

GEOLOGIC EVALUATION OF ALLUVIAL FAN FLOOD HAZARDS ON LOWER BUCKBRUSH WASH, DOUGLAS COUNTY, NEVADA

FINAL REPORT TO THE BUCKBRUSH FLOOD SAFETY COALITION

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INTRODUCTION

This report describes an attempt to use geologic information to help characterize flood hazardous areas on the alluvial fan of lower Buckbrush Wash in Douglas County, Nevada. Buckbrush Wash is a small ephemeral wash draining approximately 10.5 km² (4 mi²) of sagebrush scrub and pinon-juniper woodlands in the western Pine Nut Mountains between Carson City and Minden, Nevada. The wash presently terminates as a small alluvial fan in a portion of the Stephanie Way neighborhood. Flood hazards are potentially severe on portions of the fan below lower Buckbrush Wash but adequate data are lacking to evaluate the hazard realistically.

The geological approach described here involves the compilation of a surficial geological map and is a valuable first step in assessing the extent of flood hazardous areas on the Buckbrush Fan. It is most useful overall as providing the appropriate spatial context for applying hydrologic and hydraulic models designed to address specific flood hazard magnitudes and associated probabilities. The area selected for detailed mapping of lower Buckbrush Wash is shown in Figure 1. It constitutes the area of the most active alluvial fan processes over approximately the last 4500–10,000 years, and thus, the area in which alluvial fan flooding has the highest probability of occurring in the foreseeable future. The resulting map is presented as a representation of the recent geological framework of the Buckbrush Wash alluvial fan, not as a specific guideline for flood hazard management because much of the area has already been developed. Suburban development can influence floodwater distribution in ways that may be inconsistent with the geologic information.

The geological map illustrates the distribution of late Quaternary surficial geologic deposits. Mapped units are unconsolidated sedimentary deposits of materials ranging from silt to boulders that are indications of past episodes of fluvial (streamflow-related) and eolian (wind related) activity in the study area. The Quaternary Period is the most recent period of the geological time scale and spans approximately the last 2 million years. It is divided into two intervals: the Pleistocene epoch (roughly 2 million years to 10,000 years before the present) and the Holocene epoch (roughly 10,000 years before present to the modern era). For the purposes of this report, the late Quaternary is assumed to span approximately the last 15,000 years. Quaternary surficial deposits record the responses of rivers, streams, washes, hillslopes, and eolian systems to active tectonics and climate changes of various magnitudes that have occurred during this time interval.

The geology of the Buckbrush Wash area was recently mapped by Garside and Rigby (1998). They indicate that portions of the watershed are underlain by unconsolidated Tertiary sedimentary deposits and Jurassic plutonic and metavolcanic rocks. They also indicate that large portions of the middle and lower watershed are overlain by a mantle of eolian (windblown) sand in the form of sand sheets and longitudinal sand dunes. It is most likely that this sand is derived from the floodplain of the Carson River immediately to the west of the study site.

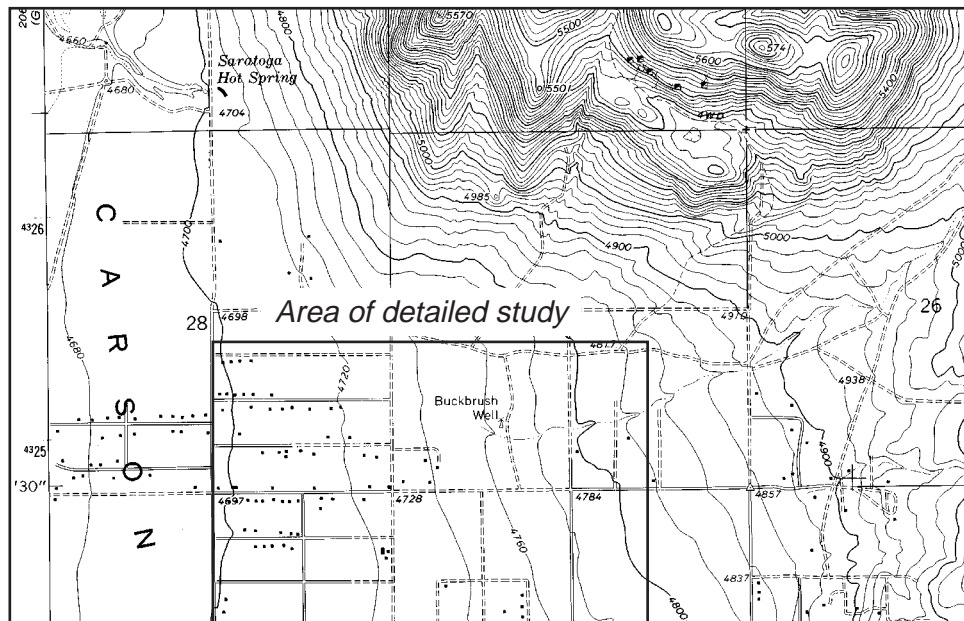


Figure 1. Location Map. Base Map Source: McTarnahan Hill, Nevada 7.5 Minute Quadrangle.

GEOLOGICAL CHARACTERISTICS OF ALLUVIAL FANS

Definition

Alluvial fans are geological features. They are distinctive, constructional landforms composed of unconsolidated sedimentary deposits of particles ranging in size from silt and sand to cobbles and boulders. Alluvial fans are ubiquitous landforms in mountainous areas, but are best expressed and preserved in desert regions. They have been the focus of study by geologists for many years (see, for example, the extensive discussions in Blair and McPherson, 1994a and 1994b). Processes that create alluvial fans range from sediment-laden water flows to highly viscous, sediment-charged debris flows. Many fans are composed of deposits from both types of process. In the case of the Buckbrush Fan, streamflow is apparently the dominant constructional process that is evident in surface depositional morphology and in stream-cut exposures.

Alluvial fans are so named because their morphology often resembles an extended fan, or a segment of a cone when viewed on maps or aerial photographs (Bull 1975, 1977). They are formed where a stream crosses a transition from a relatively steep and confined channel to a less-confined, occasionally less steep reach where the area of flow expands. Immediately below this point of expansion, sediment is deposited over a broad area as the once single channel diverges into multiple channels and broad areas of relatively shallow unconfined flow. This is a common situation, for example, at the base of mountains and at the mouths of tributaries in large river valleys. The alluvial fans on the west flank of the Pine Nut Mountains terminate as broad, gently westward sloping alluvial plains on the floodplain of the Carson River.

In the simplest sense, the cumulative effects of multiple flows and shifts in the locations of distributary channels over 100s to 1000s of years result in the construction of the alluvial fan landform, although there are notable instances in which alluvial fans were constructed by an individual catastrophic event (e.g. Blair, 1987; Wells and Harvey, 1987). However, despite the often uniform shape of alluvial fans on topographic maps, they are almost always composed of a mosaic of deposits that record the evolution of the landform over periods of time in excess of several 10,000s of years (e.g. Ritter et al. 1993).

