JOHN M. TETTEMER & ASSOCIATES, LTD.

SELECTED PUBLISHED PAPERS
ON
ALLUVIAL CONES, SEDIMENT, FLOOD PLAINS
AND OTHER WESTERN STATES HAZARDS

ENGINEERING MANAGEMENT PLANNING
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SELECTED PUBLISHED PAPERS
ON
ALLUVIAL CONES, SEDIMENT, FLOOD PLAINS
AND OTHER WESTERN STATES HAZARDS

This group of published papers was compiled to assist the reader in planning the management of flood hazard areas, particularly those of the arid southwest.

John M. Tettemer & Associates, Ltd's. principal and senior engineers have pioneered applications of alluvial cone, flood plain, and sediment management in several western states for over ten years. Clients include government agencies and private landowners. We have prepared a number of master plans for properties or communities that include these hazards.

John M. Tettemer & Associates, Ltd.

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Proceedings of a Workshop

IMPROVING THE EFFECTIVENESS OF FLOODPLAIN MANAGEMENT IN WESTERN STATE HIGH-RISK AREAS

Alluvial Fans, Mudflows, Mud Floods

Special Publication
9

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In cooperation with

The Federal Emergency Management Agency
The California Department of Water Resources

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MANAGEMENT OF HIGH RISK FLOOD HAZARD AREAS

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Pilot Mapping and Modeling

Alluvial cones, mudflows, and sediment laden streams need to be mapped as Special Flood Hazard Areas requiring special management. Management considerations include radial flow, sensitivity to diversion and collection, erosion, and sedimentation. The entire cone or floodplain should be identified for management, based on topographic and geologic evidence of previous flows, not just a limited area based on clear water hydraulics.

Areas in need of such mapping include portions of Los Angeles, San Bernardino, Orange, Riverside, Ventura, Santa Barbara, and Imperial Counties in California; Clark County in Nevada; Davis, Salt Lake, and Utah Counties in Utah; Pima, and Maricopa Counties in Arizona; and Bernalillo County in New Mexico.

One of the most serious policy issues affecting the mapping of these areas is concern about accuracy and precision. Mudflows and alluvial cone mapping procedures are not yet advanced to the same level of "accuracy" as those of clear water hydraulics. Program administrators have been reluctant to proceed with mapping such areas because of concern about accuracy and defensibility of the maps. This caution may have had its origin in the early days of the NFIP when the "approximate" Flood Hazard Boundary Maps were found to contain many errors.

The result is that after 11 years into the program there are still many areas that need to be managed but which are unmappable under the clear water criteria. These are the areas subject to development. Local officials responsible for regulation of development consider these areas to be free of problems and routinely approve roads, grading, walls, and other improvements that may be subject to hazard or may increase the hazard to other developments.

We cannot afford to wait for refined procedures. We should get these areas identified, even approximately, and give floodplain managers, local politicians, and developers improved visibility over potentially hazardous areas. We recommend adoption of a pilot program as described in the section below entitled, "Recommended Changes in the Flood Insurance Program for Alluvial Cones."

Model Regulatory Approaches

The City of Las Vegas ordinance is one that brings to bear a broad cross-section of city functions on flood hazard reduction. Existing programs do not require any recognition of the hazards. The Los Angeles County Flood Control District floodway mapping and community information program, the Las Vegas alluvial cone master planning model, and the Las Vegas development permit review procedure are all innovative approaches that can be used as models by other local entities.

Several specific research tasks should be undertaken. In priority order to set required standards immediately, they are:

- Development of improved engineering design for stabilizers, toe protection, drop structure, and cutoffs;
- Development of engineering procedures for predicting erosion and mudflow; and
- Development of standards relations governing mudflow behavior.

A long-range objective would be the scientific verification of the standards, based on continuing research.

Recommended Changes in the Flood Insurance Program for Alluvial Cones

1) Identify alluvial cones on the flood insurance map as Special Flood Hazard Areas requiring special consideration of radial flow, sensitivity to diversion and collection, erosion, and sedimentation. This identification should be based on the topographic and geologic extent of the cone, rather than on hydraulic flow computations.

2) Require local government to develop and adopt a master plan for each alluvial cone, showing the relationship between development and flood flows. The master plan should address development assumptions, erosion and sedimentation, and how the transition from existing conditions to the master plan configuration will be managed.

   If flood and sediment control facilities are part of the master plan, the areas in which development is conditional on the availability of the master plan facilities should be identified.

3) Provide for removal of the Special Flood Hazard Area designation upon demonstration by local government that the hazard has been mitigated by the installation of elements of the master plan.

4) Benefits of NFIP (availability of flood insurance and grants-in-aid within the SFHA) are dependent on adoption of the master plan and management plan. The master plan describes the ultimate development configuration safe for 100-year flood. The management plan describes how the transition from existing conditions to the master plan will be

managed. Implementation of the master plan element is the only basis for appeal.

5) Apply the A Zone insurance rate over the entire cone.

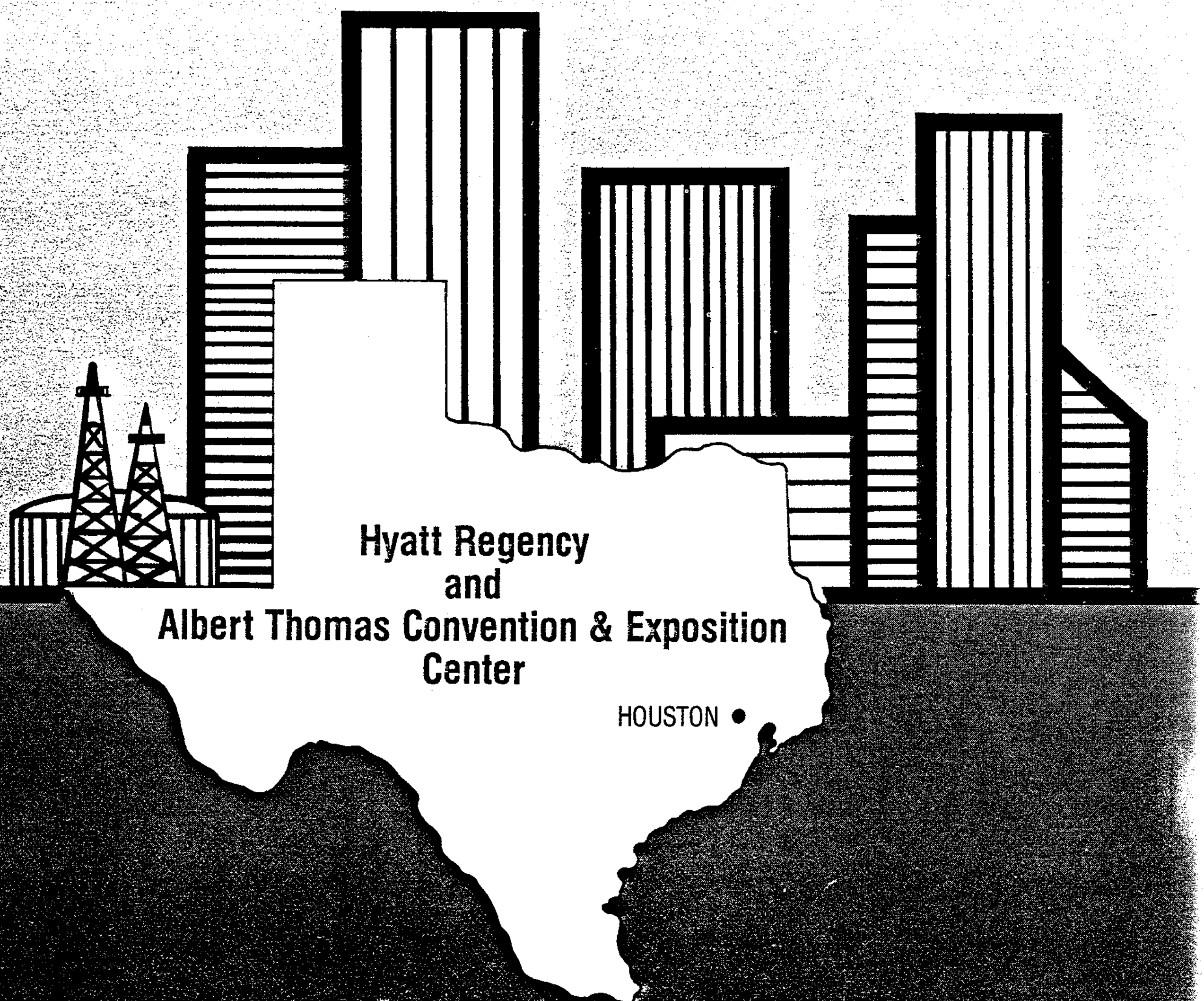
FINAL PROGRAM

1983 ASCE ANNUAL CONVENTION

& Continuing Education Courses

October 17-21, 1983

"The City and the Civil Engineer"



STRUCTURES '83

Congress & Exposition

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STATE-OF-THE-ART FLOOD PLAIN MANAGEMENT IN THE WEST

By

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STATE-OF-THE-ART FLOOD PLAIN MANAGEMENT IN THE WEST[1]

by John M. Tettemer[2]

WHY THIS PAPER?

The West is a special place. Its extremes of topography and weather, which are responsible for its many natural wonders, present special situations to the flood plain manager which are not addressed in flood plain literature. Classic engineering approaches do not fit, and the western community tends to be impatient with restrictive regulations for flood plains or otherwise.

We know from the devastating floods throughout the West in recent years that the opportunity for improved flood plain management is enormous, and it is clear that the future consequences of inaction or failure are grave.

Over my professional lifetime I have had the opportunity to be deeply involved in flood plain management in a variety of western situations. There are proven, field-tested approaches that are working. My purpose in this paper is to present practical, common sense insights on how to develop and maintain a flood hazard reduction program in each of the special situations confronting us in the West. I hope to kindle your imagination and stretch your aspirations.

CHARACTERISTICS OF THE WEST

METEOROLOGICAL

First of all, except for the Pacific Northwest, the West is generally dry. This plays an important part not only in western land forms, but also in the way westerners perceive water, water development projects, and the likelihood of flooding.

While the region is generally dry, there are wide variations in precipitation, both temporally and areally. Each year has a "wet" and "dry" season. Most years are below average in annual rainfall. An occasional year brings intense storms, thundershowers, or heavy snow pack. Almost every year somewhere in the West there is at least one major flood disaster.

PHYSICAL

Extreme Variation in Topography

The elevation change of 16,000 feet within the 100 miles between Mt. Whitney and Death Valley is an extreme, but it illustrates the dramatic variation in western topography. The Rockies and the Sierra Nevada contain many 14,000

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[1] Presented at the October 17-21, 1983 ASCE Annual Convention and Exposition, Houston, Texas

[2] President, John M. Tettemer & Associates, Ltd., Los Angeles, California

foot peaks, and form the headwaters for great rivers which play major roles in downstream cities, farm lands, and flood plain management challenges. Steep, rugged canyons are popular resort, recreational, and, increasingly, residential areas. Their erosive velocities and sediment transport capability make them particularly important as objects of flood plain management. At the canyon mouths and around the rim of the deserts we find alluvial cones, which are deceptive by their lack of well-defined stream channels, but which account for a large percentage of flood disasters. River valleys present another topographic variation, as do the deserts, each with its own list of flooding case histories. Finally we have an abundance of lakes, both natural and manmade, which, due to the general dryness, are all the more prized for development and vulnerable to encroachments within the flood plain. With the wide variety of topographic situations the flood plain manager must have a variety of engineering approaches.

Influence of Manmade Structures

As if the natural terrain were not irregular enough, man has provided an overlay of works which exert influence on drainage and flood patterns. Dams regulate flows so well in dry periods that people become careless in their flood plain encroachments. When a truly wet year arrives the river again occupies the land it needs.

In many places, particularly in the deserts and on alluvial cones, railroads, freeways, highways, and aqueducts are the dominant drainage features, sometimes diverting flows great distances and sometimes concentrating sheet flows into a gully.

Other manmade works such as subdivisions, buildings, fills, walls, and streets greatly influence drainage, particularly in sheet flow areas where drainage channels are not well defined.

Highly Developed Water Resource System

An important manmade system that presents both challenges and opportunities to the flood plain manager is the highly developed water resource system. In the thirsty and energy-hungry West, there is hardly a major river or stream without a reservoir and the related power plant, irrigation diversion and urban water supply aqueduct. These water developments are often said to have made the West what it is today, and in truth they did. Most major cities and agricultural districts depend on water supplies developed far away in snowcapped back country and controlled by networks of dams, channels, pipelines, and pumps.

Most water projects provide incidental flood control benefits, and were economically justified in part due to flood control benefits calculated in the benefit/cost ratio. To the extent these dams provide flood protection, they further the objectives of the flood plain manager. The problem comes when the pressure for water storage and power generation takes precedence over flood control and the system is operated in such a way its flood control potential is not realized. Also, lack of communication between the operators and flood plain managers combined with the normally dry years when flow is well controlled lull valley communities into the notion that the river will remain within its bank, promoting encroachments into the flood plain.

CULTURAL

Several cultural attributes of the West have influenced our present level of achievement in flood plain management, and need to be understood if we are to succeed.

Pioneer Spirit

First of all, underlying everything else is the "pioneer spirit". Westerners are proud of their heritage of carving empires out of the hostile wilderness. The essence of the western pioneer is his self-reliance and individualism. He is used to making his own way, taking his own chances, and reaping the rewards or suffering the consequences. When it comes to building his house or developing his land he wants no interference from government regulations. He is particularly put off by limitations on building and development based on a "computed 100-year flood". He is firm in his conviction that the "Noachian Deluge" predicted by the hydrologist could never happen. He, himself, has lived here "x" years and "the water has never been more than this high". Obviously, flood plain management, presented insensitively, and without sufficient communication to reach the common sense level, was not the most popular government program in the West.

Water Consciousness

Another attribute of western society the flood plain manager finds himself dealing with is the water-consciousness of the westerner. Most westerners live in water-short regions. They are instinctively water conservationists. They have a high regard for water projects which can assure reliable water supplies for farm lands, municipal and industrial uses, power generation, and recreation. The irrigation districts, metropolitan water districts, and power companies which sponsor and operate the water systems are core fibers in the fabric of western society. The directors and administrators of these organizations are the respected leaders of the community.

It is widely accepted that what is good for the water business is good for the community, and that water system operators can do no wrong. Thus, when conservative water policy dictates keeping reservoirs as full as possible so as to minimize chances for a future shortfall, the western community has tended to accept this policy -- the more rural the community the stronger the acceptance.

In a wet year, when flooding is imminent, the full reservoir policy prevents the use of the dams to reduce flooding. If the reservoir is already full when the flood crest arrives, the flood goes right over the spillway into the downstream community. From the flood plain manager's standpoint a more responsible operation policy when all signs point to high runoff would be to retain capacity in the reservoir for flood peak reduction, and still wind up at the end of the runoff season with a full reservoir. One of our challenges is to promote a more equitable operating policy for the many dams in the West, so we obtain a fair share of flood protection in wet years when water shortage is not a problem.

Growing Urban Interest

Wherever there is water in the West, there are people. The first ranches and farms were along rivers and streams that could provide water for crops and livestock. The successful settlements were those with enough water for growth. Some communities went far afield to obtain sufficient water to maintain their growth. The canyon areas were first popular as resorts, but they are now completely urbanized. In the foothills and deserts, the alluvial cones not only offered the most easily developed sites but also contained the groundwater on which these communities depend.

As rural communities are changing over to urban, there is a changing of values. The urban dweller cannot control his environment to the extent the pioneer, the rancher and the farmer could. The urban dweller looks to his community to provide what he considers a satisfactory environment in terms of safety, health, and convenience. His values include indoor plumbing, paved streets, and flood control. He is not as likely as the rural dweller to accept flooding. If he is a canyon dweller walking among the houses wrecked by debris flow, or an inhabitant of a flooded community beside a river or lake with dams upstream he will be asking, "How could those responsible have allowed this to happen?" He will be pressing for improvement and will press the button available to him: the political button.

Politicians are aware of this growing electorate. Where the agricultural community, the water community, the power community and the land development community once comprised the important constituencies, and had little interest in flood plain management, the urban community is now finding itself, and is providing, for astute politicians, a constituency for flood plain management.

Traditionally Laissez-Faire Flood Plain Management

Since World War II the migration to the West has been enormous. Pressure for housing, business, and industrial sites dictated speedy processing of plans and permits. With the variety and extremes of topographic conditions, and the normally dry weather, technical approaches for dealing with all types of flood, erosion, and debris hazards were not well understood. The political climate was for growth, and those responsible for regulating growth were responsive to their political leaders. And, for many years, there was ample federal, state, and local funding for remedial flood control works. In this environment, and with the underlying pioneer spirit, it was natural that flood plain management did not receive high priority in the building of today's West.

STATUS OF FLOOD PLAIN MANAGEMENT

PARTICIPATION IN THE NATIONAL FLOOD INSURANCE PROGRAM (NFIP)

The NFIP is fifteen years old. The detailed mapping has been underway more than ten years. Almost every community of any size has an approximate study and most of them have a detailed study. They have almost all met the federal requirements for participation in the program. The statistics on number of communities participating and number of policies sold are impressive. But as flood plain managers at the local level we are interested in more than nationwide statistics. How effective are our programs? How well have we thought beyond the limitations of the federal program? What are we doing about old problems while we regulate new starts? How well have we woven flood prevention through the fabric of local government?

CURRENT PERFORMANCE

By the summer of 1983, there had been at least thirteen Presidential declarations of flood disaster within the past two years in the western states. Requests for a billion dollars in federal disaster assistance funds were filed. Actual damages and disruption of community and family life far exceeded the items eligible for federal reimbursement.

The cost of damages increases yearly as human occupancy expands. The Las Vegas sediment flood of July 3, 1975 caused $4,000,000 worth of damages. Tropical storm Kathleen, in September 1976, caused $23,000,000 worth of flood and sediment damage in the City of Palm Desert, California, plus additional millions to utility, transportation, and communications facilities. The same area was struck again in 1979 with damages estimated at $50,000,000. Sediment flow during February and March 1978 in Los Angeles took ten lives and caused $100,000,000 worth of damage to private and public structures, roads, utilities, and flood control works. Southern California floods in 1980 caused the loss of eighteen lives and $350,000,000 in damage. The January 1982 San Francisco Bay Area disaster took thirty-three lives and cost $281,000,000. In January 1983 flooding in California caused twelve deaths and resulted in applications for $63,000,000 in federal Public Assistance disaster recovery funds. Back-to-back floods in Washington state in 1983 displaced 122 people and destroyed 306 structures. The Utah flood disaster in 1983 affected 4,500 people and cost $250,000,000. Floods in Arizona earlier this month have taken several lives and have caused an estimated $100,000,000 to $200,000,000 worth of damage.

IMPACTS

Individuals

The most tragic impact of floods is upon individuals and families. Not only do western communities have to deal with uncontrolled water, but they are also subject to debris flows, which leave behind crushed stucco walls, thousands of tons of rock, mud, and debris, and automobiles hammered around standing trees. The destruction and the cleanup problems are staggering. Homes representing a family's major financial asset are destroyed. Livestock and pets are lost forever. One father leading the family horse to safety across a stream was swept away and drowned. Others have been stricken with heart attacks while shoveling mud and lifting sandbags. Highway workers placing barricades in front of a dip crossing of a normally dry stream have been swept away and drowned. Caretaker residents of a church camp resort area have been swept away in the night. Bodies not yet recovered are probably buried in downstream reservoir sediments.

