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SOCIAL, TECHNOLOGICAL, AND RESEARCH RESPONSES TO POTENTIAL EROSION AND SEDIMENT DISASTERS IN THE WESTERN UNITED STATES, WITH EXAMPLES FROM CALIFORNIA

By

R.M. Rice
Principal Hydrologist
Pacific Southwest Forest and Range Experiment Station
Forest Service
United States Department of Agriculture
Arcata, CA. USA

SYNOPSIS

Examples from California are used to illustrate typical responses to erosion and debris flow disasters in the United States. Political institutions leave virtually all responsibility for disaster prevention to the lowest levels of government or to individuals. Three circumstances in which disasters occur are discussed: urbanized debris cones, urbanized unstable landforms, and logging of unstable terrain. By far the greatest economic losses result from the urbanization of unstable landforms. These losses occur not because of a lack of appropriate mitigative technology, but as the result of the reluctance of local governments impose effective land use controls. Although logging-related erosion and debris flows receive much public attention, the associated costs are slight in comparison to other disasters. In comparison with other natural disasters, funds devoted to landslide research are much less than warranted by the associated economic costs and loss of life.

INTRODUCTION

Unlike most areas to be discussed at this symposium, the western United States is a sparsely populated, recently settled region of the globe. This demographic distinction affects both the nature of our erosion and sediment problems and the responses of our society to them. Slope instability, landslides, and debris flow damages are more prevalent in the West than elsewhere in the United States. Brabb (1984) estimates that 608 of the landslide damage in the 1973-1983 decade occurred in the 12 western states. California experienced damages approximating 1 billion dollars, about 40% of the total. To give more coherence to this paper, the disasters that illustrate it all occurred in California.

A large proportion of the recent research related to landslide and debris flow problems in the United States has focused on western conditions. Three types of problems are isolated that illustrate typical social and technical responses to the potential for sediment or erosion disasters. Those problems are associated with the urbanization of debris cones, the urban development of potentially unstable landforms, and the erosion and debris flows originating on steep lands following clearcut logging. Erosion and debris flow damage to highways and railroads are not discussed. With the exception of truly huge events, such as the Thistle landslide in Utah in 1983 (Atwood and Kaliser, in press), such occurances are not usually perceived as disasters by the public. This attitude may be a vestige of our pioneer heritage, when travel was expected to be fraught with hardships.

SOCIAL CONDITIONS AFFECTING DISASTER RESPONSES

Compared to other industrialized nations with serious slope stability problems, the western United States has a very sparse population (Table I). Even California, the most populous state, has a population density of only 60 persons per square kilometer. The western United States differs from the other industrialized nations in one other important characteristic: modern civilization reached the area only a little over two centuries ago, and

Table I. Population densities of nations with serious erosion and debris flow problems compared to the western United States and California.

Nation or Region	Population Density
	People/km^2
Austria	90
Italy	190
Japan	316
New Zealand	12
Switzerland	157
Western USA	10
California	60

most development likely to interact with geomorphic processes is even more recent. This recency of development and low population density has fostered the retention of a pioneer spirit that is reflected in public attitudes dealing with erosion and sedimentation problems. Specifically, government regulation of private property is often strongly resisted. Consequently, land-use restrictions which could serve to mitigate or prevent erosion or debris flow damages are usually weak. The reasoning is, with plenty of land, vulnerable areas need not be settled. Consequently, little aid is forthcoming to individuals harmed by erosion or debris flow disasters since they presumably exposed themselves knowingly to that risk. When actions are taken with regard to erosion and debris flow problems a decided preference prevails for disaster relief over disaster prevention. This attitude apparently stems from the perception that such disasters are rare and society in general should not be burdened with the expense and government intrusion that might be necessary to substantially reduce the risk of disaster.

Nor does our political structure promote a coordinated approach to the management of erosion and debris flow problems. Reponsibility for activities related to the problems is dispersed throughout various levels of government and even throughout different agencies within each level of government. Preventative measures such as zoning or construction of protective structures are normally the responsibility of local governments . --the cities and counties. But cities and counties often lack the financial resources to construct adequate structures. Moreover, local politicians tend to rank natural hazards low in priority compared to other community issues (Rossi et al. 1982). And rarely does a political constituency lobby for preventative measures. Consequently, the public official normally receives little reward for taking action and little penalty for inaction. Some local governments may also be reluctant to impose land-use restraints to reduce the risk of erosion or debris flow disasters. Such restraints on property use usually retard the economic development of an area and reduce local tax revenues. In consequence of this primary dependance on local governments to prevent disasters, most high-risk areas remain vulnerable.

Nevertheless, the situation is improving. In recent years, many communities have adopted grading regulations based on the Uniform Building Code (International Conference of Building Officials 1979). As noted by Erley and Kockelman (1981), however, “strict enforcement is still absent in too many slide-prone areas.” The experience of the City of Los Angeles during the exceptionally wet winter of 1968-1969 clearly demonstrates the benefit of effective regulations that are strictly enforced. Before 1952, Los Angeles had no ordinances to govern construction on natural or engineered slopes. Between 1952 and 1962, moderatly effective controls were imposed. And since 1963, very stringent standards considerably in excess of Uniform Building Code specifications have been in effect and consistantly enforced. In a large 1969 storm, 10.4% of the pre-1962 sites were damaged; of the sites developed between 1952 and 1962, 1.3% were damaged; and of the post-1963 sites, only 0.15% were damaged (Table II).

