

Section 1400

Development of Alluvial Fans

1401 INTRODUCTION

By commonly accepted definition, an alluvial fan is a triangular or fan-shaped deposit of boulders, sand and fine sediment at the base of desert mountain slopes deposited by ephemeral (intermittent) streams as they debauch onto the valley floor (STONE, 1967). Alluvial fans are a common and dominant landscape feature in the Clark County area. The rather symmetric shape of the alluvial fan is attained through geologic time by the active flow channel migrating back and forth over the alluvial surface. All engineers designing facilities on alluvial fans for drainage and flood control should become familiar with the geologic and hydrologic processes by consulting one or more of the standard references. These references include, for example, FRENCH (1987), COOKE and WARREN (1973), or RACHOCKI (1981). It must be noted that most of the alluvial fans observed in the Clark County area will not have the idealized shape because over geologic time the fans have coalesced creating complex and poorly defined shapes.

FEMA and others have recognized that definition of a floodplain on an alluvial fan cannot be accurately accomplished by using traditional methods of floodplain analysis (i.e., HEC-2 (FRENCH, 1985 or HOGGAN, 1989)). Given the fact that hydraulic processes on active alluvial fans are quite different than those in humid regions, a probabilistic methodology for defining floodplains on active virgin (undeveloped) alluvial fans that recognizes the potential for the flow channel to change location during a single flood event has been developed. The original methodology is described in DAWDY (1979), FEMA (1983), and FRENCH (1987). As development in the Southwest proceeded, and the problem of flooding on active alluvial fans became a primary concern, additional data has become available; and the original methodology was modified to take these new data into account; (see for example FEMA (1985) or FRENCH (1987)).

The engineer is cautioned that the study of hydraulic processes on active alluvial fans is an area of current research interest. The methods available for addressing drainage problems on active alluvial fans at the time this manual was prepared should be considered initial or preliminary results, and rapid change in these methods must be anticipated. It is recommended that the engineer should examine the literature to determine the current state-of-the-art at the time of analysis.

The engineer is further cautioned that while the methodology described in DAWDY (1979), FEMA (1983 and 1985) and FRENCH (1987) appears straightforward, there are inherent subtleties in these techniques that may not be initially recognized. The accurate application of these methods required --

experience in arid region hydrology, geology, and sound engineering judgment. A crucial consideration is the determination that the area of interest is an "active alluvial fan." The definition of an alluvial fan provided in the initial paragraphs of this section is a geomorphological rather than an engineering definition. The methodology discussed in this section is appropriate to all alluvial surfaces that exhibit hydraulic behavior similar to that on an active alluvial fan. In identifying areas where the alluvial fan approach discussed in the manual is appropriate, the engineer should examine the following criteria:

1. Lack of Defined, Stable Channels: On an alluvial fan where the methodology discussed in this manual is appropriate, flow channels are neither well-defined nor stable. Both the area of interest and surrounding area should be examined to determine if (1) there are well-defined natural channels capable of conveying the 100-year flood with only minor modification in depth and width and (2) the channels identified are sufficiently incised to be stable during the 100 year flow event. FRENCH (1987) provides equations to estimate natural channel capacity.
2. Surface Slope: In general, the longitudinal slope of an alluvial fan should lie between 0.0087 and 0.1405 ft/ft. Lesser slopes may preclude alluvial fan behavior by flow events.
3. Canyon/Fan Slope Ratio: The ratio of the slope of the canyon above the fan to the slope of the fan has been found to be a key parameter in determining the number of channels that will be formed by an extreme event. Use of this ratio with the figures in FEMA (1985) and FRENCH (1987) allow the alluvial surface to be divided into single channel and multiple channel (not sheet flow) regions.
4. Upstream Sediment Production: It is generally believed that channels on alluvial fans change location either in response to massive deposition (channel blockage) or erosion that causes a breakthrough to topographically low areas on the alluvial surface. Thus, upstream sediment production is a parameter that should be examined. If the sediment available upstream is capable of satisfying the equilibrium sediment transport requirements and the channels are stable, then a probabilistic method of floodplain analysis may not be appropriate.
5. Surficial Geology: The geology of the area of interest plays a crucial role in determining hydraulic behavior. For example, is the flow constrained by the geology such as outcrops of bedrock in the transverse direction or by caliche in the vertical dimension?
6. Surface Stability: The methods discussed here are applicable to active alluvial surfaces and not all alluvial surfaces are active. If a surface is not active, then flood hazard is reduced. For example, within Clark County there

are a number of alluvial surfaces that have been abandoned because of nearby channel incision; and these surfaces should not be considered active alluvial surfaces.

If the site being investigated exhibits the characteristics noted above, then it may be an alluvial surface which should be analyzed with the techniques discussed in this section of the manual. Of the above, the problems of channel stability and surface stability are the most important in making a decision regarding the method of analysis.