Community

At the community level the flood brings several reactions. During the emergency, the shock of disaster stimulates heroic and unselfish acts of courage and strength. Natural leaders take charge of evacuations, seeing to it that the elderly, disabled, and the young are carried to safety. Strapping teenage boys and girls set up sandbag operations, filling and placing the heavy bags long past the point of exhaustion. Emergency forces from all sources -- utilities, contractors and public agencies -- all find ways to contribute without concern for jurisdiction or red tape.

The morning after the flood, when the shock has worn off, residents walk the streets, canyons, lakesides and river valleys, surveying the wreckage. As they look at the path of destruction leading from canyon mouths and spreading randomly across alluvial cones, or see the effect of high water along rivers and lakes, they realize how certain it was for disaster to strike where it did. After the flood, it does not take an expert to observe that mudflows which have always poured out of the canyons will continue to occur, even if houses are placed in their way. Rivers and lakes will again claim their needed space. As people gather, the question is asked over and over: "How did they ever approve a building permit in that spot?" The feeling of betrayal by the officials entrusted with public safety spreads rapidly under these circumstances.

Local government

The impact of floods on local government is staggering. Types of impact include financial, service delivery, regulatory and political. In one Southern California flood there was $175,000,000 in damages to public properties, roads, bridges, and flood control facilities. Although restoration of public facilities is eligible for federal disaster funding under certain circumstances, it takes about 60 days to receive the first payments. Local agencies must be able to finance emergency flood fighting activities during the interim, which may involve enormous cash outlays for rental equipment, operators, and contractors.

Diversion of local financing to flood fighting and restoration operations means deferral of other projects and services which were scheduled and financed. Energy and money expended on restoring public facilities damaged by floods can never be recovered and is a permanent loss of societal resources.

Repeated floods have had an impact on the way local officials view their responsibilities for controlling development. At the technical level attention has been drawn to the engineering aspects of western flooding. Improved procedures for evaluating proposed developments, for predicting the quantity and location of potential flood and sediment flows, and criteria for mitigating their hazards, have been developed. Planning, zoning, subdivision, and building departments have become much more aware of flood and sediment hazards, and receptive to procedures and techniques for avoiding or mitigating them. Although only a few communities have taken positive mitigating steps, they have demonstrated that workable procedures and criteria can be developed and implemented without upsetting the housing industry.

At the political level, the same thing has happened. Immediate reactions have included ordering re-evaluations of planning and building criteria. Beneficial results have included a good understanding of the seriousness of flood and sediment hazards and a willingness to stand behind technical staff recommendations on safety criteria. Again, this political perspective is not widespread but it does indicate that concerned engineering officials can work effectively with elected officials to improve public safety.

Federal and State Government

Disaster relief laws authorize the Federal government to assume most of the cost of restoration of public facilities whenever the President declares a national disaster. Repair and restoration of public buildings, streets, parks, and flood control facilities due to flood and sediment damage is costing hundreds of millions of dollars per year. States are also impacted, particularly when the situation does not qualify for a national disaster proclamation. Since states do not normally maintain an appropriation for the purpose, it is usually necessary to enact special assistance legislation. The overall effort amounts to a substantial deployment of energy and money that the West can ill afford.

CONCLUSION

Current experience indicates that western flood plain management is just as effective as some flood control facilities I have seen -- they work fine until it rains. I haven't seen a community in perfect shape. In many of the most critical communities, those undergoing rapid growth into hazardous flood plain, lakeside, alluvial cone, canyon, and hillside areas, many of which are not mapped on the flood insurance maps, the staff is undertrained and undermanned, and there is no clear commitment to flood plain management at the policy-making level. Under these circumstances the level of flood-related costs cited above could double in ten years.

At the same time, with the number of dramatic flood disasters throughout the West in the last few years there is an unprecedented opportunity to make progress while the memory is fresh in mind. It's hard to get people excited about flood plain management in a five-year drought.

SHORTCOMINGS OF THE NFIP

The NFIP is a step in the right direction, but, by its own admission, it is not sufficient. The regulations encourage communities to go further, but FEMA does not provide the technical data from which to work. Major shortcomings in the program which are crucial to western situations include the following:

FUTURE DEVELOPMENT

Flood Insurance Studies (FIS) are done on the basis of existing development. Building setbacks, finish floor elevations, and floodways designed on the basis of the FIS can become obsolete in a few years as the drainage area develops. A homeowner who built outside the Special Flood Hazard Area could be in a mandatory flood insurance area the next year after an area was remapped. Communities cannot live with this. They must adopt standards that will assure reasonable permanence.

EROSION AND MUDFLOW/MUDFLOOD

In many western communities the most serious damages are caused not by clear water flooding but by erosion and/or debris flows. While these hazards are recognized in the NFIP legislation, FEMA has not yet implemented on a meaningful scale a mapping program. This leads many communities to a false sense of security when their Flood Insurance Rate Map (FIRM) does not show any Special Flood Hazard Area in the canyons and alluvial cones. To avoid the type of debris-flow disasters experienced throughout the West in recent years, communities must obtain accurate delineation of debris hazard areas. Techniques are available.

QUALITY OF FIS

Many communities which have taken the NFIP seriously set out to develop criteria for building and development based on their FIRMS's, only to discover errors in the maps. The appeal process is long and frustrating, and the burden of proof rests with the community, many of which do not have the technical and financial resources to evaluate the quality of their maps. Errors have been found both overstating and understating the flood hazard.

EFFORT REQUIRED BY THE COMMUNITY

A substantial effort is required by the community to make effective, practical use of the FIRM. If the community wishes to adopt a flood plain or floodway zone, it must convert the FIRM boundaries to a metes-and-bounds map with a legal description. It must locate the zone on the ground. If it wishes to have its flood plain management program reflect the effect of future development, erosion, and sediment, it must obtain additional hydrology and hydraulic studies. If it wishes to have mapping errors corrected, it must submit engineering and scientific proof of the error which amounts to redoing the map. If it wishes to manage development on alluvial cones, it must develop its own criteria and review all activity on the cone, both private developments and public works.

Some of these requirements are properly the responsibility of the community, and some could be reduced by an improved federal level work product. But the real deficiency in the NFIP as to community effort is in failing to impress on communities the commitment involved and the level of effort required.

OBSOLESCENCE

FIRMs prepared on the basis of existing development begin to become obsolete before they are published. As drainage areas are developed, and flood control improvements constructed, the depth and extent of flooding will change. At this writing the Congress is debating whether or not to continue doing Flood Insurance Studies for communities which do not have detailed studies. If first-time studies are in jeopardy, we cannot expect high priority on updating and maintenance of obsolete studies.

LEVEE CRITERIA

Lakes, rivers, and ocean fronts protected by levees and sea walls present a risk of quite different proportions from that associated with a riverine situation. In the riverine situation a flood which exceeds the design flood increases flood depths a small percentage above the design flood depth. But if the river is contained by a levee with houses and businesses behind the levee, a flood which exceeds the design flood may completely destroy the community. The situation of the levee is similar to that of a dam. When the dam fails the community is worse off than if there had been no dam. This situation presents complicated questions of design, maintenance, land use standards, and insurance rate setting which are not yet satisfactorily resolved.

RESERVOIR/DIVERSION SYSTEMS

The FIS requires not only a hydrologic analysis of the 100-year flood, but also, when reservoirs and diversions are present, their operation must be simulated to determine the 100-year flood downstream. The reservoir and diversion operating assumptions are not explained in detail in the FIS. This provides the opportunity for misunderstanding and misinterpretation, and for error if operating rules are changed or incorrect assumptions are made. The program provides no mechanism to establish communication and understanding between system operators and flood plain managers.

FLOOD PLAIN MANAGEMENT OPPORTUNITIES

It is clear that there are opportunities for great accomplishment in flood plain management in the West.

RIVERS

Encroachment limits, elevations, and armoring requirements can be established for river reaches that allow property owners to improve their land and repair flood damage in a coordinated and adequate manner. Future development can be incorporated as appropriate, so the criteria do not become obsolete. Erosion and sedimentation can be incorporated. The level of maintenance to assure performance as planned can be agreed upon and arranged for. Agreement can be reached with the operators of dams and diversions on the operating rules and assumptions, and an open interchange can take place in planning for high runoff seasons.

CANYONS

Improved hazard mapping can be done to include the effect of mudflood, erosion, and debris. Development criteria for canyon floors and hillsides can be established to allow productive use of attractive canyon areas without undue risk to life and property. Effects of future development, erosion, and deposition can be incorporated to insure long-lasting effectiveness.

LAKES

Lakes are frequently part of a river system, often with dams upstream or downstream. Agreement can be reached among the communities affected by the lake/river/dam system on how to equitably share the advantages and risks of living along the system. Wet-year planning can minimize damages and provide a cooperative basis for system improvements if needed.

ALLUVIAL CONES

Alluvial cones present the greatest opportunity for management, because almost every activity on the cone affects drainage. Several years of typical checkerboarded, gerrymandering development on the cone, with related highways and freeways, without a drainage strategy can result in diversions of flow and damage to existing developments. A drainage strategy on the cone can assure that each development activity fits with the rest and works toward the drainage master plan.

GROUNDWATER

Groundwater is included in this paper because high groundwater often accompanies heavy runoff seasons, and the flood plain manager may find himself dealing with complaints about flooded basements. The ideal time to establish development standards for high groundwater areas is at the same time standards are being established for mitigation of surface flood hazards.

GENERAL REQUIREMENTS COMMON TO ALL SITUATIONS

Western communities and their environments are so diverse that no single flood management strategy is applicable to all; however, there are several elements that are necessary, regardless of the specific situation. This section describes the essential ingredients for political and administrative success.

POLITICAL COMFORT

Regardless of how much money and effort are devoted to flood prevention by Federal agencies, states, and flood control districts, flood plain management cannot be effective without effective building controls at the local level. The local elected official is the key player in flood plain management. Securing his commitment is essential.

Of all politicians the local councilman, supervisor, and mayor are closest to their constituencies and are extremely sensitive to community attitudes. Because zoning and building matters are administered locally there is frequent interchange on a first name basis between the building industry and local officials. If local officials are to champion flood plain management, it must be presented to the community in a format and at a pace designed to resolve controversy and develop consensus. Prospects are best with a program based on common sense and specifically tailored to the community in terms of hazards addressed, development criteria, and permit processing. Local elected officials should be briefed in advance on the community's obligation under the NFIP, and the approach to be used in soliciting community input. The official at this stage may offer suggestions on the structuring of the process and may decide to front it himself. In any event, he is fully informed in advance. As the process unfolds the elected officials should be kept informed of progress and of how their constituents' concerns are being dealt with.

The objective of the process is to provide ample advance opportunity for discussion and resolution of issues so that when the ordinance comes before the legislative body there is no controversy.

COMMUNITY RELATIONS

Affected segments of the community should be involved in the process of developing the flood plain management program. The main affected segments are the land development industry from the standpoint of impact on development costs, and the taxpayers from the the standpoints of cost to local government and level of protection to be provided. In a given community there may be additional special interests.

The land development industry includes realtors, developers, engineers, and lenders. In many communities these groups are organized into associations. Taxpayer groups and civic support groups offer access to the general public interest.

Involvement of these groups may be accomplished by presentations and workshops at their functions, and/or by the creation of a special work group or committee with representation from each group. An agenda and timetable should be provided for ample discussion of concerns and evaluation of options.

It is important that the options available be clarified at the outset, along with the costs and consequences of each one. Of key importance is the significance of participation in the NFIP in terms of the advantages and responsibilities of participation, and the sanctions regarding loss of flood insurance and certain important grant opportunities if the community should drop out of the program.

ORDINANCE

The most effective way to bring all city or county functions to bear on the goal of flood hazard reduction is to adopt a comprehensive flood hazard reduction ordinance. This gathers in one place the policy and the implementation tools for all aspects of drainage.

The ordinance should contain references to the statutory authority for the city or county to engage in flood plain management activities, findings of fact by the governing body on the nature of the local hazards and the consequences to citizens and local government of repeated flooding , and methods of reducing losses. It should designate a person to administer and implement the ordinance. It should provide for the establishment of development permits, a master plan of drainage, a drainage manual, a drainage deficiency inventory, and a public works program. It should require the administrator to review the general plan, zoning proposals, subdivision proposals, building permits, street and highway plans, and other public and private construction to assure conformity with the ordinance.

MASTER PLAN

The Master Plan of Drainage should contain a description of the flood, snowmelt, erosion, and mudflow hazards facing the community, including drainage area maps, flood discharges, and overflow areas. It should contain standards and criteria on level of protection for hazard categories and proposed land use. It should contain conceptual plans and cost estimates for master plan projects, including detention basins, debris basins, storm drains, flood channels, and levees. A master plan serves as the basis for securing financing, and provides for the construction of units of the plan as part of land developments and public works projects.

DRAINAGE MANUAL

The drainage manual contains the technical criteria and standards for determining flood discharges for design purposes, hydraulic design criteria, structural design criteria, and standard drainage structures. The manual assures consistency of the drainage system, saves money in the design and review of plans, and assures maintainability and durability of drainage structures.

DEVELOPMENT REVIEW AND GUIDANCE

Review of subdivison proposals and building permits is essential to safe development, but does not provide the level of service necessary to attain the most satisfactory results. By the time a tract map or building permit is submitted the most important decision has already been made: whether to purchase the land or not. Once the land is purchased, the developer may become committed, even if the land has a serious flood, erosion, or mudflow hazard. A more desirable objective is to make prospective developers aware of the flood hazards on various available properties, so they may select one with the fewest problems. This can be done by providing a flood hazard statement on request, based on information available in agency files. Availability of flood hazard reports can be made known by means of brochures placed at real estate offices, banks, and other points of public contact.

The subsequent planning and design of the development should be done with drainage as the basic consideration. Land uses, street layout, and lot design can readily be determined after drainage requirements have been established. An iterative process will assure balance. On the other hand, if drainage is left to the last, difficult situations can arise with unfortunate results. The local agency should encourage close communication with the developer during the planning stage to assure that drainage is adequately addressed.

In this way the final tract map and building permit are routine approvals of concepts worked out in advance. The developer's schedule is maintained, his design budget is not impacted, and a better result is obtained.

PUBLIC WORKS PROGRAM

New developments should shoulder their fair share of drainage improvements. They should be safe themselves and they should not impact adversely on their neighbors -- upstream, downstream, or laterally. They should install units of the master plan where necessary to protect their development and dedicate rights of way where required for future master plan projects. But developers alone cannot complete a master plan. A public works program is necessary.

Older developed areas have flood problems that cannot be addressed by new developments. These "old wounds" must be cured by public works. Backbone systems to provide outlets for development drainage may have to be provided by public works. Gaps in the system must be closed by public works.

The public works program requires a master plan, priorities, and financing. Ad valorem taxes, benefit assessments, improvement districts, and bond issues are used to finance local public works programs. Reliance on federal funds should be viewed with great discretion. The lengthy timetable for a federal project leaves needed projects in limbo for years. Federal single-purpose project design criteria may not be sensitive to community standards and desires. These factors together with the matching fund requirement dim the attractiveness of federal dollars.

OPERATION AND MAINTENANCE

Drainage, flood control, and debris control facilities are especially vulnerable to plugging, erosion, deposition, weeds, rodents, fire hazards, trespass, attractive nuisance, and eyesore. Maintenance must be provided if the facilities are to perform as designed and last an economical lifetime.

Dollars being scarce, design of the maintenance system is extremely important to assure that critical maintenance tasks are performed within available funds. Fortunately 85 percent to 90 percent of the required maintenance of flood control works can be pre-planned, pre-scheduled, and pre-budgeted, once acceptable maintenance conditions, maintenance standards, and routines have been established. The discipline required to put the maintenance function on a systematic basis is well worth the effort. Large systems are known to have saved millions of dollars through maintenance management.

COORDINATION

The western community lives in a complex network of construction activity, carried on by itself and by others. All construction affects drainage. It is extremely important to stay in touch with the construction plans of other departments in the city or county, neighboring jurisdictions, developers, the state highway department, and water development agencies. Freeways and aqueducts are among the dominant influences in western local drainage. Coordination can assure compatibility with local master plans and construction programs. Joint projects can often be developed to achieve results unattainable by either agency alone. On the other hand, we live with many reminders of the unfortunate consequences of inadequate coordination.

Common sense is the key. For example, rescheduling the paving of a street until after the storm drain is installed is easily accomplished, and may eliminate a lot of heat in the councilman's office.

SPECIFIC REQUIREMENTS FOR SPECIAL SITUATIONS

RIVERS

Between the Los Angeles River and the Rio Grande, the west contains a variety of rivers -- narrow, wide, clear, muddy, steep, flat, even wet and dry. However, they can all be classified into two types of flood plains. In the entrenched type flooding produces great change in depth and little change in width. In the shallow type the flooding overflows the low flow and produces a great change in width. Both kinds can present problems to unwary developers and designers. Special care must be used when levees are part of the plan.

Development Criteria

Long-lasting, safe development beside a river requires a master plan approach. Under this approach development criteria must not only recognize the past behavior of the river but make allowances for future changes. Future development of the watershed and channelization of the river may result in higher flood peaks than ever experienced before.

The master plan requires that the level of protection be determined as a policy issue by each community. The NFIP requires as a minimum 100-year protection for homes and buildings, based on existing watershed development. Where the consequences of failure are grave, it is appropriate to adopt a higher standard. For uses not involving houses and the safety of people, lesser standards make sense.

Encroachment policy likewise must be established by the community. The NFIP provides that encroachments may be allowed which do not increase the 100-year flood level more than one foot. In adopting the master plan, consideration should be given to the effect of encroachments on river velocity, and the effect on existing development which may not have one foot of freeboard. There may be situations where any increase in flood levels and velocities is unacceptable.

Finally, the master plan should contain the structural requirements for containment structures and encroachments, so that river modifications may resist scour and erosion.

With policy, standards and criteria set, the community can establish line and grade for encroachments with assurance. Private developers, bridge builders, and public works agencies can work to these lines, each adding a segment to the master plan.

Levees

Levees are frequently used to contain or encroach into wide shallow rivers. They require special considerations. They present special risks because the development outside the levee may be below the 100-year level. In the event of a levee failure the damage is vastly disproportionate to the increment of flow that caused the failure. For this reason special development requirements are needed.

First, the level of protection should be set commensurate with the consequence of failure. In any event, a leveed section should have a higher level of protection than an entrenched river.

Special attention must be given to side drainage. Parallel drains or pump plants may be required to prevent flooding outside the levees by local runoff. If flap-gated inlets are provided special care must be taken to supervise construction of fills and walls in the area draining to the flap-gated inlet, to avoid blocking drainage access to the inlets.

If sedimentation occurs in the river, levees should be used only with great discretion. Engineering analysis should be performed to demonstrate that the design waterway will not be obstructed by sediment and that flap gates will operate properly.

Maintenance is essential to levees. Erosion, undermining of revetment and tunneling by burrowing animals are common causes of levee failure. Rigorous inspection and prompt attention to deficiencies is important.