The Los Angeles code (with exceptions) prohibits construction on slopes steeper than 50%, specifies the separation between buildings and edges of engineered slopes, requires drainage around buildings and correction of existing hazardous slope conditions, and limits fill heights. Geologic and soil information must be supplied by an engineering geologist in order to obtain construction permits. A most effective part of the Los Angeles code is the specification that city officials inspect engineered slopes at seven critical construction stages. Another important feature is that engineers and geologists responsible for projects assume legal liability for the adequacy of their work. Undoubtedly, all of these special requirements increase the cost of development in potentially hazardous areas. Considering the dramatic reduction in damages (Table II) and the possibility that lives also may be saved, these stringent restrictions do not seem unreasonable.

Federal and state governments contribute to disaster prevention primarily by providing technical information to lower levels of government. Such data are often provided on a cost-sharing basis in cooperation with the local political unit desiring the information. At the federal level, such maps and reports are provided by the United States Geological Survey (USGS). In addition to general geological investigations and basic and applied research into geomorphic processes, the USGS conducts geological investigations that address specific concerns of individual counties and states. The USGS also investigates erosion and debris flow disasters in order to determine the causes and to make that information widely available. Most states have a geological survey or bureau of mines and minerals which provides technical information to local government and the public. California has a particularly vigorous state geologic program. The California Division of Mines and Geology (CDMG) publishes a monthly report of its investigations. The CDMG also develops and publishes a series of geologic maps at a scale of 1:250,000 covering the entire State. In 1983, the CDMG was also directed by the State legislature to develop landslide hazard maps for urban and urbanizing areas within California. Similar maps have been prepared for the commercial forest lands of the State. Also, CDMG geologists serve on the Department of Forestry staff, making geological evaluations of critical timber harvest plans.

The State of California, through its forest practice rules, regulates timber harvesting in order to reduce the risk of erosion or debris flows. Those rules, promulgated by the Board of Forestry, limit the size of clearcut areas, affect the type of equipment used transporting logs from the forest to the road, and affect the design and maintenance of roads and log-loading areas. These rules serve to protect site productivity, water quality, and fish habitat. They also have the practical effect of minimizing the risk of erosion and debris flow disasters.

Table II. The effect of land-use management on landslide damages in Los Angeles during the wet winter of 1969 (Erley and Kockelman 1981)

Pre-1952	1952-62*	1963 to present
No grading codes; no soils engineering; no engineering	Semiadequate grading code; soils engineering required; very limited geology, but no status and no responsibility.	New modern grading codes; soils engineering and engineering geology required during design; soils engineering and engineering geology required during construction; design engineer, geologist all assume legal responsibility.
Approximately 10,000 sites constructed	Approximately 27,000 sites constructed	Approximately 11,000 sites constructed.
Approximately $3,3000,000 damage.	Approximately $2,767,000 damage	Approximately $182,400 damage.**
Approximately 1,040 sites	Approximately 350 sites damaged.	Approximately 17 sites damaged
An average of $330 per site for the total produced:	An average of $100 per site for the total produced:	An average of $7 per site for The total produced:
$3,300,000 / Sites 10,000	$2,767,000 / Sites 27,000	$80,000 / Sites 11,000
Predictable failure: 10.4%	Predicable failure: 1.3%	Predictable failure: 0.15%
1,040 damaged / 10,000 total sites	350 damaged / 37,000 total sites	17 damaged / 11,000 total sites

*It should be noted that the storms of 1952, 1957-58, 1962, 1965, and 1969 all produced similar total losses associated with similar destructive storms.

**Over $100,000 of the $182,000 was incurred on projects where grading was in operation and no residences were involved, thus less than $80,000 occurred on sites constructed since 1963.

Generally, insurance covering losses due to landslides, erosion, or debris flows is not available. The federal government has included mudflow areas in the National Flood Insurance Program. This program requires that some type of insurance must be purchased in order to qualify for government financial assistance for construction or acquisition of property in harzardous areas. But the legislation's definition of a mudflow-hazard is ambiguous. As a result, the delineation of hazardous areas has lagged far behind the deliniation of flood-hazard areas. Consequently, the program has consistantly paid for any damages resulting from concentrated flows which were predominantly water. There are no actuarial tables relative to damages from landslides. As a result, people living in mudflow, debris avalanche, and torrent areas probably have their insurance subsidized by the large populations living in flood-prone areas.

Once a disaster has occurred, the responsibility for mitigating its effects begins with the individual property owner and progresses through successively higher levels of government as the magnitude of the disaster increases. The amount and type of disaster relief available depends on formal declarations by the ruling bodies at various levels of governments. Practically all aid, however, is directed toward repair or protection of public facilities. Special Low-interest loans and emergency housing, available in some circumstances, are about the only relief provided to individuals. Consequently, about one-fourth of the damages from erosion and debris flows receive no government relief.

Initially, in an emergency affecting the general public in California, the primary responsibility for protecting life and property rests with local government, as does the responsibility for repairing damage to public facilities. If the magnitude of the emergency exceeds the capabilities of local government, the county board of supervisors may declare a Local Emergency. At this point, a limited amount of assistance is available from outside the county. If these resources are insufficient, the board of supervisors may petition the governor of the State to declare a State of Emergency. If coping with the disaster exceeds the State's capabilities, the Governor may ask the President to issue a Presidential Emergency Declaration which gives federal agencies authority to provide a broad range of services. Ultimately, in the most severe circumstances, the President may issue a Major Disaster Proclamation, which makes additional federal assistance available.

With the declaration of a Local Emergency, the county board of supervisors may request assistance from other California counties and cities. The State Department of Water Resources and the U.S. Army Corps of Engineers may use their resources to prevent or combat floods. The Federal Highways Administration may repair or reconstruct highways damaged by the disaster. The U.S. Department of Education may provide assistance to damaged schools and, in special circumstances, the Small Business Administration and the Farmers Home Administration may provide low-interest loans.

