newly-proposed sites could have significant problems.

During report review local government staff apply several critiera to determine adequacy. Conceptually, four areas are considered. First, do the reports address completely all issues as required by law? Local land-development regulations can be quite specific as to which geologic issues must be covered. A partial listing from the Jefferson County Land-Development Regulations is given in Table 3. Such requirements serve to guide consultants in determining the minimum necessary scope of their investigations. Site-specific conditions may dictate further work in problem areas. Requirements may vary from area to area depending on the type and severity of geologic problems. A checklist of issues deemed critical for California (Stewart et al., 1977), for example, emphasizes seismic hazards, whereas in Colorado local regulations consider ground failures (landsliding, expansive soils) more important.

Secondly, are the interpretations of site geology reasonably compatible with other published or unpublished geologic data for the area? Failure of a report to mention conditions routinely found in all adjacent areas might be sufficient cause for questioning the report. Where geologic interpretation is critical and report rejection could delay development, it especially behooves local governments to rely on a geologist reviewer rather than on a land-use planner with a limited geologic background.

Table 2. *Specific issue that must be addressed in pre-development reports, and the corresponding required documentation.*[1]

1. Area Grading
   —Grading Plan
2. School and Park Tract Grading
   —Grading Plan
3. Circulation
   —Street and Road Plans
   —Trail Plans
4. Water Supply[2]
   —Central Water Supply Report
   —Individual Water Supply Report
   —Water System Plans
5. Sewage Disposal[2]
   —Central Sewage Disposal Report
   —Individual Sewage Disposal Report
6. Utilities
   —Utility Report and Plans
7. Fire Protection
   —Fire Protection Report and Plans
8. Drainage[2]
   —Drainage Map, Report, Plans
9. Geology[2]
   —Geologic Map, Report, Plans, including bedrock geology, surficial geology, hydrology, and mineral resources
10. Soils[2]
    —Soils Map, Report, Plans
11. Radiation[2]
    —Radiation Map, Report, Plans
12. Sensory Impact
    —Sensory Impact Map, Report, Plans
13. Wildlife, Vegetation and Landscaping
14. Historical, Archeological,[2] and Paleontological Sites

[1] Source: Jefferson County Land Development Regulations (Jefferson County, Colorado, 1981).
[2] Indicates an issue area with significant geologic input.

Table 3. *Geologic topics that must be addressed in geologic reports for platted subdivisions.*[1]

9.2.	Geologic Report: A report as required by 4.2.6. of Section 4. of Part I shall include, if applicable, the following:
9.2.1.	Bedrock Geology:
9.2.1.1.	Rock types present including formation names and ages, if possible.
9.2.1.2.	Bedrock characteristics including, but not limited to the following:
9.2.1.2.1.	Degree of weathering.
9.2.1.2.2.	Erodability.
9.2.1.2.3.	Aquifer characteristics.
9.2.1.2.4.	Susceptibility of landslides, mudflows, rockfalls, creep, subsidence, settlement, slumping, shrink-swell potential.
9.2.1.2.5.	Response to seismic activity.
9.2.1.2.6.	Radioactivity (naturally occurring and man-made).
9.2.1.2.7.	Slope stability in natural and excavated states.
9.2.1.2.8.	Attitudes of planar features in the bedrock such as bedding planes, foliation, joints and faults.
9.2.1.2.9.	Relative ease of excavation.
9.2.1.2.10.	Foundation suitability.
9.2.1.2.11.	Well and septic system suitability.
9.2.1.3.	Cross Sections used to show representative subsurface bedrock relationships.
9.2.2.	Surficial Geology:
9.2.2.1.	Location and description of all surficial materials present including artificial fill utilizing unit names and ages, if possible.
9.2.2.2.	Thickness and distribution of surficial materials utilizing isopach map, if necessary.
9.2.2.3.	Surficial material characteristics including, but not limited to the following:
9.2.2.3.1.	Erodability.
9.2.2.3.2.	Degree of weathering.
9.2.2.3.3.	Aquifer characteristics.
9.2.2.3.4.	Susceptibility to landslides, mudflows, creep, subsidence, settlement, slumping and shrink-swell potential.
9.2.2.3.5.	Response to seismic activity.
9.2.2.3.6.	Radioactivity (naturally occurring and man-made).
9.2.2.3.7.	Slope stability in natural and excavated states.
9.2.2.3.8.	Relative ease of excavation.
9.2.2.3.9.	Foundation suitability.
9.2.2.4	Type and amount of topsoil and existing vegetation.
9.2.2.5.	Cross sections used to show representative subsurface surficial material relationships.
9.2.3.	Hydrology:
9.2.3.1.	Depth to ground water utilizing isopach map, if necessary.
9.2.3.2.	Perched water tables.
9.2.3.3.	Expected seasonal variations in ground water.
9.2.4.	Mineral Resources:
9.2.4.1.	Amount and quality of any mineral resources including but not limited to sand and gravel, quarry aggregate, coal, limestone, mineral fuels (e.g. oil, gas, uranium), metallic resources (e.g. gold, copper) and non-metallic resources (e.g. clay).
9.2.4.2.	Existing mining site or prospects.