The Fan Apex and Fanhead Entrenchment

The apex of an alluvial fan is, in a geological sense, the highest point on the alluvial fan surface and is located immediately at the point where the feeder channel issues from the mountainous watershed. However, it is not always the case that the area of active alluvial fan building occurs at this point. It is common for the upper portion of the alluvial fan deposit to be entrenched and for the geological fan apex to then be associated with a relict portion of the alluvial fan that was deposited under a different climatic regime, or has been isolated from the feeder channel due to tectonic activity. A change in the balance between sediment yield and the amount of available runoff from the contributing watershed that enhances channel erosion is a primary mechanism for fanhead entrenchment. This type

of change can be the result of various extrinsic processes (climatic, tectonic) or intrinsic processes (e.g. progressive erosion of watershed and depletion of sediment) that may operate over a large range of time scales; see extensive discussions in Blair and McPherson, 1994a, 1994b; Bull 1964, 1977, 1991; and Field and Pearthree, 1997).

Alluvial fans are generally composite landforms composed of a mosaic of alluvial deposits of potentially widely different ages—some of which are actively being constructed by the feeder channel and some of which have been isolated from active alluvial fan sedimentation for 1000s of years (Bull, 1964, 1977; Ritter et al., 1993). These different portions of the composite alluvial fan landform can be characterized as active or inactive. Active fans are those that are presently being constructed through fluvial depositional processes. Inactive fans are relict landforms associated with distinctly different hydrological conditions (a period of time in which the sediment production and runoff in the watershed were quite different than at the present—a period of wetter climate and alpine glaciation, for example). It is also possible that relict fan surfaces have been isolated from active alluvial fan deposition due to faulting. The most important point is that inactive fans are no longer being constructed by active fluvial processes.

The presence of inactive, relict fan surfaces adjacent to the presently active fan are indications of fanhead entrenchment or incision of the feeder channel below the level of the geological apex. Through the process of fanhead entrenchment, the point separating the zone of net transport of sedimentary materials from the zone of net deposition and accumulation of sediment (the intersection point or hydrographic apex) migrates down the surface of the composite alluvial fan landform. It is important to recognize, then, that the geological fan apex is not necessarily the point below which active fan deposition is presently occurring.

REGULATORY PERSPECTIVES ON ALLUVIAL FANS

The primary difference between the regulatory approach and the geological approach is the degree of reliance on site-specific, physical data that bear on the nature of the alluvial fan of interest. The regulatory approach is founded on an idealized conception of a generic alluvial fan, a theoretically or empirically design discharge usually extrapolated from a small data set, and a series of broad generalizations about the nature of streamflow on alluvial fan surfaces. The geological approach is presented here as a sort of reality check on the regulatory approach. The intent is not to supplant the conventional procedure because the geological approach is not a complete regulatory tool. It does, however, provide an essential physical context for the application of regulatory models.

The rendition of piedmont flood hazards provided by Flood Insurance Rate Maps (FIRMs) is not necessarily representative of the real characteristics of fluvial processes; in particular, it cannot be confidently assumed that flood hazard zones depicted on flood insurance rate maps (FIRMs) accurately reflect the geometry of actual, active alluvial fans. The principal problem

with this approach to evaluating flood hazards on fans is rooted in a general lack of consideration of the long and short term processes that operate on alluvial fans, their rates and magnitudes, and their variability among fans in diverse settings (NRC, 1996; Field and Pearthree, 1993; French, Fuller, and Waters, 1993; O'Brien and Fuller, 1993, Pearthree, 1991). The net result is a high potential for improper characterization of the distribution and magnitude of flood hazards.

The regulatory approach is meant to serve an actuarial purpose and is driven by expedience, simplicity, and consistency of application. It depends almost exclusively on a combination of topography and hydrologic and hydraulic modeling. In this context, the extent of the alluvial fan is estimated from the shape depicted on a topographic map and not necessarily by geological information. In absence of geological information, the accuracy of the location of the alluvial fan is controlled by the resolution of the available topographic map and the investigator's knowledge about alluvial fans. For example, it is common for the regulatory approach to assume that the geological apex of the fan as inferred from topographic maps is the point below which active alluvial fan deposition is occurring and thus, the point at which alluvial fan flood hazards should be mapped. As noted previously in the discussion of active vs. inactive fans, this assumption does not always hold true.

FLOODING ON ALLUVIAL FANS

Overview

Flooding on alluvial fans is, by nature, difficult to precisely characterize. Floods on active fans can follow multiple paths which may gradually or abruptly shift position, and can also occur as broad, unconfined shallow sheet flows that inundate large areas on the fan, particularly at their distal ends. The most important characteristic of flooding on alluvial fans is that it is spatially unpredictable, particularly when compared to flooding on single-thread rivers with generally stable channel positions (where most flood hazard regulation models have been developed).

The mobility of channels on alluvial fans and the propensity for relatively broad inundation have presented problems for conventional flood hazard management techniques. This is the basis for the regulatory model's assumption of complete uncertainty, or equal probability of channel location below the designated fan apex (Dawdy, 1979; FEMA, 1990). This is a broad assumption that may be valid on some alluvial fans if it is assumed that the active fan apex has been accurately identified. However, there are numerous exceptions to this generalization that can contribute to erroneous flood hazard mapping. This is a problem that has been discussed by several investigators (e.g. NRC, 1996; French, 1992; Field and Pearthree, 1997; O'Brien and Fuller, 1993) and it is possible to minimize its effect through a more thorough approach to initially characterizing the problem.

The approach used in this study

The approach I used to evaluate flood hazards on the Buckbrush fan adhere to guidelines presented in a recent report on alluvial fan flooding from the National Research Council (NRC, 1996). The NRC report was commissioned by FEMA to provide a reasoned, objective appraisal of their technique of alluvial fan flood hazard assessment. The recommendations in the report involve a considerably more substantial consideration of the physical characteristics of alluvial fans and their related hazards. Three principal steps in flood hazard evaluation are presented in the NRC report:

1. Recognition and characterization of the alluvial fan landform
2. Defining the nature of the alluvial fan environment and the location of active erosion and deposition
3. Defining and characterizing areas of "100-year" alluvial fan flooding.

In this report, I have emphasized points one and two which essentially amount to a recommendation for geological mapping of the fan(s) in question. Point three requires a more detailed topographic and hydrologic analysis than I had resources to perform—although there is a concurrent USGS study underway in this same area that is addressing this issue directly (Glen Hess, USGS Carson City, personal communication). Unfortunately, the USGS team is currently not in a position to share their information. It is clear, though, that combining our data would result in the best characterization of existing flood hazards on the piedmont.

USING GEOLOGICAL MAPS TO EVALUATE FLOOD HAZARDS ON ALLUVIAL FANS

The NRC guidelines emphasize the collection of site-specific information for the purposes of realistic flood hazard evaluation on alluvial fans. In effect, they advocate the integration of geological data into the arena of flood hazard evaluation.