1402 ANALYSIS REQUIREMENTS

In preparation of the analysis for development on an alluvial fan, the following items must be addressed:

1. Analysis to quantify the design discharges and the volumes of water, debris, and sediment associated with the major storm at the apex of the fan under current watershed conditions and under potential adverse conditions (e.g., deforestation of the watershed by fire). The potential for debris flow and sediment movement must be assessed considering the characteristics and availability of sediment in the drainage basin above the apex and on the alluvial fan.
2. Analysis which demonstrates that the proposed facilities will accommodate the major storm peak discharge, consisting of the total volume of water, debris, and sediment previously determined as well as the associated hydrodynamic and hydrostatic forces.
3. Analysis which demonstrates that the proposed facilities have been designed to withstand the potential erosion and scour forces.
4. Analysis or evidence which demonstrates that the proposed facilities will provide protection against flows that migrate or suddenly move to the project site from other portions of the fan.
5. Analysis which assesses the methods by which concentrated floodwater and the associated sediment load will be disposed of and the effect of those methods on adjacent properties.
6. Analysis which demonstrates that flooding from local runoff, or sources other than the fan apex, will be insignificant or will otherwise be accommodated by appropriate flood control or drainage measures.

Recently, FRENCH (1992) described a method to provide discharge estimate as a function of return period for drainage protection for developments crossing alluvial fans. The methodology is a modification of that used by FEMA to define floodplains on alluvial fans, and has been accepted by FEMA for such analyses in Clark County.

1403 PENINSULA DEVELOPMENT

A common occurrence in the Clark County area is peninsula development up an alluvial fan (see **Figure 1401**). A typical and appropriate question that the developer of the peninsula is asked is the effect of the development on downstream property owners. If the developer passes the flood flow through the development in a manner that simulates undeveloped conditions, then flow is neither concentrated nor diverted. As with all other design alternatives, there would be an increase in the quantity of flow due to the development. Routing of flows along streets with junctions can be handled with traditional hydraulics. If the developer chooses to build a hydraulic structure that does not pass the flow through the development, then he has the obligation to analyze the effect of his development on downstream property owners. (See **Figure 1402**).

It is recommended that peninsula development that does not pass flood flows through the development such as that shown in **Figure 1402** treat the development as a reduction in fan arc width. An example of an analysis appropriate to this problem is presented in Section 1406.

Finally, the engineer is reminded that even though down fan developments may be outside the currently defined alluvial fan flood hazard zone, large developments can modify the flood plain boundaries. That is, size of the development may become a factor. For examples, see Mifflin (1988), French (1987) and the example given in Section 1406.

1404 ADDITIONAL CONSIDERATIONS

The existing FIRM's, in general, estimate the extent of floodplains under conditions existing at the time of analysis.

The engineer must recognize and take into consideration that the development of areas on alluvial fans - even minor development such as streets and culverts - can have a very significant and crucial impact on drainage patterns. The engineer must ensure that all drainage systems match.

Sediment transport on alluvial fans is a crucial concern to both CCRFCD and FEMA. The analysis of the effects of sediment transport is to a large degree more of an art than a science. The engineer must consider in a reasonable fashion sediment transport. The engineer must realize that in unlined channels

there is an equilibrium sediment load. If the actual sediment load transported exceeds the equilibrium load, then deposition occurs. However, if the sediment load is less than the equilibrium load, erosion will occur.

1405 ALLUVIAL FAN FLOOD PROTECTION MEASURES

Three general approaches may be taken to flood management on alluvial fans. They are based on size and density of the planned development. The approaches are:

1. Whole Fan Protection
2. Subdivision or Localized Protection
3. Single Lot/Structure Protection

1405.1 Whole Fan Protection

Whole fan protection can be achieved by utilizing the following measures:

1. Levees
2. Channels
3. Detention basins
4. Debris basins/fences/deflectors/dams

Whole-fan protection includes large scale structural measures appropriate to use on extensively developed fans, and which are most cost effective in high density situations. Structures must be designed to intercept upstream watershed flow and debris at the apex and to transport water and sediment around the entire urbanized fan. Structures must be designed to withstand scour, erosion, sediment deposition, hydrostatic forces, impact and hydrodynamic forces, and high velocity flows. Continual maintenance is essential for optimal operation and can be costly. These structures are most often funded through federal and state sources, but can also be financed through special regional districts, local governments or developers.

1405.2 Subdivision or Localized Protection

Individual subdivision or a localized development can be protected from flood hazards by utilizing the following measures:

1. Drop structures
2. Debris fences
3. Local dikes, channels
4. Site plans to convey flow
5. Street design to convey flow
6. Elevation on armored fill

These are smaller scale measures that can be used throughout moderate density fans to safely trap debris and to route water and sediment around or through individual residential developments.

