GEOMORPHIC ANALYSIS OF FLOOD HAZARDS ON THE NORTHERN MCDOWELL MOUNTAINS PIEDMONT, MARICOPA COUNTY

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by

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INTRODUCTION

The principal objective of this study is to evaluate the western piedmont of the McDowell Mountains to determine which areas may be subject to alluvial-fan flooding. The McDowell Mountains piedmont (MMP) is the gently sloping plain that lies west of the McDowell Mountains and extends into north Phoenix. An alluvial fan flooding methodology mandated by the Federal Emergency Agency (FEMA) has been used to delimit 100-year floodplains in this area. In this report we consider whether the areas on the MMP determined by FEMA to be active alluvial fans, and therefore within the 100-year floodplain, are consistent with evidence of flooding recorded in the geomorphology of the piedmont. This study has been conducted as part of a formal appeal of the preliminary flood insurance rate maps (FIRMs) released for this area (FEMA, 1991b) by the City of Scottsdale, the City of Phoenix, and the Flood Control District of Maricopa County.

Potential flood hazards associated with six drainages that head in the McDowell Mountains and cross the MMP were analyzed using the FEMA alluvial fan flooding model. A previous assessment of the geomorphology of the MMP indicated that broad areas of the piedmont may be subject to alluvial-fan flooding (Pearthree and Wellendorf, 1988). In the northern portion of the MMP, however, there are serious discrepancies between this earlier geomorphic analysis and the extent of active alluvial fans shown on the preliminary FIRMs released in late 1991. Given the fundamental assumptions about flood behavior on alluvial fans that underpin the FEMA alluvial fan flooding model (derived from Dawdy, 1979, and DMA Associates, 1985), it clearly should only be used where active alluvial fans actually exist.

In this study, we examine the geomorphic and geologic environment in the northern portion of the MMP in more detail (figure 1). This is the area associated with drainages designated 5 and 6 in the initial flood insurance study for this area (Cella-Barr Associates, 1989). The headwaters of drainages 5 and 6 initiate on the pediment associated with the Pinnacle Peak Granites. The drainage courses leave the pediment near Scottsdale Road and become incised into the basin sediments to the west. Ultimately, these water courses are tributary to Cave Creek. Drainages 5 and 6 have distributary (branching downstream) channel patterns both on the pediment and farther downslope.

There are significant discrepancies between the zones of alluvial-fan flooding shown on the preliminary FIRMs and the geomorphic and geologic evidence of long-term flooding patterns on the northern MMP. We used variations in local topography, surface characteristics, drainage patterns, and soil development to delineate piedmont areas that have been modified by alluvial-fan processes fairly recently (during approximately the past 10,000 years). Using geomorphic information of this type, active alluvial fan areas on the piedmont can be readily identified (Pearthree and Pearthree, 1989; Pearthree, 1991). Substantial soil development, tributary drainage-network development, and dissection (stream downcutting) in areas between modern channels indicate that much of the MMP associated with drainages 5 and 6 is composed of alluvial-fan deposits that are more than