[1] Source: Jefferson County Land Development Regulations (Jefferson County, Colorado, 1981).

Thirdly, review seeks to establish whether any mitigating measures proposed by consultants are sufficient to minimize potential adverse impacts. This phase of case review is the most difficult, because it deals with the predictive issue of "what will happen?" rather than the issue of "what is there?" Disagreements arising between reviewers and consultants can often be mediated by a disinterested State or Federal geologist who is a recognized expert in the subject. Alternatively, a trial period or monitoring program may be required as a condition to plat approval. Because a sizeable portion of development costs on marginal land might be tied up in a geotechnical mitigation scheme, a switch from one scheme to another could make development unprofitable. Importantly, local regulations are often worded to place the burden of proof for site safety on the developer.

Fourth, are there internal contradictions within the report? For example, do test data in report appendices support conclusions about material properties used for design purposes? Because the reviewing geologist is usually not present during the drilling phase, he usually has no first-hand knowledge of site subsurface conditions. Hart and Williams (1978) reported that in California, on-site investigations by reviewers occur only if documentation is seemingly erroneous or incomplete. Even in such rare cases a busy reviewing geologist can't spend much time at a site. In practice, much reliance must be placed on consultants to honestly portray site conditions.

Disagreement may also arise concerning the consultant's final conclusions or recommendations. This problem could have several facets: 1) the reviewer believes that not enough basic data are provided in the reports to confirm some conclusions, 2) he makes different interpretations based on published data, or 3) he makes different interpretations based on site-specific data. In the first case the reviewing agency may ask for more data on key issues. In the second and third cases, use of judgement and experience, plus referrals to outside agencies with geologic expertise may result in an acceptable solution.

Geologic Input to Long-Range Planning

The formal application of geology to long range land-use planning (as contrasted to site design) is a fairly recent development. Many works describing geologic contributions to land-use planning suddenly appeared in the late 1960's and 1970's under the broader heading of "environmental geology" (e.g., Nichols and Campbell, 1969; Flawn, 1970; Turner and Coffman, 1973; Wermund, 1974; Robinson and Spieker, 1978; Howard and Remson, 1978; and Utgard et al., 1978). Simultaneously, some state governments adopted laws dealing with environmental concerns. The wording of such laws in Colorado was developed from input by the State Geological Survey with help from citizen's task forces. However, implementation (and, inevitably, interpretation) of such statutes was left to local governments under their existing land-use control powers. Geologic concerns in long range planning therefore were codified within an existing framework of local regulations, consisting mainly of a Master Plan, Policy Plans, and a Zoning Ordinance.

The Master Plan

The guiding policy document for local land-use decisions in most areas is called the Master Plan. The Plan combines the input of individual citizens and task forces with staff reports compiled by planners to identify what trends are deemed desirable in future land use. Within the Plan goals are set and then policies are suggested which will most likely help to achieve those goals. For a development project subject to geologic constraints such policy-oriented planning means that elimination of problems is the goal, but the method is left in large measure to the discretion of the developer.

Geologic input to Master Plan policies has traditionally come under three broad headings: 1) natural hazards, 2) water quality and quantity, and 3) mineral resources. Natural hazards may be further subdivided into geologic, seismic, or hydrologic hazards. Two recent publications (Shelton and Prouty, 1979; Hays, 1981) provide useful summaries of natural hazards for planning-oriented audiences.