Reliable trained personnel, material, and equipment must be available for flood fighting. Overtopping, sand boils, and seepage through rodent holes can be managed by quick action, avoiding a levee failure and disaster.

Considering the vulnerability of levees, a special design strategy is appropriate, wherein overtopping of the levee is planned in advance. The strategy includes a hardened overtopping section designed to pass a large flood without washing out the levee, a planned overflow route and ponding area, and an evacuation plan. Such a strategy assures that only the peak flows overtop the levee, a breach is avoided, and the affected people have time to reach safety.

LAKES

In the arid West lakes are highly prized community assets. As most years are dry there is a tendency over time to encroach into the high water zone of the lake, first with farming operations and then with development. Then, when the lake fills in a season or series of seasons of high runoff, there is a flood emergency. Communities must be evacuated or emergency floodproofing dikes installed.

Lake flood plains lend themselves to rational management. The elevation-frequency relationship of the lake can be established by analysis of gage records. Levels of protection can be adopted commensurate with the type of development and consequence of flooding. Development strategy can be devised, using four options: Comingling, marina, fill encroachments, and levee encroachments.

Comingling allows high lake water to comingle with the development. Sensitive developments are elevated, while uses and improvements compatible with flooding are allowed to go under water.

Marina-type development creates channels and fills, increasing lake frontage without reducing lake storage. All sensitive improvements are elevated.

Fill encroachment into the lake margin allows development to occur on dry land and increases the usable land around the lake. The fill must be designed with consideration for surface drainage. The effect of the fill on the stage-storage relationship of the lake must be taken into consideration in setting the fill elevation.

Levee encroachment can create usable dry land within the lake margin, but must be carefully planned, constructed, operated and maintained. Not only must loss of storage be considered, but all the cautions and requirements related to levees apply: structural soundness, level of protection, interior drainage and pumping, contingency planning and flood fighting.

Finally, all of the lake development strategies must incorporate design criteria for wind setup, wave runup, and erosion of lakeshore embankments.

RIVERS AND LAKES WITH DAMS AND DIVERSIONS

As if the weather did not introduce enough uncertainty into river and lake management, most western rivers and lakes are also influenced by manmade structures. Dams exert a stabilizing effect on rivers and there is a strong tendency for river- and lake-front dwellers to assume that the dams always have everything under control.

This is not the case. Most western dams are for water supply and power. In a water conservation-conscious society, it is traditional for western dams to be operated primarily for water conservation unless the structure itself is threatened. Most of the time this operating policy produces incidental flood control benefits, and downstream communities get used to seeing river levels maintained within a predictable range. Most years are not high runoff years, so upstream lakeshore communities get used to stable water levels.

Over the long term, the pressure to develop along such rivers and lakes has proved in many cases to be irresistible, and the development criteria was based on the stable-appearing norm created by the dams. Then, in those rare years when there is a real surplus of water, the reservoirs are so full they have no flood storage capability. Upstream lakes experience record high water levels and widespread flooding. Downstream river front communities are washed out or under water for months as the excessive runoff flows unabated through the system.

The key to developing and implementing flood plain management programs along rivers and lakes with dams and diversions is the system operating criteria. These criteria prescribe the opening and closing of gates to carry out operating policy in response to water demand, inflow, available storage, and weather forecast. Where the operating policy is solely based on water supply and power generation, the operations will result in keeping the reservoir as full as possible. If the operating policy is solely flood control, the operations will be aimed toward keeping the reservoir empty, so as to have as much storage capacity as possible available for flood runoff.

If the dam is multi-purpose, with both water supply and flood control objectives, it must be operated with some concessions to water supply, based on the season of the year and the weather forecast.

The justification, authorization, and financing of most western dams was based on multi-purpose benefits including flood control. However, there is rarely a need to operate for flood control, while there is continuing pressure to maximize water and power sales and to maintain high, stable lake levels for recreation. As a result, operating procedures tend to become biased in favor of water conservation, at the expense of flood control preparedness.

With the increased development around the lakes above the dams and along the rivers below the dams it is important that the dam operations be sensitive to flood potential. Flood plain managers need to participate with dam operators in the evaluation of weather forecasts and in the development of balanced operating criteria which fairly share the risks of flooding with the risks of revenue loss from water and power sales.

During years of high runoff forecast, a clear understanding of the reservoir operating policy will assist the flood plain manager in establishing contingency plans and constructing emergency protection.

In the long term, an agreed-upon operating policy will allow the flood plain manager to establish practical building regulations, reserving appropriate capacity in the flood plain for the passage of peak flows. Dissemination of information about weather cycles, dam operations, river performance, and development requirements will improve community understanding of this aspect of its environment.

CANYONS

Southern California has long experienced damaging mudflows in canyon communities. As cities in other western areas expand into the adjacent canyons mudflow events are becoming more frequent. Safe development in canyons requires special hazard analysis and special development criteria.

Mudflow hazard mapping requires estimating the rate and volume of mudflow that will be produced on the watershed under the design event and the delineation of the areas that will be affected.

Local mudflow rate and volume measurements are usually not available. A procedure developed by the Los Angeles County Flood Control District for Flood Insurance Mudflow mapping provides an approach for estimating the 100-year mudflow volume. It involves the following steps.

1. Compute average annual "normal" debris production from the watershed ($\overline{X}$).

2. Compute the standard deviation of annual "normal" watershed debris production (S).

3. Determine Pearson Frequency Factor K.

4. Compute 100-year "normal" debris production (X) from the relationship

$$X = \overline{X} + KS$$

5. Adjust "normal" debris production for effect of fire.

The watershed relationships, based on Los Angeles County data, are as follows:

Step 1.

$$V_D = \frac{7,764,000\ (Rr)^{0.4399}\ (Slope)^{.3174}\ (Expos)^{.2736}}{(Area)^{.0344}\ (Veg)^{2.1302}(90\text{-}year)^{0.1365}}$$

Where

V_D = Average Annual Debris Production ($Yd^3/Mi^2/Yr$)
Rr = Relief Ratio (Ft/Ft)
Slope = Average Watershed Slope (Ft/Ft)
Expos = Exposure Ratio (Ft/Ft)
Area = Watershed Area ($Mile^2$)
Veg = Vegetative Index (No Units)*
90-year = 90-year Normal Rainfall (inches)

*A measure of type of vegetation and extent of cover described in "Report on Debris Reduction Studies for Mountain Watersheds", LACFCD, 1959

The regression equation is sensitive to the vegetative index, relief ratio, exposure ratio, and average watershed slope. The equation is relatively insensitive to the other factors.

Step 2.

$$S = \frac{5,830,000\ (Rr)^{.78012}\ (Area)^{.06930}}{(Slope)^{.65543}\ (Expos)^{.00723}\ (Veg)^{1.78871}\ (90\text{-}year)^{.11157}}$$

As with the average annual debris production, the standard deviation regression equation is sensitive to relief ratio, slope, and vegetative index.

Step 3.

The K factor for the desired return interval is taken from Figure 1.

Step 4.

The 100-year "normal" debris production can now be calculated.

Step 5.

The fire adjustment is made using Figure 2.

The resulting debris volume can be distributed through the flood hydrograph using the relationship

$$Q_D = K\ Q_C^{1.67}$$

Where

Q_D = the instantaneous debris discharge
K = a watershed constant
Q_C = the instantaneous clear water Q

This provides a peak debris flow rate which, when added to the peak clear water Q, gives a peak bulked flow rate for mapping mudflow hazard areas. At obstructions and reductions in slope sediment deposition should be estimated by assuming deposition at one-half the upstream slope.

Each canyon should be mapped showing the boundaries and elevations of mudflow hazard. Until mapping is completed, each proposed development should be checked against debris hazards using the above approach.

The following check list should be used to evaluate development proposals in canyons and hillside developments:

1. Adjust grading concept, street layout, and lot design to recognize and accommodate mudflow hazard.

2. Determine flood and mudflow hazard to each lot.

3. Redesign lots if a safe building site cannot be developed on each lot.

4. Provide a safe pathway for each source of mudflow through the development to a safe point of discharge. If mudflow cannot be carried through, provide adequate debris basin with access for cleanout and disposal site.

5. Avoid flattening grade or changing direction of mudflow.

6. Avoid covered conduits because of difficulty of cleanout.

7. Allow access to backyards for cleanup.

ALLUVIAL CONES

Hydrologic Setting

You will recall from driving or flying across the West that much of the countryside consists of alluvial cones. They are covered with the typical braided watercourse patterns formed by sediment outwash from the mountains. The natural drainage pattern is sheet and gully flow radiating off the cone, diffusing as it travels downstream.

In its natural environment, this radial flow off the cone is perhaps the safest and least aggressive of all types of natural runoff -- because it is not being collected and concentrated into brooks, streams, and rivers. The further it goes, the greater its tendency to split and diffuse itself, dissipating its energy across a wide arc.

Human Impact

When man arrives on the scene drainage patterns begin to change. The desert topography is so subtle that even minor alterations have major influence on the drainage patterns. In the past, the desert was so vast that the impact of man's work on drainage patterns received little attention.

Railroads were important to the growth of the west. Railroad embankments formed drainage barriers. Culverts and underpasses established permanent drainage patterns.

The land was divided into townships and sections by the Government Land Survey, and it became standard practice to place the major and secondary highways on the section lines and quarter section lines. Later on the aqueducts and freeways came. The embankments, culverts, and underpasses became major drainage constraints.

If an isolated home owner on the alluvial cone was flooded, he would raise a dike to deflect the water around his property. As subdivisions were built they would be protected from sheet flow by a block wall.

Now, every earth dike, every block-walled subdivision, every major street, the freeways, the aqueducts, and the railroads have become part of the drainage environment. In most cases their effect on drainage was inadvertent, because in the desert, water is so scarce that drainage is not uppermost in people's minds. Yet the effect is major, in terms of drainage planning. Manmade structures collect, concentrate, and sometimes divert flows for miles, with great impact, both favorable and unfavorable, on downstream properties.

Flooding Problems

In the last decade, desert floods have attracted notice. The "Caesar's Palace" flood of July 3 and 4, 1975, the Palm Desert flood from tropical storm Kathleen in September 1976, the Rancho Mirage flood a year later, the Moapa Valley, Nevada flood of August 10, 1981, the Las Vegas flood of August 10, 1983, and the Tucson, Arizona flood of October 2 and 3, 1983, have reminded us that even a desert is not safe from flooding, given man's intervention.

The Master Planning Challenge

Drainage planners, like everyone else, tend to think in terms of what has succeeded. Sometimes they think in terms of their own situation without consideration of impacts on others -- particularly in the desert where there has always been plenty of room.

Therefore, it's not surprising that when asked for solutions to the desert flooding problems, some offered a version of the Los Angeles County system -- a backbone channel with tributaries, branching and rebranching until every corner of the city had its own drain. From a hydraulic standpoint, there's no question this type of system will work, but it is usually viewed as unnecessary. From the cost standpoint in today's public works budget environment, it's out of the question.

Others proposed a different approach -- put a big dike around the entire upper end of a community and let the water run around the side. There are serious engineering and planning questions about this approach, but the main reason it fails is that it is simply a diversion of water from one community to another. Even in the desert, adjacent communities and land owners will no longer accept diversions of water onto their property.

I think the main reason desert drainage planners were frustrated in their efforts on alluvial cones was the fact that the drainage patterns are so diffused. There usually is no natural collector system. Flows may split differently from one storm to the next, depending on erosion and deposition. Even the definition of drainage area boundaries can result in different interpretations by different engineers. Add to these natural frustrations the unpredictable actions of man with his block walls, future street patterns, etc., and it's easy to see why a drainage planner would recommend traditional drainage solutions.

A "Natural" Solution

What is needed is a solution which exerts the least pressure on the natural scheme of things, which exerts the least pressure on the pocketbook of the city and the land development industry, and which rationally anticipates the future actions of man.

In studying the nature of desert floods, one repeatedly is struck by the term "flash flood". A look at a desert raingage chart explains why this term is so descriptive. In almost every flood producing rainstorm, the heaviest period of rainfall occurs during the first hour, most of the rainfall occurs within three hours, and the storm totals usually do not exceed three inches. It is commonplace for a "wall of water" to roar down a desert wash, but the flow only lasts for a brief period of time.

In hydrologic terms, desert thunderstorms have high intensities, but low volumes of runoff.

To approach this situation from the standpoint of conveying the peak runoff through the community would mean very large channels, very high velocities, and huge costs. Furthermore, the channels would be useful for no other community purpose, and would seldom be called upon to carry their full capacity -- a poor investment.

To approach it from the standpoint of storing the runoff in a detention basin produces happy results. It turns out that the required volume per acre of tributary drainage area is attainable at a fraction of the cost of a channel. Furthermore, the detention basin can be designed as a regional recreation center, so that it is fully utilized by the community throughout the year, providing a much greater return on the investment.

The Hydraulic Modeling Challenge

So much for the hydrology of desert drainage planning. What about the hydraulics? How can one define a drainage area boundary on the cone and be certain that it will not change in the future? How can one bring into his calculations the effect of future street patterns? How does one deal with flow splits at street intersections? What about diversions, deflectors, block walls, and fills?

The answer is: You must model and manage the cone! When a city establishes a drainage area boundary for master planning purposes the City takes on the obligation of physically accomplishing and preserving that boundary. Its main tools are subdivision approvals, street planning, and review of proposals for freeways and other construction projects. Its main legal basis is drainage law prohibiting diversions. The West is accumulating strong case law whereby local government can be held accountable for creating or allowing the creation of diversions.

This means that a city intending to control its drainage destiny must first allocate all the runoff on the cone to reasonable, natural paths, and then, from that day forward, diligently see that every activity on the cone is consistent with the allocations. On a day to day basis, this means discouraging diversions. On a long term basis, this means managing the way subdivisions are graded and master plan highways are designed.

Role of Streets

If the master plan is to be effective in the future when the street system is constructed, it must be developed with recognition of the effect of the streets. This means that the hydrologic and hydraulic model used for planning the cone must simulate the hydraulic performance of the future streets.

Historically, the major through streets which serve as water carriers have been located on section lines and quarter section lines, forming a 1/4 square mile grid. For planning purposes, it is practical to assume the practice will be continued in the future.

Streets which happen to be aligned radially down the cone, perpendicular to the contours, will tend to carry their water straight through intersections, with little contribution from side streets except for local runoff, and with little splitting of flows to side streets. In most cases, however, streets are aligned at an angle to the radial line, and intersections have flow arriving from two directions and leaving in two directions. In order to have a planning model which will accurately represent amounts and location of flow and potential flooding in the future, it is necessary to model each intersection as a hydraulic structure which receives two hydrographs, combines them, splits the combined hydrograph in accordance with the hydraulics of the intersection, and routes them down the exit streets.

"Leaky" Drainage Area Boundaries

The riverine concept of fixed drainage area boundaries loses its usefulness on the alluvial cone. This is because of the flow splits at intersections. In defining the boundaries of the drainage area tributary to any given point, one notes that a portion of the drainage area will deliver all of its runoff to the site, while another portion will deliver only part of its runoff. The remainder proceeds down the cone, bypassing the point. We must get used to the concept of a "leaky" drainage area boundary.

Modeling Requirements

Obviously, none of the traditional hydrology models fits this situation. The Rational Method (Q=CIA), for example, requires that the drainage area be defined. And, of course, the Rational Method provides no information on volume of runoff or timing of peaks. The unit hydrograph methods provide volumes and timing, but they too require fixed drainage areas. They do not have the capability of performing hydraulic split computations on the runoff within a subarea.

What is required to accurately model the alluvial cone with an overlay of future streets on a 1/4 sq. mi. grid is a fine-meshed model which produces elemental hydrographs, routes them to intersections, combines them, splits them, and repeats the process. The result is a dynamic model able to predict at each 1/4 sq. mi. node the Q and depth of flow. This provides powerful insight into defining and prioritizing future drainage problems before they happen, while there are still options available.

Masterplanning options include drainage systems, detention basins, and adjustments to the grade and alignment of critical streets to favorably modify the runoff pattern.

Project Evaluation

To evaluate an option, one adjusts the model to simulate the option being tested, and runs it again, noting the downstream benefits in terms of reduced Q's, reduced depth of flow, extent of area benefited, and possible reduction in mandatory flood insurance areas. These benefits can then be evaluated -- either in terms of reduced flood damages, or reduced flood insurance premiums. By comparing the costs of various options with the resulting benefits one may systematically converge on the optimum option and most cost effective projects.

Cone Management Requirements

Once the diffusion strategy and the master plan are adopted it becomes necessary to manage all activities on the cone to assure that established drainage patterns are preserved. This requires discipline on the part of the city staff and an ongoing community education process.

GROUNDWATER

High groundwater often accompanies high runoff. Groundwater levels in developing areas are usually low, so little attention is given to groundwater hazards when planning new subdivisions in many areas.

Groundwater should be considered in establishing development requirements and in formulating the flood control plan.

There is abundant data on potential high groundwater areas. Many western settlements came into being because of accessible groundwater, springs, and cienegas. Community old-timers, farmers, ranchers, well drillers, and contractors can provide information on historical high groundwater areas to identify potential hazard areas. In wet years special efforts should be made to acquire groundwater data. Building and construction standards for high groundwater areas should incorporate requirements aimed at minimizing basement flooding, seepage through floors and walls, settlement, and rising water.

The flood control plan should also be sensitive to high groundwater. Unlined retarding basins and channels can aggravate high groundwater problems by increasing recharge. On the other hand, in areas where high groundwater is not a problem unlined flood control facilities can perform a dual function by promoting water conservation.

Where groundwater control subdrains must be retrofitted into a community, the drainage master plan should accommodate the subdrainage system as well as the surface collection system.

YOUR OBLIGATIONS FOR ACTION

Western extremes of topography and precipitation, arid hydrology, unique runoff patterns, mudflows, and manmade structures present a complex and varied challenge to flood plain managers. An independent streak in westerners tends to question regulations and requires that flood plain managers have a practical, common sense, community-oriented approach.

Flood losses in recent years demonstrate that our predecessors have not been as successful as we might wish. This is not due to a lack of right-minded people but to unclear policy direction and inadequate technical understanding. Communities are growing. Problems will only get worse in the future as hazardous land is developed.

The opportunity is here. The NFIP provides a basic incentive from which to start. Practical, proven techniques are available for managing water, mud, and erosion hazards and gaining community acceptance.

Local government needs to view itself as the primary resource. Bailout programs will not be fully funded in the future and the future of the NFIP is not clear.

An early commitment to a common sense approach, tailored to the specific features and goals of each community will pay big dividends. The cost of inaction is unacceptable.

The opportunity and responsibility for reducing future flood losses in the West rests with a very few people in policy-making and technical positions: elected officials, local government public works and engineering officials, and the consulting engineering community. Each of these segments must fulfill its obligation.

ELECTED OFFICIALS

Mayors, councilmen, and supervisors establish direction and set priorities. The discipline required to reduce flood loss will only come from enlightened, far-thinking policy makers. These individuals are chosen for their leadership. As a member of this group you must provide the fresh view and the straight thinking necessary to put local government on a course toward eliminating the financial loss and human suffering related to floods. Many of us look to federal disaster funds as the "insurer of last resort". These funds may be hard to get in the future. You must insist that the technical and administrative personnel with city and county government and your consultants have a thorough understanding of the specific flood situations faced by the community, and the experience to devise and implement an effective flood plain management program that is workable in your community. Extend your perspective to include regional, state, and national issues on water systems that affect your community and involve yourself in the policies being used or developed.