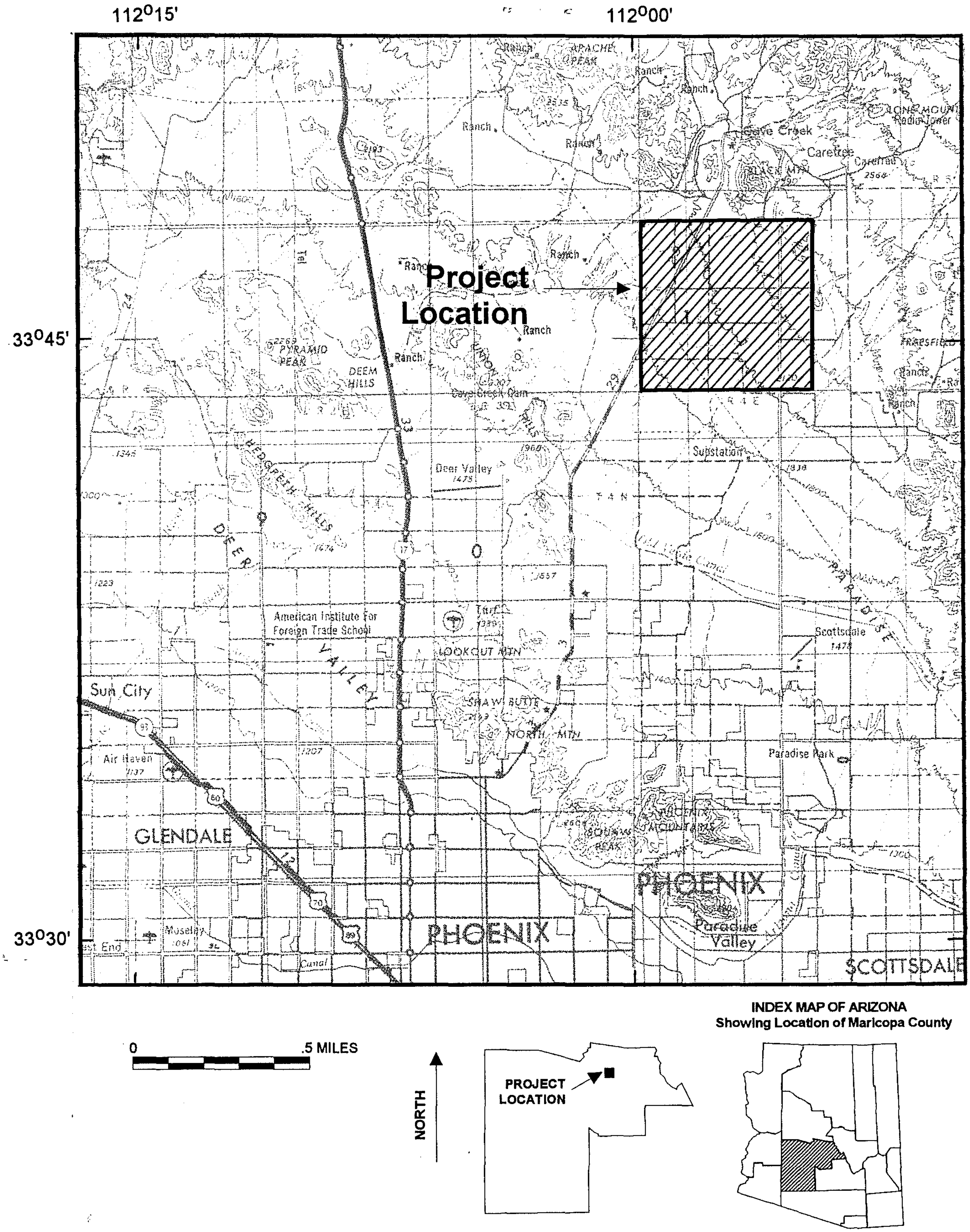

Figure 1. Map showing the location of the McDowell Mountains piedmont. The project area includes portions of the City of Scottsdale, the City of Phoenix, and unincorporated Maricopa County.

10,000 years old. The channel patterns in these areas are stable and have not shifted substantially for thousands of years. Thus, the piedmont areas associated with drainages 5 and 6 are not active alluvial fans, because they are not likely to be subject to drastic shifts in channel positions during floods.

BACKGROUND

The geomorphology and flood hazards of the MMP have been studied a number of times since the mid 1970's. Christenson and others (1978) defined numerous areas of flood hazards on the piedmont. These flood hazard areas generally corresponded with the alluvial-fan areas associated with drainages 1 through 4 on the preliminary FIRMs. Anderson-Nichols, Inc. (1985) evaluated the Peripheral Planning Areas B,C,and D for the City of Phoenix. This study also identified areas in the MMP that would require drainage improvements to convey floodwaters; however, it also stated that "the more well-defined existing washes in areas other than alluvial fans would generally serve as drainage systems...and would require some improvement to safely convey the existing 100-year discharge."

A soil survey covering the MMP published by the U.S. Soil Conservation Service (Camp, 1986) included an interpretation of the extent of active alluvial fans. By their interpretation, soils associated with active alluvial fans are restricted to the lowermost portions of the piedmont. Young soils in middle and upper piedmont areas are restricted in extent and occur either in channels or on low terraces. Most of the middle and upper piedmont areas were interpreted to be fan terraces, which are inactive fans.