With the declaration of a State of Emergency by the Governor, such assistance as required becomes mandatory for all political jurisdictions in California. The Governor may use the National Guard and the Conservation Corps, expend emergency funds, and direct all State agencies to make personnel available to combat the disaster.

With a Presidential Emergency Declaration, emergency mass care, shelter, medicine, food, and water can be provided by federal agencies. Federal agencies can use their resources to facilitate emergency clearance of debris and assist in communications, search, and rescue.

A presidential proclamation of a Major Disaster may authorize a wide range of assistance programs for relief, recovery, and rehabilitation for individuals and families affected by a disaster. Individuals and families may receive grants to cover disaster-related expenses. Up to 12 months temporary housing assistance may be provided. Low-interest loans become available for individuals and businesses damaged by the disaster. In a Major Disaster a Disaster Assistance Office is set up in the locality to provide a single facility dispensing all emergency services.

In summary, the United States has a political and social structure that is better adjusted to deal with disasters than to prevent them. Prevention is almost the exclusive responsibility of the individual or smallest governmental entities. Ironically, these parties are least likely to have the will or resources to take effective preventative actions. In principal, disaster relief is relegated to the lowest governmental unit feasible. Consequently, the Nation's full capabilities for dealing with disasters are brought to bear only on the most extreme events.

VULNERABLE DEBRIS CONES

The erosion and debris flow problems of the community of Glendora, about 50 km east of Los Angeles in southern California, are typical of many communities in the semiarid southwestern portion of the United States. Settlements developed on debris cones where steep mountain streams debouched onto the valley floor. The settlers were lured to such locations by the yearlong availability of surface water. Such streams usually vanish into the alluvium a short distance from the mouths of canyons. Typically, communities which have developed on debris cones continue to grow even after surface waters become fully utilized. This continued growth is based on the development of readily available groundwater within the alluvial cone. Normally, by the time this groundwater supply is fully utilized, the community has sufficient finanacial and political resources to import water from more distant areas in order to sustain growth.

The immigrants to the San Gabriel Valley, where Glendora is located, failed to recognize the potential debris flow hazard to settlements on the debris cone. They had come for the most part from the well-watered portions of the eastern United States or Europe. They had little experience with mountains as precipitous as the San Gabriels north of Glendora. And they were probably unaware of the effects of the intermittent brushfires that denuded the mountains of vegetation. Damages resulting from the settlers' lack of foresight were modest until 1969. Until that time, the more vulnerable portions of the debris cone were either undeveloped or planted with citrus orchards. Little development took place until 1890 because of uncertainty over land titles resulting from the transfer of sovereignty over the area from Mexico to the United States. From 1890 to 1930 there was modest, steady growth in the population, reaching a total of 2500 inhabitants (Figure 1).

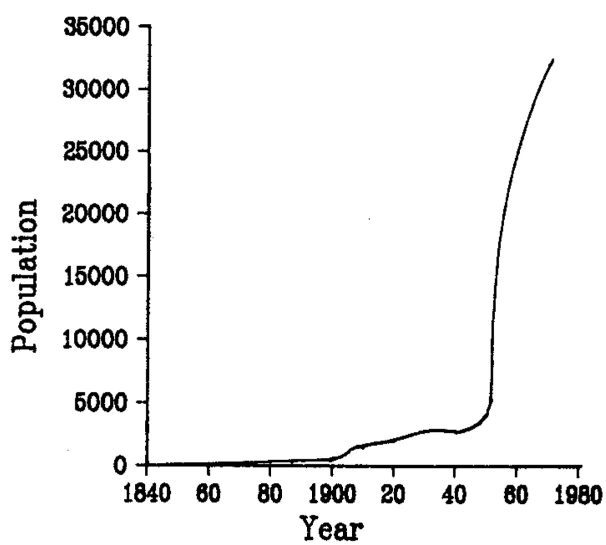

Figure 1. Population of Glendora, California USA, 1840-1970.

In 1919, vegetation on the mountains draining onto the southeast portion of Glendora burned, but little debris flow damage was reported during the following winters. This was probably due to the prolonged period of generally below-normal precipitation following the fire. Consequently, dry ravel (Krammes 1965) eroded from the steeper slopes following the fire accumulated in stream channels, and was stabilized there when vegetation became established on the deposits. Also, several hundred small loose-rock check dams had been constructed in the channels prior to the fire

(Munns 1920). These structures filled with sediment during the winter of 1919-1920. Other check dams in canyons unaffected by the fire probably took longer to fill. Due to these circumstances, many channels passed the next 50 years buried under 1 to 3 meters of quasistable alluvium. The remobilization of this material in 1969 had a dramatic effect on the community below.

Damages caused by runoff and debris flows from watersheds burned in 1913, 1915, and 1919 prompted the County of Los Angeles to construct flood control reservoirs in the major drainages of the San Gabriel mountains. One such reservoir, with a capacity of 1.3 x 10^6 m^3, was constructed in the main canyon draining onto the alluvial cone upon which Glendora was built. The explosive population growth of Glendora during the 1950's (Figure 1) led the Los Angeles County Flood Control District to construct seven debris basins at the mouths of minor drainages tributary to the Glendora debris cone. These debris basins ranged in capacity from 22,000 m^3 to 561,000 m^3. It was intended that debris deposited in them would be excavated periodically and disposed elsewhere. During the same period, concrete lined flood channels were constructed to safely pass flood flows through the city. As a consequence of these measures, it appeared that the community of Glendora was well protected from potential debris flow disasters. Certainly, its protective system exceeded that found in most similarly vulnerable communities in the western United States.