The long view is often difficult to maintain in the hand-to-hand combat at the real-life local level. Your contribution to the community will be measured most of all by your wise policy direction to avoid the losses rather than your ability to cope with them after they have happened. Many community "self help" programs can be devised that do not require taxes -- they do however require your leadership.

PUBLIC WORKS OFFICIALS

Translation of policy direction into implementable criteria and procedures is your responsibility. You are also in a key position to provide guidance, support, and education to your elected officials on the nature of and management options available for community flood hazards.

To do this you must keep current on the advancements in technical understanding of floods, erosion, sediment, statistics, hydrology, hydraulics, hazard mapping and development criteria. You must seek out those staff members and consultants who can provide leadership and who are experienced in implementing change in the community and within the technical and administrative staff. A background in traditional approaches will not suffice.

THE PRIVATE ENGINEER

The opportunity is unprecedented for professional contribution to the future of the West. Be sensitive to the varied water, mud, and erosion hazards facing your public and private clients. Become highly conversant with the long term implications of your recommendations to your clients. We must stress living in harmony with our environment and we must stay current with the technical, policy and financial aspects of our recommendations.

As we have graphically seen during the last few years, and in Arizona in the last few weeks, the suffering and loss of tax dollars from inadequate facilities is unnecessary. We can always point to the "unusual weather" as the cause of the unpredicted losses. However, in fact, much of the loss could have been predicted and prevented within the economic limitations of the individual projects if we pay attention to nature's requirements. We must accept the challenge and professional responsibility and press policy makers, both private and public, to meet professional standards that do not leave others, including our children, to finance and correct our errors.

PROCEEDINGS

ENGINEERING WORKSHOP ON HYDRAULICS OF FLOOD WORKS

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STUDENT CHAPTER

CALIFORNIA STATE UNIVERSITY, LONG BEACH

ANGEL PARK

KEYSTONE OF A MASTER PLAN ON AN ALLUVIAL CONE

by

John M. Tettemer[1]

ABSTRACT

Master planning of drainage on an alluvial cone presents special problems of hydrology, hydraulics, and design. When the alluvial cone is occupied by a major city like Las Vegas, Nevada, the problems inherent on an alluvial cone are compounded by man-made features which divert, collect, and concentrate drainage. At the same time opportunities are maximized for adopting an effective alluvial cone strategy, achieving a cost-effective flood control design, and creating an outstanding public recreation facility. Angel Park is a major flood control detention basin being designed in a regional recreation center which will included a championship golf course. Special modeling requirements unique to alluvial cones are discussed.

INTRODUCTION

I call Angel Park the keystone of a master plan because the keystone symbol fits in so many ways. In an arch, the keystone locks the other pieces in place. The word keystone has come to mean something on which associated things depend for support. In the master plan of drainage for the City of Las Vegas Angel Park embodies the concepts and principles that lock together the other elements of the master plan. Hydrologically, selecting the Angel Park site and controlling its tributary drainage area fix the key element of the master plan about which other elements can be planned and from which they draw support. Functionally, Angel Park is the focus of two community needs -- flood control and recreation, again calling to mind the two balanced facets of the keystone.

HYDROLOGIC SETTING

You will recall from driving or flying into Las Vegas that the city is located on a large alluvial cone between Las Vegas Wash and the La Madre mountains some twenty-five miles to the west. There is no major drainage course through the city from the mountains to the Las Vegas Wash on the east side of the city. The cone is covered with the typical braided watercourse patterns found on desert alluvial cones formed by sediment outwash from the mountains. The natural drainage pattern is sheet and gully flow radiating off the cone, diffusing as it travels downstream.

In its natural environment, this radial flow off the cone is perhaps the safest and least aggressive of all types of natural runoff -- because it is

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not being collected and concentrated into brooks, streams, and rivers. The further it goes, the greater its tendency to split and diffuse itself, dissipating its energy across a wide arc.

HUMAN IMPACT

When man arrives on the scene drainage patterns begin to change. The desert topography is so subtle that even minor alterations have major influence on the drainage patterns. In the past, the desert was so vast that the impact of man's work on drainage patterns received little attention.

Railroads were important to the growth of the west. Railroad embankments formed drainage barriers. Culverts and underpasses established permanent drainage patterns.

The land was divided into townships and sections by the Government Land Survey, and it became standard practice to place the major and secondary highways on the section lines and quarter section lines. Later on the freeways came. The embankments, culverts, and underpasses became major drainage constraints.

If an isolated home owner on the alluvial cone was flooded, he would raise a dike to deflect the water around his property. As subdivisions were built they would be protected from sheet flow by a block wall.

And while all this was going on, the city itself grew from 30,000 inhabitants to 180,000, covering dozens of square miles of land with urban development.

Now, every earth dike, every block-walled subdivision, every major street, the freeways, and the railroad have become part of the drainage environment. In most cases their effect on drainage was inadvertent, because in the desert, water is so scarce that drainage is not uppermost in peoples' minds. Yet the effect is major, in terms of drainage planning. Man-made structures collect, concentrate, and sometimes divert flows for miles, with great impact, both favorable and unfavorable, on downstream properties.

FLOODING PROBLEMS

In the last decade, desert floods have attracted notice. The "Caesar's Palace" flood of July 3 and 4, 1975, the Palm Desert flood from tropical storm Kathleen in September 1976, the Rancho Mirage flood a year later, and the Moapa Valley, Nevada flood of August 10, 1981, have reminded us that even a desert is not safe from flooding, given man's intervention.

THE MASTER PLANNING CHALLENGE

Drainage planners, like everyone else, tend to think in terms of what has succeeded. Sometimes they think in terms of their own situation without consideration of impacts on others — particularly in the desert where there has always been plenty of room.

Therefore, it's not surprising that when asked for solutions to the desert flooding problems, some offered a Las Vegas version of the Los Angeles County system -- a backbone channel with tributaries, branching and rebranching until every corner of the city had its own drain. From a hydraulic standpoint, there's no question this type of system will work, but it has always been viewed as unnecessary; and from the cost standpoint in today's public works budget environment, it's out of the question.

Others proposed a different approach — put a big dike around the entire upper end of the city and let the water run around the side. There are serious engineering and planning questions about this approach, but the main reason it fails is that it is simply a diversion of water from one city to another. Even in the desert, adjacent communities and land owners will no longer accept diversions of water onto their property.

I think the main reason desert drainage planners were frustrated in their efforts on alluvial cones was the fact that the drainage patterns are so diffused. There usually is no natural collector system. Flows may split differently from one storm to the next, depending on erosion and deposition. Even the definition of a drainage area boundary can result in different interpretations by different engineers. Add to these natural frustrations the unpredictable actions of man with his block walls, future street patterns, etc., and it's easy to see why a drainage planner would recommend traditional drainage solutions.

A "NATURAL" SOLUTION

What is needed is a solution which exerts the least pressure on the natural scheme of things, which exerts the least pressure on the pocketbook of the city and the land development industry, and which rationally anticipates the future actions of man.

In studying the nature of desert floods, one repeatedly is struck by the term "flash flood". A look at a desert raingage chart explains why this term is so descriptive. In almost every flood producing rainstorm, the heaviest period of rainfall occurs during the first hour, most of the rainfall occurs within three hours, and the storm totals usually do not exceed three inches. It is commonplace for a "wall of water" to roar down a desert wash, but the flow only lasts for a brief period of time.

In hydrologic terms, desert thunderstorms have high intensities, but low volumes of runoff.

To approach this situation from the standpoint of conveying the peak runoff through the community would mean very large channels, very high velocities, and huge costs. Furthermore, the channels would be useful for no other community purpose, and would seldom be called upon to carry their full capacity — a poor investment.

To approach it from the standpoint of storing the runoff in a detention basin produces happy results. It turns out that the required volume per acre of tributary drainage area is attainable at a fraction of the cost of a channel. Furthermore, the detention basin can be designed as a regional recreation center, so that it is fully utilized by the community throughout the year, providing a much greater return on the investment.

THE HYDRAULIC MODELING CHALLENGE

So much for the hydrology of desert drainage planning. What about the hydraulics? How can one define a drainage area boundary on the cone and be certain that it will not change in the future? How can one bring into his calculations the effect of future street patterns? How does one deal with flow splits at street intersections? What about diversions, deflectors, block walls, and fills?

The answer is: You must model and manage the cone! When a city establishes a drainage area boundary for master planning purposes the City takes on the obligation of physically accomplishing and preserving that boundary. Its main tools are subdivision approvals, street planning, and review of proposals for freeways and other construction projects. Its main legal basis is drainage law prohibiting diversions. Nevada has strong case law whereby local government can be held accountable for creating or allowing the creation of diversions.

This means that a city intending to control its drainage destiny must first allocate all the runoff on the cone to reasonable, natural paths, and then, from that day forward, diligently see that every activity on the cone is consistent with the allocations. On a day to day basis, this means discouraging diversions. On a long term basis, this means managing the way subdivisions are graded and master plan highways are designed.

ROLE OF STREETS

If the master plan is to be effective in the future when the street system is constructed, it must be developed with recognition of the effect of the streets. This means that the hydrologic and hydraulic model used for planning the cone must simulate the hydraulic performance of the future streets.

Historically, the major through streets which serve as water carriers have been located on section lines and quarter section lines, forming a 1/4 sq. mi. grid. For planning purposes, it is practical to assume the practice will be continued in the future.

Streets which happen to be aligned radially down the cone, perpendicular to the contours, will tend to carry their water straight through intersections, with little contribution from side streets except for local runoff, and with little splitting of flows to side streets. In most cases, however, streets are aligned at an angle to the radial line, and intersections have flow arriving from two directions and leaving in two directions. In order to have a planning model which will accurately represent amounts and location of flow and potential flooding in the future, it is necessary to model each intersection as a hydraulic structure which receives two hydrographs, combines them, splits the combined hydrograph in accordance with the hydraulics of the intersection, and routes them down the exit streets.

"LEAKY" DRAINAGE AREA BOUNDARIES

The riverine concept of fixed drainage area boundaries loses its usefulness on the alluvial cone. This is because of the flow splits at intersections. In defining the boundaries of the drainage area tributary to any given point, one notes that a portion of the drainage area will deliver all of its runoff to the site, while another portion will deliver only part of its runoff. The remainder proceeds down the cone, bypassing the point. We must get used to the concept of a "leaky" drainage area boundary.

MODELING REQUIREMENTS

Obviously, none of the traditional hydrology models fits this situation. The Rational Method (Q=CIA), for example, requires that the drainage area be defined. And, of course, the Rational Method provides no information on volume of runoff or timing of peaks. The unit hydrograph methods provide volumes and timing, but they too require fixed drainage areas. They do not have the capability of performing hydraulic split computations on the runoff within a subarea.

What is required to accurately model the alluvial cone with an overlay of future streets on a 1/4 sq. mi. grid is a fine-meshed model which produces elemental hydrographs, routes them to intersections, combines them, splits them, and repeats the process. The result is a dynamic model able to predict at each 1/4 sq. mi. node the Q and depth of flow. This provides powerful insight into defining and prioritizing future drainage problems before they happen, while there are still options available.

Masterplanning options include drainage systems, detention basins, and adjustments to the grade and alignment of critical streets to favorably modify the runoff pattern.

PROJECT EVALUATION

To evaluate an option, one adjusts the model to simulate the option being tested, and runs it again, noting the downstream benefits in terms of reduced Q's, reduced depth of flow, extent of area benefited, and possible reduction in mandatory flood insurance areas. These benefits can then be evaluated -- either in terms of reduced flood damages, or reduced flood insurance premiums. By comparing the costs of various options with the resulting benefits one may systematically converge on the optimum option and most cost effective projects.

ANGEL PARK

Angel Park came about through the confluence of four somewhat unrelated events. The first was the fact that the City of Las Vegas had obtained a large parcel of U. S. Government Bureau of Land Management land west of the developed part of the city for use as a regional recreation facility. It was conceived that Angel Park would have playing fields for baseball, soccer and football, tennis and other court games, picnic areas, riding and hiking facilities, a golf course and the necessary support facilities, shops, stables, clubhouse, lodging, and restaurants. The site was large enough that the various activities could be accommodated without mutual interference, and without impacting the adjacent community.

The second was the fact that the city was becoming increasingly aware of its flooding potential. The fourth of July flood in 1975 had claimed the lives of two city street workers in the neighboring community of North Las Vegas. The federal government had published the Flood Insurance Rate Map for the city, showing several square miles of the developed portion of the city subject to flood hazard and mandatory flood insurance. The city was rapidly expanding to the west, and the increased urbanization and extension of streets up the cone would aggravate the existing flood hazards. The city became committed to a program of flood hazard reduction.

The third was the passage by the electorate in 1981 of a flood control bond issue which provided financing for some of the highest priority city flood control projects.

The fourth was the finding that due to the large drainage area tributary to Angel Park, the heavily developed community downstream of the site, the topography of the site and the tributary stream system, Angel Park was the most effective location on the west side of the city for a detention basin.

The large drainage area produced very damaging flood flows and the community downstream was heavily developed for miles, and continuing to develop. The site itself contained several sizeable canyons which could provide efficient flood control storage when dammed by an embankment. The tributary stream system, instead of fanning out across the cone, was well entrenched and capable of delivering 100-year flows to the site. This is the only site in the area where the natural delivery system is so well developed. Furthermore, the hydraulic analysis of the cone with the 1/4 sq. mi. grid system of streets showed that the future street system would be capable of delivering a significant additional amount of runoff that under existing conditions bypasses the site.

This fortuitous confluence of events presented a unique opportunity to obtain an outstanding dual-purpose community facility at a minimum of cost. It was decided to proceed with a joint-use project to fulfill all of the objectives of a regional recreation facility plus those of a major flood control facility, without compromising the values of either one.

For funding purposes the Angel Park detention basin project has been unitized. Phase I was a starter project built with City funds. Phase IIA is an expansion of Phase I to full 100-year protection and is to be built with the available bond issue funds. Phase IIB will expand the Phase IIA basin to the north, capturing additional tributary drainage area and providing additional protection to the downstream area.

HYDROLOGY OF PHASES I AND IIA

The Phase I and IIA basins are designed to control the 100-year runoff from the drainage area naturally tributary to the basins under existing conditions. The natural drainage area tributary to the Phase I and IIA basins is 6.4 sq. mi. For basin volume design a 3-hour, 100-year convective type design storm was developed in accordance with the U. S. Department of Commerce Precipitation-Frequency Atlas. One hundred-year, 3-hour point rainfall is 2.2 inches. For spillway design Probable Maximum Precipitation (PMP) storms were developed for 6-hour local and 24-hour general storms in accordance with the U. S. Department of Commerce Hydrometeorological Report No. 49. The 6-hour PMP storm produced the highest discharge and was used for spillway design. Six-hour local PMP rainfall is 12.5 inches.

Land use assumptions were based on current large-scale development planning adjacent to Angel park with the following distribution:

Commercial	18.8%
Residential	79.7%
Civic Use	1.5%

Soil types were based on studies by the U. S. Soil Conservation Service (SCS). Soil types in the tributary drainage area are generally high runoff producers classified by the SCS as Hydrologic Soil Type D. The SCS Composite Curve Number for the Phase I and IIA drainage area is 89.5.

The 100-year runoff volume for the Phase I and IIA basins is 327 acre-feet, with a peak inflow of 1,530 cfs. The PMP runoff volume is 3,584 acre-feet with a peak inflow of 17,600 cfs.

HYDROLOGY AND HYDRAULICS OF PHASE IIB, WITH FUTURE STREET GRID

The full potential of the Angel Park detention basin project will be realized with the Phase IIB basin. For design of the Phase IIB basin, the entire tributary watershed was modeled using the 1/4 sq. mi. grid of major streets. The drainage area tributary to Angel Park extends to the west in an arc concave to the north. Some of the drainage immediately north of the arc would normally bypass Angel Park to the north, given the normal development of street intersections. The incremental cost of providing additional basin capacity to capture this water is very economical. Accordingly, the basin will be sized to accommodate this water and the design of the streets west of Angel Park will be managed in the future to deliver these flows directly to the basin. This is an example of managing development on the cone to conform to master planning objectives and will lead to reduced development costs and less hardware for the City to maintain.

The area contributing all of its runoff to Angel Park is 17.7 sq. mi. and produces a runoff volume of 686 acre-feet. An additional area of 9.3 sq. mi. contributes part of its runoff to the basin, producing 264 acre-feet of inflow. Using the 1/4 sq. mi/ grid arrangement, the 100-year peak discharges and volumes are as follows:

Basin	Peak Discharge (cfs)	Peak Time (hrs.)	Runoff Volume (acre-feet)
I	333	1.24	49.6
IIA	2621	1.78	478.9
IIB	2357	1.75	421.4
			949.9

The total PMP inflow for spillway design from the combined drainage areas is 32,000 cfs.

EFFECT ON FLOWS DOWNSTREAM

The entire 100-year runoff will be captured in the Angel Park basin. The downstream drainage areas, which without the basin would receive the peak flows tabulated above, will benefit from reduced flows. To evaluate the benefit, the entire cone area upstream and downstream of Angel Park was modeled without Angel Park and with Angel Park. The flow rates and depths of each node on the model were compared to determine the extent and amount of effect produced by Angel Park. An area of 326 sq. mi. was determined to be within the influence of Angel Park.

BENEFIT/COST ANALYSIS

Annual flood damage costs to structures were computed with and without Angel Park using procedures developed by the Corps of Engineers from data gathered in flood studies of Rancho Mirage, California. Damage to highways, utilities, and vehicles was computed as a function of structural damage based on flood damage reports from the Palm Desert, California flood of 1976. The average annual reduction in flood damage is the benefit attributed to Angel Park.

The cost of Angel Park consists of the construction cost, plus the annual cost of operation, maintenance and repair. The ratio of benefits to cost for Angel Park is 2.8. In terms of future potential flood insurance premiums, the B/C ratio is 1.8.

The cost of the Angel Park basin is estimated at $5.5 million. A channel to carry the same flow rate to Las Vegas Wash would cost a minimum of $25 million, plus large-scale disruption of the community and removal of houses.

CONE MANAGEMENT REQUIREMENTS

In order to develop the full potential of Angel Park it will be necessary to monitor activities on the cone in the future. The street patterns and flow splits used to develop the basin design are based on expected street alignments and close adherence to existing gradients on the cone. It would be possible to bypass the basin with significant amounts of water intended for Angel Park by adjustments in the alignment and grade of future streets. Also, discontinuities in streets resulting from the timing of developments could result in re-routing of flows. Therefore, it is important that the underlying concepts and objectives of Angel Park be understood by developers, transportation planners, and the officials responsible for planning and approving developments on the cone, so that as development on the cone proceeds, it accomplishes the drainage objectives of the Angel Park master plan.

THE DESIGN CHALLENGE

The engineering requirements of the Angel Park Detention Basin were straightforward. There was a budget limitation established by the bond issue. It was determined that the existing drainage system downstream of Angel Park through the developed area of the city was so overtaxed that it could not provide a safe outlet for any flood releases from Angel Park. It was therefore decided to size the Angel Park basin to contain all of the runoff from the 100-year flood.

