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Review of the U.S. Army Corps of Engineers Involvement with Alluvial Fan Flooding Problems

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REVIEW OF THE U.S. ARMY CORPS OF ENGINEERS INVOLVEMENT WITH ALLUVIAL FAN FLOODING PROBLEMS[1]

The Hydrologic Engineering Center[2]

INTRODUCTION

The U.S. Army Corps of Engineers has shared responsibility for resolving flood problems in the United States. Alluvial fans are areas of special interest that present some of the most complex analytical and managerial challenges to engineers and floodplain managers. Successful analysis and management of alluvial fan flooding problems are often elusive and quite costly. There are many different analytical approaches used to assess flood hazards on alluvial fans. The present consensus among experienced engineers and geologists, however, is that there is no single, clearly superior method for accurate assessment of flood hazards on alluvial fans. The choice of methods should be based on the goals and objectives of the particular study, the complexity of the hazard situation, the applicable regulatory policies, and the availability of field data. Experience and good engineering judgement are the most important factors in the successful selection and application of any technique.

This paper presents a general overview of the Corps of Engineers past involvements, present practices, and the future roles in dealing with alluvial fan flooding problems.

Mission and Historical Perspective

The U.S. Army Corps of Engineers is the largest water resources development and management agency in the federal government. The Corps began its Civil Works program in 1824 when Congress first appropriated money for improving river navigation. Since then, the Corps' mission has been expanded to include activities for reducing flooding, controlling beach erosion, continuing to improve river navigation, developing hydropower, providing urban and industrial water supply, regulating development in navigable waterways and on floodplains, managing a nationwide recreation program and conserving fish and wildlife resources.

June 1988, marked the 52nd anniversary of the Flood Control Act of 1936 that officially established flood control as a Federal

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[1]Presented at the Association of State Floodplain Managers Conference on "Arid West Issues," 19-21 October, 1988, in Las Vegas, NV. Authors: Robert C. MacArthur and Douglas L. Hamilton.

[2]Department of the Army, Water Resources Support Center, Corps of Engineers, The Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616-4687.

responsibility. The purpose of flood control is to regulate flood flows and thereby reduce flooding damage. This is accomplished primarily through structural methods that are planned, designed and constructed by the Corps in conjunction with state, county and local agencies. The Corps also addresses the Nation's flood problems by providing (upon request) flood hazard information, technical assistance and planning guidance to other Federal agencies, states, local governments and private individuals. The data and assistance are designed to reduce unwise use of floodplains, correct present flood problems, and to avoid future flood hazards. In fiscal year 1988 alone, the Corps provided some 87,000 responses to inquiries relating to potential floodplain development valued at over $14 billion.

The Corps is intent upon using up-to-date methods and technical procedures for solving complex flooding problems in the areas of planning, design, construction and management. Close ties with the private engineering community and universities ensure the availability and use of sophisticated state-of-the-art technology wherever and whenever possible. This is particularly true when dealing with complex flooding problems such as those often found on alluvial fans in the arid West.

THE CORPS OF ENGINEERS' APPROACH TO ALLUVIAL FAN FLOODING

The degree of flood hazard at different locations on an alluvial fan is difficult to predict except in a simplified probabilistic or general way. Behavior of individual flood events on alluvial fans depends on the history of past events as well as the geological, topographic and hydrologic characteristics of the drainage basin and fan area during the present event. Non-uniform distribution of flow and of sediment and debris loads over the fan surface during an event may result in scour, deposition, blockage, avulsion and redistribution of flow over the fan. The size, direction and location of the main channels and distributaries can change rapidly during a severe event. The net result is that a flood moving across the upper portion of an alluvial fan may not follow the same flow path, have the same velocity, depth, and distribution of flow, have the same sediment load, or cause the same channel blockages as previous floods with the same peak flow characteristics. Cultivation, grading and urbanization activities often contribute to the erratic nature of the movement of water and debris during a flood. These inherent characteristics of alluvial fans make quantitative analysis of fan processes extremely difficult.

Analytical Methods

Although many flood assessment procedures for alluvial fans have been developed during the past 10 to 15 years, no single procedure is clearly superior or completely appropriate for general application. Consequently, the Corps of Engineers may use several different procedures depending on the nature of the flooding problem and purpose of the particular study. Those procedures include methods reported by Tatum (1963), Dawdy (1979), Magura and Wood (1980), Anderson-Nichols and Company, Inc. (1981), FEMA (1983, 1985), Edwards and Thielmann (1984), Squires and Young (1984), DMA Consulting Engineers (1985), the Hydrologic Engineering Center (1985), the L.A. County Flood Control District (Kumar and Pederson, 1986), MacArthur and Hamilton (1986), French (1987a), Hamilton, et al. (1987), MacArthur, et al. (1987), Los Angeles District Corps of Engineers (1987a, 1987b) Omaha District Corps of Engineers (1988), and the Hydrologic Engineering Center (1988). An excellent synopsis of the presently available management and technical practices for alluvial fan areas has just been completed by Ward (1988). This document should be available from the Arizona Department of Transportation or the Federal Highway Administration in a few months.