The Surficial Geological Map of the Study Area

The inherent uncertainty about the position of channels on alluvial fans over time, and the identification of the active fan apex constitute an important rationale for using geological information to improve flood hazard delineation. Because an alluvial fan is a geological feature that reflects the cumulative effects of streamflow over 100s to 1000s of years, it is logical that a geological map focusing on the distribution of alluvial fan deposits conveys a faithful representation of the past and present distribution of flood hazardous areas. In the case of active alluvial fan surfaces that are residentially developed, the utility of such a map for characterizing future flood hazardous locations is less clear. Modification of the fan surface by road construction, lot grading, localized bank protection, and localized channel stabilization can alter the distribution of flood hazardous areas. The presence of residential development also complicates the compilation of a surficial geological map because natural features are obscured or obliterated.

Methods of map compilation

The surficial geological map (Fig. 2) is the focus of this report. It was prepared using a combination of aerial photograph analysis and field reconnaissance. Stereoscopic analysis of a chronological series of aerial photographs was used extensively in compiling the map. Pairs of overlapping aerial photographs evaluated with a binocular stereoscope are rendered in three dimensions. This is a universally accepted technique for mapping surficial geological deposits.

Numerous investigators have established useful guidelines for mapping alluvial fans, both in the context of Quaternary geology and flood hazards (Christenson and Purcell, 1985; Bull, 1991; Ritter et al., 1993; Field and Pearthree, 1997). In developing the map of the Buckbrush Fan, I relied on the following criteria:

1. Presence, degree and nature of drainage development. Active alluvial fans have an obvious distributary drainage pattern (number of channels increase downfan), whereas relict, inactive alluvial fan surfaces are characterized by a dendritic drainage pattern (number of channels increases downfan) or, in the case with portions of the east side of Carson Valley, the drainage pattern on older fans is masked by an eolian mantle. This indicates that the cumulative influence of eolian processes outweighs that of fluvial processes on inactive or rarely active fan surfaces.
2. Topography. Different aged fan surfaces are typically topographically separated from each other, the degree of separation depends somewhat on the scale of the system and its history. In delineating active vs. inactive fan surfaces. It is important to evaluate the degree of continuity with the active feeder channel. Relict fan surfaces are distinctly disconnected from the active channel.
3. Patterns of faulting. Fault relations are important criteria for differentiating different aged fan deposits. Some of the topographic separation in the different map units may be due to faulting, and older deposits may be faulted whereas immediately adjacent, younger fans may not be.

To maximize the value of the aerial photography and to eliminate the problems associated with progressive residential development in the study area, I examined a chronological series of aerial photographs with different scales, film types, sun angle, and amounts of illumination. The photos are listed in Table 1. The photographic comparison of the study area shown in Figure 3 illustrates the degree of development that has occurred in the period October 1938–October 1997 and underscores the value of historical aerial photos in surficial geological mapping. The study area had essentially no development in 1938 and the surficial geology is more easily mapped than it is with the more recent photos. The final mapping was compiled on a base photo from the 1997 Series enlarged to a scale of 1 inch to 540 feet. This photo was also used in the field for final checking of the mapping (Fig. 4).

Table 1. Aerial photographs used in compiling the map

Source	Date	Scale	Film
USDA	20-Oct-38	1:21,200	B/W
USGS	05-Sep-54	1:38,600	B/W
USAF	10-Jul-68	1:126,720	B/W
UNR	1972	1:13,000	B/W
USGS	04-Jul-74	1:83,300	B/W
NDOT	12-Jul-77	1:83,300	B/W
NDOT	16-Mar-81	1:24,000	B/W
Intrasearch	25-May-89	1:24,000	Color
Great Basin	17-Oct-97	1:19,200	Color

In mapping lower Buckbrush Wash, I differentiated 6 mappable units, 3 of which are presently flood hazardous to some degree, and 3 of which are less hazardous to non-hazardous. For the sake of simplicity, the deposits can be grouped into three classes of young, intermediate, and old.

Mapping criteria and individual map units

Most of the undisturbed, infrequently active to inactive fan surfaces in the study area are overlain by a mantle of eolian sand that varies in thickness from several inches to possibly several 10s of feet. Notable eolian features in the study area include thick accumulations of sand clogging several of the canyons draining Hot Springs Mountain (a feature known as a sand ramp) and extensive, thick longitudinal dunes on the southern and eastern slopes of Hot Springs Mountain. The longitudinal dunes that extend into the area of detailed study are mapped in dark blue.

It is possible to map much of the study area as eolian sand since it forms much of the surface layer (e.g. Garside and Rigby, 1998), however, the eolian sand occurs principally in the form of a variably thick sheet mantling inactive alluvial fan deposits. The thickness and smoothness of the mantle reflects the age of the underlying alluvial fan surface. Therefore, the presence of a thick, relatively smooth eolian mantle, or sand sheet, is useful for flood hazard mapping because it indicates the absence or great infrequency of active alluvial fan processes. This observation is substantiated by the fact that the active alluvial fan surfaces are associated with only a very thin mantle of eolian sand or no eolian sand cover at all.

The eolian sands are derived from the Carson River floodplain immediately to the west of the study area. The development of an eolian mantle and sand dunes requires a plentiful source of sand, a mechanism for transport (wind), an area for deposition, and time for accumulation (100s to 1000s of years). In absence of quantitative geochronologic control on the age of deposits underlying the eolian mantle, there are two reasonable minimum age interpretations. One possibility is that the sand mantle dates to the latest Pleistocene to earliest Holocene (approximately 10,000 years ago). During periods of Pleistocene glaciation and deglaciation, the Carson River was a significant course for glacial meltwater. Fine-grained glacial outwash sediments deposited in the Carson Valley would have provided an extremely plentiful supply of sand for eolian transport. Thus one reasonable minimum estimate for the age