The rainy season of 1968-69 provided a severe test of the disaster prevention facilities protecting Glendora. During July and August 1968, two separate fires denuded the slopes along 5 kilometers of the northern boundary of the city. Both fires burned intensely due to very heavy stands of brush: these watersheds had not burned in the last great fire of 1919. The city engineer recognized the community's vulnerability. About half of the burned area above Glendora was not tributary to a debris basin. He stated, "Glendora cannot possibly cope with the inundation of mud and debris which will come from a heavy storm or series of storms" (Jackson 1982). The city directed its limited resources toward providing as much emergency protection as possible. Citizens in threatened areas were advised to build temporary dikes and to raise or reinforce existing walls in order to protect their property from possible debris flows. The city established stockpiles of sandbags, sand, and cement. The city council, well aware of the danger, declared a "State of Disaster" and petitioned the Governor to declare a State of Emergency and to petition the President to proclaim the area a Major Disaster. City officials were dismayed to learn that those declarations and the programs stemming from them were strictly for disaster relief, not for disaster prevention. Left without any outside sources of assistance, the city proceeded to build temporary barricades in the most vulnerable locations.

The weather was dry through fall and early winter. Less them 50 millimeters of precipitation had fallen by mid-January. On January 18, 1969 that situation changed drastically. It rained 525 mm in the ensuing 9 days. All debris basins were filled and passed debris flows over their spillways briefly during the peak intensity of the storm. At that time, it raining at an intensity of 40 to 50 mm hr^{-1}. At nine different locations, debris flows escaped control and surged through residential portions of the city. The overtopping of the debris basins surprised many. They had been designed to accommodate a 50-year storm -- but only on a watershed which had significantly recovered from fire (Los Angeles County Flood Control District 1971). This standard approximately equates to protection from a 5 to 10 year storm on a freshly burned watershed. Simpson (1982) has estimated the return period of the maximum 24 hour amount of precipitation for several rainfall monitoring stations in the vicinity to be from 5 to 50 years. The recurrence interval for the flooding has been estimated to be greater than 70 years, and perhaps even greater than 100 years (Giessner and Price 1971).

The overtopping of the debris basins and the absence of preventative structures in most of the smaller drainages results in part from the way funds are allocated for preventative structures. Economic analyses of those structures are made to determine both benefits and costs. Only those projects whose benefits exceed costs are considered. As a practical matter, a benefit/cost ratio in excess of 1.3 is usually necessary before a project receives serious consideration. This procedure tends to favor large projects over small ores; hence, most watersheds smaller than 1 km are not candidates for debris basins. This policy also means that it is usually not economic to construct structures that will assure protection from the largest potential disasters.

Following the January storm and debris flows, Glendora was declared a Major Disaster and generous federal help became available. The debris flows destroyed six houses and damaged an additional 200 homes (Jackson 1982). Not only was there money to repair damages to public property and low-interest loans to repair private property, but work begun on an extensive system of check dams and debris basins to protect vulnerable areas from future flood emergencies. Since most channels scoured to bedrock during the 1969 storms, those emergencies (from which the city is now protected) may be far in the future. Most structures stored but little debris at the end of the 1985 runoff season (Figure 2). The purpose here is not an economic analysis of the preventative structures and the rehabilitation which followed the 1969 disaster, but it does seem that the generous funding of relief efforts after the disaster is inconsistent with the limited support extended to the community for preventative measures prior to the disaster.

URBANIZED UNSTABLE LANDFORMS

Economic losses resulting from unwise urbanization of potentially unstable landforms greatly exceed those associated with the urbanization of debris cones or the logging of steep lands. This is unfortunate, since such losses are largely preventable. Existing knowledge is adaquate to appraise the nature and magnitude of geologic risk associated with the

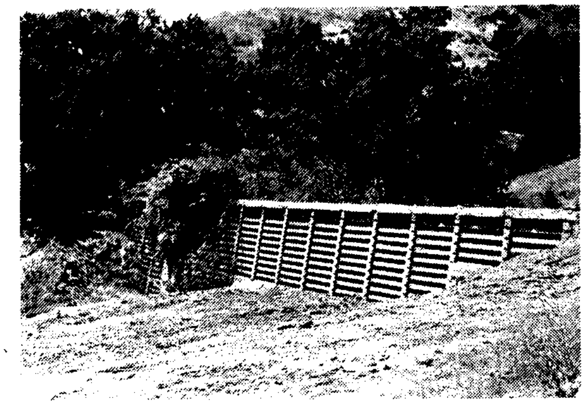

Figure 2. Channel-stabilizing check dam above Glendora, California USA. The structure, built in 1969, is only partially filled with sediment.

development of a site. In most situations, existing geotechnical engineering procedures can eliminate or greatly reduce the risk of mass failure. Also, the urban development of such sites carries with it the economic capability to install the needed mitigative measures. Why severe economic losses occur in spite of seemingly favorable circumstances for their prevention is illustrated by a few case histories from southern California, where recent, rapid urbanization has led to a number of landslide disasters. Moreover, the potential for similar disasters exists in other parts of the western United States.

All case histories discussed here are from coastal areas. All are underlain by marine sedimentary formations laid down in the Miocene Epoch or later. These areas were settled much later than the Los Angeles basin and its surrounding alluvial cones. The sage-covered hills were of little interest to early settlers. The low rainfall of only about 300 mm annually also conspired against development. Consequently, although a few small beach-oriented coastal communities developed during the first third of this century, substantial urbanization dates from the late 1950's. In other words, they date from a period when earth moving equipment could be extensively employed to reform steep terrain in order to accommodate more building sites than would have been otherwise possible. In earlier developments, economics dictated that excavation be held to a minimum. Consequently, unstable landforms were less likely to be disturbed.

The source of the information concerning each case history is identified at the beginning of each discussion. However, I am responsible for interpreting the facts presented by the various authors. In particular, inferences concerning political or social factors affecting the disasters are mine.