At the present time the Corps does not have any specific Nationwide guidelines or engineering manuals for conducting alluvial fan analyses. This is because of the simple fact that was mentioned previously - there is no method yet available that is valid for generalized applications on alluvial fans. Consequently, each Corps district office uses methods and procedures they feel are the most appropriate for the specific problems they are addressing, according to the project's purpose and the specific characteristics of the fan area. As more project investigations are completed by the various district offices, more and more experience will develop. Eventually, if there is enough demand within the Corps to conduct these kinds of flooding studies regularly, official engineering procedures manuals will be developed. However, a few special projects reports and draft guidelines for conducting specific kinds of analyses on alluvial fans have been recently completed. The Los Angeles District recently prepared two draft documents entitled "Engineering Standards For Flood Protection of Single Lot Developments On Alluvial Fans" (L.A. COE, 1987a) and "Los Angeles District Method For Prediction of Debris Yield From Coastal Southern California Watersheds" (L.A. COE, 1987b). The Omaha District just completed a draft project report entitled "Mudflow Modelling, One- and Two-Dimensional, Davis County, Utah" (Omaha COE, 1988a). The Hydrologic Engineering Center (HEC) has also completed a draft Special Projects Report entitled "Incorporating The Effects of Mudflows Into Flood Studies On Alluvial Fans," (HEC, 1988). The Corps will continue to work closely with Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), Association of State Floodplain Managers (ASFPM), state and local agencies and the universities to develop better and more standard procedures for alluvial fan flooding problems.

French (1987a) provides a thorough and up-to-date evaluation of the most commonly used methods and procedures in his book entitled Hydraulic Processes On Alluvial Fans. He concludes that further basic and applied research is necessary in order to incorporate geomorphologic fan processes into present analytical procedures. Numerical models capable of estimating the location and size of channels formed by unsteady, high Froude number flows on alluvial fans should also be developed. The Hydrologic Engineering Center (1985 and 1987) developed a pair of "first generation" models for simulating the dynamics of mudflow events in confining channels and on alluvial fans. These tools show good promise but need further refinement for general applications. Case study results from the application of these methods are presented later in this paper.

Model verification is an essential, yet often difficult part of model development. Coordinated physical and numerical model studies with field verification of the results must be designed and conducted. An example of this type of study was the laboratory and numerical verification of the one-dimensional mudflow model conducted by the Portland District Corps of Engineers (MacArthur, et al., 1987). Computed results from their numerical mudflow model were compared to experimental data for laminar and turbulent dam break problems using various concentrations of bentonite slurries in an adjustable slope flume.

Finally, in those areas where adequate stream gaging records are not available, new methods for estimating accurate hydrologic characteristics of single event storms must be developed. Present regional methods and envelope curve methods are often inappropriate for some situations and drainage basins in the arid west. At the present time, the Corps has not developed any new approaches for synthesizing the hydrology on alluvial fans because there hasn't been the project support to do so. However, recent work by the Los Angeles District Corps, with assistance from HEC (Brunner, 1988), evaluated the applicability and accuracy of the HEC-1 Kinematic Wave method for estimating "feasibility level" hydrology for the Las Vegas Drainage Basin for Clark County, Nevada (HEC, 1986 and Brunner, 1988). As further urbanization and development occurs on alluvial fans and population centers in and around these kinds of geological features grow, more need for improved methods will develop.

CASE STUDIES

Selected case studies conducted by the Corps of Engineers are presented here. They provide examples of the types of projects conducted by the Corps and the variety of analytical methods used by the Corps to evaluate different kinds of flooding problems.

Alluvial Fan Flood Protection Studies In Coachella Valley, CA.

The City of Rancho Mirage is located in the Coachella Valley, about 10 miles southeast of Palm Springs, California. Figure 1 presents an aerial view of Rancho Mirage after the July, 1979 flood. Situated on the alluvial fan of Magnesia Spring Creek, the community of Rancho Mirage is subject to high velocity flood flows and associated sediment and debris deposition. Flooding events in 1976 and 1979 caused widespread destruction that led to the design and construction of a flood control project by the Corps' Los Angeles District. The project consists of a debris retention basin