Since the basin would be located upstream of a heavily populated area, the spillways were designed to accommodate the runoff rate from the Probable Maximum Precipitation applied to the fully developed tributary drainage area. Spillways were located at each canyon crossed by the continuous embankment, sized in proportion to their tributary drainage area.

To empty the basin after flows had receded in the downstream drainage system, a low flow drain was designed to connect to an existing downstream storm drain.

The real design challenge was found in meeting the joint-use requirements and remaining within the budget limitations. Overall, aesthetics and recreational requirements controlled the design, since the land had been acquired from the government for regional recreation purposes.

The recreational criteria required that certain uses involving buildings, clubhouses, etc. had to be located on high ground, out of the basin ponding area. Other uses, such as playing fields and fairways, could be located within the basin, but had size and slope requirements that had to be met.

The embankment which forms the basin must be a part of the park landscape. This means it cannot look like Santa Fe Dam, with straight, engineered lines. It must be a rolling, contoured, meandering form, with pathways, view spots, and landscaping. The side slopes must be walkable and mowable.

The bottom of the basin cannot become a sump for the collection of waterborne trash and debris. Minor storm and irrigation runoff must be managed so as to control trash dispersion. Permanent lakes are desired for the golf course, but they must be drainable for maintenance. All parts of the basin bottom, which includes several canyons, must be drainable.

The entire facility in the future will be surrounded by urban development. A major highway passes along the downstream side. It is desired that the project appear as a natural park-like setting from the highway and the adjacent community, rather than a massive embankment looming overhead. This requires that the embankment be set back from the road, sculpted into natural forms, and landscaped.

In the resulting plan the main tributary canyon enters from the west on the south end of the basin. Three other canyons also enter the basin. Stables, active recreation, passive recreation, field games, golf, court games, parking and service areas are suitably separated and functionally related. The embankment is located so as to obtain efficient flood control storage. Embankment material is developed from within the basin so as to create additional flood storage. The grading for development of the embankment material is gently contoured to conform to golf course requirements. There will be 3 lakes within the basin. Nuisance water is carried through the park from north to south and discharged into the outlet drain. Spillways will be armored for erosion protection and blended in with the park environment. And, the project is within the budget.

CONCLUSION

Angel Park is a good example of the challenge facing hydraulic engineers. Hydraulics of engineered structures are well understood. Computers enable us to get answers so fast we have to stop and think about what we've got. Our challenge is to apply our knowledge of hydraulics in new contexts so as to get the most benefit out of the money spent and to get better projects.

This often means working as a team with professionals from other disciplines such as policy makers, urban planners, recreational developers, golf course architects, and naturalists.

Using an approach which recognized community needs and policy objectives, the Angel Park concept was developed to achieve the following results:

- The park provides the "keystone" for future urban development on the the west side of the city.

- Flood hazard is eliminated or reduced for hundreds of properties extending miles downstream, resulting in a favorable benefit cost ratio.

- Mandatory flood insurance areas may be reduced on appeal to the federal government.

- By using City-owned property the flood control project did not incur any right of way costs.

- A major sector of drainage tributary to the city has been controlled, providing a "keystone" in the development of the City Master Plan of Drainage.

- In the monotonous relief of the alluvial fan, the sculpted, contoured embankment of the basin created a much more interesting park and golf course than would have been possible otherwise.

Angel Park is a better park because of the flood control project. The flood control project may not have been feasible without the availability of the Angel Park site. Combining the projects required imaginative, resourceful hydraulic design work, but the resulting joint project is better than either one would have been by itself.

Finally, Angel Park provides a concrete example of the special modeling and cone management requirements of drainage planning on an alluvial cone.

ACTION REQUIRED NOW TO MANAGE DEVELOPING FLOOD PLAINS

by John M. Tettemer, Acting Chief Deputy Engineer
Los Angeles County Flood Control District

INTRODUCTION

Flood management on alluvial cones and broad flood plains requires immediate action. The Federal Flood Insurance Program and the pressure for additional growth are forcing political and engineering decisions which are long overdue. Options available to local government are being restricted each day as new building permits, subdivisions, and lot splits are approved in the absence of a master plan for flood plain management. The future cost of not having a master plan could be enormous in terms of lives and property lost and money needed for flood control construction.

Alluvial cones and broad flood plains consist of debris deposits (top soil, rocks, sand, and gravel) washed down from mountains and deposited on relatively flat valley floors. The management problems created are particularly frustrating because nature has not created a sure path for flood flows. The result is that storm waters wander across the alluvial cone or across the flood plain controlled only by the peculiarities of the particular storm and related sediment movement, or by accidents such as the clogging of an existing watercourse by trees, automobiles, or debris from houses.

In a major flood, the entire cone or flood plain must be considered as subject to severe inundation, erosion, and deposition of debris. While one might expect very little habitation in these unsafe areas, many are already extensively developed and more people are occupying them every day.

PRESSURE TO USE THE LAND

The infrequent nature of major flood events, has led many hale and hearty types to develop homes and businesses in these unsafe areas. During the '40's and '50's, growth was spotty, and the pioneer spirit of "taking the risk" was the predominant attitude. As the need for additional recreational or nonurban land grew in the '60's and '70's, interest in foothill living increased. The areas are picturesque and dangerous. Communities grew and eventually cities were incorporated. Their view of the hazard was based primarily on the attitudes of those who preceded them; namely, the development is sparse, the risk is low, so we can live without unusual building controls.

Times have changed dramatically. The sleepy foothill towns are growing into urban communities indistinguishable from traditional large urban centers. They are too young to have memories of flood disasters. In the typical case, homes, condominiums, schools, and businesses are presently being constructed under a "laissez faire" growth policy, without recognition of the extreme hazard. Many involved in city government are unaware of the extent of the hazard and assume that the low-flow channels which can be readily seen in the field are capable of protecting the city. This is rarely the case.

THE PROBLEM IS CRITICAL

The flood hazard on alluvial cones and broad flood plains has reached critical proportions because the management of these areas is more difficult than the management of riverine valleys. In a riverine valley the stream occupies the lowest part of the valley. When it floods, the waters rise out of the banks, overflowing the flood plain in a predictable pattern. No matter how high the water rises, it is always contained by the higher ground of the flood plain, sloping up from the river. Determining the boundary and depth of flooding is a straightforward engineering task, requiring only suitable streamflow records, topographic maps, and standard engineering procedures. The results are easily understood and readily communicated to the community.

In contrast, the alluvial cones and broad flood plains present much more difficult technical problems. These cones and flood plains are created by the outwash of soil, rock, sand, and gravel from the mountains. As these new materials are deposited on the valley flood, they fill existing channels, the stream is deflected and seeks a new route. At one time or another the watercourse finds its way across the entire flood plain. Residents of communities located on such flood plains typically accept the present location of the stream bed as the flow path, their conviction often reinforced by the presence of man-made levees, revetments, etc., which make the stream route look more "official". Actually the next flood could choke the present stream bed with debris, sending the overflow along another path into homes and businesses.

The problem is in predicting which path the water will take. Conventional procedures for riverine flood plain analysis do not offer a satisfactory solution to the problem, so many practitioners have despaired and allowed development to proceed with inadequate special requirements.

From a general flood plain management standpoint, it is irrelevant what path a particular flood will take; the significant conclusion is that the entire alluvial cone or broad flood plain is subject to severe flood hazard, and must be managed accordingly.

FEDERAL FLOOD INSURANCE

The Federal Flood Insurance Program has as a major objective the protection of people from flood waters and debris flows. Cities that have joined the Federal program must look forward to the day when they will be required to enforce, through their own activity, a form of master plan to assure the elimination of flood hazard to all new buildings within their jurisdiction.

The problem exists, the Federal program and good land management practice require action, and the solutions are available. Let us look at the alternatives.

ALTERNATIVES

The nature of the solution to the problem of protecting people and property is up to local government. The alternatives available to the local public agency are quite simple in a riverine situation where an organized floodway has been provided by nature. The solution involves controlling development in and along the existing river.

On alluvial cones or in extremely broad flood plains with ill-defined or inadequate floodways, this becomes a difficult problem, and several strategies can be developed. Three are worth detailed consideration.

Alternative 1

The local agency can decide to allow people to comingle with the major flood flows by considering the entire alluvial cone to be a floodway and by requiring flood-proofing of the structures within the floodway. See Plate I. Flood-proofing usually means raising the level of all new buildings to keep them above the expected flood and debris flows. Comingling is an acceptable approach in very low-density housing or farm areas where the land is predominantly being left in its natural state. Some cities are using this idea while allowing the densities to creep up and exceed safe levels. In more urbanized settings, where higher density development would require that the majority of the land be removed from its natural state, this option becomes hazardous since the available paths for major floods become filled with homes and commercial structures.

Alternative 2

This alternative requires separating the people and businesses from the storm and debris flows. This is done by directing storm flows down the cone or along the plain areas reserved for flood flows. See Plate II. A self-managing floodway can be developed with levee work that will assure protection of homes and businesses. The major benefits are low cost and little environmental impacts. This alternative requires the development and adoption of master plans which define the areas reserved for storm flows and may reduce substantially further land development. This is politically difficult but necessary to assure a safe community.

Alternative 3

This alternative is the only practical solution for a highly urbanized community. (See Plate III.) It requires very expensive debris control structures and high ongoing maintenance costs coupled with expensive high velocity-lined channels. Though it allows maximum use of the flood plain, it is usually financially impractical.

All three, comingling and the two separation alternatives can be engineered. The comingling approach requires strong land use and building controls far beyond those that are normally exercised. The separation policies require either the use of large areas of land for debris-carrying floodways or construction of expensive flood control works. The author has fully developed both approaches into management plans for major watersheds in California. The plans were carried through community involvement steps to approval by a public agency. It is important to note that Alternatives 1, 2, and 3 form a logical progression as a community grows. Each alternative, if properly planned, can provide safety and a method of preparing for the next alternative.

POLITICAL JUDGEMENTS

The dilemma then is primarily political. It is the responsibility of local government to achieve safe development within the community, and yet in many communities today there exist numerous homes and businesses which have been built in extremely hazardous areas. This has occurred because of government's perception that the problem was not serious and did not warrant special action. This could have been a valid assumption 20 years ago, but it is now clear that preventive planning is long overdue and that the options available to local government are rapidly being reduced as more of the flood plain or alluvial cone is being devoted to new construction.

Local government, in concert with the community, must make difficult choices about the type of community it wants on the cone or the broad plain. They can remain a rural low-density area and use Alternative 1. They can accommodate some growth under the low-cost Alternative 2 or they can plan for dense development as set forth by Alternative 3. They may wish to move from 1 to 2 to 3 under a controlled plan as the community grows. The decision may have already been made and reflected in local zoning ordinances. If so, these should be reviewed and reconsidered in light of the need to relate zoning to flood hazard. As an example, a flood hazard area should not be designated for dense urban development unless the community has the means to control storm flows in floodways or formal channels. Rural zoning on the other hand, can offer less costly alternatives, including comingling people with storm waters. Both require the adoption of a management plan.

Present local development practices may be worsening the hazard to existing development through additional expansion in the absence of a community-wide flood plain management program. The Federal Flood Insurance Program will within a few years act as a strong catalyst to force local government to recognize and adjust such practices. The Federal program does not, however, provide the solution. The solution is up to local government. The challenge to local government is to devise a plan which satisfies Federal requirements, furthers community objectives, and is financially feasible.

ACTION REQUIRED

Local government should immediately determine what engineering options are available. In reviewing the options, they should consider the wide, relaxed floodway which preserves for nature's use a large portion of the alluvial cone or flood plain. The benefits of this concept include a relatively modest cost for construction, a very low maintenance cost, and opportunity for open space or multiple-use. This approach is only applicable where portions of the floodway remain unused. Where major development has taken place on the cone or plain, the construction of flood control projects must be considered. Here again there are options: debris-carrying channels vs. debris basins and lined channels. Inherent in these types of projects are higher maintenance costs and vastly increased initial levels of investment.

The engineering work must come first to define the range of acceptable alternatives, their costs, land use requirements, etc. These engineering solutions must be developed in light of the Federal Flood Insurance Program to assure they are compatible. In developing these basic engineered alternatives, it is necessary for the governing body to establish a level of flood protection for the community. As a minimum, the level of protection should satisfy the Federal Flood Insurance Program requirement of the 100-year flood. In highly urbanized areas, a higher level of protection is economically justified and nearly mandatory due to the potential loss from a catastrophic event. The Corps of Engineers and major urban flood control agencies normally design for a higher level of protection than the 100-year flood.

This decision must be conscientiously made by a governing body at the time it considers alternatives. Ideally, the community should establish its standard for flood protection prior to initial engineering studies. Most often, this is not politically practical since there is a need to understand the range of costs and the impact associated with more than one level of protection before the decision is made.

THE TIME IS NOW

Now is the time to act. All of the parameters are available. They are:

1. The very real constraints of existing development.
2. The very real hazard of periodic flooding episodes.

3. The Federal Flood Insurance requirement that local government adopt practices for regulating development in flood-prone areas.
4. The financial resources of the community.
5. The community's attitude about growth.

It is important that the engineering studies be made immediately. To delay very quickly limits the range of options available to a community and necessarily raises the cost of the solution. As an example, should a city within the next six months allow development to encroach onto one of the few possible alignments for a natural floodway, they have added to the cost of that floodway the cost of condemnation of the development being approved. If condemnation is impractical, an alternative solution must be found, which could mean concrete channels and debris control costing several times what the natural floodway would have cost. Each and every action taken by a planning commission or building officer between now and the time of the adoption of a sensible master plan related to flood plain management has the possibility of reducing the jurisdiction's opportunities and thereby substantially increasing its costs.

Recent experience in developing flood plain management plans shows that the engineering studies, development of alternatives, the community involvement, and political decision making can take place smoothly and economically. From a hydrologic viewpoint, there is absolutely no question that the major flood will occur. All cities should make the necessary decisions and arrange for safe habitation of the cones and flood plains. The recent floods with attendant loss of life and property should remind us all of our obligations.

Plate I

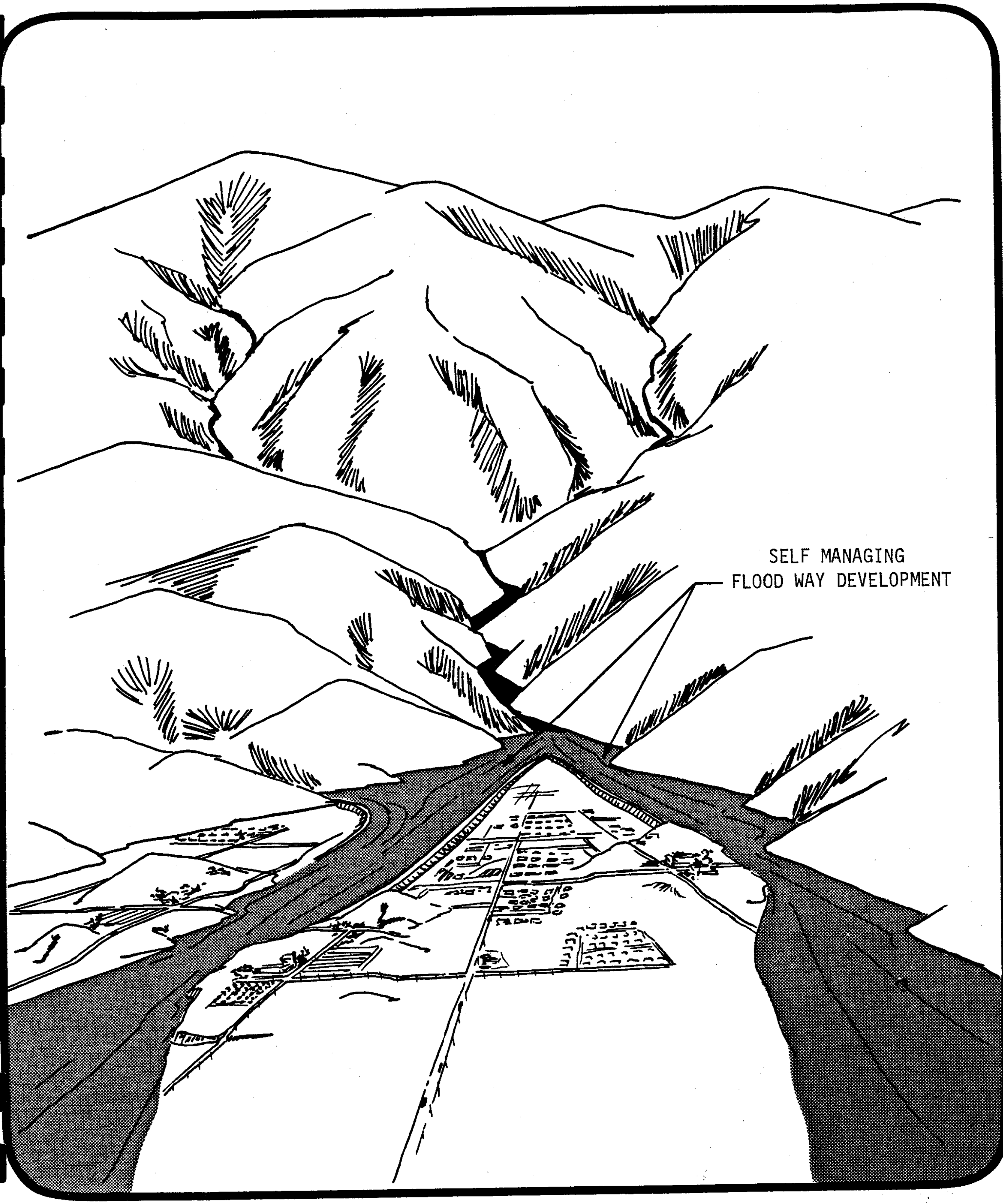

Plate II

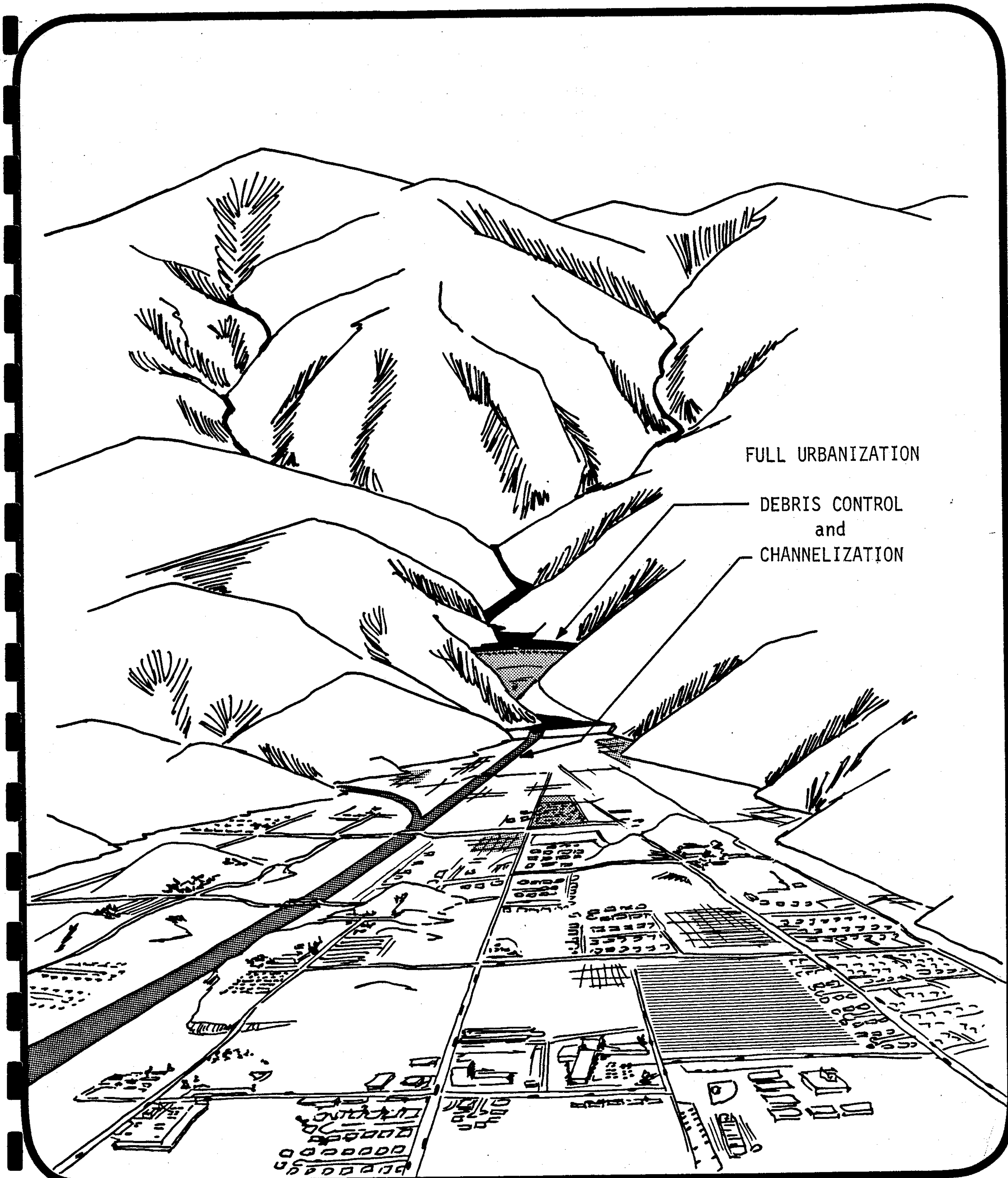

Plate III

Sediment Flow Hazards - A Special Hydrologic Event

by
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I. Background

A. Nature of the Problem

Sediment-laden flood flow has caused millions of dollars worth of damage in the southwest during the last decade. Almost every year some community having an annual rainfall of less than 20 inches is struck by devastating flash floods of water, rock, sand, and mud. The watercourse producing the damaging mudflows is dry most of the time. The concentration of solids in the flow ranges up to 50 per cent.