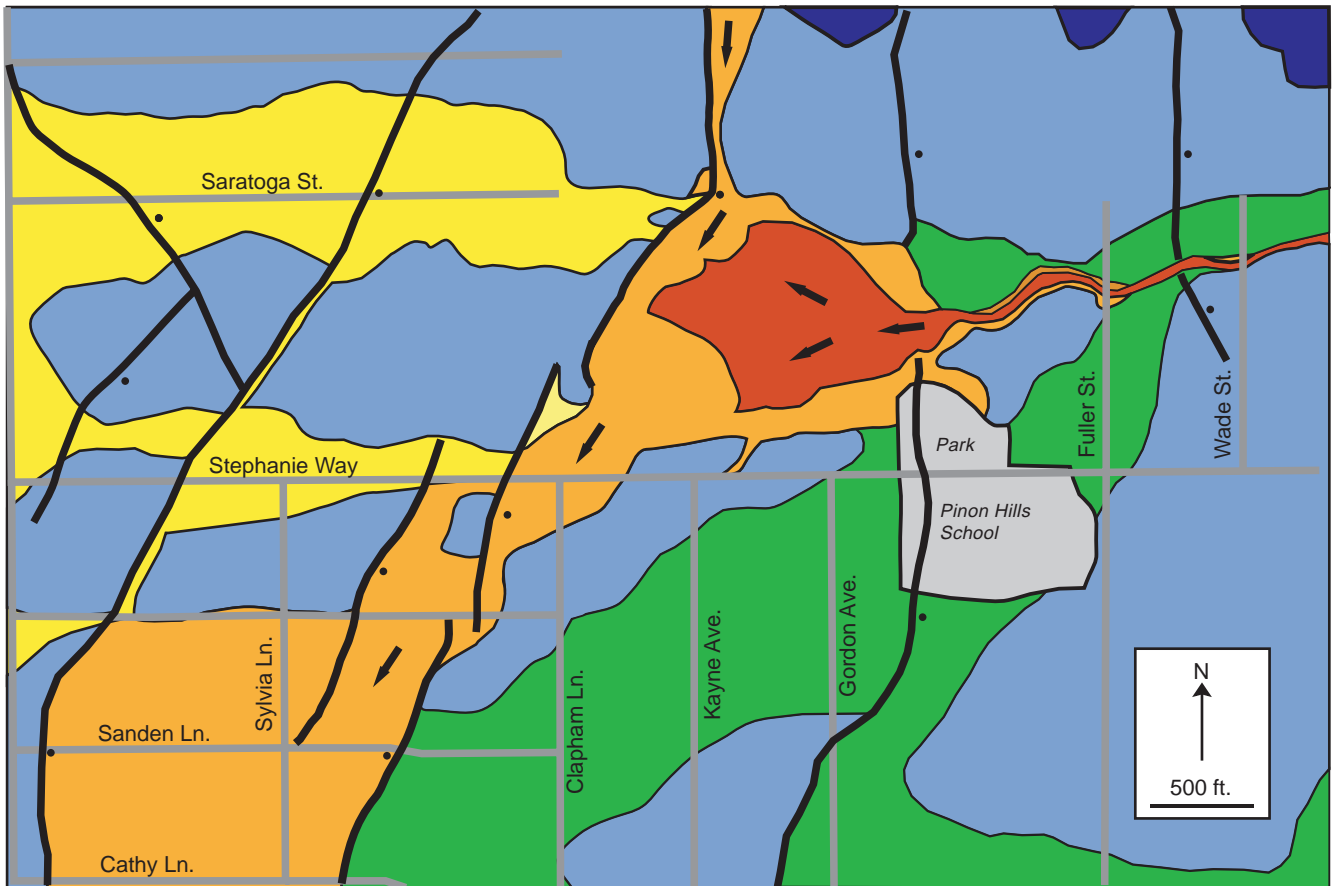


Figure 2. Surficial Geologic Map of the Lower Buckbrush Wash Area, Douglas County, Nevada. Units differentiated with respect to relative flood hazardousness.

Map Explanation

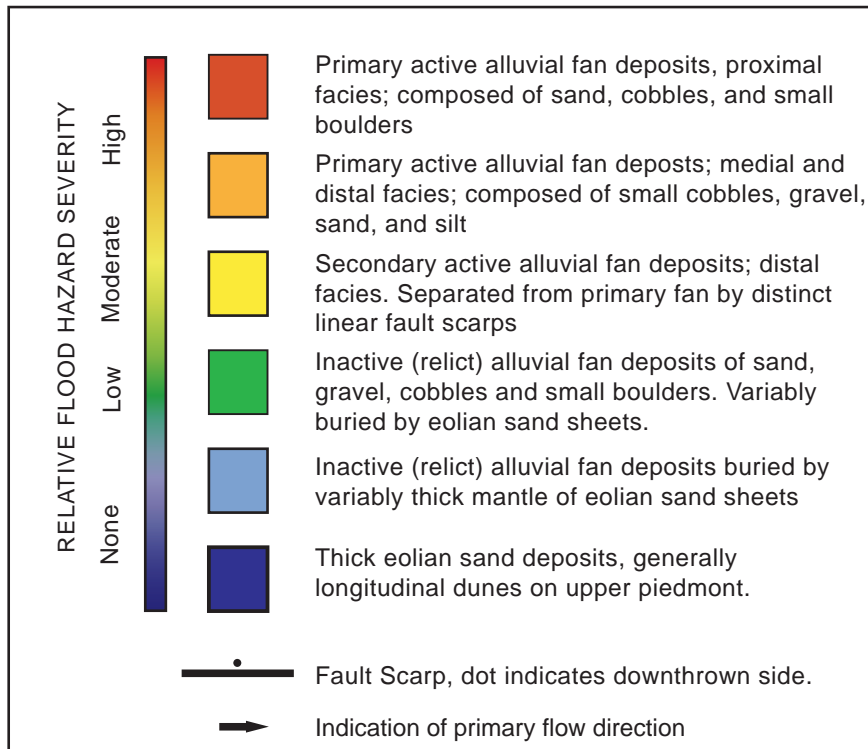
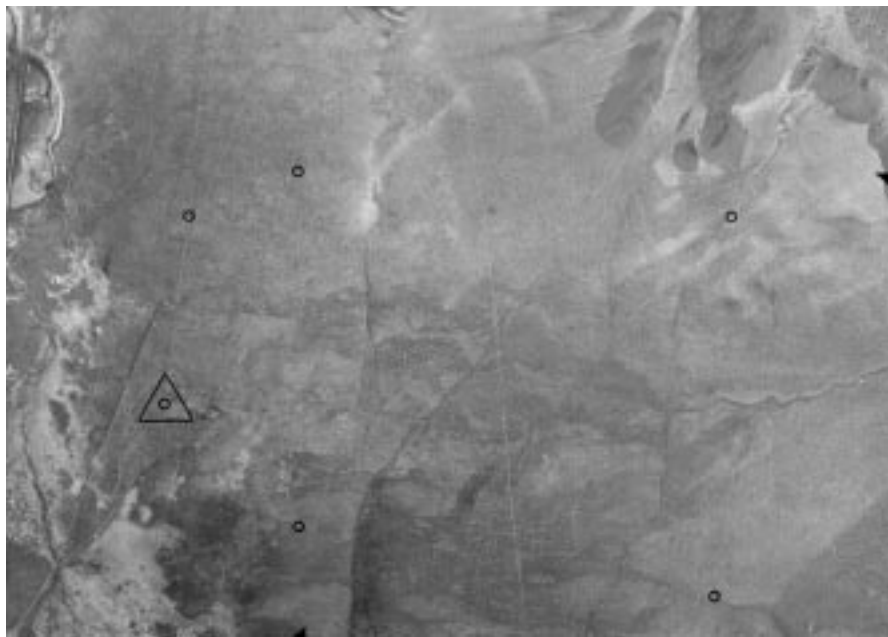


Figure 2, continued. Map explanation.

of the fan deposits blanketed by the most extensive and continuous eolian sand sheets are late Pleistocene to early Holocene in age (age of approximately 10,000 years). A second possibility is that the eolian sands are associated with desiccation of the Carson floodplain during a well-documented middle-Holocene drought period that occurred between approximately 7500 and 4500 years ago (see discussion in Grayson, 1993, pp. 208–220). Given these possibilities A conservative range for the minimum age of the units blanketed with eolian sediment is between approximately 10,000 and 4500 years. This unit is mapped in light blue in Figure 2 and constitutes the oldest alluvial fan unit mapped in the study area. Note that there are older deposits in the general area.