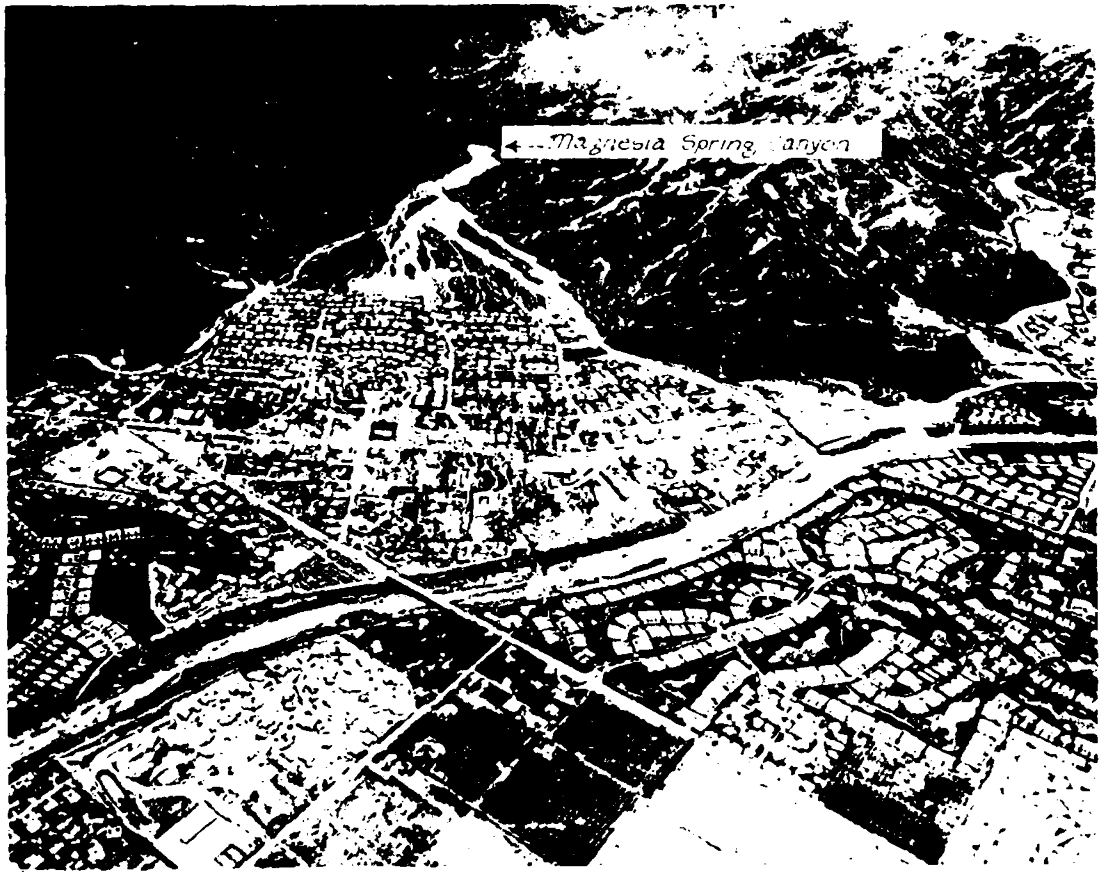


Figure 1

Aerial View of City of Rancho Mirage in Coachella Valley, CA, After the July, 1979 Flood (from L.A. COE, 1982).

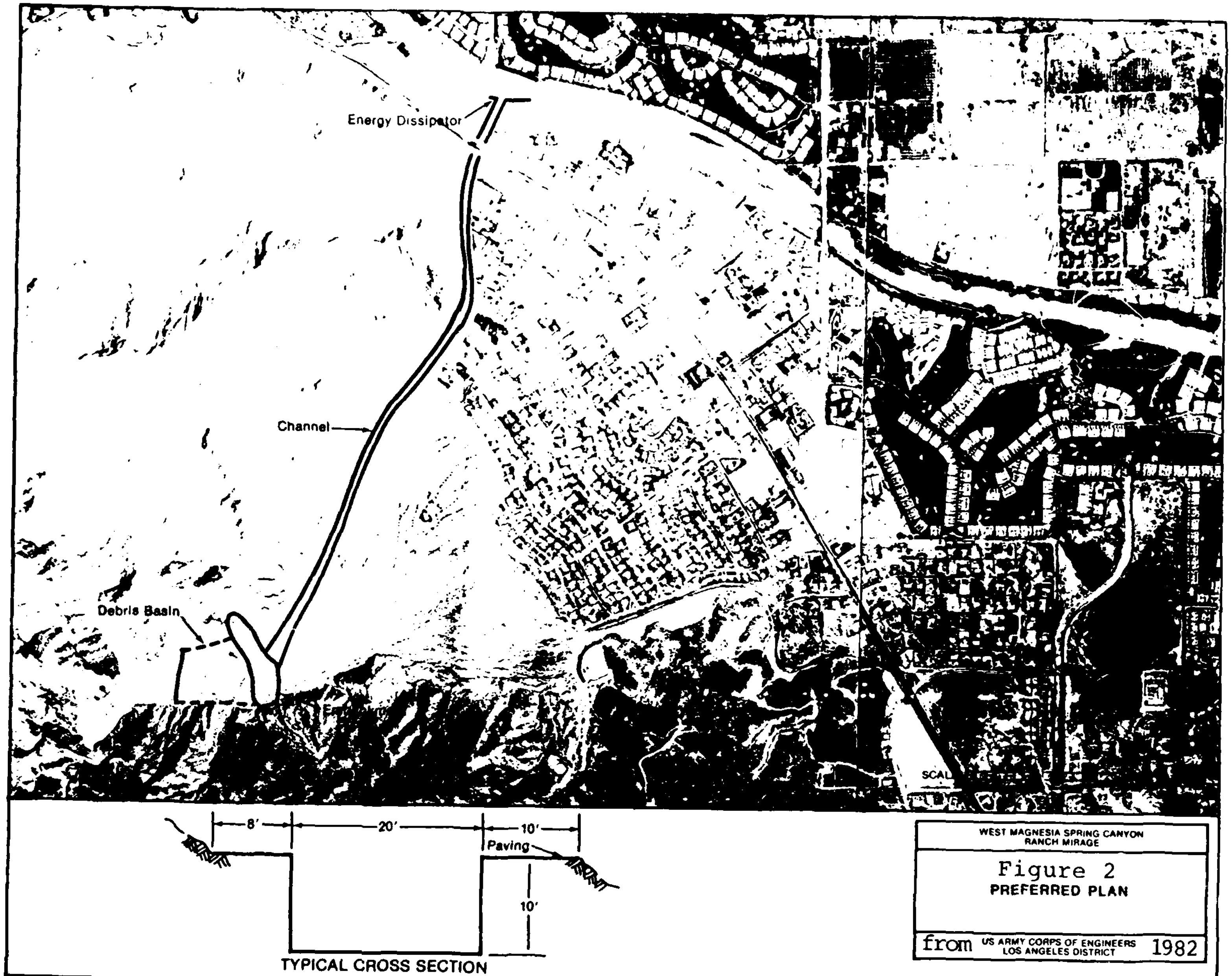
with a spillway and a concrete-lined flood channel with an energy dissipator at the downstream end where it enters the Whitewater River. Figure 2 shows the components of the preferred plan developed by the Los Angeles District. The project is designed to provide standard project flood (SPF) protection for the community.