Water quality and quantity must be protected from several deleterious natural and human processes. Construction accompanying development often increases local runoff and sediment yield, decreasing surface water quality. Decreased recharge due to paving combines with increasing ground-water withdrawals to lower water tables or potentiometric heads. Individual sewage disposal systems, if not properly located or maintained, can decrease ground-water quality.

Mineral resources planning represents a positive element within Master Plans. Rather than avoiding a hazard, planners seek to identify and conserve mineral reources which might otherwise be lost to urban development. Industrial minerals such as sand and gravel, quarry aggregate, and limestone are commonly mined in or near urban areas. More rarely, coal, lignite, oil shale, uranium, or metallic minerals may occur in developing areas.

Decisions on land-use changes by the Planning Commission or Board of County Commissioners will usually be based on the degree of conformance to policies of the Master Plan. The more non-conforming issue areas occur within a site plan, the smaller is the chance for rezoning or platting approval. In geologic matters it is the consultant's responsibility to correctly anticipate geologic constraints and to devise the best solution to overcome unfavorable conditions. The local government may assist in problem solution by identifying approved mitigation measures (Site Development Policies, see next section) which have been used successfully in the past.

Policy Plans

Policy Plans define policy within specific issue areas in more detail than does the Master Plan. As a rule, Policy Plans have no regulatory or enforcement authority, but serve as working guides for planning staff in their daily activities. However, because such plans may be officially adopted by the Board of Commissioners, the suitability of developments with marginal conformance to Master Plan policies may be referenced to Policy Plan guidelines. Therefore, consultants should be familiar with any existing local Policy Plans that involve geologic subjects.

The components of Policy Plans in the Jefferson County, Colorado, system are Goals, Site Suitability Policies, and Site Development Policies. Goals state in general terms what results are sought within subareas of any issue. Site Suitability Policies set out those factors which might make a site particularly suitable (or unsuitable) for a specific type of land use. Site Development Policies are actions or tech-

Table 4. *Relevant sub-areas within the issue area of Mineral Extraction, from a typical Policy Plan Document.*[1]

1. Visual Impact	9. Historic Sites
2. Air Quality	10. Geologic Sites
3. Noise Pollution	11. Site Safety
4. Water Quality	12. Blasting Safety
5. Water Quantity	13. Truck Traffic Safety
6. Vegetation	14. Reclamation
7. Wildlife	15. Economic Issues
8. Archaeologic Sites	

[1] Source: Jefferson County, Colorado, Mineral Extraction Policy Plan (Jefferson County, Colorado, 1977).

Table 5. *A typical hierarchy of goals, suitability and development policies from a Policy Plan.*[1]

Goal 10: Preserve and protect significant geologic sites.*
Site Suitability Policy

Policy 10.1—The suitability of an area for mineral extraction should conform to the following guidelines with respect to significant geologic sites:

Contains no significant geologic sites—high suitability
Contains significant geologic sites
 a. Culturally significant landforms—low suitability
 b. Dinosaur fossils—low suitability
 c. Unusual mineral accumulations—low suitability

Site Development Policy

Policy 10.2—Significant geologic sites that are encountered during a mining operation should be preserved.

* A significant geologic site is a site which contains; (a) a culturally significant landform, (b) dinosaur fossils, or (c) unusual mineral accumulations. Culturally significant landforms are natural features having an historic or visually pleasing characteristic and have been used historically as a geographic landmark. Such areas include colorful or unique outcrops, mountain fronts, table mountains, and hogbacks. Dinosaur fossil localities are primarily footprints left in the Morrison Formation along the flanks of the hogbacks. Unusual mineral accumulations are sites that contain minerals such as fluorite, mica, quartz, feldspar, beryl, etc. which are present in such large quantities or which have such spectacular crystal development as to be scientifically or culturally significant.

[1] Source: Jefferson County, Colorado, Mineral Extraction Policy Plan (Jefferson County, Colorado, 1977).

niques which can upgrade a site for a particular use, thus increasing its suitability.