A geomorphic assessment of the MMP by Pearthree and Wellendorf (1988) was prepared for the initial flood insurance study for this area by Cella-Barr Associates (CBA). They used geomorphic information and data from the published soil survey (Camp, 1986) to assess the maximum extent of possible active alluvial fans on the MMP. They concluded that the extent of potentially active alluvial fans varied greatly on the MMP from south to north. They found that most of the piedmont north of Jomax Road (the area which contains drainages 5 and 6) is covered with deposits that are more that 10,000 years old. Thus these areas were not interpreted to be potentially active alluvial fans. Their interpretation of the drainage networks in the northern portion of the MMP was that the streams probably became entrenched into the piedmont surface in late Quaternary time in response to downcutting along Cave Creek, into which they drain. The young deposits associated with these streams are channel deposits and restricted low terraces, and there is no evidence of extensive active alluvial fans in this area.

In 1989, CBA prepared a report entitled "Hydrologic Analysis of Scottsdale Alluvial Fans 1-6, Maricopa County; for Maricopa County Flood Insurance Study, Federal Emergency Management Agency." This report contained maps of the modeled flow depths and velocities related to alluvial fan flooding in the area. The CBA study was based in part on the Pearthree and Wellendorf (1988) geomorphic assessment, which was used to help define the boundaries within which to apply the FEMA alluvial-fan methodology. Significant areas that have not been subject to alluvial-fan flooding for at least 10,000 years were included within the final CBA alluvial-fan limits, as was pointed out by Pearthree and Wellendorf (1989). Subsequent changes in the flood insurance study made by FEMA and Michael Baker, Jr., Engineers, their technical review consultant, led to inclusion of even more inactive fan areas along drainages 5 and 6 within the active alluvial fan boundaries used to define 100-year floodplain limits in the preliminary FIRMs released in 1991.

Water Resources Associates, Inc. submitted a letter report in September 1991 regarding the reinterpretation of the geomorphology of the MMP. This report reiterated the previous work presented in 1988 and 1989 to CBA regarding the ages of the piedmont surfaces and associated active versus inactive alluvial fan areas. This letter emphasized that the areas in north Scottsdale and Phoenix associated with drainages 5 and 6 should not be considered active alluvial fans. The washes in this area are incised into sediments that are cohesive and commonly cemented with calcium carbonate (caliche). Furthermore, there was no modern evidence that the drainages in this region have changed or migrated to form new channels during high runoff events. The conclusions of this letter were that the FEMA alluvial-fan methodology may be appropriate for drainages 1 through 4, but it is not appropriate for drainages 5 and 6.

GENERAL GEOMORPHOLOGY OF PIEDMONTS IN ARIZONA

The physical characteristics of alluvial surfaces (alluvial fans and stream terraces) on piedmonts may be used to differentiate them by age (Pearthree and Pearthree, 1989; Pearthree, 1991). Extensive alluvial surfaces are typically deposited by the larger drainages that cross a piedmont; thus, the initial surface features are shaped by large-scale depositional processes. After surfaces are isolated from further deposition or reworking by large streams, they are gradually modified over thousands of years by other processes, which operate very slowly and on a smaller scale. These modifying processes include (1) small-scale erosion and deposition that smooth the original surface topography; (2) churning and disruption of sediments by plants and animals, which obliterate depositional structures; (3) development of soils, primarily through accumulation of silt, clay, and calcium carbonate; (4) development of surficial gravel pavements (desert pavements) above zones of accumulated silt and clay; (5) accumulation of rock varnish on surface gravel; (6) development of tributary dendritic stream networks on surfaces; and (7) entrenchment of these stream networks below original depositional surfaces and subsequent surface dissection.