The Corps used traditional procedures to develop the SPF hydrology. However, in order to size and design the sediment retention basin, the L.A. District engineers worked closely with geologists, soil scientists and Coachella Valley Water District personnel to evaluate soil erodibility and the basin sediment production volume for the SPF. Working together, the multi-disciplinary team modified the Tatum Method (1963) so it could be applied to the Magnesia Spring Canyon drainage basin. Based on the soil type, vegetative cover, slope angle and soil erodibility, the team estimated that a 10-year Tatum burn recurrence condition would best represent the drainage basin sediment production characteristics. Computed sediment yield values compared favorably to observed yield values from a similar debris basin located in Coachella Valley near Rancho Mirage. After verifying the sediment and debris production volume as accurately as possible with measured field data, the sediment basin was sized to capture the SPF sediment load. The spillway and concrete channel sections were designed according to standard Corps of Engineers flood control structures design procedures found in EM-1110-2-1601 (USACE, 1970).

Two similar projects were investigated by the L.A. District in Coachella Valley at the request of the Coachella Valley Water District. The communities of Palm Desert and La Quinta both had similar alluvial fan flooding problems. The Coachella Valley Water District constructed the Corps-designed flood control project for the community of Palm Desert. However, following reconnaissance and feasibility level studies conducted by the Corps, the costs associated with the La Quinta project were too high to justify construction of the proposed project.

Mudflow Studies On The Alluvial Fans of Davis County, UT.

In the spring of 1983, widespread flooding and mudflows caused an estimated $250 million in damages to communities located on the numerous alluvial fans along the base of the Wasatch Mountains in Utah. The destruction was so extensive that 22 of Utah's 28 counties were declared national disaster areas. Flash flooding and mudflows resulted from a rapidly melting snow pack that triggered over 1000 landslides in the steep canyons above the communities. Detailed flood insurance studies had been completed for the communities in Davis County just prior to the events. Traditional steady state, clear water flood insurance study methods were used to delineate potential flood hazard zones for the communities of Farmington, Centerville and Bountiful. However, these studies did not account for mud and debris flows or the magnitude of the damage they cause. As a result, the predicted hazard regions within Davis County were considerably smaller than the actual damage areas that occurred. Therefore, the Corps' primary objectives for this case



WEST MAGNESIA SPRING CANYON
RANCH MIRAGE

Figure 2
PREFERRED PLAN

from US ARMY CORPS OF ENGINEERS LOS ANGELES DISTRICT 1982 study were to develop new flood hazard maps for FEMA considering the potential for the combined effects of mudflows as well as clear water flooding. The Hydrologic Engineering Center (HEC) was asked to develop practical methods for use in these studies, capable of simulating the dynamic behavior of the mudflow events that occurred in Davis County, Utah, in 1983.

Many of the mudflows that occurred in the region can be described with reference to Figure 3. A mudflow is initiated by a landslide occurring in region A. The flow then proceeds down a steep confining canyon along path A-B. At point B, the apex of the fan, the channel opens onto an unbounded plain (alluvial fan) that no longer confines the fluid. The mudflow then spreads out over the fan-shaped area depicted by region B-C-D. After determining that there were no methods available for handling these types of non-Newtonian flow problems, the Corps, with the help of the University of Utah, developed two first generation mudflow routing models for use in these studies. The one-dimensional mudflow simulation model (Schamber and MacArthur, 1985) is used to describe the mudflow behavior between points A and B. Results from the one-dimensional model provide the mudflow hydrograph characteristics needed at the apex of the fan. The Corps' two-dimensional mudflow model (MacArthur and Schamber, 1986 and MacArthur, et al., 1986) uses results from the one-dimensional model to describe the mudflow movement in the region B-C-D. At the end of a simulated mudflow event, the maximum depth and velocity at each computational grid point in the hazard region is determined and displayed as contour maps of depth and velocity. Figure 4 shows computed results for a simulated mudflow event in Rudd Creek, Utah. Figure 5 shows a map outlining the actual damage area for the 1983 event and the simulated damage area from the modeling results. The agreement is quite good.