The Verde Canyon Landslide
(Leighton et al 1984)

The Verde Canyon landslide occurred on December 30, 1983, nearly two decades after urbanization. The 20-year lag between development and disaster is common to two other case histories discussed here. Rainfall trends which existed in the area during the middle of this century (Figure 3) are the cause. By 1977, the accumulated rainfall had deviated almost 900 mm below the long-term average. The above-normal rainfall that dominated the next 5 years produced severe stress in those areas which had been disturbed by urbanization during the preceding two decades. The consequences in Verde Canyon were disastrous. The tract was graded in 1964, three years before the city of San Clemente adopted a building code that required geologic investigations in hillside areas. Home owners in the tract had been using approximately 300 mm of irrigation water on their landscaping each year. Consequently, the groundwater deficit, which would have been available in a natural environment, was nearly absent in the residential area. Rainfall averaged 500 mm a year during the 5 years preceding the disaster and, of course, the householders continued to irrigate their landscaping during summer. Indications are that movement began about 24 hours earlier than the main landslide. This movement ruptured a 150 mm diameter water main, but the break was not discovered for 13 hours, no doubt exacerbating the hydrologic conditions related to the slide. The slide occurred on a steep, natural slope of from 26^0 to 34^0 . It was a block glide of about 2,300 m . The block, which was about 1.6 ha in area and 30 m thick, moved about 15 m. Three homes were destroyed. Site investigation revealed old landslide material above and below the ruptured surface of this slide, suggesting multiple prehistoric landsliding episodes. Two principal causes of this disaster are evident. Perhaps most important, development was undertaken without adequate geotechnical investigation of the site. Of almost equal importance, no attempt was made to manage surface water in order to maintain or improve slope stability.

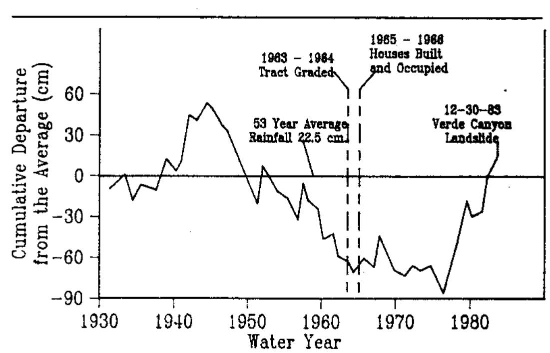

Figure 3. Cumulative rainfall departures, 1930-1983.

The Blue Bird Canyon Landslide
(Miller and Tan 1979)

Five years earlier and 16 km northward along the coast, a very similar but much larger disaster occurred. Unlike Verde Canyon, the Blue Bird Canyon landslide occurred on October 2, 1978, 7 months after an unusually heavy March rain. In this case, perhaps, it was the householders' irrigation during the intervening summer which finally forced the factor of safety of the slope below 1.0. However, the principal investigator believed that the low permeability of the slide mass was the cause of the delay (Leighton 1982). Another possible cause of the disaster was the undercutting by the stream of the toe of the ancient slide upon which the 1978 landslide occurred.

In the first few hours of the slide, which moved at a rate of about 12 m hr , 19 homes and portions of 14 others were carried away. By the end of the day, a total of 50 homes had been damaged or destroyed; 10 days later, a small failure on the headscarp destroyed an additional home. The result: the destruction of 25 homes and $15 million in losses. Here, as in Verde Canyon, a geological investigation revealed a possible, old landslide scarp, suggesting that adjacent homes unaffected by this slide might be in jeopardy. Intensive geotechnical investigations were made that resulted in reshaping, reinforcing, and draining of the slide mass. These mitigation measures not only protected adjacent homes , but also permitted the redevelpopment of the slide mass itself.

The Big_Rock Mesa Landslide
(Keene 1985.)

The Big Rock Mesa landslide in Malibu, California, about 65 km west of Los Angeles, involves those factors previously discussed, but on a grander scale. This coastal community is a favored suburb by the southern California entertainment industry. Typical homes range in value from $200,000 to $1,000,000. A total of 320 homes have been affected by the slide. The slide has reached movement rates of 3 mm day^{-1} and has a surface 6arsea of 63 ha and estimated volume of 38 x 10 m . Renewed movement of the ancient landslide underlying the area probably began in 1978, but the movement was not obvious until 1983. To date, several of the 320 homes have been severely damaged and half a dozen or so have been abandoned. Water lines on the developed mesa have broken and been repaired in many places and the 76 cm water main at the toe of the slide has been repaired at five different places. In 1983, the county created a $1.3 million assessment district to develop a groundwater extraction program.

The slope stability hazard associated with the residential development of Big Rock Mesa was recognized from the start. It appeared to be an ancient landslide. The abundance of subsurface water was attested to by the fact that the area supported a water well field until 1958. Consequently, when the development was proposed in 1961, county officials questioned the wisdom of developing the area without providing offsite sewage disposal to reduce the addition of water to the slope. The development proceeded, however, with onsite sewage disposal for individual lots. To guard against reactivating of the slide by adding to the ground water, 850 m of horizontal drains were installed in the bluffs at the base of the slide. This arrangement proved inadequate to maintain the stability of the slide. The period of high rainfall, begun in 1978 (Figure 3) brought the groundwater level to within 12 to 15 m of the surface. In 1983, in recognition of the problem, a special district was formed to reactivate the abandoned water wells and drill new ones. In 1985 a system of 18 wells with a capacity of 1700 m^3 day was operating and more horizontal drains and wells were being drilled. In some areas the groundwater level has lowered more than 30 m, which has slowed the movement of the slide. The total cost of these mitigative measures and their effect have yet to be seen. It is clear, however, that the potential still exists for a disaster of astronomical proportions.