Active alluvial fans on piedmonts in Arizona are typically characterized by distributary channel networks and extensive young alluvial surfaces. Young alluvial surfaces (less than about 10,000 years old) still retain clear evidence of the original depositional topography, such as bars of coarse deposits, swales where low flows passed between bars, and distributary channel networks, which are characteristic of active alluvial fans. Young fan surfaces also show minimal development of soil and are basically undissected. Very old alluvial surfaces have not been subject to large-scale flooding for hundreds of thousands of years. These surfaces are characterized by strongly developed soils with clay- and calcium carbonate-rich horizons, well-developed dendritic stream networks that are entrenched several meters below the fan surface, and strongly developed varnish on surface rocks. Old alluvial-fan surfaces may also have smooth, closely packed desert pavements between the entrenched drainages. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

The distribution, character, and relative abundance of surfaces of different ages clarify the long-term history of stream behavior on piedmonts, which, in turn, illuminates the nature and distribution of potential flood hazards. The broad spectrum of stream behavior on the piedmonts of Arizona is illustrated by variations in the areal extent of young deposits. Some piedmonts have extensive deposits of Holocene age (less than 10,000 years old) associated with distributary drainage networks; these characteristics indicate the presence of active alluvial fans. Other piedmonts have very limited Holocene deposits, indicating an absence of active alluvial fans. Whether active alluvial fans exist on a piedmont depends on a number of factors, including the rock types in the adjacent mountains and the stability of base-level at the lower end of the piedmont. Geomorphic analyses of piedmonts that assess drainage patterns and delineate the extent of young alluvial deposits are the most reliable way to determine if active alluvial fans exist on a piedmont and how extensive they are.

GEOMORPHIC MAPPING OF THE MCDOWELL MOUNTAINS PIEDMONT

The geomorphic investigations were conducted for this report in order to assess whether active alluvial fans exist in the areas of drainages 5 and 6 on the northern MMP. We utilized aerial photographs of various scales, topographic maps, and extensive field investigations to produce maps of alluvial surfaces of different ages. The purpose of these mapping efforts was to compare the distribution of young alluvial surfaces, which indicate the extent of flooding over the past few thousand years, with the 100-year floodplains and implied alluvial-fan areas illustrated on recently released preliminary FIRMs (FEMA, 1991b).

We produced generalized and detailed geomorphic maps of most of the MMP area associated with drainages 5 and 6. A generalized, 1:12,000-scale map of the piedmont north of Jomax Road and east of 40th Street was developed using relatively small-scale aerial photographs and field investigations (plate 1). We also produced a detailed, 1:6,000-scale geomorphic map of the ~5 mi^2 area of drainages 5 and 6 bounded by Dynamite Road on the south, 56th Street on the west, and Scottsdale Road on the east (plates 2 and 3). Particular emphasis is given to this area because the availability of both large-scale aerial photographs and a detailed topographic base map, and the amount of field investigations conducted there, increase our confidence in our geomorphic mapping.

Several distinct ages of alluvial surfaces can be distinguished in the mapped areas based on differences in surface characteristics. Surfaces of Holocene age (less that 10,000 years old) include active channels (unit Yc), low terraces adjacent to channels (unit Y), and some more extensive areas between channels (unit Y). Holocene terraces and interchannel surfaces are characterized by brownish colors, little topographic relief relative to active channels, little or no dissection, and minimal soil development. Late Pleistocene terraces and inactive fan surfaces (unit M2; 10,000 to 150,000 years old) are more extensive. These surfaces typically are reddish-brown, have fairly extensive tributary drainage networks but are only modestly dissected, and have moderate soil development. Very old middle Pleistocene inactive alluvial fan surfaces (unit M1; 150,000 to 800,000 years old) are also extensive, dominating upper piedmont areas. Extremely old early Pleistocene surfaces (unit O; 800,000 to 2,000,000 years old) were found in a few areas. Middle and early Pleistocene surfaces typically are distinctly red or white, they are strongly dissected by tributary drainage networks developed on them, and they have strong soil development. These old alluvial surfaces tend to be more isolated from active channels than any of the younger surfaces.

Our geomorphic mapping indicates that the extent of surfaces less than 10,000 years old associated with drainages 5 and 6 is very limited. Both the generalized 1:12,000-scale map (plate 1) and the more detailed 1:6,000-scale maps (plates 2 and 3) show that the vast majority of the northern MMP is composed of Pleistocene units M2 and M1, which are estimated to be more than 10,000 years old. Much of the piedmont area included within the 100-year floodplain limits shown on the preliminary FIRMs is composed of these inactive alluvial fans and inactive terraces (plate 2). Extensive old alluvial surfaces between active channels indicate that the distributary channel patterns associated with drainages 5 and 6 are quite stable; channels have not shifted positions to occupy these interchannel areas for at least 10,000 years.