As an example, the Jefferson County Mineral Extraction Policy Plan (MEPP) breaks the larger area of mineral extraction into 15 impact sub-areas (Table 4), and then analyzes each of the sub-areas in detail. Within each sub-area goals are identified, suitability policies are formulated, and development policies are adopted. Table 5 shows a typical hierarchy within the sub-area of impacts on significant geologic sites. The wording "should" emphasizes the non-regulatory nature of the MEPP.

Geologic Input to the Zoning Ordinance

The local government Zoning Ordinance is a regulatory rather than a policy document. Although most of the ordinance deals with defining zoning districts and the permitted uses allowed therein, it can also deal with geologic matters. In particular, Zoning Ordinances can be used effectively in administering identified natural hazard areas such as floodplains and geologic hazard zones.

In regulating natural hazard areas a local government has several options. The first is to ignore any problems and hope they will prove unimportant. This approach has practical, as well as legal, shortcomings. A second option is to deal with development requests in any hazard areas as part of the regular case review process, and to make development approval contingent on successful mitigation or avoidance of known hazards. One limitation of this approach is that it does not provide advance public disclosure of potentially hazardous conditions. Thus, a parcel could be advertised and sold as "prime" land, and the buyer (a homeowner or developer) could find out only after closing about the hazard, and about serious difficulties standing in the way of development or building permit approval. A third option is to control hazard areas by zoning. Identified hazard areas can be placed in a unique zoning category which imposes restrictions on development appropriate to the nature and degree of hazards existing there. In this option public notice of hazard is given in writing on deeds or property descriptions.

The Geologic Hazard Overlay Zone

A working example (since 1976) of the third option is the Geologic Hazard (G-H) Overlay Zone developed by Jefferson County. The G-H Zone District *overlies* pre-existing zoning; its regulations are *in addition to* those governing the underlying zone district. The purpose of the G-H Zone is to insure that development be prohibited in such areas unless it can be proven that the hazard does not actually exist, or has been successfully mitigated. In areas so zoned, the burden of proof rests on the developer to show that his development does not, and will not, constitute a danger to public health or safety. Because interest in this form of regulation appears to be increasing nationwide, the G-H ordinance has been reprinted as Appendix A of this article. More detail on the G-H Zone is given by McCalpin (in press).

Engineering geologists may be called in to investigate two general aspects of zoned geohazard areas. First, does the hazard actually exist at the site, is it operative today, and is it limited to the boundaries as shown on zoning maps. State-of-the-art methods will be needed to assess the magnitude, recurrence time, and distribution of processes such as landslides and earthquakes. Detailed sampling and testing may be necessary to define hazardous conditions such as swelling soils. Secondly, can the hazard be mitigated, and if so, what is the most feasible method?

Modification of Zone Boundaries

Regardless of the way hazard boundaries are drawn, eventually there may be an attempt to modify them. A developer may be interested in a tract, but unwilling to develop unless the stigma of G-H zoning is removed. The local government may also initiate changes in zone boundaries based on new data (see Appendix A, Section B.2).

Developer's justifications for zone alteration may fall into two broad categories: 1) the hazard is present within some of the zone, but not in that part that he wishes to develop, or 2) the hazard is present within his parcel, but can be overcome with engineering measures. If the developer proves his contentions, the zone boundary can be pulled back to his property line, thus taking a "bite" out of the zone.

Information presented in support of zone modification can be either the same type of data on which the zoning was originally based, or it may be of a different kind. For example, a zone delineating highly swelling clays may have been originally based on geologic mapping of a formation known to have swelling properties. The zone could either be challenged by proving that the formation does not crop out as indicated on the zoning map (same-kind data), or alternatively, that the unit does crop out as indicated, but that at the particular site the formation does not have swelling properties, based on soil testing (different-kind data).

The repeated modification of zone boundaries by different-kind data may raise some philosophical questions about the legitimacy of how the zones were made. The basis for the Jefferson County zones are published geologic maps at 1:24,000 scale. If later site-specific work of same or different kind can refine the boundaries, such revision should be allowed. In designing a workable geo-hazard ordinance, the section on zone modification should be carefully structured. Too little flexibility will "lock up" land and invite challenges from developers; too much flexibility will undermine the zone's function of protecting the public.