To most Americans, the word "flood" evokes images of the Johnstown flood, Hurricane Agnes, and the unruly Missouri River sweeping out of its bank through the Kansas City stockyards. Television newscasts of "eastern" type floods illustrate broad areas covered with standing water, people and livestock clustered on roofs, and rowboats carrying people to safety.

In the arid southwest, there is a completely different, special hydrologic event: the sediment-laden flood.

Sediment flows are part of the natural process by which the mountains are worn away and washed toward the sea. Over geologic time the sand, rock, and soil eroded from the mountains has been laid down at their feet in broad, sloping, cone- or fan-shaped deposits. The entire surface of these "alluvial cones" is laced with abandoned gullies and stream channels. At one time or another, sediment laden flows have traversed all these routes. Flow paths are unpredictable. Each flood causes sediment deposits, which obstruct the channel and send the next flow in a new direction. Over the centuries, imperceptibly, the cones grow larger and the mountains grow smaller.

After the cone has been urbanized, as it has in Las Vegas, Palm Springs, Pasadena, and many other southwestern sun belt communities, the "imperceptible" growth rate can suddenly become unmistakably apparent. The flash sediment flood on an urbanized cone is an unforgettable experience involving the battering and destruction of homes and automobiles, and the filling of houses with sediments.

B. Factors Involved

Sediment floods occur in the southwestern United States; West Texas, New Mexico, Arizona, Southern California, Nevada, and Utah. Several ingredients are common to communities subject to this hazard. The first is an arid climate. Rainfall ranges from 3 1/2 inches per year to 20 inches. In the drier interior regions vegetation is sparse. Desert soils are not protected by a canopy of leaves to absorb the impact of rainfall. Ground cover and roots are not present to stabilize the soil against erosion. In the wetter coastal regions the vegetation is hardy chaparral brush which can survive months of drought, but which can be destroyed in a few hours of brushfire. With the protective cover burned away, the delicate soils are exposed to erosion.

The next ingredient is intense rainfall. Coastal regions experience large, slow-moving cyclonic winter rainstorms originating in the northern Pacific Ocean. Sediment production is maximized when, after several days of saturating rainfall, frontal passage is accompanied by extremely high intensities. Raindrop impact, overland flow, and gully erosion can strip tons of sediment from an acre of land in a few minutes. In the interior deserts, the Pacific winter storms usually have abated their force by the time they arrive, so they do not present the most critical threat of erosion. Instead, it is the tropicals and the convective thundershowers. Tropical storms originate in the Gulf of Mexico, the Gulf of California, and the Pacific Ocean, and occur most frequently from July through September. Summer thunderstorms result from the heating, convergence, orographic lift, and frontal lift of moist air passing through the region. The most dangerous flood-producing storm is one covering an area of about 400 square miles, lasting about 3 hours, and characterized by intense downpouring of rainfall.

Erosive soils constitute the next ingredient. In California the formation and adjustment of the mountains by continental plate movement and earthquakes has left the mountains in a fractured, pulverized condition. Alluvial cones are often not well-cemented and are unstable when erosion starts. Brushfires on coastal hillsides glaze the surface, increasing the runoff until rills and gullies form and soil begins to move. Wind-deposited soils in the deserts are fine grained and non-cohesive. All of these situations are prone to scouring and gullying, producing a flow of liquid mud and rock that can be carried downhill with destructive force.

Another troublesome factor is a change of slope, from steeper to flatter, proceeding downhill. The higher, steeper areas often receive more rainfall, and the steepness promotes high velocity run-off and erosion. The steep canyons concentrate high velocity flows, providing the energy to move rock and mud rapidly downstream. When the flow emerges from the steep canyon and strikes the flatter alluvial cone it loses some of its kinetic energy, and its ability to keep sediment moving. The rock and mud drop out of the flow, clogging channels; filling streets, yards, and houses; and building up the ground level for the next flow.

Brush fire is an extremely important factor in those areas having sufficient rainfall to support chaparral.

With its compact canopy and tenacious roots, the chaparral community of plants provides good protection for the fragile soils on steep southern California hillsides. After a burn, the dry soils are so unstable they may run like hourglass sand, collecting at the bottoms of slopes in cones. Of all erosive soil conditions, the burned steep chaparral hillside seems to be the worst.

Finally, the ingredient without which none of the natural phenomena listed above would be such a costly problem: urbanization. The alluvial cones with their breathtaking views of city lights below and mountain ranges in the distance, and the wooded canyons surrounded by chaparral hillsides, make up the suburban fringe that has been undergoing extensive development during the last twenty years. The sites have prestige and command high prices. For the most part, the development in place today was not designed with adequate recognition of the sediment flow hazard to which it is exposed.

C. Size of Problem

The sediment flow damage problem is serious not so much because vast areas are involved, but because of the concentration of high value improvements within relatively narrow areas. Of the 500,000 square mile area comprising the nation's southwest, about one-half is mountainous and mostly in Federal ownership. Another 200,000 square miles is desert, much of which is Federal land. Only 50,000 square miles is river valley land, with agriculture and cities. The areas affected by sediment flow are the sloping alluvial plains located below the mountain ranges. Such plains make up about 40,000 square miles of land. In 1979 it is estimated that only about 3,500 square miles of these plains are completely or partially urbanized. About 14,000 structures are involved, with a replacement value of $1.5 billion.

The cost of damages increases yearly as human occupancy expands. The Las Vegas sediment flood of July 3, 1975 caused $4,000,000 worth of damages. Tropical storm Kathleen, in September 1976, caused $23,000,000 worth of flood and sediment damage in the City of Palm Desert, California, plus additional millions to utility, transportation, and communications facilities. The same area was struck again in 1979, with damages estimated at $50 million. Sediment flow during February and March, 1978 in Los Angeles caused $100,000,000 worth of damage to private and public structures, roads, utilities, and flood control works. It is estimated that the total average annual cost of sediment-related flood damages in the southwest, in 1979 dollars is $20,000,000. These figures could double in the next 10 years unless development policies and criteria are modified to recognize and mitigate sediment hazards.

D. Impacts

1. Individuals

The most tragic impact of sediment floods is upon individuals and families. Unlike riverine flooding, sediment flooding leaves behind crushed stucco walls, thousand of tons of rock, mud, and debris, and automobiles hammered around standing trees. The destruction and the cleanup problems are staggering. Homes representing a family's major financial asset are destroyed.* Livestock and pets are lost forever. One father leading the family horse to safety across a stream was swept away and drowned. Others have been stricken with heart attacks while shoveling mud and lifting sandbags. Highway workers placing barricades in front of a dip crossing of a normally dry stream have been swept away and drowned. Caretaker residents of a church camp resort area have been swept away in the night. Bodies not yet recovered are probably buried in downstream reservoir sediments.

*At this writing, almost none of the structures damaged and destroyed to date have been insured, although Federal Flood Insurance has been available since 1968.

2. Community

At the community level the sediment flood brings several reactions. During the emergency, the shock of the disaster stimulates heroic and unselfish acts of courage and strength. Natural leaders take charge of evacuations, seeing to it that the elderly, disabled, and the young are carried to safety. Strapping teenage boys and girls set up sandbag operations, filling and placing the heavy bags long past the point of exhaustion. Emergency forces from all sources - utilities, contractors, and public agencies - all find ways to contribute without concern for jurisdiction or red tape.

The morning after the flood, when the shock has worn off, residents walk the streets and canyons, surveying the wreckage. As they look at the path of destruction leading from canyon mouths and spreading randomly across alluvial cones, they realize how certain it was for disaster to strike where it did. After the flood, it does not take an expert to observe that mudflows which have always poured out of the canyons will continue to occur, even if houses are placed in their way. As people gather, the question is asked over and over: "How did they ever approve a building permit in that spot?" The feeling of betrayal by the officials entrusted with public safety spreads rapidly under these circumstances. At a time when distrust of government is already at a high level, we do not need to add fuel to the fire or increase public liabilities. Past practices governing development of sediment hazard areas are sure to leave the community with a feeling of bitterness, resentment, and betrayal toward agencies that regulate development in the name of public safety.

3. Local Government

The impact of sediment floods on local government is staggering. Types of impact include financial, service delivery, regulatory and political. In one Southern California flood there was $84 million in damages to public properties, roads, bridges, and flood control facilities. Although restoration of public facilities is eligible for federal disaster funding under certain circumstances, it takes about 60 days to receive the first payments. Local agencies must be able to finance emergency flood fighting activities during the interim, which may involve enormous cash outlays for rental equipment, operators, and contracts.

Diversion of local financing to flood fighting and restoration operations means deferral of other projects and services which were scheduled and financed. Energy and money expended on restoring public facilities damaged by sediment floods can never be recovered and is a permanent loss of societal resources.

Repeated sediment floods have had an impact on the way local officials view their responsibilities for controlling development. At the technical level attention has been drawn to the enginering aspects of sediment flooding. Improved procedures for evaluating proposed developments, for predicting the quantity and location of potential sediment flows, and criteria for mitigating their hazard, have been developed. Planning, zoning, subdivision, and building departments have become much more aware of sediment hazards, and receptive to procedures and techniques for avoiding or mitigating them. Although only a few communties have taken positive mitigating steps, they have demonstrated that workable procedures and criteria can be developed and implemented without upsetting the housing industry.

At the political level, the same thing has happened. Immediate reactions have included ordering re-evaluations of planning and building criteria. beneficial results have included a good understanding of the seriousness of sediment hazards and a willingness to stand behind technical staff recommendations on safety criteria. Again, this political perspective is not widespread but it does indicate that concerned engineering officials can work effectively with elected officials to improve public safety.

4. Federal and State Government

Disaster relief laws authorize the Federal government to assume most of the cost of restoration of public facilities whenever the President declares a national disaster. Repair and restoration of public buildings, streets, parks, and flood control facilities due to sediment flood damage costs an estimated $10,000,000 per year. States are also impacted, particularly when the situation does not qualify for a national disaster proclamation. Since states do not normally maintain an appropriation for the purpose, it is usually necessary to enact special assistance legislation. The overall effort amounts to a substantial deployment of energy and money that the nation can ill afford.

II. Engineering Aspects

A. Factors Affecting Sediment Production

Sediment flow as used in this paper means a high concentration of rock, sand, and soil in the water, such that great destructive force is generated. Sediment production rates for a single storm have been measured as high as 240,000 cubic yards per square mile. At peak sediment flow rates, it is estimated that the sediments comprise up to one-half the total volume of flow. The largest body of quantitative engineering data on sediment production is in the records of the Los Angeles County Flood Control District.

The District has several flood control reservoirs with 50 years of record. Of the 100 debris basins presently operated, 18 have more than 36 years of record, and 25 have at least 25 years of record. It has generally been believed that sediment production was a function of watershed variables such as soil types, size of drainage area, steepness, vegetative cover, rainfall, fire frequency, aspect, and relief ratio. Recent regression analyses have indicated that sediment production rates per unit of watershed area are most influenced by the vegetative cover (which is a measure of fire history), followed by relief ratio and rainfall. The other factors measured did not significantly improve the results. No practical way has been found to introduce soil and geology data into the regression analysis.

B. Sediment Volume Prediction Models

For many years the Los Angeles County Flood Control District debris basin design standards relied on enveloping curves based upon historical sediment measurements. By 1956, sufficient data had been accumulated to perform regression analyses using watershed variables. This resulted in the following sediment production equation:

$$\text{Sediment Production Rate in cu. yd./sq. mi.} = \frac{35{,}600\ Q^{1.67}\ Rr^{0.72}}{(5+ V.I.)^{2.67}}$$

Where Q is peak run-off rate in cfs per square mile resulting from maximum 24 hour rainfall of a given storm

Rr is relief ratio of the watershed, and

V.I. is the Vegetation Index

The volumes used in the analysis were annual sediment volumes, which were treated as storm events, and in most cases actually were single storm events.

In 1979, a new regression analysis was performed for the U.S. Department of Housing and Urban Development, Federal Insurance Administration using a much expanded data base, and with a specific objective of establishing a frequency basis, so that flood insurance rates for mudflow might be calculated.

The procedure required (1) determining an appropriate frequency distribution that would fit historical data and extrapolate to reasonable values, (2) relating sediment production to measurable watershed parameters for estimating sediment production from ungaged watersheds, and (3) properly accounting for the effect of burn in expected sediment production.

Frequency Distribution

Pearson Type III and Log Pearson III distributions, which are used in Los Angeles County for rainfall and run-off analysis, were first tried on the sediment data. Extrapolation of the data using these frequency distributions produced values far higher than the sedimentation rates historically observed. Figure I shows the Log Pearson III distribution. For this reason, it was decided to use the Chow form of frequency distribution:

$$X = \overline{X} + K\sigma$$

where X = Annual sediment production for the desired frequency

$\overline{X}$ = Mean annual sediment production

σ = Standard deviation of the sample

K = Frequency factor as described by Chow

Regression Analysis

The mean annual sediment production and standard deviation were related to measurable watershed variables by regression analysis of sediment basin records. Since the raw basin record data contains certain systematic errors, the following corrections were first made:

1. Developed areas were accounted for by reducing the total watershed area by the amount of the developed area. Computations were then completed using only the sediment-producing portion of the watershed.
2. Upstream engineering or watershed stabilization work, such as check dams constructed by the District or U.S. Forest Service, was accounted for by adding the amount of sediment stored by check dam systems to the downstream sediment basin records.
3. The effect of watershed burn was taken out so the means and standard deviations could be computed on the basis of homogeneous, "normalized" data. While the effect of fire is important and must be reflected in the final frequency determinations, the mixture of burned and unburned data is troublesome in the development of a statistical model. The effect of fire was studied by Rowe, Countryman, and Storey (Reference No. 3). Figure II is based on that study and was used to reduce sediment production from burned watersheds to what it would have been if the same storm had occurred on a "normal" watershed.
4. An adjustment was made for trap efficiency. Some basins have outlet towers and pass some sediment through, while others have no drains and trap all sediment. There were no measurements of passed-through sediments, so the adjustment was made based on comparison of long-term yield under similar conditions of basins with and without drains.

The mean sediment debris production was developed for the normal unburned watershed condition by regressing watershed parameters with adjusted average annual sediment production. The variables chosed for the regression equation were watershed area, average slope, relief ratio, exposure ratio, vegetative index, and 90-year normal rainfall.

The normal watershed regression resulted in the equation

$$V_D = 7,764,000 \frac{(Rr)^{0.4339} (Slope)^{.3174} (Expos)^{.2736}}{(Area)^{.0344} (Veg)^{2.1302} (90\text{-}year)^{0.1365}}$$

Where

V_D = Average Annual Debris Production ($Yd^3/Mi^2/Yr$)

Rr = Relief Ratio (FT/FT)

Slope = Average Watershed Slope (FT/FT)

Expos = Exposure Ratio (FT/FT)

Area = Watershed Area ($Mile^2$)

Veg = Vegetative Index (No Units)

90-year = 90-year Normal Rainfall (inches)

The regression equation is sensitive to the vegetative index, relief ratio, exposure ratio, and average watershed slope. The equation is relatively insensitive to the other factors.

The regression analysis for standard deviation was completed using the same input factors as for the average annual debris production. The final standard deviation regression analysis equation for the normal watershed is:

$$\sigma = 5,830,000 \frac{(Rr)^{.78012} (Area)^{.06930}}{(Slope)^{.65543} (Exp)^{.00723} (Veg)^{1.78871} (90\text{-}year)^{.11157}}$$

As with the average annual debris production, the standard deviation regression equation is sensitive to relief ratio, slope, and vegetative index.

Frequency Factor K

The frequency factor K was developed by determining the general long-term sediment production frequency distribution. This general distribution, termed "normal distribution curve" was developed by modifying the Log Pearson III distribution.

Since the Log Pearson III distribution does fit well within the data range, it was used as the basis for the normal watershed frequency curve for the more frequent events. The normal watershed frequency distribution was taken as the average of those distributions shown on Figure I up to the 40-year level. To adjust the Log Pearson III distribution for the rarer events, three criteria were used. First, for extremely rare events (10,000 years±) the debris frequency curve was made to parallel the extrapolated Log Pearson III rainfall frequency curve. Parallel curves are appropriate in that once the erosion-transportation sequence is well established, response of the erosional system should be directly proportional to the rainfall input. The rain gage selected for plotting was the Bailey Canyon gage in the City of Sierra Madre, a centrally located record of relatively long length. The second criterion for adjustment was that the area under the normal watershed curve must approximate the normal watershed average annual debris production. The length of record at the existing debris basins is sufficient to assume a degree of stability in the normal watershed average annual debris production. The third criterion was that the shape of the normal watershed frequency curve for rare events was compared to the shape of the final base distribution curve when completed. Figure III shows the normal watershed frequency distribution curve.