1405.3 Single Lot or Structure Protection

A single lot or a structure can be protected from flood hazard by using the following protection measures:

1. Elevate and properly design foundations
2. Floodwalls and berms
3. Reinforcement of uphill walls, windows and doors against debris impact

These measures are most cost effective when implemented at low development densities.

1406 EXAMPLE APPLICATION

1406.1 Introduction

The following example is provided to demonstrate basic problems and analysis for developments on alluvial fans and may not necessarily represent the best method of alluvial fan analysis for all situations. For all submittals to FEMA for conditional or final Letters of Map Amendment or Revision, the engineer must analyze alluvial fans with a method acceptable to FEMA. The CCRFCD and the local entities do not guarantee that the analysis and information presented in this example is acceptable to FEMA.

1406.2 Example Development

In **Figure 1403**, a typical virgin (undeveloped) alluvial fan with FEMA flood hazard zones is delineated. In **Figure 1404**, an example proposed development on this typical virgin fan is shown. With regard to the proposed development on the alluvial fan (**Figure 1404**), the following should be noted:

1. The proposed development is within the 100-year floodplain defined by FEMA. It has been previously decided that potential flood flows will not be passed through the development.
2. The northern boundary of the proposed development, line M', will consist of a street and floodwall. The street/floodwall system will be designed such that all flows impinging on M' will be discharged at point A. Given the size of this development relative to the width of the alluvial fan, the method of Mifflin (1988) should be considered in designing the floodwall.

3. The line AB is a street/floodwall system. However, the intersection at point A of Streets M' and AB is designed so that there is no preferential flow direction.
4. The line CBD is an existing street. and the down-fan point beyond which FEMA alluvial fan methods of analysis are no longer appropriate since there are preferential directions of flow.

Given the situation shown in **Figures 1403** and **1404**, the question is what effect will the proposed development have on the downstream undeveloped property.

1406.3 Example Analysis

It must be realized that from a technical viewpoint it is virtually impossible to develop rectilinear street systems on an alluvial fan without concentrating and diverting flow since alluvial fans are best described by curvilinear coordinate systems. In the following steps, a method of analyzing the hypothetical situation is suggested. This is not the only procedure available, and it may not be the best procedure in other situations. The engineer evaluating the hypothesized situation must be experienced and willing to exercise sound engineering judgment.

Step 1: The procedures used by FEMA contractors to define flood hazard zones on alluvial fans should be carefully reviewed. First, review FEMA (1983) which is summarized in French (1987). Second, review FEMA (1985) that presents a modified and improved methodology. It is important to determine which methodology was used to determine the flood hazard zones. In **Table 1401** (A and B) the difference in the flood hazard zone boundaries between FEMA (1983) and FEMA (1985) for depth and velocity are summarized based on the example in Section 1406. These results indicate that the new methodology is significantly more conservative than the former methodology.

The flood hazard zones in **Figures 1403** and **1404** were determined using FEMA (1985). If the previous FEMA methodology had been used, it is recommended that the analysis be redone using the FEMA (1985) methodology.

Step 2: Obtain values of the FEMA alluvial hazard zone parameters Z , S_z and C used in delineating the flood hazard zones shown in **Figures 1403** and **1404**. Also, obtain any additional information or data that is available regarding the analysis. For the alluvial fan in **Figure 1403**:

$$\begin{aligned} Z &= 2.29 \text{ (transformation mean)} \\ S_z &= 0.4965 \text{ (transformation standard deviation)} \\ C &= 7.4 \text{ (transformation coefficient)} \end{aligned}$$

Note: These values are those used in examples by FEMA (1983, 1985) and FRENCH (1987).

Step 3: The proposed development lies below the bifurcation point on the alluvial fan (see **Figure 1404**) and is therefore in the FEMA (1985) multiple channel area. Within the multiple channel region, the various FEMA depth zone boundaries are estimated by the trial and error solution of

$$Y = [(0.0917 (n)^{0.6} (S)^{-0.3} (Q)^{0.36}] + [(0.001426 (n)^{-1.2} (S)^{0.6} (Q)^{0.48}] \quad (1401)$$

where y = depth of flow (ft), n = Manning's "n" value for the fan (n = 0.02 is a reasonable assumption), S = fan slope (ft / ft), and Q = flow rate (cfs) corresponding to y.

Within the multiple channel region, the FEMA velocity zone boundaries are calculated by

$$Q = 99314 (n)^{4.17} (S)^{-1.25} (U)^{4.17} \quad (1402)$$

where u = velocity (ft / s) and Q = flow rate (cfs).

Step 4: The positioning of the proposed development on the alluvial fan suggests that its effect is equivalent to a transverse reduction in alluvial fan width. That is, the new alluvial fan boundary is on the west side TEC and on the east side TA'AB. Given these fan boundaries, the FEMA analysis for delineating flood hazard zones must be repeated.