If on-site investigations indicate that the hazard is not present, the developer can apply to have G-H zoning removed from his parcel during the regular rezoning process (Figure 1). If the application is denied, there are several options: 1) proceed with development under the restrictions of G-H zoning, 2) petition the Board of Adjustment for a zoning variance, or 3) abandon the project. If the G-H zone occupies only a portion of the tract, it may be possible to design around it by using the hazardous area as park or open space.

The Mitigation Option

Developers may contend that a mapped hazard does exist within a parcel but that it can be remedied with engineering measures. The hazard may be relatively minor (e.g., expansive soils), in which case standard engineering and construction techniques can probably alleviate the problem. Hazards such as landslides, rockfalls, and debris flows are potentially more serious. Engineered structures to alleviate such hazards may be retaining walls, crib dams, detention structures, or similar works. The regulatory agency is interested in two aspects of engineering solutions: will it work, and is it a permanent or a temporary solution? If the mitigating technique permanently removes the hazard, then rezoning and urban development (which is effectively irreversible) may be justified. Permanent techniques may be the complete removal of a landslide mass, for example. However, many engineering structures must be maintained to be effective, and cannot be strictly considered permanent. A debris basin functions to trap debris flow material only when periodically excavated; if allowed to fill, it may no longer exercise its mitigating function.

The question thus arises: can a temporary mitigation technique serve as sufficient basis for rezoning or platting? Rezoning can be construed as an implicit guarantee by the local government that development is safe, with possible assumption of liability. If the hazard still potentially exists but has been temporarily abated by an engineered structure, one alternative is to allow development to take place within the G-H zone by granting a variance. In this option the parcel remains zoned G-H, thus serving public notice of the hazard potential. The variance would allow development to proceed contingent on

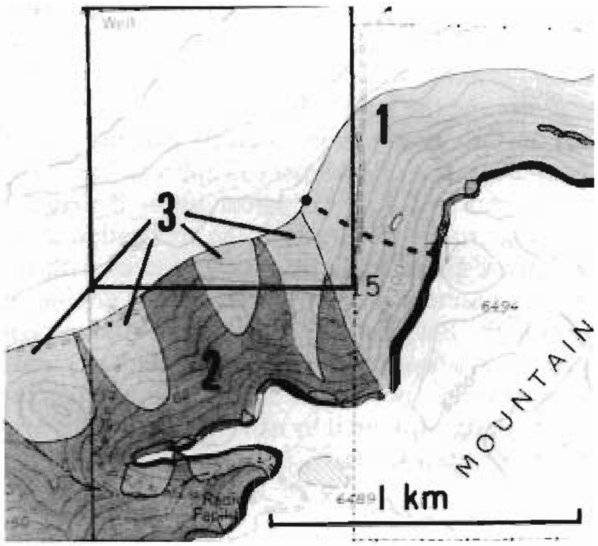

Figure 4. Map of a proposed subdivision site (outlined, upper left) in an area of mapped rockfall hazard. Rockfall Hazard zones are: 1—High to Moderate Hazard; 2—Moderate to Low Hazard; 3—Low Hazard. Only zone 1 was G-H zoned by the county. Rockfall path (dashed line) and final resting place (circle) from experiment crossed into subdivision site. Source of mapping: USGS Map I-761-C, 1:24,000. Elevations are in feet above sea level.

maintenance and inspection of mitigating structures. If the responsible authority (perhaps a Homeowners Association) neglects to keep the mitigating technique operative, then the variance could be rescinded. Presumably homeowners within the development would want to avoid revokation of their variance. While this option does present some tough choices, so does allowing development on the basis of non-permanent mitigation schemes.

CASE HISTORY: CHALLENGING A GEOLOGIC-HAZARD ZONE

In 1982 a hazard zone based on published geologic mapping was challenged by a developer's consultant, based on different-kind data. The case was typical in many respects. A developer filed to create a 200-lot subdivision of 200 acres. Twelve of the lots sat on the toe of an erosional escarpment 150 m high topped by resistant bedrock cliffs. The entire slope including the cliff had been designated as a rockfall hazard zone by Jefferson County (Figure 4). Distinctive boulders of the caprock up to 3.7 m long lay on the slope in a random fashion (Figure 5A). Most boulders were lichen-covered, weathered, and partially buried by windblown material; however some rocks were considerably fresher. No rockfalls had been reported on that particular slope in historic time, although historic rockfalls on similar slopes nearby were well documented (Van Horn, 1976, p. 89–91, 108–109; Simpson, 1973).