An intermediate alluvial fan unit was also delineated. It is mapped in green in Figure 2. This unit was mapped separately from the basis of a generally thinner and spottier cover of eolian sand and a topographic position intermediate between the active fan and the inactive fan surfaces buried by thicker sand sheets. It appears that this unit is removed from presently active alluvial fan processes on lower Buckbrush Wash (due in part to channel downcutting associated with faulting and apparently the effect of road crossings). It is possible that some portions of this surface could be inundated during extremely large floods, but this is not a certainty. It is possible that they could convey shallow flow from overbank flooding from the entrenched portion of Buckbrush Wash. The most realistic and cautiously



1938



1997

Figure 3. Aerial photographs of the Buckbrush Wash study area showing changes over a period of 59 years. The distributions of young alluvial fan deposits and faults are most evident in the older photograph.

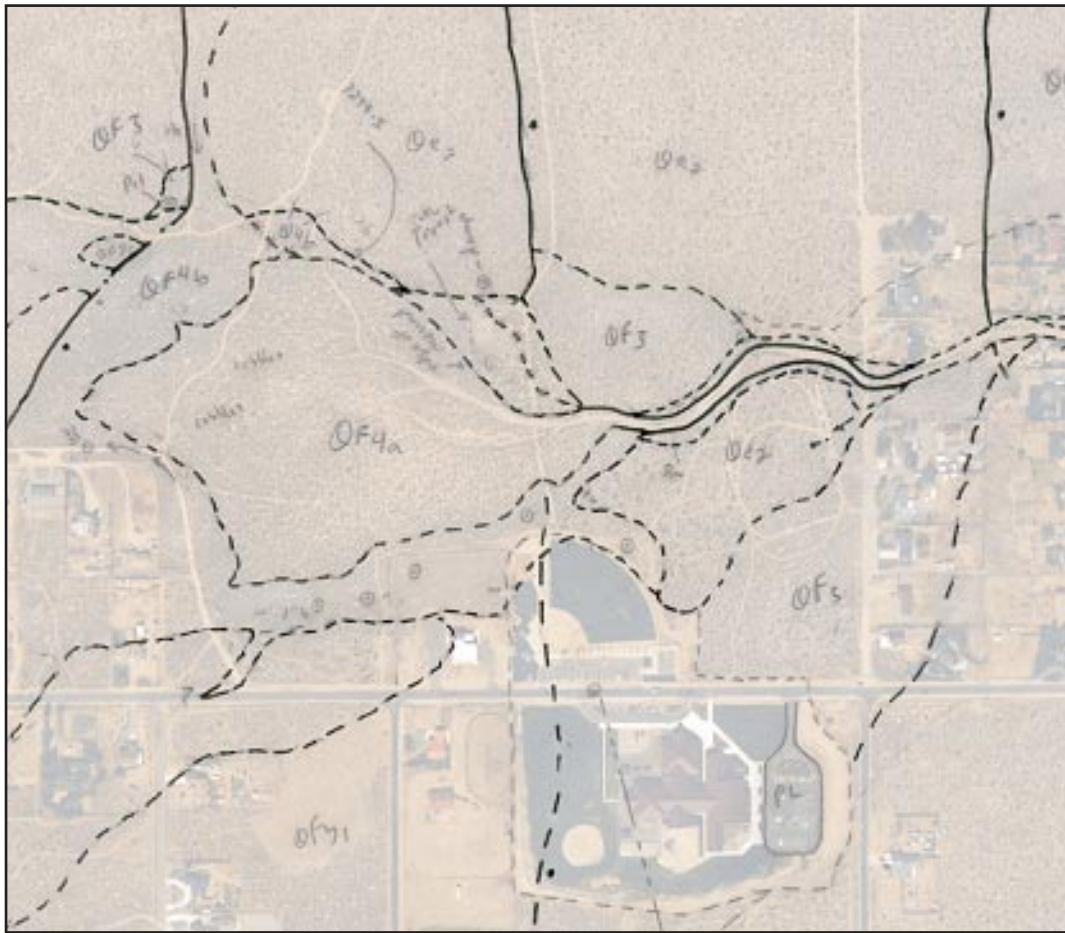


Figure 4. Enlarged 1997 aerial photograph used for final office and field compilation. Shown actual size. Linework on mylar overlay which slightly obscures the underlying color photo.

conservative approach would be to assume that these deposits are flood hazardous.

The youngest alluvial fan deposits mapped in the study area are associated with the presently active alluvial fan. When warranted by the field and photographic evidence, the active fan deposits are subdivided into 3 facies (interrelated deposits that are representative of a range of depositional environments and related sedimentary composition): proximal, medial, and distal. Furthermore, they have been divided into two categories: primary and secondary to indicate the degree of their association with existing, fault-related topographic conditions on the fan.

The proximal, medial, and distal terms refer in part to the position of the unit with respect to the active fan apex. The proximal facies is the deposit nearest the apex and constitutes the portion of the fan with the highest (most severe) flood hazard. This facies of the active fan deposit is composed of sediments ranging from coarse sand to large cobbles and small boulders. Flow on this portion of the fan is characterized by high velocity and a high degree of spatial variability. The medial facies is generally a lower energy environment with deposit composition ranging from silt to coarse sand and small gravel. The distal facies is dominantly composed of silt and sand and represents the terminal deposit of the active alluvial fan. For the most part, it is difficult to separate these facies because of

the degree of residential development on this portion of the active fan. The distal facies has only been mapped as a single unit where the deposits are classified as secondary active alluvial fan deposits. This reflects my interpretation of the influence of Quaternary fault scarps on the location of active alluvial fan processes.

The Role of Fault Scarps and lineaments

Quaternary fault scarps and related lineaments have an undeniably important role in controlling the location of active alluvial fan deposition on lower Buckbrush Wash. Their influence nullifies the assumption of complete uncertainty in channel position below the active fan apex (aside from the area mapped in red). The faults and lineaments cut across the overall topographic grain of the alluvial fan deposits. On the Buckbrush Fan, these features strongly influence the patterns of alluvial fan activity and thus the distribution of flood hazardous areas. The fact that the scarps do play such a prominent role is an indication of the general infrequency of large flood events sufficient to subdue these topographic features. In many examples of larger systems, active alluvial fans often subdue or eliminate the topographic expression of fault scarps through erosion or deposition.

The presence of faults in late Quaternary alluvium in this area is not surprising. This portion of the Carson Valley has a remarkably high concentration of fault scarps in Quaternary alluvial deposits (Dohrenwend, 1981, 1982; Bell, 1984). Figure 5 shows a portion of a map of all of the significant scarps previously mapped in the study area. More faults are shown in the map presented in Figure 2 because of the different scale of the analysis. Faults in the Buckbrush map area are easily recognized in historical aerial photographs. Figure 6 shows a low sun angle photograph of the study area taken in 1972. This photo was taken specifically to highlight the presence of fault scarps which cast prominent shadows in the right lighting conditions.

Anthropogenic Features: Road Beds, Culverts, Graded Lots, etc.