A similar approach was used to evaluate the other canyons in Davis County, Utah (Omaha District, Corps of Engineers, 1988b). Using these methods, flood insurance study mappings for 15 different streams along the Wasatch Range were prepared. The new modeling procedures provide a practical method for simulating mudflow behavior on alluvial fans that can be used to address some special kinds of flood insurance study needs. The HEC, the Omaha District, and FEMA do not profess that these new methods have been finalized or are now the recommended methods to use. Additional refinement of the codes and generalization of the procedures are necessary.

SIX IMPORTANT ISSUES FOR THE FUTURE

The amount of scientific research necessary to develop a closed form approach to alluvial fan management is almost intimidating. The development of solutions and even the formulation of the problem statement cannot be conducted without regard to a wide range of issues. While conducting projects dealing with alluvial fan flooding, the Corps has identified six important issues that need to be a part of an effective management approach.

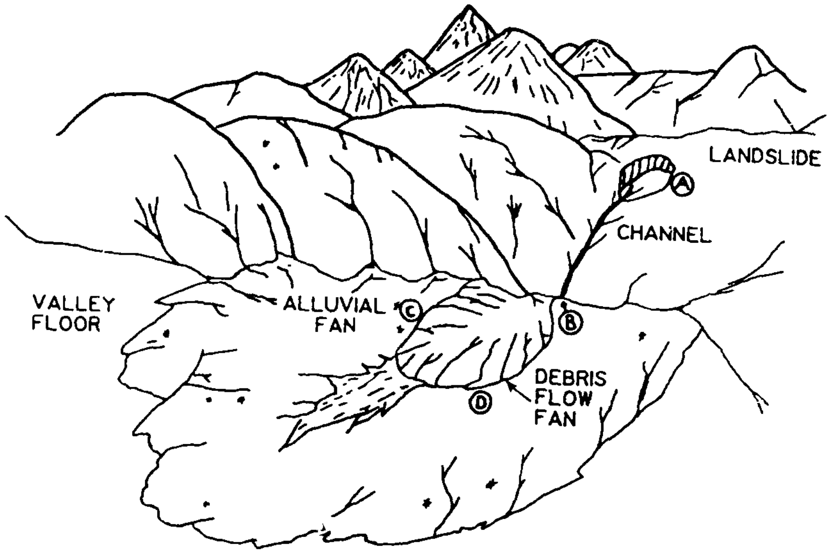


Figure 3

Mudflow Path On An Alluvial Fan.

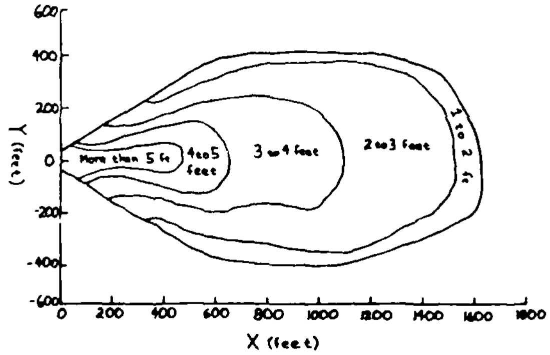


Figure 4-a

Depth Contours For Simulated Mudflow.

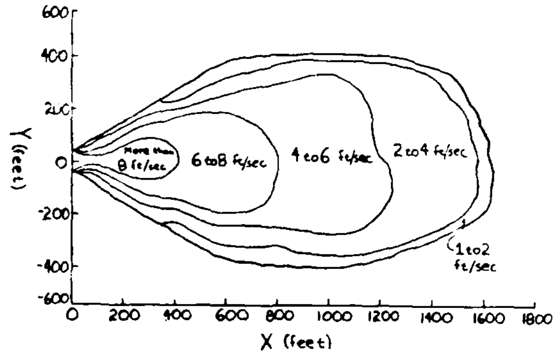


Figure 4-b

Velocity Contours for Simulated Mudflow.