The developer's geotechnical consultant claimed that geologic hazards inferred from geologic evidence actually posed no threat because: 1) the process had not been active at the site in historic time, 2) the boulders were relict, reflecting a Pleistocene climate wetter than the one at present, and 3) the process had such a low probability of occurring within the design life of the development that it could safely be neglected. The reviewing geologist took a longer view based on more qualitative geologic evidence, but was unable to deduce recurrence times for rockfalls because of poor age control for the deposits, and ambiguity as to the exact number of events. The consultant argued that zoning should be removed. The reviewer defended the zoning, citing historical rockfalls on nearby slopes and the published hazard designation. Because the consultant presented no new on-site evidence to support his contention, the situation reached a deadlock.

Finally the consultant proposed a field test. Several loose blocks would be pried off the caprock cliff by hand and their progress down the slope would be monitored visually and photographically. Calculation of the mass and velocity of the blocks would allow a quantitative description of their hazard to any development. This, the consultant proposed, would show that only a negligible hazard existed.

The reviewer resisted such a test for several reasons. First, it was unclear how the probability of future rockfalls of various sizes could be calculated from a few man-induced events. Secondly, the test would result in modifying hazard zone boundaries originally drawn from geologic evidence by a probabilistic engineering approach drawn from a limited data base. The zoning ordinance provided for modification of boundaries based on new evidence, but this was construed to mean evidence somehow compatible with the original field evidence. Thirdly, at what particular value of inertia would the boundary be redrawn and how would this be decided? Finally, the test, if allowed, would set a precedent for modification of any zone boundary by a sophisticated probabilistic test, something which would be technically difficult for county staff to review. However, conversations with county officials and the State Geologist indicated that the developer had a legal right to perform such testing with the goal of modifying hazard zone boundaries.

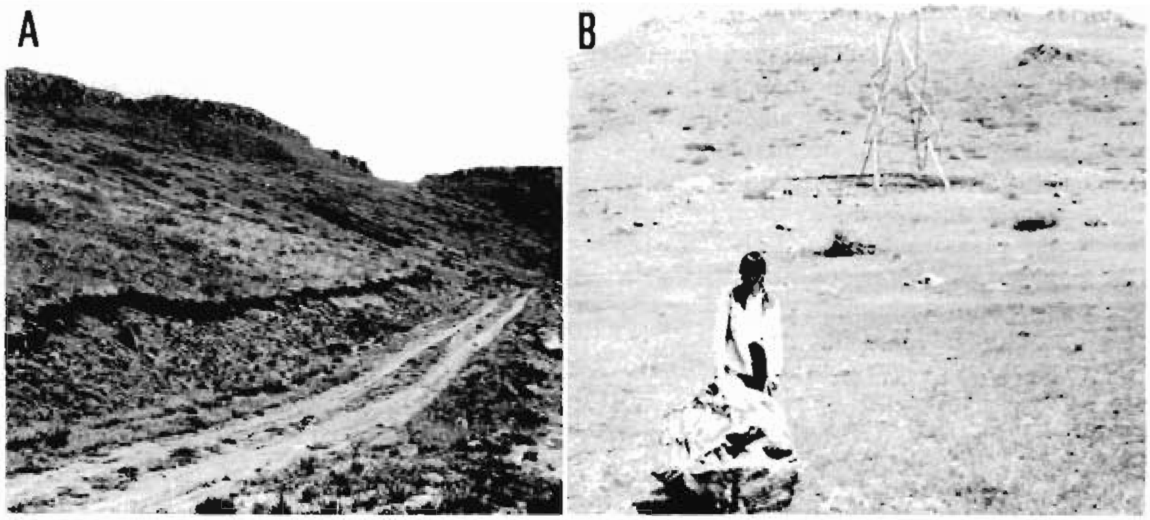

Figure 5. A) Slope profile at the site of the rock-rolling experiment. Blocks detached from the caprock (upper left) simulated natural rockfall events, similar to those responsible for boulders on the slope. Slope angle is 33 degrees. Transmission tower at right is the same as in Figure 5B. B) A 1,000-kg boulder dislodged in the rock-rolling experiment. The boulder travelled approximately 145 m vertically and 450 m horizontally from its original position at the top of the slope in background. The subdivision boundary lies immediately downslope of the tower.