Using annual sedimentation production rates x from this curve, values of frequency factor K were computed for various frequencies using the relationship

$$K = \frac{x - \bar{x}}{\sigma}$$

The plot of K values vs. frequency is the K-t curve shown in Figure IV.

<u>Fire Factor</u>

To properly reflect the effect of fire on sediment production, the normal production must be increased by the use of a fire factor. The fire factor is defined as the ratio between the base distribution curve including fire and the normal distribution curve.

The frequency distribution of fire-flood events was determined using the station-year approach.

Three variations of the station-year approach were examined before developing the base distribution curve.

1. <u>Total Record</u>

   This attempt to establish the base distribution curve involved plotting the recorded debris volumes from all the debris basins. The existing debris basin records represent a total of about 1,600 station years. However, many debris production records were taken from basins burned by the same fire. This approach was rejected because of the dependency between basins for major recorded events.

2. <u>In Terms of Mean</u>

   To eliminate error introduced by the use of rare data, recorded data was reduced to multiples of the normal watershed average annual debris production. Shorter term (20+ years) records were extended by correlation with average yearly debris production factors. Each station record was expressed in terms of the mean (average annual) debris production for that particular station. The total record years were shortened to account for multiple basins burned by one fire in one year. The data was then plotted using the reduced number of station years. This approach was rejected because the following analysis of independent stations gave somewhat more conservative results.

3. Independent Station Analysis

This technique involved examining the entire record to determine those basins which were burned by the same fire. Wherever this occurred only one representative basin was selected and the remaining basin records were rejected. This had the effect of reducing the number of station years from 1,600 to 914.

The data was then plotted and a base distribution curve drawn. The area under the curve was compared to the long-term average annual debris production and found to be essentially the same. This curve (see Figure III) was adopted as the base distribution curve to be used in completing the methodology.

Fire Factor Curve

A fire factor curve was plotted by calculating the ration of the base distribution frequency curve to the normal watershed frequency curve throughout the range of probabilities. The fire factor curve is shown on Figure V.

C. "Hydraulics" of Sediment Flow

The hydraulics of mud and sediment flow present problems. Hydraulic equations used for water cannot be fully relied upon because the density and viscosity of sediment flows are so different from those of water. Flow records are scarce because gaging stations which receive sediment-laden flow are often buried by the event for which the record is desired. Post-storm observations using the slope-area method are questionable because of flow density and viscosity problems. Accurate velocity measurements are hard to get because of the difficulty of operating a current meter in sediment-carrying streams. It has been observed that sediment-laden flood flows often arrive in tremendous surges or waves many times the average flow rate. The effects of this slug flow are several:

1. Instantaneous flow rates and velocities are much higher than one might expect.
2. Depth of flow and corresponding damage potential are higher than one might expect.
3. The tremendous kinetic energy can destroy structures on impact and can overwhelm a debris basin designed for a steady inflow rate. Reliable post-flood measurements of sediments that passed debris basins is nearly impossible.

The evaluation of sediment hazard potential requires the ability to predict the location and amount of deposition, because the recession flows will be passing over the deposited material. Where deposits have occurred in the past, there is a basis for estimating future deposition and for extrapolating the relationships to other locations. Factors which influence deposition are those which influence velocity: slope and cross section. Changes of slope and obstructions caused by walls, fills, automobiles, and houses are the main indicators of sediment deposition.

While the hydraulic flow characteristics of sediment laden flows present some technical problems to the engineer, adequate representation of the potential hazard can be made by approximate methods. This enable the identification of hazardous areas and the design of mitigation measures, both nonstructural and structural. It is more important to recognize the hazard and apply a common sense approach than to worry about the precise width and depth of the flow.

Debris basin capacity has come under new scrutiny recently. As a result of heavy rains following a large local brushfire after two years of drought, erosion and sediment production were maximized. The watershed had been saturated by intermittent showers for several weeks. High-intensity rainfall produced surges of sediment-laden flow containing 10-ton boulders. The flood crest hit debris basins in a wave, overrunning the structures and sending boulders and mud downstream. Boulders and chain link fence from the channel walls plugged underground channels downstream, and the communities were devastated by boulders and mud. This event demonstrated that under freshly burned watershed conditions the previous understanding of sediment deposition, based on experience, was inadequate. The dynamics of the sediment-laden mass entering basins obviously governed their performance. The data gathered during this flood will be evaluated to establish the determining relationships.

III. Controls

A. Keep it Moving

Engineers have only two choices with sediment flow: either stop it or keep it moving. Where it is physically possible to keep it moving without causing damage, there are advantages. If the stream is a coastal stream, beach starvation can be avoided by allowing sediment to pass to the ocean. Also, if the sediment can be carried downstream by the water, it will not have to be cleaned out of expensive sediment containment structures and carried away at substantial cost.

There are problems with and limitations to the concept of sediment-carrying improved channels. There may be insufficient slope to keep sediment moving. With insufficient slope, the channel will plug and the community will be flooded. Where this is the case, there is no choice but to trap the sediment. Where there is sufficient channel slope to carry sediment to a safe destination, the channel will perform satisfactorily but will wear out due to abrasion of the concrete channel bottom. After a few years, the steel will be exposed and the channel bottom will have to be relined.

Situations where sediment transport will work include streams upstream of existing debris basins or reservoirs where there is adequate capacity for the sediment. Also, small sediment-carrying side canyons may be introduced into a large channel, where the main channel flow will always be great enough to handle the sediment load. It is also possible to design a sediment-carrying floodway with a natural bottom and revetted levees. Such a floodway may act as a linear sediment basin. Adequate freeboard must be provided to contain the deposition and arrangements must be made to excavate aggrading deposits to restore channel capacity.

Sediment-carrying channels should be designed for bulked flow, free from grade breaks which flatten the grade, free from restrictions and expansions, and as straight as possible. The channel should be open for ease of maintenance. Trapezoidal and V sections provide better scouring velocities at low discharges than rectangular channels. Invert concrete should be extra thick to allow for abrasion, and scour gages consisting of colored concrete cones should be imbedded in the invert so wear can be monitored. Studies show that concrete is the least expensive material at this time.

Restrictions and expansions are hard to avoid in stream systems undergoing urbanization. Sections of leveed channel may alternate with natural flood flood plains. Special care is needed to maintain sediment transport.

B. Separation of Sediment from Water

If the sediment-laden flow cannot be safely carried through the community to a safe point of discharge, it will be necessary to remove the sediments and carry only the water. Sediment removal is accomplished by providing a reservoir or basin large enough to contain the sediment from at least one major flood. A spillway is provided to protect the embankment from overflow. A drain should be provided to dewater the basin to simplify cleanout operations. In areas having high sediment rates, the basin capacity measured to the spillway crest may be as much as 240,000 cubic yards/square mile of drainage area. Sediment tends to deposit in the basin on a slope, so basin capacity is sometimes computed to a plane extending upstream from the spillway crest at a slope one-half that of the natural stream bed. Sediment basins are usually located in populated areas where it is necessary to fence them for security. The basins must be cleaned out after storms, so all-weather access is necessary. A sediment disposal site suitable for the long-term must be provided as near as possible, which may be difficult where land value and environmental concerns stir a strong public response. The site must be planned with regard to the stability of the fill, access, drainage, and truck traffic during cleanout operations. Community public relations during prolonged floodfighting periods when trucks are operating day and night can become a significant effort. Typical design features of a sediment basin are shown in Figure No. VI.

Sediment basins are high-cost, high-maintenance facilities that can provide a high level of protection. They are justified only in situations where land use requirements and real estate values preclude leaving the hazardous area open for sediment flows. Most sediment basins are built to protect existing communities located in hazardous areas. New developments can often be designed to occupy safer ground and leave the sediment-carrying canyons alone, if adequate information on sediment flow hazards is available during the planning stage.

IV. Political-Engineering Strategies

A. Problem Identification

The sediment flow hazard is not well understood by many public works engineers or public officials. As understanding of the relationship of sediment flow to other hydraulic considerations in flood control improves, it will be possible for governmental agencies to identify specific problems on a drainage area-by-drainage area basis. Clear understanding of sediment flow by public works officials will increase confrontations with land developers and therefore with political leadership interested in healthy growth. Advanced agencies are already mapping areas where sediment flow is a consideration. This will be seen on zoning and other master-plan documents. This is a first step; it provides notice to prospective buyers and elected officials that a special problem exists. It is the responsibility of public works officials to obtain sufficient knowledge to allow the controlling public agencies to adopt land-use management plans which consider sediment flow. National Flood Insurance Program (NFIP) mudflow mapping will go a long way in this direction.

B. 100-Year Versus Other Standards

The NFIP mapping and regulatory standard basis of 100-year clear water and 100-year mudflow hazards has serious limitations in urban areas. Greater flows have a demonstrated record of doing major damage. It is probable that this flood protection level may have to be increased in some areas as more statistics on loss are available. Some flood control agencies use standards considerably higher than the 100-year standard when designing facilities or establishing flood plain management techniques for high-density urban development. Each agency should knowingly adopt a flood protection standard and develop with it strategies that reflect that standard for flood plain management. If the flood plain will be relatively sparsely developed, the 100-year protection level may be adequate if structures are raised and properly located. For higher density urban property, the 100-year protection level may be inadequate where sediment flows may cause extensive damage. This is a local problem which should be resolved by local flood plain management regulations. It is important that political bodies take specific actions to establish a level of protection for sediment flows since they will be called upon to provide public assistance when the NFIP standards are exceeded, and because they and their employees may incur total liability for either inaction or for negligent actions. Public works engineers need to educate educate elected officials about these realities even though their occurrence may be relatively infrequent.

C. Hazard Reduction

The objective of flood plain management is to reduce hazards and economic losses. Hazard reduction has political overtones, since land use is restricted or costs are increased for flood control structures. Engineers bear responsibility to develop alternative proposals consistent with their drainage and sediment flow master plans. These proposals must be communicated to political bodies concisely and clearly, so the regulations and related land use or construction costs are understood. Without such understanding, political bodies are prone to approve individual developments because they do not each have a significant impact, without recognizing that on a long-term cumulative basis they may be creating limitations upon master plan implementation committing the community to enormous remedial costs, or setting the stage for a future flooding catastrophe.

D. Government Obligations

Federal government initiatives are motivating local government regulation of hazardous areas. The significance of this is apparent when one reflects on the decades of "laissez faire" local government development policies. Although it is too early to evaluate the flood insurance program, indications are that communities are ready to regulate hazardous areas if they have the necessary information and the political reassurance that they have no choice under the Federal mandates.

One important element in a comprehensive solution is an obligation of the Federal government but has not been implemented. Section 1362 of the Nationa Flood Insurance Act of 1968 as amended authorizes Federal purchase of severely flood damaged properties provided the properties are insured under NFIP, the local building department will not allow their reconstruction, and a local elected official requests the action. Until this element of the program is implemented, there is no mechanism for breaking the cycle of damage, repair, and resale. Homes in hazardous areas have been struck as many as four times by sediment floods, suffered each time by new owners.

Local government now must proceed with care that its program goes beyond minimum Federal requirements, and meets its own long-term needs.

E. Developer's Obligations

The key to sound development is not government regulations, but practical understanding and resolution of the sediment and flood problems by developers.

When sediment flood hazards have been identified on the land at an early stage, key decisions can be impacted - such as whether to purchase one parcel or another, and what type of development to plan. During development planning, the grading concept, street layout, and lot designs can all be adjusted to accommodate and mitigate sediment hazard. Finally, dwelling placement and orientation on the lot, and its construction and elevation, should reflect awareness of sediment hazard. The basic rules are as follows:

1. Determine the flood and sediment hazard to each lot.
2. Provide a safe pathway for sediment-laden flow to a safe point of discharge, without harm to structures and improvements.
3. Do not flatten the grade of sediment flow paths or try to change their alignments.
4. If a drainage facility is necessary, design it as an open channel so it can be cleaned out.
5. Allow equipment access for cleanup.
6. If sediment cannot be safely carried through on the surface, provide an adequate basin, with access for maintenance.

F. Homeowner Obligations

Homeowners must understand the problem so as to mitigate it within their means and at least not make it worse. They must particularly be aware of the sediment flow path and the room it requires. This path must be left clear, so block walls, accessory buildings, and landscaping should be planned accordingly. Homeowners can also improve their safety by constructing properly designed deflector walls to keep sediment-laden flow moving in the right direction. Finally, they should protect against loss by taking out flood insurance.

G. Insurance Aspects

The sediment hazard to many existing developments is so diffused that it cannot be cured by a major flood control project. The only recourses available to owners of such properties are to maintain and improve sediment flow paths as well as they can and take out insurance. The insurance will defray the cost to individuals of restoring damaged structures and significantly reduce the impact on family finances. On a longer term basis, the flood insurance program requires a buy-out when the structure is damaged more than one-half its value. This provision will eventually abate many existing hazards by allowing hazardous lots to revert to open space or safe uses.

V. The Future

A. The Public Works Construction Outlook

Public works construction accounted for a significant portion of Federal, State, and local funds during the 1960's. Since that time, rising costs and changing priorities, together with environmental awareness, have markedly reduced the amount of money available for public works. Now that the nation has entered an era of insufficient energy and escalating costs, it appears that there will be increasing competition for the nation's scarce dollars. Public works will probably receive relatively low priority within the next generation. Consequently, there should be no expectation that even the existing flood and sediment hazards can be cured. There is certainly no reason to expect that public works will rescue new developments placed in unsafe areas. Local planners and elected officials must realize this and shift gears from the old viewpoint that the Corps or the Flood Control District will correct any problems caused by unwise development.

B. Impact of Federal Flood Insurance

Despite some recognized shortcomings, the flood insurance program is still the only game in town in terms of an organized effort to focus attention of local officials on their responsibilities for safe development. With the flood insurance program as a catalyst, local flood plain management programs can be developed which can have significant positive impact on future sediment damages. Local agencies can set standards of protection commensurate with their community plans, so long as they at least satisfy Federal requirements. Mechanisms for implementation can vary, depending on local philosophy and existing ordinance structure. Most importantly, the effects of future development can be reflected in hazard calculations and be kept consistent with the community's own goals. Eventually, the need for government purchase of severely damaged properties will be recognized. Implementation of this program will go far toward eliminating the most serious existing hazards. The flood insurance maps may provide the stimulus needed by communities to support public works flood control programs. When mandatory flood insurance is in full effect, property owners may find they would be better off to support a bond issue to eliminate the mandatory insurance than to continue paying the premiums. In any event, the flood insurance program does offer better financial protection for property owners in flood hazard areas, better public information about flood hazards, and better regulation of new development.

C. The Impact of Local Flood Plain Management

Pressure for development of new land will continue. New lands generally are those which either have been passed over before or have not been reached by development. Either way, it often turns out that the land available for development has problems such as a sediment hazard. Recognition and mitigation of the hazard will tend to increase the cost of development, so flood plain management is initially viewed unpopularly by developers. In the long run, if the criteria are reasonable and fairly applied by all jurisdictions in an area, the housing industry accepts them as part of the cost of providing quality housing. There is no question but that the widespread adoption of sediment hazard mitigation measures described earlier in this paper will have enormous impact on the future loss of life and property to sediment flood related disasters.

1. Chow, Ven Te, "Handbook of Applied Hydrology", McGraw-Hill Inc., 1964, pages 8-1 through 8-41.

2. Hydrology Manual, Los Angeles County Flood Control District, 1971.

3. Rowe, Countryman, and Storey, "Hydrologic Analysis Used to Determine the Effects of Fire on Peak Discharge and Erosion Rates in Southern California Watersheds". California Forest and Range Experiment Station, U.S. Forest Service - Department of Agriculture, 1954.

4. "Report on Debris Reduction Studies for Mountain Watershed of Los Angeles County" - Los Angeles County Flood Control District, 1959.

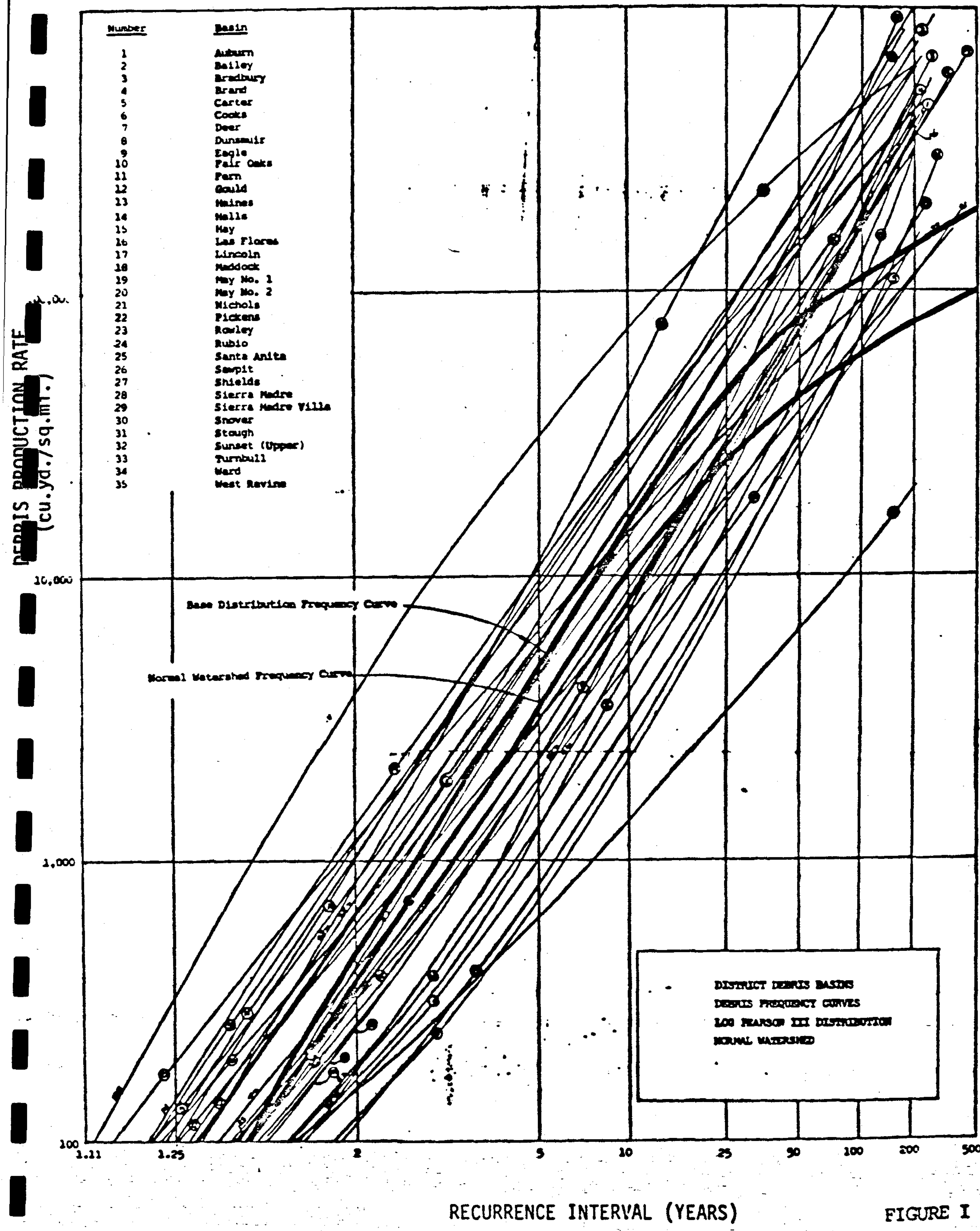

Number Basin
1 Auburn
2 Bailey
3 Bradbury
4 Brand
5 Carter
6 Cooks
7 Deer
8 Dunsmuir
9 Eagle
10 Fair Oaks
11 Fern
12 Gould
13 Haines
14 Halls
15 Hay
16 Las Flores
17 Lincoln
18 Maddock
19 May No. 1
20 May No. 2
21 Nichols
22 Pickens
23 Rowley
24 Rubio
25 Santa Anita
26 Sawpit
27 Shields
28 Sierra Madre
29 Sierra Madre Villa
30 Snover
31 Stough
32 Sunset (Upper)
33 Turnbull
34 Ward
35 West Ravine
Base Distribution Frequency Curve
Normal Watershed Frequency Curve
DISTRICT DEBRIS BASINS
DEBRIS FREQUENCY CURVES
LOG PEARSON III DISTRIBUTION
NORMAL WATERSHED
DEBRIS PRODUCTION RATE (cu.yd./sq.mi.)
10,000
1,000
100
1.11
1.25
2
5
10
25
50
100
200
500
RECURRENCE INTERVAL (YEARS)

