<論 文>

Social, Technological, and Research Responses to Potential Erosion and Sediment Disasters in the Western United States, With Examples From California*

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SYNOPSIS

Examples from California 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 a result of the reluctance of local governments to 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 associated economic costs and loss of life.

INTRODUCTION

Unlike most areas having serious erosion and debris flow problems, 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 60% of the landslide damage in the 1973-1983 decade occurred in the 12 western states. California alone experienced damages approximating 1 billion dollars, about 40% of the total. In the interest of coherence, the disasters that illustrate this paper 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.

SOCIAL CONDITIONS AFFECTING DISASTER RESPONSES

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

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processes is even more recent. This recent 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. 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. 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. In consequence of this primary dependence 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, moderately effective controls were imposed. And since 1963, very stringent standards considerably in excess of Uniform Building Code specifications have been in effect and consistently 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.

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 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. At the federal level, such maps and reports are

provided by the United States Geological Survey (USGS). 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 limit the size of clear-cut areas, affect the type of equipment used to transport 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 fist habitat. They also have the practical effect of minimizing the risk of erosion and debris flow disasters.

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 government. 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.

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 debauched onto the valley floor. Their geomorphic settings are similar to that of Kobe City. 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 financial 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 Gabriel’s 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.

The explosive population growth of Glendora during the 1950's led the Los Angeles County Flood Control District to construct seven debris basins at the mouths of drainages tributary to the Glendora debris cone. These debris basins ranged from 22, 000 m^3 to 561, 000 m^3 in capacity. 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, the city's 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. 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. It was raining at an intensity of 40 to 50 mm hr^{-1} at that time. 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 ones ; hence, most watersheds smaller than 1 km^2 are not candidates for debris basins. This policy also means that it is usually not economic to build structures that ensure 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 was begun on an extensive system of check dams and debris basins to protect vulnerable areas from future flood emergencies. 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 adequate to appraise the nature and magnitude of geologic risk associated with the 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 case history 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.

The Verde Canyon landslide occurred on December 30, 1983, nearly two decades after urbanization (Leighton et al. 1984). The 20-year lag between development and disaster is common to other similar incidents in southern California. Rainfall trends which existed in the area during the middle of this century (Fig. 1) 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.

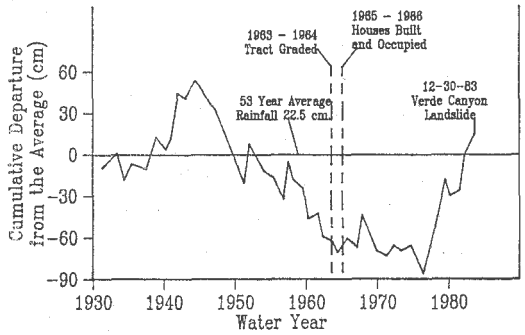

Fig. 1 Cumulative rainfall departures, 1930–1983.

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 present 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° to 40°. It was a block glide of about 23, 000 m^3. 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.

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, 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 damaged spawning and rearing habitat resulting from debris flows and sediment originating on recently logged timberlands.

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 (Fig. 2) is viewed as evidence that habitat degradation is an important factor (Demon 1974).

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 erodable. 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.

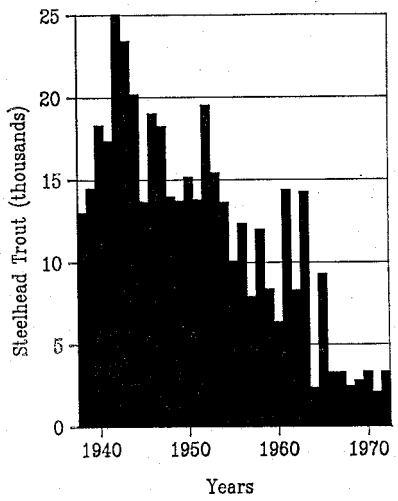

Fig. 2 Steelhead trout counted in the south fork of the Eel River, 1938-1972.

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 102 landslides. The environmental costs were 90 m^3 of soil loss and 93 m^2 of bare soil created for every 100 m^3 of timber harvested. 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.

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 rewriting of California's forest practice rules in 1973, the requirement that all timber harvests be planned by licensed foresters, and the review of those plans by the California Department of Forestry before work could begin. The resulting rules were almost completely rewritten between 1980 and 1984 in response to a portion of the Federal Pollution Control Act.

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.

RESEARCH

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).

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). 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. Landslides (including debris flows) caused greater loss of life than any other ground-failure hazard. Though they are the second greatest cause of economic losses, research funding in this category ranks fourth, behind subsidence, 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.

In is axiomatic that it is difficult to manage a phenomenon that is not understood. Consequently, basic research enlarging our understanding of erosion processes, landslide mechanisms, and debris flow genesis is paramount. Basic studies should approach the problem from different perspectives, including controlled laboratory experiments, careful monitoring of naturally occurring erosion and debris flows, monitoring of purposely caused slope failures, and correlative studies of site conditions and meteorological 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.

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 criteria 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 broad scale 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.

Lastly, a comprehensive investigation is needed into ways of making research findings more acceptable and more useful to 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 rank 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 responsibility 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. The. weak link in our current attempts to reduce erosion and debris flow disasters is neither research nor 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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