The experiment was therefore carried out, with the following results. Two of the six blocks dislodged rolled down the entire slope, bounced over a dirt road and over a four-foot tall fence at the property line, and continued rolling through the site of several proposed lots. The larger of these two rocks came to rest approximately 150 m inside the property line and had an estimated mass of 1,000 kg, having lost about one-fourth its initial mass in transport (Figure 5B). A third boulder with an estimated mass of 3,000 kg also rolled the length of the slope and bounced over the road, but was stopped from entering the proposed subdivision when it hit a steel power transmission tower immediately upslope of the property line. The impact sheared off one of the tower's cross braces and dissipated the rock's energy.

In summary, half of the rolling rocks could have caused damage within the development. The rock which rolled furthest came to rest within about one m of the hazard boundary as indicated on existing county maps. Trajectory data based on impact scars indicated that boulders weighing up to 3,000 kg each were bouncing in the acceleration zone up to 2 m above ground level over slope distances of 18 m. Construction of a combination trench and berm large enough to intercept such rocks was deemed impractical. Stabilization of loose blocks on the cliff would have required extensive cleaning and rock bolting; however, this land was not owned by the developer. As a result of the test the developer withdrew his application to remove G-H zoning and began to make necessary changes in his site plan.

OUTLOOK FOR THE FUTURE

As development on urban fringes continues to spread outward, the number of geotechnical problems is expected to increase. Marginal lands previously avoided are now being pressed into development due to increasing real-estate values. The growing sophistication of geotechnical firms will be matched by a growing multiplicity and complexity of geotechnical problems.

Concurrently, public interest in geology is on the rise. Each new occurrence of property damage or loss of life due to geologic hazards forces governments to consider adopting some kind of geo-hazard regulations. Local governments in particular are becoming increasingly concerned with such land-use problems, and are looking for geological advice of their own to help in planning, policy making, case review, and enforcement. The trend of increased geologic employment at the local government level is therefore expected to continue. With this trend, geological consultants may find that their reports will be subjected to an increasingly specific and critical review at the local government level.

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Appendix A. *G-H Geologic Hazard Overlay District (Orig. 1-20-76) Section 41 of the Jefferson County, Colorado, Zoning Resolution* (Jefferson County, Colorado, 1983).

A. *INTENT AND PURPOSE*

This District is intended to promote the public health, safety and general welfare of the citizens of Jefferson County; minimize the risk of loss of life and property; encourage and regulate prudent land use; permit only such uses that will minimize the danger to the public health, safety, welfare and property; reduce the demands for public expenditures for relief and protection of structures and facilities permitted in this district and regulate buildings and structures so as to minimize the hazard to the public health or property. (orig. 1-20-76; am. 6-15-76; am. 9-7-82)

B. *GENERAL PROVISIONS AND RESTRICTIONS*

The Geologic Hazard (G-H) Overlay Zone District shall overlay that portion of any other zone district, including Planned Development (P-D) Zone District, located in the geologic hazard area. The regulations of this district shall be construed as being supplementary to the regulations imposed on the same lands by any underlying zone district or other overlay district. When the regulations of this district conflict with any provision of the underlying zone district, the provisions of the Geologic Hazard Overlay District shall control; otherwise, the provisions of any underlying district shall remain in full force and effect. (orig. 1-20-76; am. 9-7-82)

2. *Boundaries:* This district shall encompass those general areas depicted on Geologic Hazard Overlay District Zoning Maps, more particularly defined by legal descriptions appearing in the County Commissioner Resolutions rezoning property to Geologic Hazard (G-H) Overlay Zone District. The boundaries of the Geologic Hazard (G-H) Overlay Zone District may be amended through the County's rezoning process when appropriate, based on site-specific geologic information (orig. 1-20-76; am. 9-7-82)