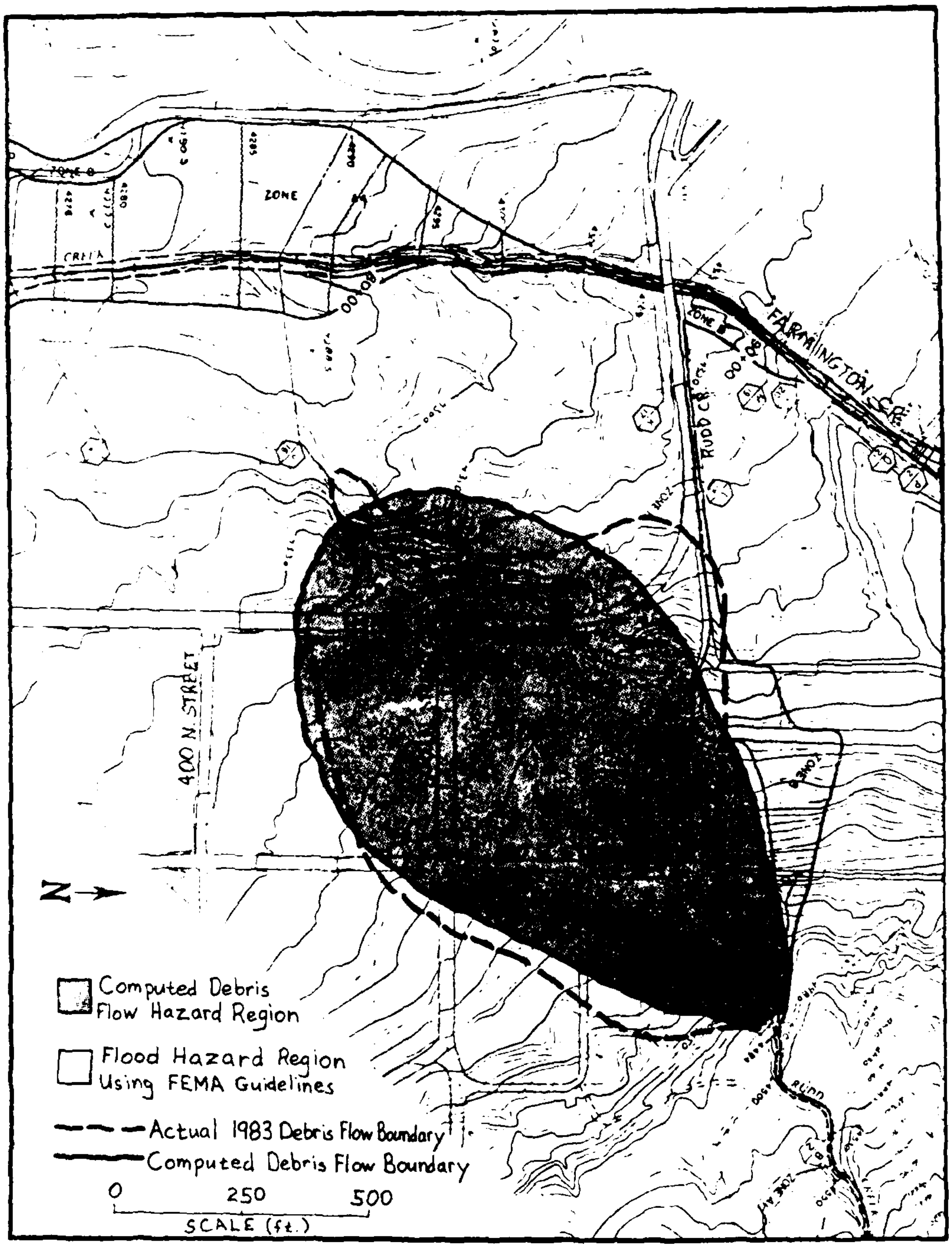


Figure 5

Computed Outline of 1983 Rudd Creek Mudflow

Compared to Observed Event

And Estimated FEMA Hazard Region, Farmington, Utah.

Issues of Historical Perspective

It is well established that the degree of public reverence for natural hazards decays with time after an event. Immediate post-event concern, however, has initiated some of the most significant contributions to our understanding of arid west processes. Consider the 1983 debris flows in Davis County, Utah, for example. The Hydrologic Engineering Center (1988), Keaton and Mathewson (1988), MacArthur, et al. (1986), Wieczorek, et al. (1983), Jeppson and Rodriguez (1983), along with several other significant works came as a response to these events. Our challenge for the future on this issue takes place along two different time scales. The first is to incorporate the knowledge gained by geologic and paleohydrologic investigation. The second is to document the relevant data contained in our relatively short written and oral history. This can take place as hydrologists and hydraulic engineers have more contact with their colleagues from the geological sciences.

Issues of Technical Knowledge

Issues dealing with technical knowledge focus on the collection of data, the conceptual and mathematical description of physical processes, and the formulation of structural and non-structural approaches to flood problems. Unlike humid region flooding, there are two major fields of technical knowledge involved in understanding arid region processes. Alluvial fan management requires the confrontation of not only a hydrologic process but also a complex geologic process. Hydrologists tend to focus on developing short-term solutions to allow safe development. Geologists tend to look at the classification of long-term erosional and depositional trends (French, 1987a). The challenge for the future on this issue is again to combine the experience and knowledge in the fields of hydrology, geology and geomorphology in order to develop an "integrated approach" to alluvial fan flooding problems.