It appears that groundwater recharge by home owners' irrigation and septic system leach fields played a key role in the reactivating the Big Rock Mesa slide. Considering the very affluent nature of the development, it seems reasonable to assume that the additional costs of offsite sewage disposal could have been borne by the residents. But neither the developer and his geotechnical consultants nor the officials of Los Angeles County insisted on offsite sewage disposal.

The Dana Cove Landslide
(Kerwin et al 1985)

A few kilometers northwest of the Verde Canyon landslide is a coastline cove created by the differential retreat of two distinct rock types. The relatively competent and resistant San Onofre breccia forms a headland, while the weaker more erodible Capistrano Formation rings the cove. The contact between these rock units is a north-south trending fault paralleled by a deformed and broken interval of the Capistrano Formation about 30 m wide. The San Onofre breccia adjacent to the fault is relatively unaffected. These circumstances and the steep inclination of the fault (60 degrees) have promoted erosion and bluff retreat along the fault trace.

In 1971, a restaurant was constructed at the top of the bluff astride the fault. It was built in that location despite expressions of geotechnical concern and vigorous political opposition. The aesthetic appeal of the view from the top of the bluff overrode technical considerations. No doubt the developers felt that the spectacular view from the dining rooms would ensure the economic success of their venture. During heavy rains in winter of 1980-81, a large wedge of the Capistrano Formation near the top of the bluff failed along the fault. Although the restaurant was not damaged by this event, it was left in a precarious situation.

The slope which failed was not on the property of the restaurant owner, but on adjacent land belonging to Orange County. After considerable litigation, an arbitrator held the County responsible for the stabilizing the slope. This has entailed the construction of a retaining wall immediately below the restaurant. The wall, approximately 10 m tall, is held in place by 34 anchors having an aggregate design capacity of 1800 tonnes (Figure 4). These anchors are fixed in the San Onofre breccia. At the toe of the slope, adjacent to a county road, a 14 m high crib-type retaining wall is to be constructed, the intervening landslide debris removed or recompacted, and a subsurface drainage system installed. These latter features are expected to be completed at the time of this symposium.

Figure 4. Anchored wall stabilizing resturant site after Dana Cove landslide.

Although this disaster is rather inconsequential, it illustrates an important point. The local authority (Orange County), by not prudently and vigorously exercising its powers to regulate development, became liable for the expense of remedial measures when the imprudent development became involved in a disaster.

In summary, potential disasters resulting from the urbanization of unstable landforms have both political and technological origins. On the political side, it is the reluctance of local governments to be assertive in either preventing development or insisting that developers institute adequate mitigative measures. On the technical side, in three of these case histories, there seems to have been inadequate allowance for the changes that urbanization would cause to groundwater regimes. Sewers could have been installed to carry off both domestic sewage and storm runoff, which might have maintained slope stability by compensating for the infiltration of irrigation water from home owners' landscaping. Alternatively, safe groundwater levels might have been by well fields.

LOGGING-RELATED EROSION AND DEBRIS FLOWS

The erosion and debris flows associated with the harvesting of timber from unstable terrain, however unfortunate, cannot be considered disasters in the same sense as those resulting from urbanization of vulnerable debris cones or unstable landforms. Lives or property are rarely endangered. The resulting damages are normally limited to reduced productivity on the eroded land, lowered water quality, and degraded fish habitat.

The loss of spawning and rearing habitat for Pacific Coast salmon has provided the greatest impetus for reducing logging-related debris flows. Unquestionably, the salmon population has declined in recent years. Considerable debate persists, however, whether the decline is attributable to overfishing, the construction of hydroelectric or irrigation dams, or to damage spawning and rearing habitat resulting from debris flows and sediment originating on recently logged timberlands. The concurrent decline in steelhead trout populations is cited as evidence that habitat degradation is an important factor in the salmon decline. Steelhead trout have a life cycle and habitat requirements similar to the salmon, but are not fished commercially. The decline of the steelhead population in rivers unaffected by dams (Figure 5) is viewed as evidence that habitat degradation is an important factor (Denton 1974).

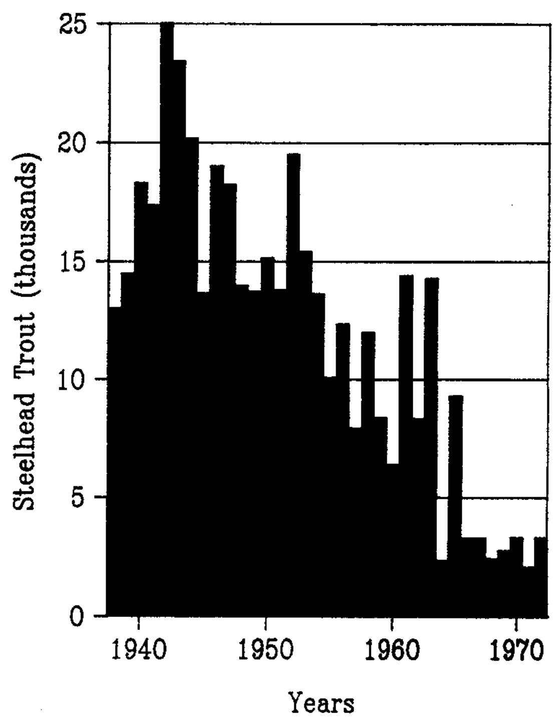

Figure 5. Steelhead trout counted in the south fork of the Eel River, 1938-1972.

The problems associated with timber harvesting on unstable terrain were little recognized until about 1960. Prior to then, most logging in the United States took place on private land. Excessive erosion or debris flows, if noticed at all, were accepted as an unavoidable by-product of forest utilization. There had also been a tendency to harvest timber from the more accessible sites first. These sites were generally less erodiable.