Appendix A. *Continued.*

3. *Hazard Description:* Properties shall be classified according to four types of hazards:
   a. Slope Failure Complex-
      A geologic hazard which means a combination of more than one of the following geologic hazards:
      1) Landslide
      2) Rockfall
      3) Mudflow
      4) Creep (orig. 9-7-82)
   b. Landslide Area-
      A geologic hazard which means a mass movement where there is a distinct surface rupture or zone of weakness which separates the slide material from more stable underlying material. (orig. 9-7-82)
   c. Rockfall Area-
      A geologic hazard which means the rapid free falling, bounding, sliding, or rolling of large masses of rock or individual rocks. (orig. 9-7-82)
   d. Subsidence Area-
      A process characterized by downward displacement of surface material caused by natural phenomena such as removal of underground fluids, natural consolidation, or dissolution of underground minerals, or by man-made phenomena such as underground mining. (orig. 9-7-82)
4. *Restrictions:* Unless authorized under the provisions of sub-sections C. or D. below, the following activities or uses are prohibited within the Geologic Hazard (G-H) Overlay Zone District. (orig. 9-7-82)
   a. Permanent or temporary structures and buildings, including signs, fences, corrals or other open facilities for the containment of livestock. (orig. 9-7-82)
   b. Physical improvements or modifications, such as roads, bridges, bikeways, excavation or fills, solid or liquid waste disposal, utilities, or underground bulk storage of fuels. (orig. 9-7-82)
   c. Other land use activities that significantly increase the danger from the geologic hazard. (orig. 1-20-76; am. 9-7-82; am. 12-28-82)
   d. Restrictions a. through c. shall not apply to legal mining operations or accessory activities (orig. 9-7-82)

C. *PERMITTED USES AND ACTIVITIES*
1. The following uses and activities are permitted:
   a. All land uses permitted by an underlying zone district, so long as the same are not in conflict with the use limitations as set forth in subparagraph B.4, above. (orig. 1-20-76; am. 9-7-82)
   b. Any land use activity permitted in an underlying zone when authorized by a plat approved by the Board of County Commissioners subsequent to the inclusion of said property within the Geologic Hazard (G-H) Overlay Zone District. (orig. 9-7-82)

D. *PROVISIONAL USES*
1. The County Engineer and County Geologist may authorize, in writing, certain uses, which are permitted in the underlying zone district, and specified below, providing that plans and design critiera have been approved by both the County Engineer and County Geologist as having reasonably mitigated the potential danger to persons and property of the geologic hazard, and that necessary permits are obtained from the Engineering Division, the Planning and Zoning and/or Building Departments prior to starting any earthwork, construction or installation. (orig. 9-7-82)
   a. Roads, bridges, bikeways and similar improvements. (orig. 9-7-82)
   b. Excavations or fills. (orig. 9-7-82)
   c. Utilities, above or below ground. (orig. 9-7-82)
   d. Energy collection devices, such as windmills or solar collectors. (orig. 9-7-82)
   e. Structures exclusively for livestock. (orig. 9-7-82)
   f. Structures exclusively for bulk storage, such as silos. (orig. 9-7-82)
   g. Park or recreational uses without occupied structures or buildings. (orig. 9-7-82)
   h. Accessory out buildings and garages. (orig. 9-7-82)
   i. Underground bulk storage of fuels. (orig. 9-7-82)
2. Under certain conditions as contained in Section 25, the Board of Adjustment may permit by special exception those uses allowed in underlying zone districts, but prohibited by the provisions of Paragraph B.4. above and not provided for in Paragraph D.1. above. (orig. 1-20-76; am. 9-7-82)

E. *BUILDING AND LOT STANDARDS*
Building and lot standards, including height, minimum area, and setback requirements, shall conform to those of the underlying zone district. (orig. 1-20-76; am. 9-7-82)

F. *WARNING AND DISCLAIMER*
Geologic Hazard (G-H) Overlay Zone Districts represent only those hazardous areas known to the County at the present time, and should not be construed to include all possible potential hazard areas. The provisions of this district do not in any way assure or imply that areas outside its boundaries, or land uses permitted within its boundaries, will be free from the possible adverse effects of geologic hazards. (orig. 1-20-76; am. 9-7-82)