The log-Pearson Type III standard deviates (K) are computed for the discharges corresponding to each depth and velocity zone boundary by

$$K = (\log Q - Z) / S_z \quad (1403)$$

The probability of occurrence (P) of the discharges for the required depth and velocity boundaries are determined by interpolation of the deviate values (K) in IAC, 1982. Given that the proposed development is in the multiple channel region the fan arc width is estimated as

$$W = 3610 (A) (C) (P) \quad (1404)$$

where A = avulsion coefficient and W = fan arc width (ft). Without additional information, a reasonable estimate of A is 1.5.

For example, to determine Q at the FEMA 0.5 ft depth boundary, solve **Equation 1401** with $y = 0.5$ ft, $n = 0.02$, and $S = 0.03$:

$$Q = 310 \text{ cfs.}$$

The log-Pearson Type III standard deviate from **Equation 1403** is:

$$K = [\log (310) - 2.29] / 0.4965 = 0.4055$$

Then, following FEMA and interpolating among the log-Pearson deviate values in IAC, 1982:

$$P (Q \$310) = P (K \$ 0.4055) = 0.3438$$

In performing the interpolation, it was assumed that the skew coefficient is zero which is a reasonable assumption for the Clark County area unless other data and information are available.

The fan width corresponding to this depth boundary is determined by **Equation 1404**:

$$W = 3,610 = 3,610 (1.5) (7.4) (0.3438)$$
$$W = 13,800 \text{ ft}$$

The fan widths corresponding to velocity boundaries are summarized in **Table 1401 (c)**.

As indicated in **Figure 1404**, the impact of the development on downstream property owners is to incorporate the whole undeveloped area (ECBA) into the 1 ft depth 6.0 fps flood hazard zone whereas previous to development part of the area was in the 6.0 fps velocity zone and part in the 5.0 fps zone. While this is a rather minor change, it should be recognized that this change may result in some increased erosion on the adjoining and downstream property.

The situation in **Figure 1405** is the same as that shown in **Figure 1404** with the exception that the development has been moved to the center of the fan. The question is whether or not this rearrangement changes the answer previously obtained.

The answer is no because the FEMA methodology is a probabilistic methodology. The proposed development again limits the fan transverse width. Thus, the answer previously obtained is valid.

HYDROLOGIC CRITERIA AND DRAINAGE DESIGN MANUAL

EXAMPLE DEPTH AND VELOCITY ZONE BOUNDARY DETERMINATIONS

A. COMPARISON OF FEMA (1983) AND FEMA (1985) RESULTS REGARDING DEPTH ZONE BOUNDARIES

DEPTH ZONE BOUNDARY FT	FEMA (1983) FT	FEMA (1985) FT
2.5	110	110
1.5	1,240	1,240
0.5	9,290	13,780

B. COMPARISON OF FEMA (1983) AND FEMA (1985) RESULTS REGARDING VELOCITY ZONE BOUNDARIES

VELOCITY BOUNDARY FT	FEMA (1983) FT	FEMA (1985) FT
6.5	390	390
5.5	1,580	4,400
4.5	4,430	12,280
3.5	8,640	26,360

C. SUMMARY OF VELOCITY ZONE BOUNDARIES FOR PROPOSED DEVELOPMENT IN FIGURE 1404.

VELOCITY ZONE BOUNDARY VALUE FT/S	Q FT ³ /S	K	P	W FT
6.5	1611	1.8471	0.0331	1330
5.5	803	1.2381	0.1099	4400
4.5	348	0.5067	0.3065	12,280
3.5	122	-0.4102	0.6578	26,360