By the mid-1960's the situation began to change. Less stable terrain was being logged, harvest of timber on public lands was rapidly increasing, and the environmental movement was gathering momentum. Public land managers were charged, unlike their private counterparts, with the protection of most resources and amenities on forestlands. And the public was becoming concerned about how their forestland was being managed.

Scientific awareness of logging-related mass-wasting by U.S. researchers dates from the Bishop and Steven (1964) report about debris avalanches in the Maybeso drainage of coastal Alaska. Reports quickly followed from Oregon (Rothacher and Glazebrook 1968), and southern California (Corbett and Rice 1966). Shortly thereafter, U.S. scientists became aware of the earlier work of their Japanese collegues (Iwatsuka 1957, Rawguchi et al. 1959, Endo et al. 1961). The recognition of the landslide problem by the research community was due in part to the fact that, as government and university research expanded in the 1960's a greater variety of disciplines were brought into forestry research and the general level of academic training of forestry researchers was raised.

At the same time, the National Forests and some larger industrial forestry organizations *were* adding earth scientists to their staffs. The Forest Service adopted the practice of using interdisciplinary teams of technical specialists to inspect proposed timber harvest areas. In spite of this, as clearcutting became more prevalent, logging-related landslides increased. The pace of cutting was such that even increased technical input to timber sale preparation and administration could not prevent disasters. For example: between 1967 and 1970, 253 ha were clearcut in the Little North Fork of the Salmon River (Pillsbury 1976). The timber was cut in patches of about 16 ha. The logging involved construction of 21 km of unsurfaced roads. By summer 1971, 55 landslides had occurred. The following winter, two major storms caused an additional 122 landslides. The environmental *costs* were 90 m of soil loss and 93 m^2 of bare soil created for every 100 m^3 of timber harvested. Part of damage was caused by the purchaser of the timber who, unaccustomed to constructing logging roads, built them wider and with larger minimum curvature than appropriate for the terrain. Nonetheless, substantial erosion occurred in harvest areas not affected by roads. As a result of the disaster the Forest Service attempted to cease timber operations in the area. The roads were "put to bed" in areas where timber was no longer being harvested, but due to contractual obligations with the purchaser of the timber, the roads were reopened into areas that had not yet been cut.

Seventy km northwest, a similar situation developed on two drainages tributary to the south fork of the Smith River. In this instance, the Forest Service was sued by the Sierra Club for improperly managing the National Forest. The suit was settled out of court, the Forest Service agreeing to modify their procedures and to initiate an extensive monitoring program to evaluate the effect of the new procedures. Such situations that result in lawsuits have become commonplace during the last decade.

The National Forests were not the only lands to come under public scrutiny in the 1970's. In California, at least, private logging practices were receiving much attention and condemnation by environmentalists. Public concern about forest practices resulted in the enactment of the Z'Berg-Nejedly Forest Practice Act of 1973. This act resulted in the rewriting of California's forest practice rules, the requirement that all timber harvests be planned by licensed foresters, and the review of those plans by the California Department of Forestry (CDF) before work could begin. The rules resulting from the Forest Practices Act of 1973 were almost completely rewritten between 1980 and 1984 in response to a portion of the Federal Pollution Control Act. Several sections in the rules prescribe mitigating measures that must be undertaken in "slide areas," "slide-prone areas," "unstable areas," and on "unstable soils." So far, implementation of these sections has been hampered by the lack of agreed-upon definitions of terms -- a situation very similar to the ambiguity surrounding mudflow-hazard areas in the National Flood Insurance Program.

To aid foresters preparing timber harvest plans the CDF undertook a landslide hazard mapping program. That program was hindered, however, by the unwillingness of some landowners to grant field parties access to their property. Timberland owners were apprehensive that the hazard maps would result in the automatic imposition of mitigative measures on areas identified as hazardous. They felt that, due to the scale at which the maps would be drawn, much stable land would be included in areas catagorized as unstable. Their concerns are supported by inventories of landslides in unstable areas in the western United States which suggest that those areas that actually fail as a result of disturbances comprise about 1% or less of the total (Amaranthus et al. 1985, Furbish and Rice 1983, Ketcheson 1978, Morrison 1975, Rice and Pillsbury 1982, Swanson and Dyrness 1975, Swanson et al. 1977).

Currently, the California Department of Forestry, in cooperation with U.S. Forest Service, U.S. Department of Agriculture, is undertaking a study of logging-related erosion. The objective is to develop linear discriminant functions (Fisher 1936) which can be used to estimate the probability of producing in excess of 189 $m^3\ ha^{-1}$ of erosion if logged. If successful, these equations could provide a rigorous method of estimating the risk of excessive erosion. The actual implementation of such a procedure, however, will be a political decision since it is normally in that arena that the value of competing resources are balanced.

In summary, due to vigorous attention by researchers, environmentalists, and the public, erosion and debris flow problems resulting from logging of potentially unstable lands appear to be largely under control. Certainly, considering the values at risk, the mitigative measures being implemented on the forestlands of California are disproportionate to those imposed on urbanized portions of the State.

Other American papers presented to the symposium illustrate our current knowlege and research related to erosion and debris flow disasters. My discussion focuses on research needs. I will draw heavily on two documents: "Goals and Tasks of the Landslide Part of a Ground-Failure Hazards Reduction Program," by the U.S. Geological Survey (1982); and "Recommendation for Reducing Losses From Landsliding in the United States," by the National Research Council, Committee on Ground-failure Hazards of the Commission on Engineering and Technical Systems (1985). What follows, however, is a more probabilistic approach to some research needs than proposed by either of those two documents.