FIGURE I

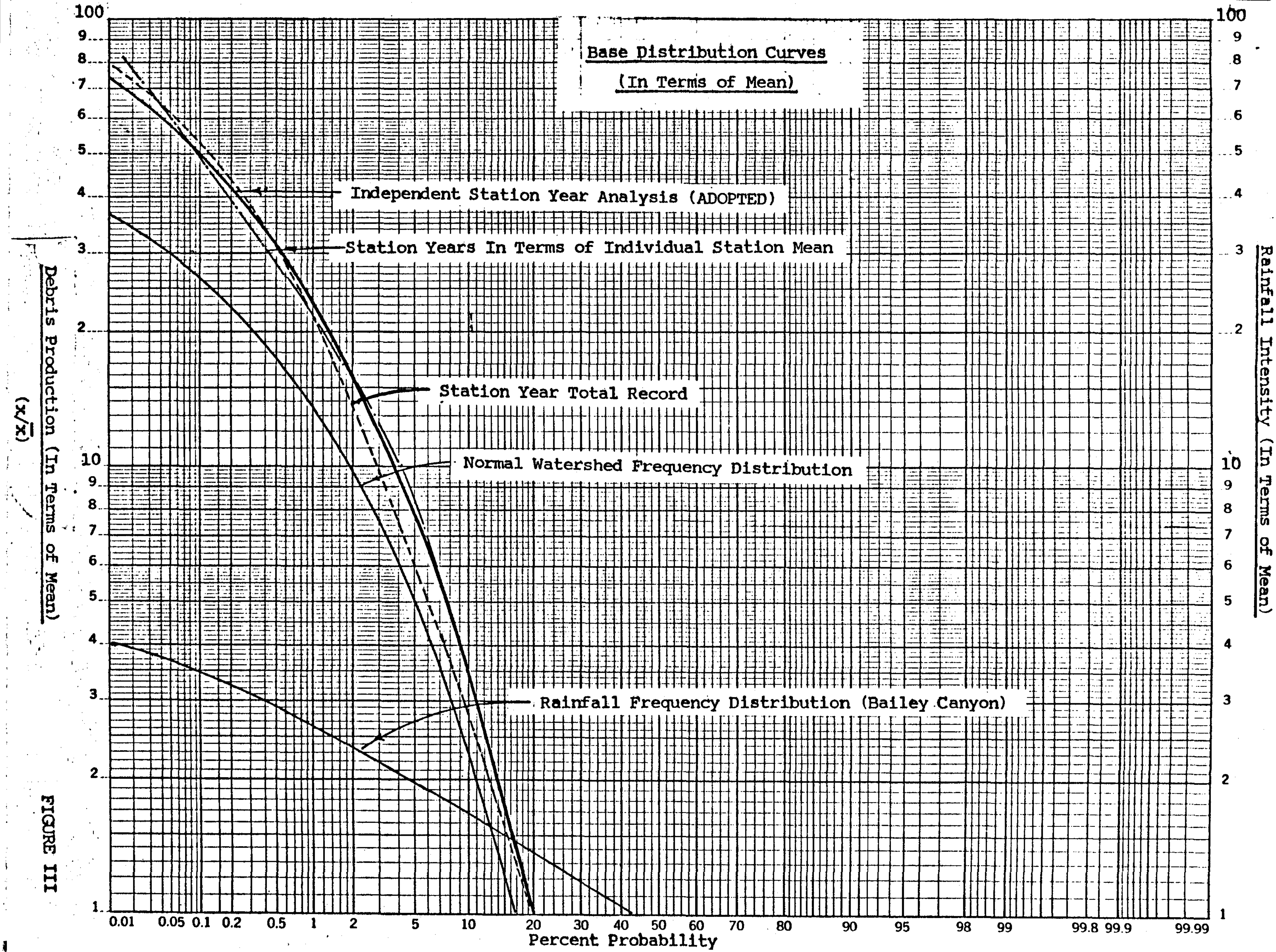

PROBABILITY X 2 LOG CYCLES
Base Distribution Curves
(In Terms of Mean)
Independent Station Year Analysis (ADOPTED)
Station Years In Terms of Individual Station Mean
Station Year Total Record
Normal Watershed Frequency Distribution
Rainfall Frequency Distribution (Bailey Canyon)
Debris Production (In Terms of Mean)
(x/x̄)
Rainfall Intensity (In Terms of Mean)
Percent Probability
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
100
10
1

FIGURE III

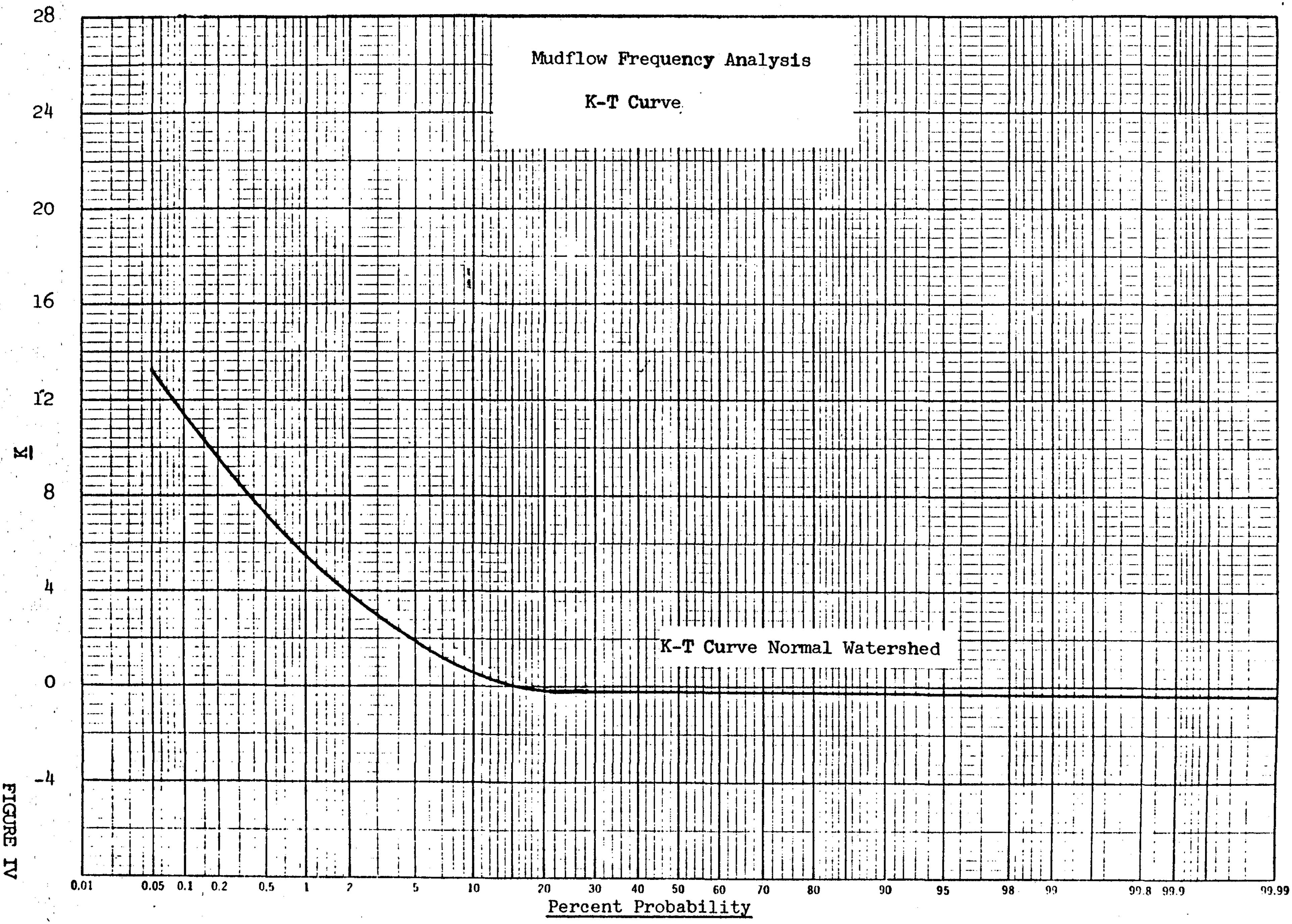

Mudflow Frequency Analysis
K-T Curve
K-T Curve Normal Watershed
K
28
24
20
16
12
8
4
0
-4
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
Percent Probability

FIGURE IV

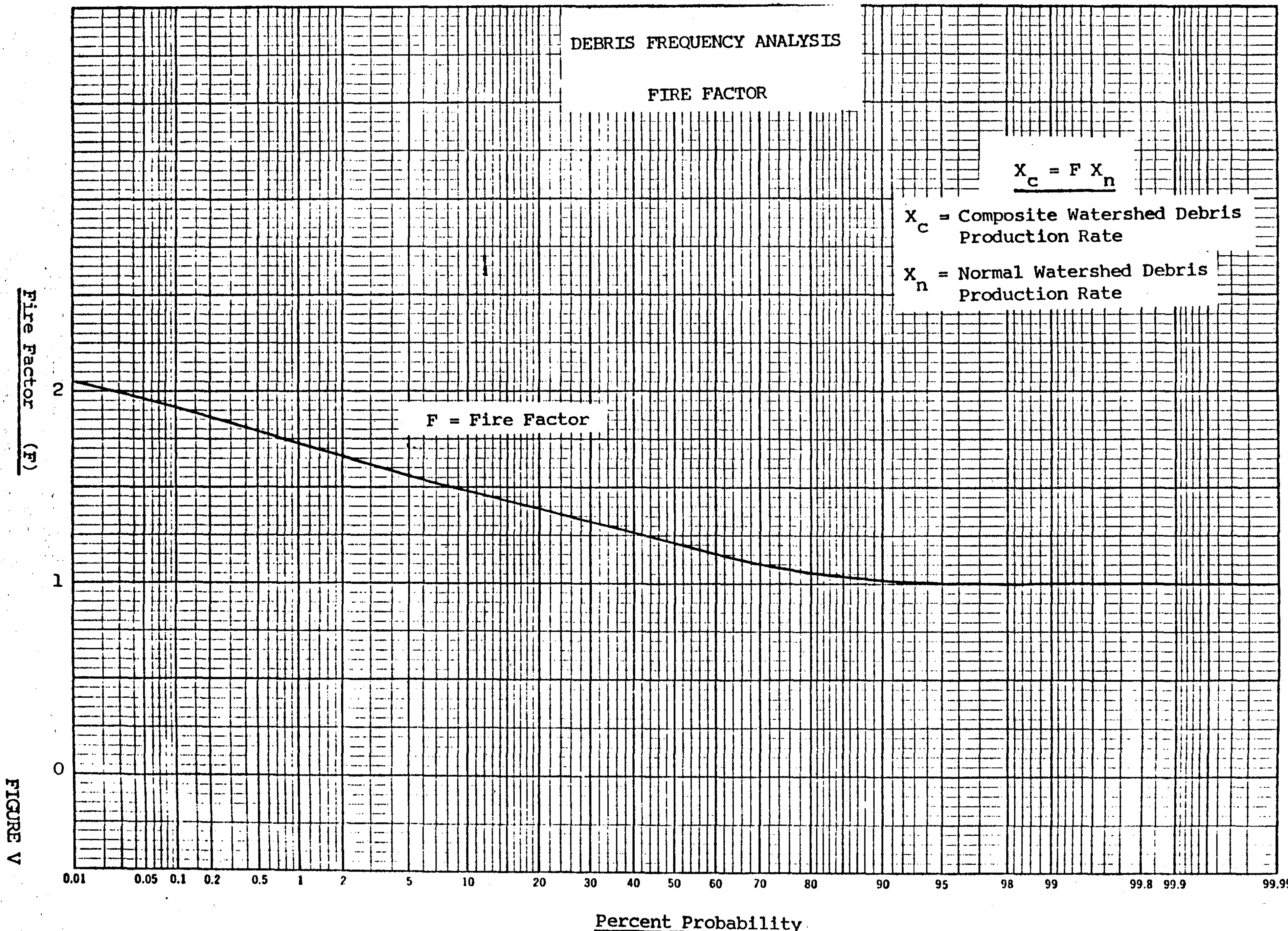
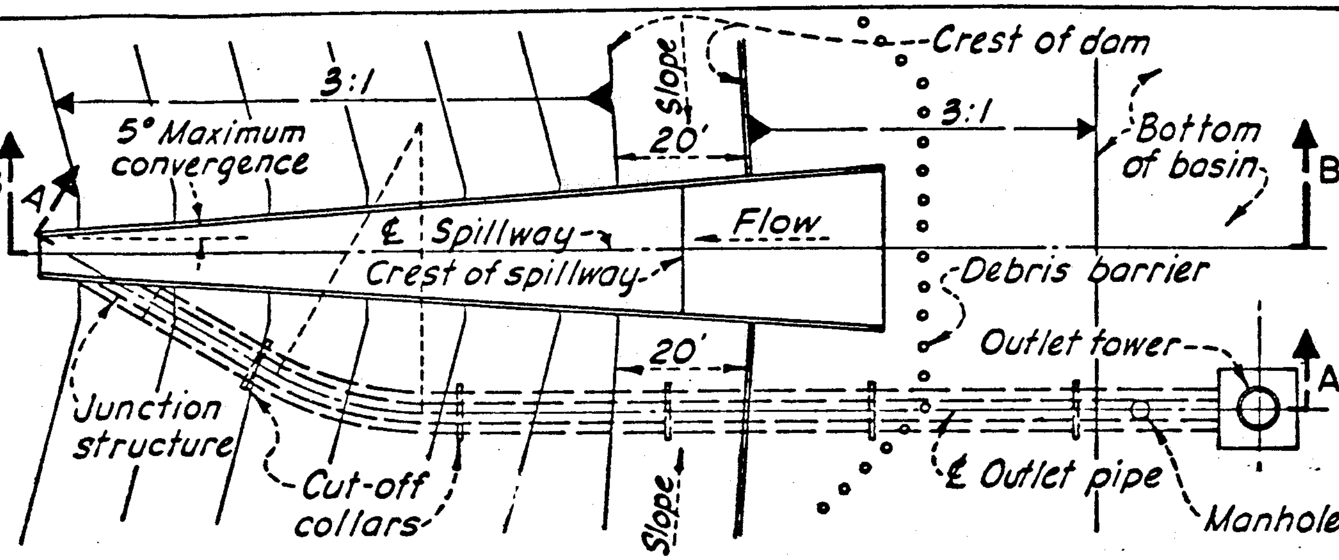
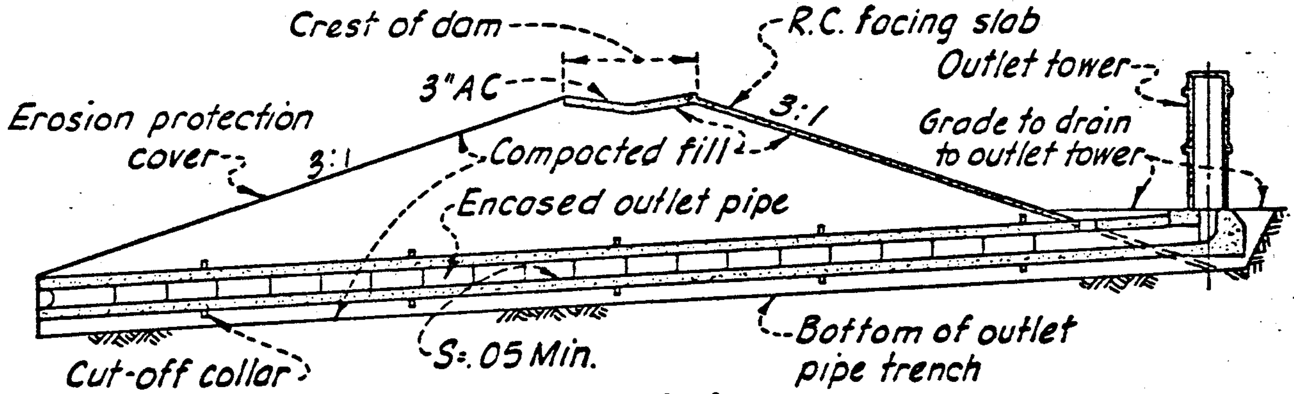

DEBRIS FREQUENCY ANALYSIS
FIRE FACTOR
$X_c = F X_n$
X_c = Composite Watershed Debris Production Rate
X_n = Normal Watershed Debris Production Rate
F = Fire Factor
Fire Factor (F)
2
1
0
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
Percent Probability

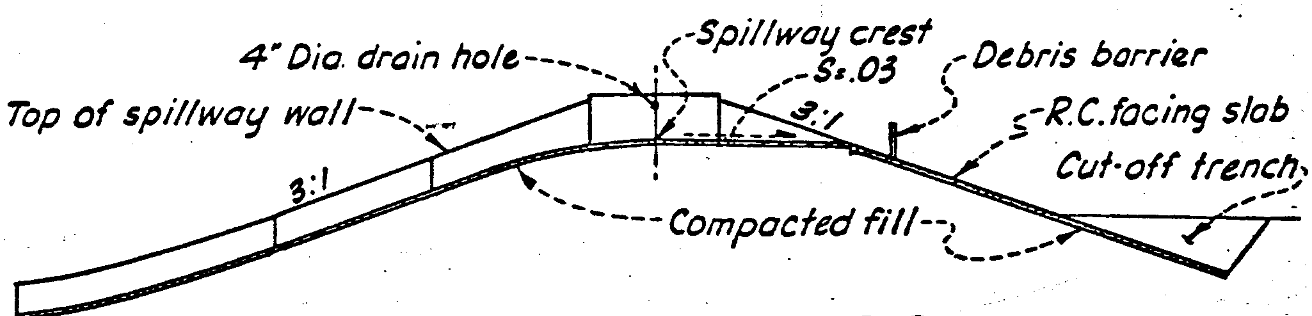
FIGURE V



PLAN
TYPICAL SPILLWAY AND OUTLET WORKS



SECTION A-A



SECTION B-B

TYPICAL SEDIMENT BASIN CONFIGURATION

FIG. VI