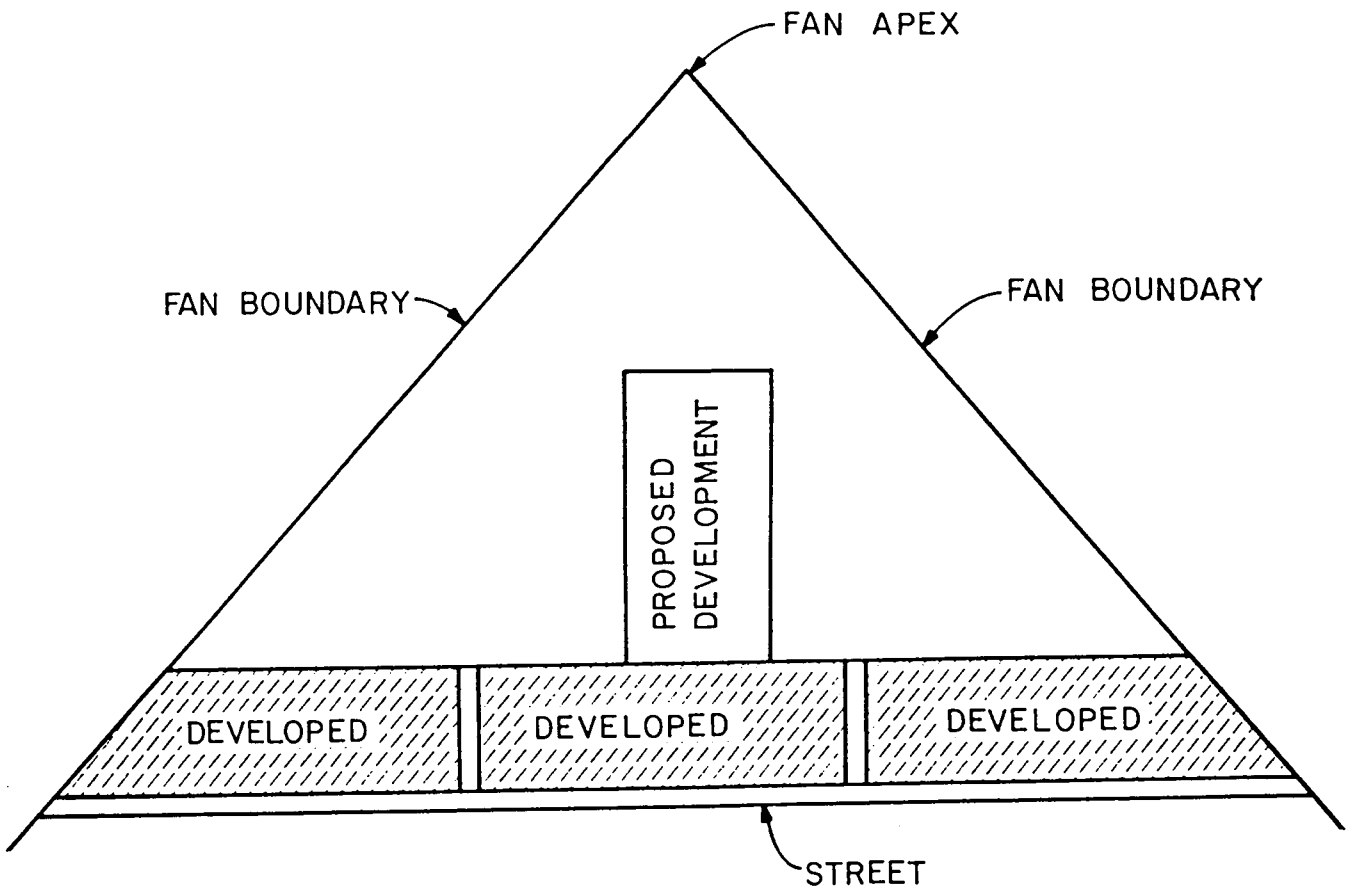
Revision	Date

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TABLE 1401

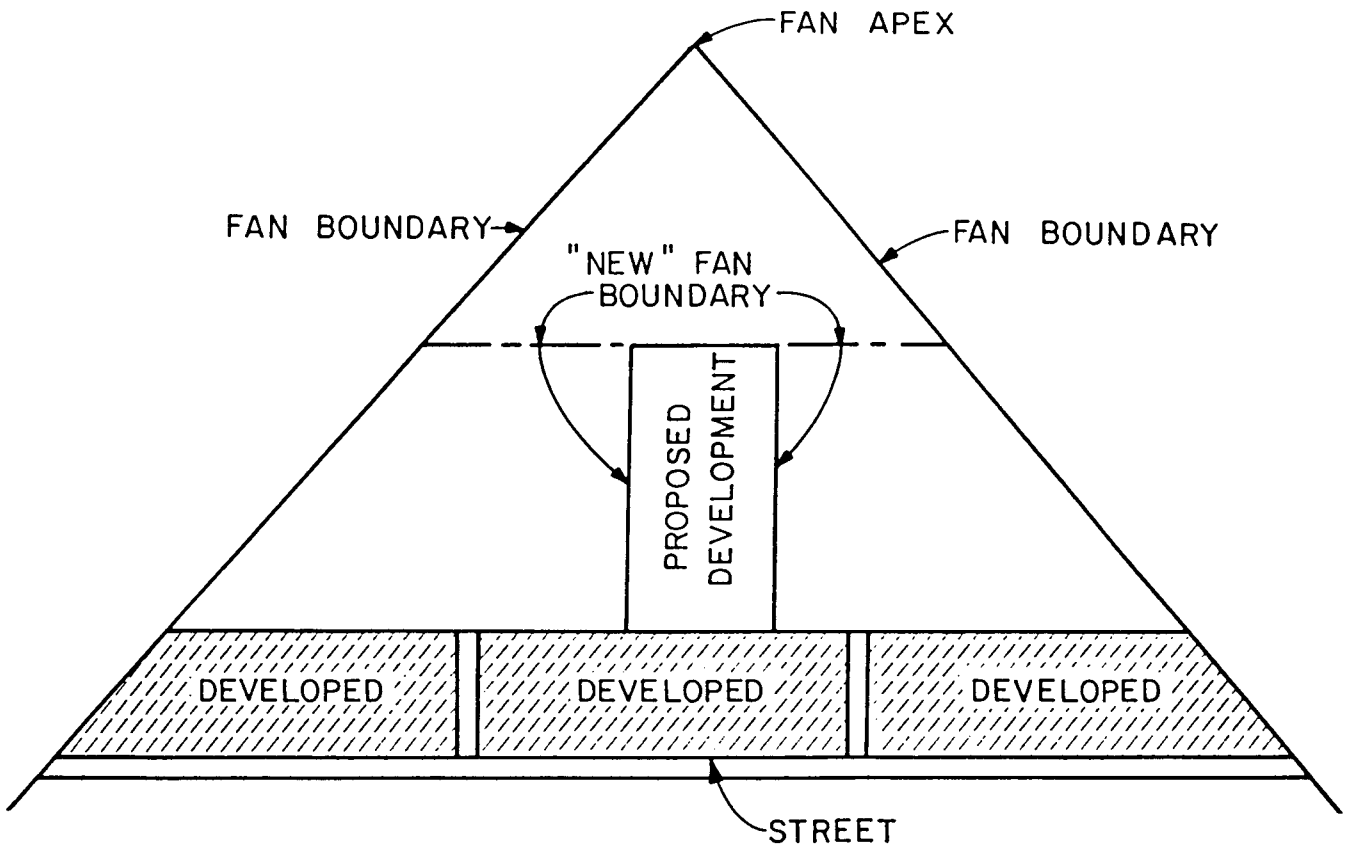