Approximately 500 scientists in the United States devote substantial research to erosion and debris flow phenomena. About half of them are on university faculties (Brabb and FitzSimmons 1984). Although this represents a substantial effort, it is weakened by its fragmentation. No entity exists at the national level responsible for either research or managment of erosion and debris flow problems. The consequence is a lack of coordinated effort and concentration of expertise, such as found here in Tsukuba. On the other hand, there are advantages to our diversity. It brings many different disciplines to bear on the problem. Scientists on university faculties of civil engineering, geography, geology, and natural resources are viewing the problem from their own unique perspectives. Within the Federal government the Agriculture Research Service, the Army Corps of Engineers, the Forest Service, and the Geological Survey all have research programs devoted to erosion and debris flows. Perhaps in time communication between these diverse groups will improve through the newly created Natural Hazards Research and Applications Information Center of the University of Colorado. I believe, however, that coordination will more likely occur if a single agency has primary responsibility for erosion and debris flow problems.

In spite of the seemingly large number of researchers, if federal expenditures are an accurate indicator, the level of effort is disproportionate to the seriousness of the problem (Table III). Landslides (including debris flows) caused greater loss of life than any other listed ground-failure hazard. Though they are the second greatest cause of economic losses, research funding in this category ranks fourth, behind earthquakes and volcanoes whose costs are one and two orders of magnitude less. Apparently, landslides lack the dramatic appeal of earthquakes or volcanoes and the certainty of damages associated with subsidence.

It is axiomatic that it is difficult to manage a phenomenon that is not understood. Consequently, basic research enlarging our understanding of erosional processes, landslide mechanisms, and debris flow genesis is paramount. Basic studies should approach the problem from different perspectives, including controled laboratory experiments, careful monitoring of naturally occurring erosion and debris flows, monitoring of purposely caused slope failures, and correlative studies of site conditions and meteorologic stresses that result in erosion and debris flow disasters. Such basic research can enable us to better predict the location and timing of erosion and debris flow disasters. It can suggest more useful mapping criteria and provide the information necessary for more rational insurance approaches to the management of erosion and debris flow problems.

Table III Estimated annual losses and annual Federal research funds for selected ground failure hazards in the United States (National Research Council 1985)

Hazard	Deaths	Losses	Research
		-- Millions of dollars --	
Landslides	25-50	1,000-2,000	3-5
Permafrost	0	20	2
Subsidence	*	500	10
Swelling Soils	0	6,000	2
Frost Action	0		
Rock Deformation	1	*	3
Earthquakes[a]	15	100	50
Volcanoes[a]	1	10	10

*Not available.

[a]A major earthquake or volcanic eruption affecting a large urban area could greatly affect the estimated annual losses from these hazards. The other hazards in this table are less episodic and the estimates given are probably more reliable as estimates of future annual losses.

The task falls to applied research to develop useful procedures for managing erosion and debris flow hazards. The development of standard mapping criteria is important. Generally accepted mapping critera would improve the quality of most hazard maps. More importantly, such criteria would make hazard maps more interpretable to engineering geologists and politicians in their decision-making processes. In addressing this problem, sufficient data must be collected and analyzed so that maps are objective, clearly showing the level of hazard in a numerical fashion. This implies that hazard maps should define precisely the event being predicted and the probability of its occurrence. Such guides would give political jurisdictions a firmer, more sound basis for resisting pressures for unwise development.

Two types of maps are envisioned. A broadscale map, based on climate, geology, geomorphology, and vegetation, would display how similar an area was to others in the region which had produced erosion or debris flow problems in the past. These maps would, in effect, predict probability of a disaster sometime. At a more local scale, maps based on the above factors plus rainfall frequency analyses could predict the probability of an event at a particular location during any particular time period.

Investigation is also needed aimed at predicting the timing of disasters. Very little of this type of work has been done, one exception being the studies of Crozier and Eyles (1980). Such investigations would be especially beneficial to emergency managment services, enabling them to issue warnings of impending disasters.

Vigorous applied research studies should be undertaken that deal with mitigative measures. Too little is known regarding the efficacy of existing mitigative procedures, and there is a reluctance to try new procedures -- fearing liability, should they fail. Evaluations of mitigative procedures could be made in low-risk, unpopulated areas managed by the Forest Service or Bureau of Land Management. If the new procedures were successful in such locales, they could provide the managing agency with effective mitigation. If they are well instrumented and fail they can provide researchers with valuable information concerning the mechanisms of failure and perhaps useful guidance in developing improved mitigative measures.

Lastly, there needs to be a thorough investigation into ways of making the findings of research more acceptable and more useful to the practitioners and politicians. As in many other branches of science, this vital technology transfer activity is the weakest link between basic research and practical land management.

CONCLUSIONS

Of the three potential hazards discussed (vulnerable debris cones, urbanized unstable landforms, and logging-related erosion and debris flows), the greatest economic losses are associated with urbanized unstable landforms. Damages to urban settlements on debris cones rank second, and debris torrents related to logging steep, unstable slopes ranks a low third in cause for concern.

Most of the western United States lacks good political mechanisms that address erosion and debris flow disasters. The responsiblity for disaster prevention has been left to the individual or local government. And they are unlikely to have the will or resources to take effective preventative actions.

Substantial research in the United States is devoted to the problems stemming from erosion and debris flow disasters. Notwithstanding, such research is funded at a level that is disproportionately lower than warranted by the economic cost and loss of life associated with such disasters. There are substantial unmet research needs. Apart from ongoing basic research, most of the needs relate to bringing greater rigor to the application of what is currently known. Research is not the weak link in our current attempts to reduce erosion and debris flow disasters, nor is technology transfer (however ineffective). The greatest need is for more effective implementation of existing capabilities.. That need exists because most responsible local governments either fail to recognize potential erosion and debris flow hazards or lack the will to resist the pressures for unwise development of high-risk areas.

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