Issues of Analytical Ability

Issues dealing with analytical ability are similar to those of technical knowledge but revolve around the actual solution and implementation of techniques, guidelines, procedures and computations. One common test for the usefulness of a technique is its reproducibility. If two people perform independent studies using the same methods they should arrive at generally the same conclusions. This does not always occur for alluvial fan flooding studies because many of the methods employed by analysts are based on judgement and personal experience. Imposing humid region procedures on arid region studies can be as much of a barrier as it is a guide. There may be site specific factors for each alluvial fan that cannot be generalized into a standard procedure without sacrificing the realism of the solution. As technical knowledge increases, the level of standardization and reproducibility for alluvial fan flooding procedures may increase. The present lack of a generalized approach should not be viewed as a weakness but as an opportunity to set the direction for future work.

Issues of Institutional Leadership

Public institutions, such as the Corps of Engineers, have historically been the leaders in the construction of flood control projects and the development of related practical knowledge. There is currently no organization clearly recognized as a source of information, guidance, and authority for arid region flood management. However, the Arid West Committee of the Association of State Floodplain Managers has done significant work within the last 3 to 4 years in providing institutional leadership. The great needs for fundamental research, continuous technology transfer and a centralized data base will probably remain unfulfilled for some time until the roles of public agencies and their ability to fund such endeavors change.

Issues of Public Behavior

Recent increases in research efforts in arid region hydrology partially result from the tremendous acceleration in residential development occurring on alluvial fans and the increasing flood damage potential associated with that development. As more people move to these high hazard areas, increasing flood damage inspires greater understanding and more mitigation measures. Part of the reason for the damage is the transfer of flatland housing concepts to steep, high hazard areas. The most common types of developments are large, high density housing tracts with designs that attempt to divert water around their perimeter. Floodplain management often takes the form of a response to such development. Although it is doubtful that residential growth in alluvial fan areas will stop, guidelines for creative approaches to drainage can be set forth in advance in order to shape public behavior. "Complete basin master planning" for flood control and drainage along with tougher zoning and drainage ordinances are becoming essential in many rapidly growing desert communities.

Issues of Legal Implication

Public agencies, developers, consultants, and private landowners have become aware in the past few years of the increase in litigation relating to "natural" hazards. Without comment on the litigation process, the response to this issue should be more care in planning and more awareness and application of state-of-the-art methods. As professional skill, knowledge and specialized expertise continue to improve and be applied to arid region floodplain management, there will be a decrease in the number of issues that need to enter the legal arena.

THE CORPS' FUTURE ACTIVITIES AND INVOLVEMENT

At the present time there are no active research activities within the Corps for the development of improved methods for analyzing alluvial fan flooding problems. Each district and division within the Corps is presently using methods and procedures their planning and engineering offices feel are the most appropriate for their specific problems. Wherever and whenever possible, the Corps utilizes the most up-to-date methods available from other state or federal agencies, or from universities or private individuals. Through the project reporting and review process, all project reports prepared by Corps district offices are thoroughly reviewed by experienced staff in each division office and eventually by technical staff in the Headquarters offices in Washington, D.C. Often criticized for taking too long, this required review process ensures consistent, accurate and defensible results from the Corps' planning and design activities.

As more projects are completed by the district offices, more and more experience will develop. Eventually, if there is enough demand within the Corps or if there are special assistance requests from FEMA or other agencies to conduct these kinds of flooding studies regularly, official engineering procedures manuals may be developed.

The Corps will continue to work closely with FEMA, the USGS and the Association of Floodplain Managers to eventually develop and document the best possible procedures for evaluating alluvial fan flooding problems.

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REFERENCES

Anderson-Nichols and Co., Inc., 1981, "Floodplain Management Tools for Alluvial Fans," prepared for FEMA Contract EMW-C-0715, Washington, D.C.

Brunner, Gary W., 1988, "Urban Watershed Modeling With HEC-1 Kinematic Wave," in Proceedings of the Corps of Engineers Workshop on Calibration and Application of Hydrologic Models, Gulf Shore, Alabama, 18-20 October, the Hydrologic Engineering Center, Davis, CA.

Dawdy, David R., 1979, "Flood Frequency Estimates on Alluvial Fans," Journal of the Hydraulics Division, ASCE 105 (HY11), pp. 1407-1413.

DMA Consulting Engineers, 1985, "Alluvial Fan Flooding Methodology, An Analysis," prepared for FEMA, Marina Del Rey, CA.

Edwards, Kenneth L. and Jens Thielmann, 1984, "Flood Plain Management, Cabazon, California," Presented at ASCE Hydraulics Division Conference, April 26-30, 1982, Las Vegas, NV.

Federal Emergency Management Agency, 1983, "Instructions to Flood Insurance Study Contractors," Washington, D.C.

French, Richard H., 1987a, Hydraulic Processes on Alluvial Fans, Elsevier Publishing, Co., NY.

French, Richard H., 1987b, "Flood Hazard Assessment On Alluvial Fans: An Examination of the Methodology," in Application of Frequency and Risk in Water Resources, edited by V.P. Singh, D. Reidel Publishing Company.