In my evaluation, anthropogenic features were not considered in relation to their effect on the distribution of flood hazardous areas. These features disrupt natural drainage patterns and can shift the loci of flood hazards in some areas. It is not possible to use the geological approach to evaluate the effects of these features except in cases where they have impacted processes recently enough and significantly enough to be expressed in the distribution of young geological deposits. To adequately

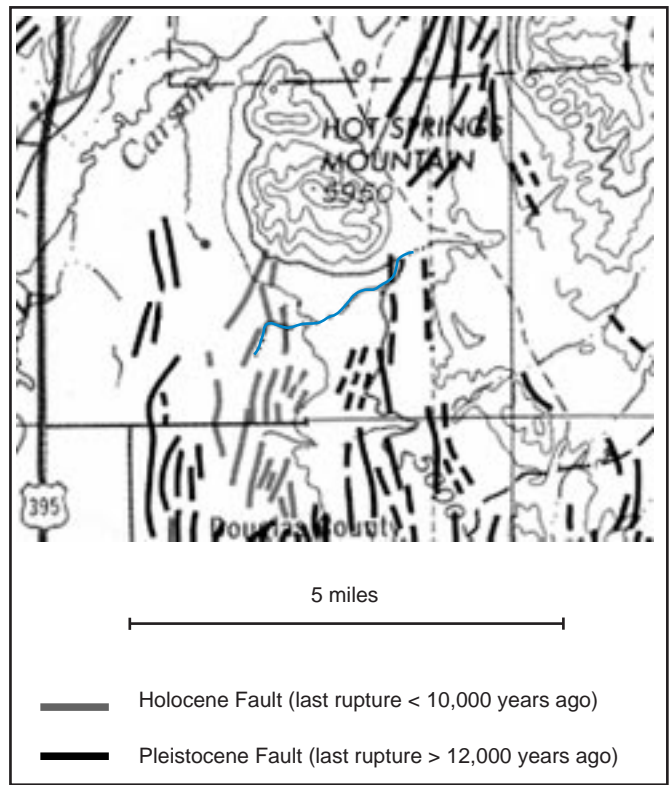


Figure 5. Map of Quaternary Faults in the Buckbrush Wash Area (from Bell, 1984). Lower Buckbrush Wash shown in blue.



Figure 6. Low sun angle aerial photograph of the Buckbrush Wash study area taken in 1972. In this photo, fault scarps are clearly evident on the piedmont. Ridges of linear sand dunes that blanket portions of Hot Springs Mountain are also obvious.

address the impact of anthropogenic features on flood hydrology and hydraulics in the study area, a detailed topographic survey and hydrological analysis is required. Such an undertaking is in the realm of civil engineering and would cost several orders of magnitude more than the cost of compiling a surficial geological map. This issue underscores the necessity to perform a geological evaluation of flood hazards prior to residential development and to develop in a way that is conformable with fan morphology.

FLOOD HAZARD IMPLICATIONS OF THE MAP

As stated previously, since an alluvial fan is a geological feature composed of flood deposits, it is obvious that a detailed geological map can provide important insights into the degree of flood hazard severity. This type of information can not be directly attained through other, more conventional means of flood hazard evaluation that rely solely on topography and theoretical estimates of flood discharge. However, it is important to realize that such a map is not intended to convey any specific element of probability (the location and severity of the “100-year” flood, for example). Such a map requires integration with a theoretical, probabilistic model of flooding in addition to more extensive analysis of fan stratigraphy augmented with geochronology.

Location of the active fan apex

The geological map indicates that the location of the present active alluvial fan is below the Fuller Road Crossing. A more conservative interpretation of the geologic map would place the active fan apex in the vicinity of the Wade Street crossing. It is likely that this once was the position of the active fan apex, but it has been largely removed from fan activity by stream incision due primarily to faulting. Note that at this point and at the point of the presently active fan apex, there is a close relation with the position of a fault scarp. This indicates that a distinct source of uncertainty regarding future distributions of flood hazardous areas arises from the response of the system to future surface ruptures associated with regional seismic activity.

Evidence for channel avulsion

Channel avulsion, a rapid relocation of the main channel due to debris blockage or from progressive erosion of small channels by overbank flow is frequently cited as a fundamental component of alluvial fan evolution and a major contributor to the uncertainty of alluvial fan flood hazard assessment. This is because the nature of the landform attests to the occurrence of multiple, potentially large scale shifts in channel position over time (although this period of time is generally well in excess of 1000s of years, much longer than engineering time scale of 100s of years). This process is restricted to the actively developing portion of the alluvial fan. In the case of Buckbrush Wash, it is very likely that channel avulsion is only a common process on the portion of the active fan surface mapped in red.

Areas mapped in orange and yellow are more likely to be characterized as shallow sheet flow zones. Historical aerial photograph comparisons indicate that the presently bifurcated main channel on the active Buckbrush Wash Fan most evident in Figures 4 and 7 was created by channel avulsion between 1989 and 1997.

Most importantly, the map depicts the shape of the presently active portions of the Buckbrush fan as not particularly fan-like—it is strongly influenced by faults, lineaments, and the locations of older fan deposits and eolian deposits. This point substantiates the value of the geological mapping for guiding the application of the regulatory model by establishing the boundaries of the active fan.

Explanation of color conventions and legend shown in map

The geological map has limitations in the existing regulatory framework. It alone cannot serve an actuarial purpose and needs to be combined with a probabilistic model in order to adhere to the prevailing paradigm of flood hazard regulation. One way to evaluate the map in the context of probability is to assume that areas composed of the youngest active alluvial fan deposits (those in red, orange, and yellow) are areas with the highest probability for future flooding; whereas those areas that have been isolated from active fan processes for 1000s of years have a distinctly lower probability of future flooding (those in green and blue). A simple application of this reasoning to a housing development would be the avoidance of building in the active channel immediately below the fan apex (which obviously has the highest probability to convey the next flood), and instead choosing to build on a relict fan surface that has been isolated from flooding for several 1000s of years. In other words, the highest probability for future flooding exists on the active fan surface (and immediately adjacent to its margins assuming there is minimal topographic relief). Of course, these simple categorizations have the most meaning prior to residential development of the alluvial fan because of potential alterations of the system that may result from development.

The flood hazard severity associated with the mapped units in the study area is illustrated in the legend accompanying the map. I have adopted a qualitative gradational and verbal scale that realistically represents the nature of flood hazards on the alluvial fan and the surrounding piedmont and the uncertainty associated with the designations. The choice of colors ranging from warm (red, orange, yellow) to cool (green, light blue, dark blue) reflect a continuum of flood hazard from extreme to non-existent. The color changes on the gradational scale do not coincide precisely with individual mapped units because in many cases, the contacts between the units are gradational. Furthermore, the position of the verbal descriptions of flood hazard severity are positioned so as to convey that the boundaries between the levels of flood hazard severity are gradational as well. This is the reality of the situation. Engineering maps which depict flood hazard zones by distinct lines separating hazard degrees are, by necessity, artificially precise.