TYPICAL PENINSULA DEVELOPMENT ON AN ALLUVIAL FAN



Revision	Date

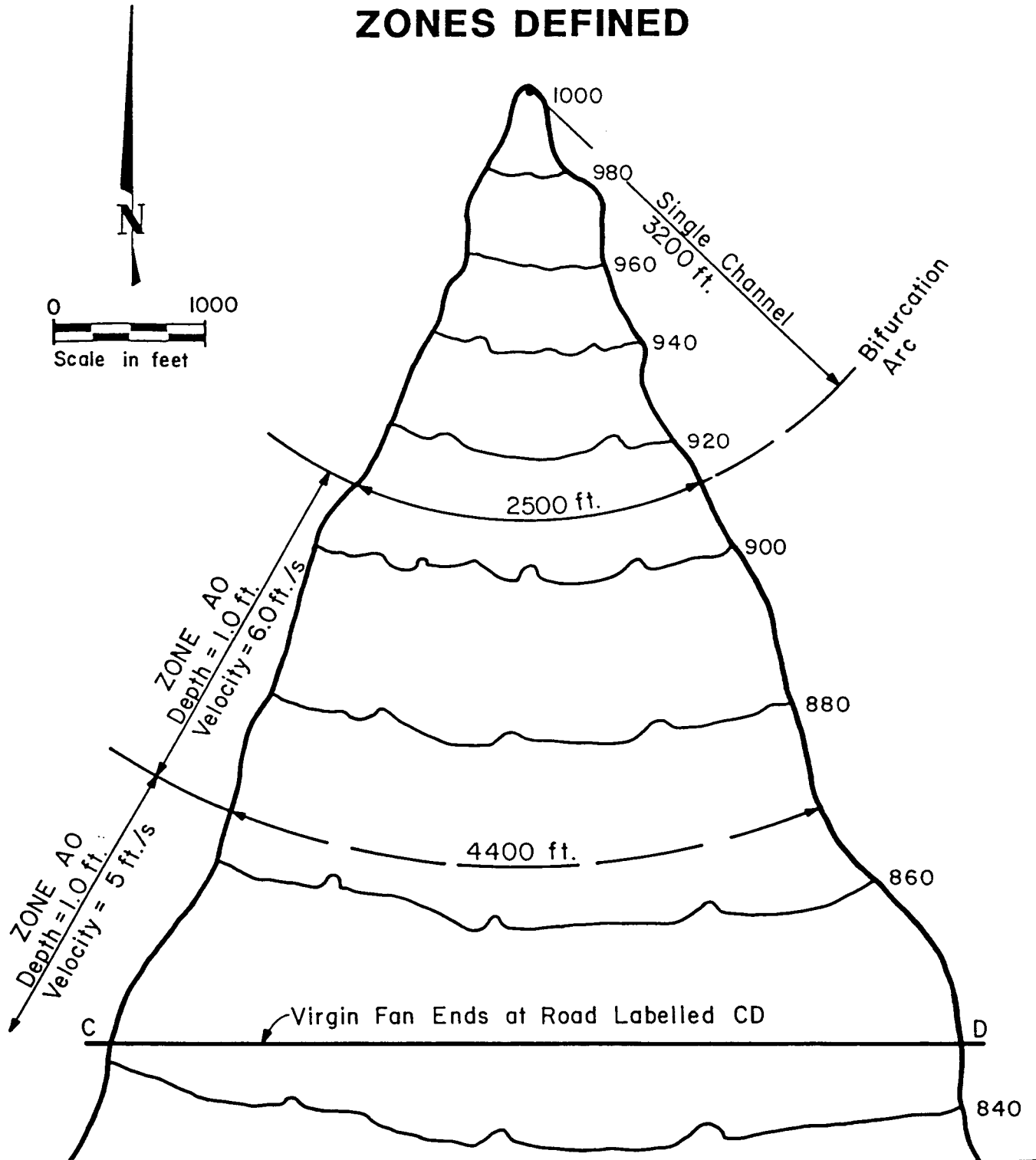
EFFECTS OF TYPICAL PENINSULA DEVELOPMENT