Hamilton, Douglas L., David R. Schamber, and Robert C. MacArthur, 1987, "Numerical Modeling of Arid Region Flood Hazards," in Computational Hydrology '87, Anaheim, CA.

Hydrologic Engineering Center, 1985, "User's Manual for the One-Dimensional Mudflow Model," Draft Report, Davis, CA.

Hydrologic Engineering Center, 1986, "Review of the Las Vegas HEC-1 Kinematic Wave Hydrology," Special Projects Memo No. 86-9, the Hydrologic Engineering Center, Davis, CA.

Hydrologic Engineering Center, 1987, "User's Manual for the Two-Dimensional Mudflow Model," Draft Report, Davis, CA.

Hydrologic Engineering Center, 1988, "Incorporating the Effects of Mudflows into Flood Studies on Alluvial Fans," Special Projects Report 86-4, Davis, CA.

Jeppson, Roland and S.A. Rodriguez, 1983, "Hydraulics of Solving Unsteady Debris Flows," Utah Water Research Laboratory, Report No. UWRL/H-83/03, Utah State University, Logan, UT.

Keaton, Jeffrey R. and Christopher C. Mathewson, 1988, "Stratigraphy of Alluvial Fan Flood Deposits," in Hydraulic Engineering, Proceedings of the August 8-12 National Conference of the Hydraulics Division, American Society of Civil Engineers, Colorado Springs, CO.

Kumar, Sree and Garvin Pederson, 1986, "Engineering Methodology for Delineating Debris Flow Hazards in Los Angeles County," in Water Forum '86, Proceedings of the National Conference of the Hydraulics Division, American Society of Civil Engineers, August 4-8, Long Beach, CA.

Los Angeles District Corps of Engineers, 1987a, "Engineering Standards For Flood Protection of Single Lot Developments On Alluvial Fans," draft report prepared for FEMA, Region IX, Los Angeles, CA.

Los Angeles District Corps of Engineers, 1987b, "Los Angeles District Method For Prediction of Debris Yield From Coastal Southern California Watersheds," draft report, Los Angeles District, Corps of Engineers, Los Angeles, CA.

MacArthur, Robert C. and Douglas L. Hamilton, 1986, "Laboratory and Numerical Modeling of Mudflows," Final Report, prepared for Portland District, Corps of Engineers, Portland, OR.

MacArthur, Robert C. and David R. Schamber, 1986, "Numerical Methods for Simulating Mudflows," published in the Proceedings of the Third International Symposium on River Sedimentation, March 31 - April 4, University, MS.

MacArthur, Robert C., David R. Schamber, Douglas L. Hamilton, and Mary H. West, 1986, "Generalized Methodology for Simulating Mudflows," in Water Forum '86, Proceedings of the National Conference of the Hydraulics Division, American Society of Civil Engineers, August 4-8, Long Beach, CA.

MacArthur, Robert C., David R. Schamber, Douglas L. Hamilton, and Mary H. West, 1987, "Verification of a Generalized Mudflow Model," in Hydraulic Engineering, Proceedings of the National Conference of the Hydraulics Division, American Society of Civil Engineers, August 3-7, Williamsburg, VA.

Magura, L.M. and D.E. Wood, 1980, "Flood Hazard Identification and Flood Plain Management on Alluvial Fans," Bulletin 16, American Water Resources Council, Washington, D.C.

Omaha District Corps of Engineers, 1988a, "Mudflow Modeling, One- and Two-dimensional, Davis County, UT," (Draft Report), Omaha District Corps of Engineers, Omaha, NE.

Omaha District Corps of Engineers, 1988b, "Flood Insurance Study for Bountiful, Centerville, and Farmington, Utah," (Draft Report) Flood Plain Management Services, Omaha, NE.

Tatum, Fred E., 1963, "A new Method of Estimating Debris Storage Requirements for Debris Basins," Los Angeles District, Corps of Engineers, Los Angeles, CA.

U.S. Army Corps of Engineers, 1970, "Hydraulic Design of Flood Control Channels," Engineering Manual EM 1110-2-1601, Department of the Army, Corps of Engineers, Office of the Chief of Engineers, Washington, D.C.

Ward, Robert L., 1988, "Present Status of Management and Technical Practices On Alluvial Fan Areas in Arizona," (presently in draft only), Report No. FHWA/AZ 88-278, prepared for The Arizona Department of Transportation, Phoenix, AZ.

Wieczorek Gerald F., et al., 1983, "Potential for Debris Flow and Debris Flood Along the Wasatch Front Between Salt Lake City and Willard, Utah, and Measures for Their Mitigation," U.S.G.S. Open File Report 83-635, U.S. Geological Survey, Menlo Park, CA.

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This technical paper presents a general overview of the Corps of Engineers' past involvements, present practices, and the future roles in dealing with alluvial fan flooding problems. The Corps' approach to alluvial fan flooding studies and the analytical methods they use to assess potential flood hazards are summarized. Selected case studies are presented. Six important issues that need to be considered as part of an effective alluvial fan management approach are presented. An extensive list of references is also included.

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22b TELEPHONE (Include Area Code)	(916) 551-1748
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