Although it is not a robust, quantitative depiction of flood hazardous areas, it is a depiction of the physical record of past floods that have impacted this area from the basis of physical information. The map is also an expression of the likelihood of flooding in certain areas.

CONCLUSIONS

It is clear that Buckbrush Wash poses a persistent danger of flooding of various degrees to homes located below the apex of the active alluvial fan. However, there is no surficial geological evidence that attests to a significant flood hazard for homes that are located upstream of the active fan apex. Had intense alluvial fan activity recently been centered at a point upstream of the present apex, there would almost certainly be geologic evidence attesting to that fact. The geologic map does suggest that there is a portion of the presently inactive portion of the alluvial fan that has probably been the site of active fan deposition sometime within the last several thousand years (the area mapped in green in Figure 2). This assertion is supported by GPR analysis described in the appendix below. However, the degree of entrenchment of the main channel of Buckbrush Wash through this area is probably sufficient to ensure a low probability of inundation of this area by significant floodwaters other than shallow overbank flow from the main channel in the foreseeable future. The entrenchment of the channel, though not appreciably deep by standards associated with much larger alluvial fans, has been sufficient to convey the majority of the discharges associated with large floods that have occurred in the 1990s. These floods had the greatest impact on the presently active alluvial fan on which they caused widespread inundation and channel avulsion.

This report is not intended to explicitly recommend future actions for managing flood hazards associated with Buckbrush Wash. It is presented solely as a type of baseline information that should be considered when evaluating flood hazard management plans for this area. Ideally, the geological data should be evaluated in tandem with conventional approaches to flood hazard evaluation to generate a more realistic portrayal of existing flood hazards. Planning decisions made after extensive development of an active alluvial fan surface do need to evaluate the implications of geological data attesting to the location of active alluvial fan processes during the Holocene. It is important to note, however, that geological information is most useful when evaluated prior to residential development. The locations of young fault scarps, and active alluvial fans should be used as a primary criteria for guiding development in a way that is consistent with constraints provided by the physical environment, even though they may not be immediately obvious.

APPENDIX: GROUND PENETRATING RADAR ANALYSIS OF ALLUVIAL FAN STRATIGRAPHY

The internal structure of alluvial fan deposits reflect the dominant processes of channeled flow and unconfined flow that occur during the construction of the landform. It is typically difficult to evaluate this internal structure without extensive natural or excavated exposures into the fan deposits. In this project, we applied the geophysical technique of Ground Penetrating Radar (GPR) to help elucidate the internal structure of the Buckbrush fan complex. Dr. Harry Jol of the University of Wisconsin at Eau Claire, performed the analysis, reduction, and presentation of the GPR data with the assistance of his students at minimal cost.

The GPR technique is a geophysical method that utilizes electromagnetic energy (EM) to evaluate contrasts in the material properties of geological deposits. The process involves the transmission and reception of electrical impulses directed into the ground. The propagation and reflection of the is affected by the nature of subsurface materials (moisture content, chemistry, texture, interlayering). The method is most effective in remotely evaluating the internal stratigraphy and sedimentology of coarse-grained sedimentary deposits (i.e. sand, gravel, cobbles, and boulders) because the signal propagates well through these materials (Davis and Annan, 1989; Jol, 1995). The signal does not propagate well through fine sediments (silt and clay) nor through soil carbonate horizons. The presence of these types of materials can thus be inferred, but the signal cannot penetrate them.

Our goal in applying GPR to the Buckbrush Wash Fan was to remotely evaluate the fan stratigraphy both beneath the eolian sand cover and across the active fan and channel. Three transects were analyzed, one below the fire station, one along Fuller Avenue and One along Wade Road. The principal conclusion is that each transect is in fact underlain by alluvial fan deposits (which was no surprise). Furthermore, the difference between older and younger deposits is not immediately obvious in the GPR data, although it appears that the younger units are more complex and older units are buried by a thicker mantle of eolian sand. The different degree of stratigraphic complexity may be related to the position of the deposits with respect to the associated active fan apex. The nearer the unit to the apex, the more complex its internal stratigraphy is likely to be. The argument for the thicker eolian sand mantle was presented earlier.

In applying the GPR approach, we also anticipated that a soil carbonate horizon may be present below the surface of the older deposits flanking the active fan and its feeder channel. When well-developed, such a horizon is indicative of substantial age in desert soils (>10,000 years; Machette, 1985) and distinct enough to be detected using GPR. The GPR data indicate that such a feature is not present along our transects. This suggests that the intermediate aged fan deposits are likely to be Holocene in age and thus is consistent with the interpretation of a minimum age of 4500 and a maximum age of 10,000 years.

INTERPRETATION OF THE GPR PROFILES

The location of each transect described below is shown in Figure 7 and the profiles are shown in Figure 8. The GPR profiles depict the results of the transmission and reception of electromagnetic energy into the upper few meters of the alluvial fan sediments. The upper line on the profiles is the airwave—it is the first signal recorded because it is rapidly transmitted through the air. The airwave is not relevant to the stratigraphy. The second distinct line on the profile is the surface wave—the wave of energy that travels across the surface. This line is taken to represent the profile of the land surface. The remaining, somewhat complex patterns reflect the patterns associated with transmitting EM energy through the sediments. One exception to this is in the instance of distinct, repeated, and highly symmetrical patterns which indicate diffraction of the EM energy by surface features including trees, houses, and fences. Such wavelike patterns are present in the lower portions of the Fuller Avenue profile, and in portions of the Wade Street profile.

In each of the profiles in Figure 8, I have indicated the presence of distinct discontinuities in the stratigraphy with red markings. These marks indicate the presence of buried gravel bars, silt / sand lenses, and abandoned channel cross-sections. These marks represent my interpretation of the GPR output. I have not highlighted every discontinuity.

The Lower Fan Profile

The lower fan profile was taken along a 440 m. (1440 ft.) north-south transect perpendicular to the active depositional lobe of the alluvial fan in line with the fence line just west of the fire station. In general, the signal from the core of the fan (approximately 100 meters to 300 meters) indicate a complex

series of layers that suggest the presence of a sequence of in-filled channels and broad sheetflow deposits. It is likely that these deposits are composed of sand, gravel, and cobbles. Near both margins of this profile, the eolian mantle appears as a distinct, rather featureless tabular unit between the surface layer and the complex zone.

The Fuller Profile

The Fuller Road profile followed a 500 m. (1640 ft.) north-south transect beginning at Stephanie Way. The version that is provided has not been corrected for topography due to a loss of data. The profile indicates the presence of rather complex stratigraphy along most of its length at a range of depths. The stratigraphy on the north half of the profile is more deeply buried by the eolian mantle, which is consistent with the geological map. Most interestingly, one rather clear buried channel appears immediately to the north (to the right on the figure) of the present channel position. The thick eolian sand mantle is expressed quite well on the north half of this profile.

The Wade Profile

The Wade profile is from a 400m (1310 ft.) north-south transect along the west side of Wade Street. Like the other profiles, the greatest complexity appears near the location of the present channel. These is a notable area of complex stratigraphy south of the channel near the beginning of the profile (near the Wade Street and Stephanie Way intersection). This is generally supportive of the inclusion of portions of this area in the intermediate map unit. The overall value of this profile was compromised somewhat by the interference created by trees, homes, and fences.