(FOR DEVELOPMENTS THAT DO NOT PASS FLOW
THROUGH THE DEVELOPMENT)



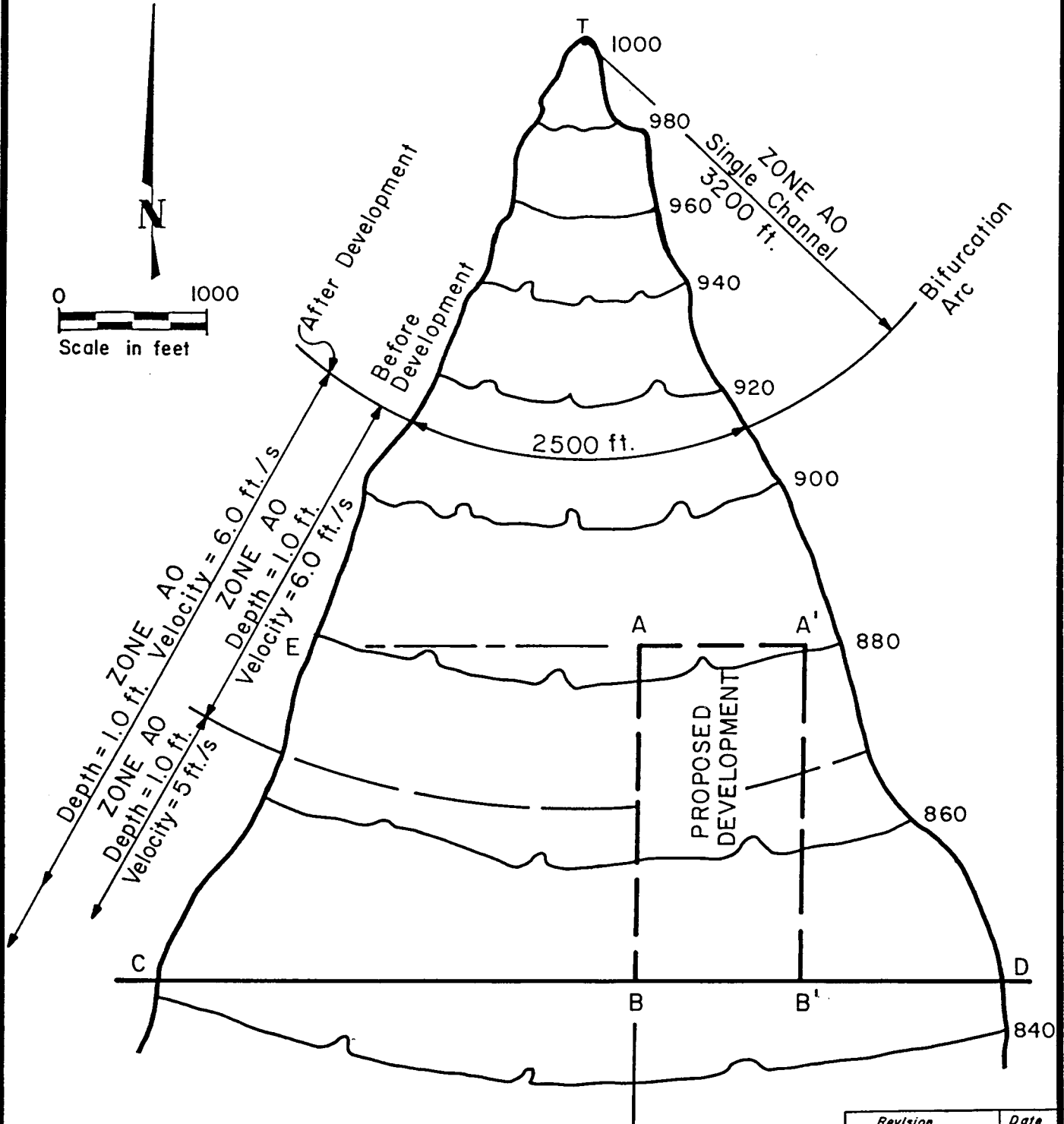
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EXAMPLE VIRGIN FAN WITH FLOOD HAZARD ZONES DEFINED