IMPLICATIONS FOR REALISTIC FLOODPLAIN MANAGEMENT ON THE MCDOWELL MOUNTAINS PIEDMONT

Our analysis of the geomorphology of the northern MMP casts grave doubt on the applicability of an alluvial-fan methodology in determining flood hazards in distributary flow areas associated with drainages 5 and 6. The presence of extensive old alluvial surfaces within the proposed 100-year floodplain boundaries (plate 2) is not consistent with the fundamental assumptions of the FEMA alluvial-fan methodology. This methodology assumes that channels are equally likely to form anywhere within the boundaries of an alluvial fan during a flow event. Once this assumption is made, it follows that there is an equal probability of flooding occurring anywhere in an arc equidistant from the fan apex. Therefore, the chance of being flooded depends on the width of the flood channels and the width of the fan (Dawdy, 1979; FEMA, 1991a). The depth and velocity of the 100-year flood depends solely on the 100-year discharge determined for the fan apex. Because alluvial fans tend to increase in width downslope, flood hazards assigned by the FEMA methodology decrease downfan. If the fundamental assumptions of the

FEMA alluvial-fan methodology are realistic, then there ought to be physical evidence for recent shifts in channel positions, and most or all of the alluvial fan ought to have been subject to channelized flooding over a period as long as the past 10,000 years.

In Arizona, the existence of distributary flow areas on piedmonts does not necessarily imply the presence of active alluvial fans. Channel positions in many distributary flow systems are quite stable and not prone to drastic shifts, and it is not appropriate to model these systems as active alluvial fans (Hjalmarson and Kemna, 1991; Pearthree, 1991; Field and Pearthree, 1992). Extensive old surfaces located between the distributary channels of drainages 5 and 6 on the MMP clearly indicate that channel positions have shifted very little over the past 10,000 years. Portions of these old surfaces may be subject to shallow sheet flooding, but deep, channelized flow has not occurred in these areas for at least 10,000 years. If the distributary channel network is stable, and channels do not shift or shift only very rarely, then it is clearly erroneous to imply that flood hazards depend primarily on fan width and (or) distance from the fan apex. Flood hazards in stable distributary flow systems in fact depend to a far greater degree on relative proximity to existing channels; areas in and immediately adjacent to existing channels clearly are much more flood-prone than interchannel areas. Because geomorphic data indicates that the distributary channel networks of drainages 5 and 6 are quite stable, floodplain delineations that emphasize hazards associated with existing channels (plate 3) are far more realistic and appropriate for this area than maps that depict broad areas of potential alluvial-fan flooding.

RECOMMENDATIONS AND CONCLUSIONS

The results of our geomorphic investigations clearly indicate the McDowell Mountains piedmont north of Jomax Road (the areas associated with drainages 5 and 6) is not composed of active alluvial fans. Although both drainages 5 and 6 have distributary drainage networks on the piedmont, the areas between channels are composed almost entirely of alluvial surfaces that are of late Pleistocene (10,000 to 150,000 years old) or middle Pleistocene (150,000 to 800,000 years old) age. These inactive fan areas are characterized by substantial soil development, tributary drainage patterns, and the dominance of erosional rather than depositional topography.

The absence of active alluvial fans the northern MMP indicates that use of an alluvial-fan methodology to establish flood-hazard zones for drainages 5 and 6 is inappropriate. Most areas between channels have not been subject to high velocity, relatively deep channelized flow for at least 10,000 years. This implies that the distributary channel patterns associated with drainages 5 and 6 are relatively stable. Because channels are not prone to drastic shifts in position, areas in and immediately adjacent to existing channels have much higher potential flood hazards that do areas between existing channels. Thus, the alluvial-fan methodology used to establish 100-year floodplains shown on the preliminary FIRMs (FEMA, 1991b) certainly overestimates flood hazards in the extensive areas between channels along drainages 5 and 6. This methodology probably underestimates 100-year flow depths and velocities in existing channels (Pearthree, 1991). Alternative floodplain delineations proposed for drainages 5 and 6 in this appeal, which emphasize flood hazards associated with existing channels, are much more consistent with geomorphic information gathered in this study.

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