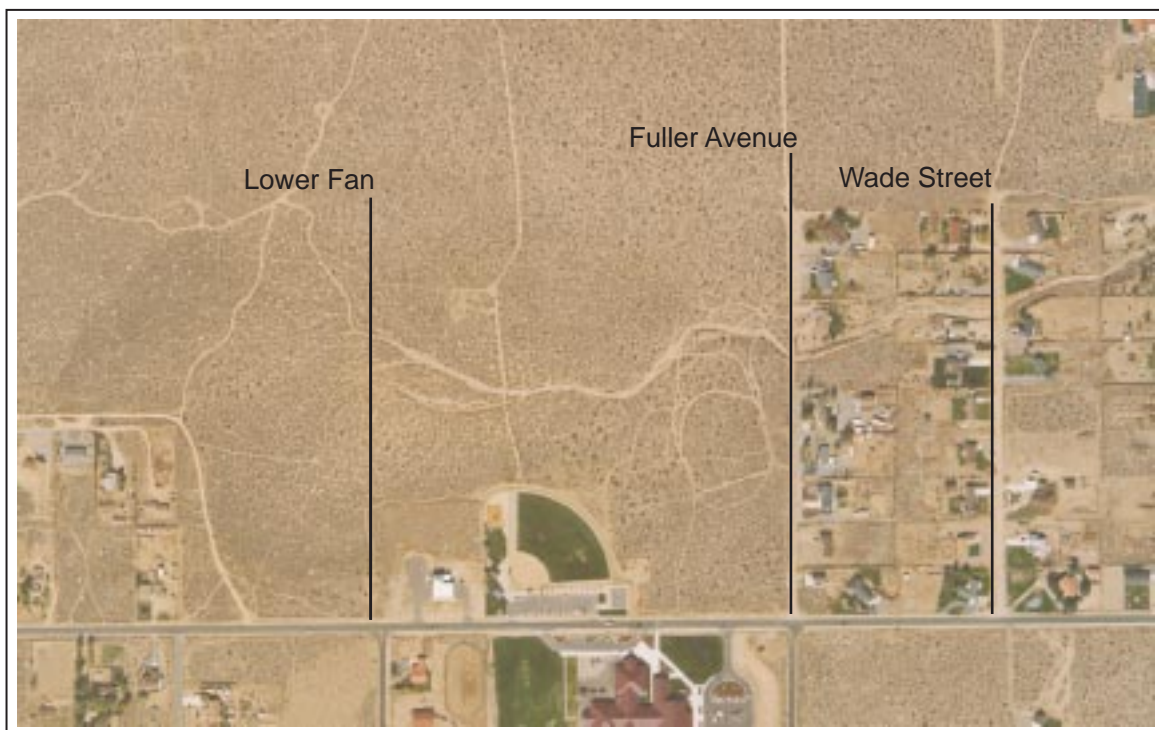


Figure 7. Location of transects for ground-penetrating radar analysis.

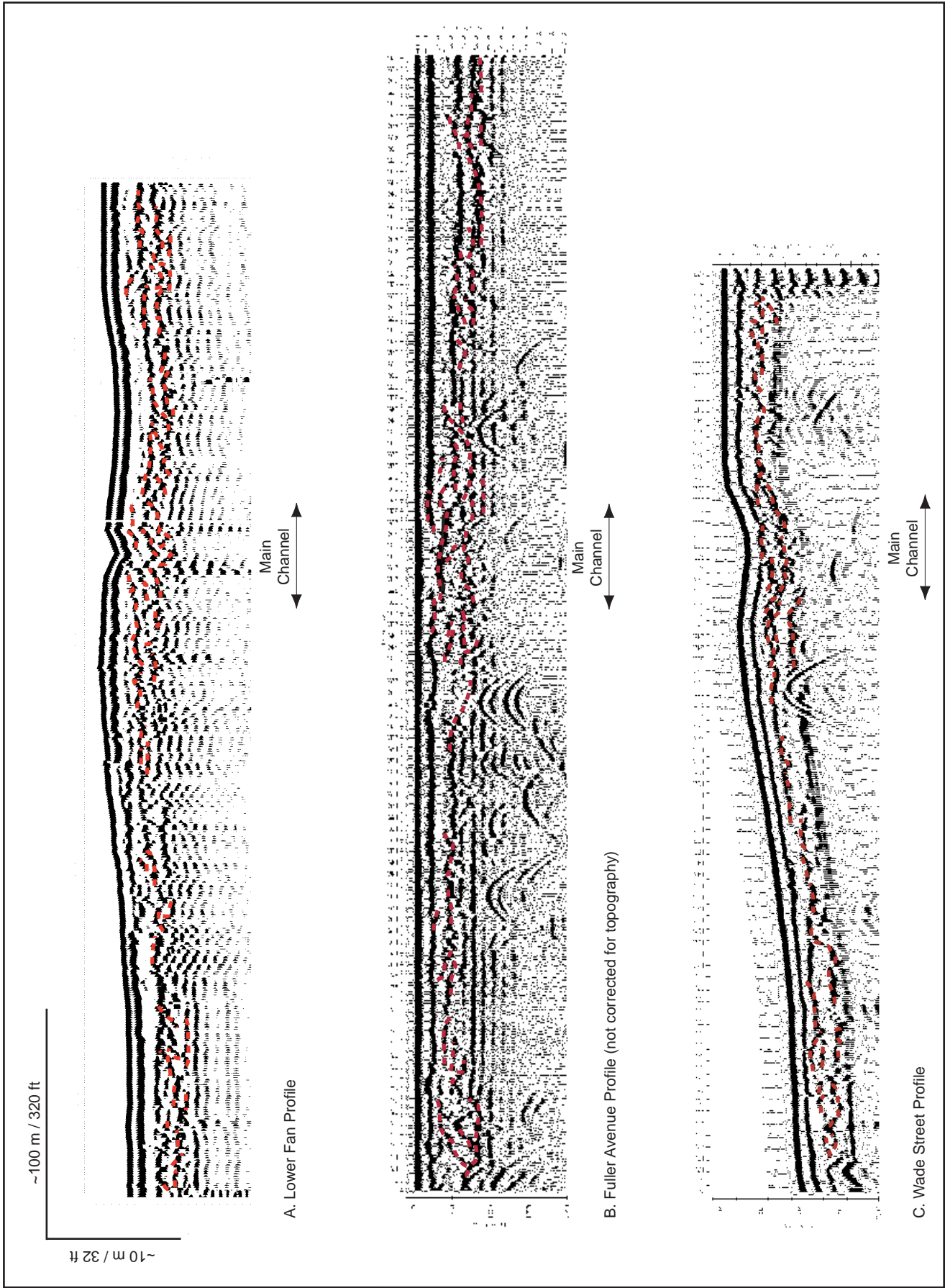


Figure 8. Results of the Ground Penetrating Radar Analysis

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