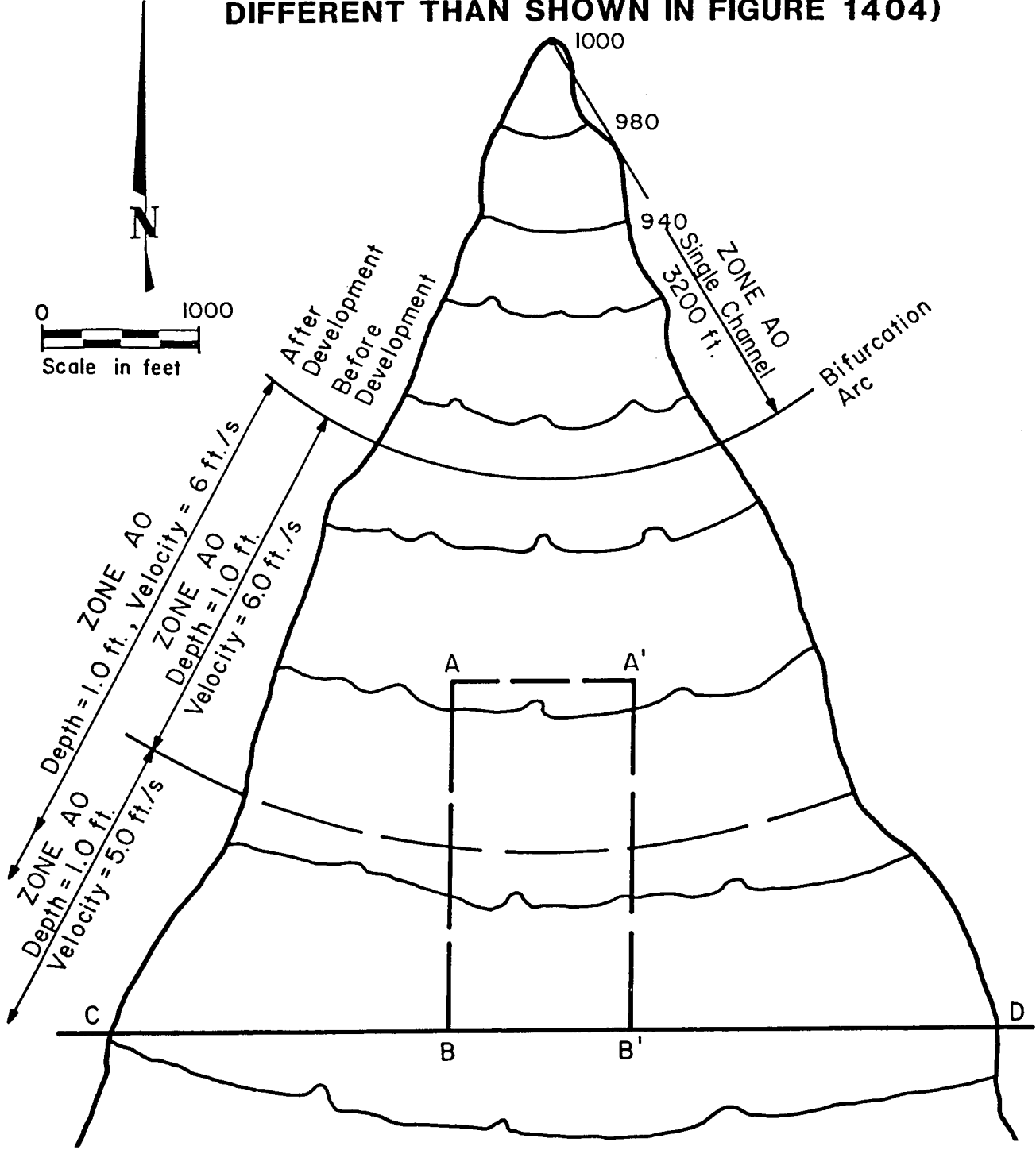
Revision	Date

EXAMPLE IMPACT OF DEVELOPMENT ON FLOOD HAZARD ZONES



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IMPACT OF DEVELOPMENT POSITIONING ON FLOOD HAZARD ZONE (LOCATION OF DEVELOPMENT DIFFERENT THAN SHOWN IN FIGURE 1404)



Revision	Date