RODGER CREEK
EROSION HAZARD STUDY

Memorandum JE Fuller/ Hydrology & Geomorphology, Inc.

DATE: September 18, 2001

TO: Joe Tram, P.E./ FCDMC

FROM: Jon Fuller, P.E.

RE: FCD #2000CO13 – Task Order #3
Rodger Creek Erosion Hazard Study

CC: Tim Murphy, P.E./ FCDMC

Introduction

This memorandum summarizes the procedures used to define the erosion hazard areas delineated for Rodger Creek. Rodger Creek, a tributary to Skunk Creek, is located in an unincorporated portion of northern Maricopa County (Figure 1).

Purpose

The Flood Control District of Maricopa County (District) has been implementing the State Standard 5-96 (SSA 5-96) Level 1 Methodology on various watercourses throughout Maricopa County to determine erosion setbacks. Based upon initial usage of SSA 5-96, concern has arisen that a more detailed assessment may be necessary for certain washes that are facing development pressure. The primary objective of the Rodger Creek Erosion Hazard Study was to identify and delineate areas near Rodger Creek that are subject to riverine erosion hazards. The identified areas were grouped into a single erosion hazard zone, encompassing severe, moderate, and long-term hazards. A secondary objective was to delineate the erosion hazard setback along Rodger Creek based on the SSA 5-96 methodology for comparison to the erosion hazard zone based on geomorphic principles.

Channel Description

Rodger Creek is an ephemeral drainage system that drains a relict alluvial fan surface located within the northern end of the Paradise Valley. The study reach extends from the confluence with Skunk Creek to the creek's headwaters located in Township 6 north, Range 4 East, Section 7. For the purposes of this study, Rodger Creek was divided into the following five subreaches, from its headwaters to the confluence with Skunk Creek:

- *Reach 1 – Upstream of R-2 Tributary*. Reach 1 has a tributary, single-channel drainage pattern. The single channel pattern is interrupted by short braided reaches in areas of deeper alluvial material. Channel widths and depths average about four feet and two feet, respectively, but in general increase in the downstream direction. Channel banks are vegetated with small trees and brush.

Figure 1. Rodger Creek location map.

No evidence of cutbanks was observed. The reach has not been impacted by any development in the floodplain. Obvious features such as terraces do not define the limits of the floodplain. Instead the creek sits in the bottom of a v-shaped valley, with the floodplain positioned on the gradual slope up from the creek (Figure 2). Laminar caliche is present on the bed of the channel in the upper parts of the reach (Figure 3).

Figure 2. General view of Reach 1, looking Upstream.

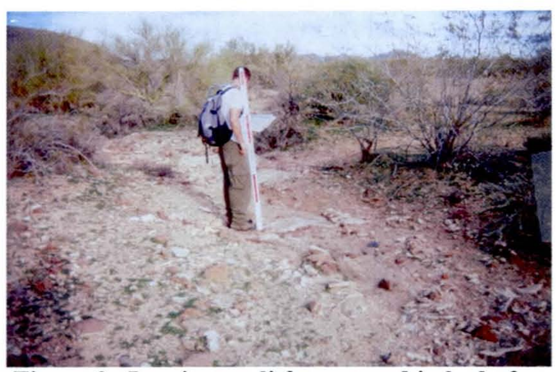

Figure 3. Laminar caliche exposed in bed of Rodger Creek, Reach 1.

- *Reach 2 – R-2 tributary to approximate 17^{th} Street alignment.* Reach 2 retains the tributary, single-channel drainage pattern of Reach 1, but has several significant differences. First, the floodplain becomes more defined, bounded either by terraces or hillslopes (Figure 4). Second, the channel bed material is much larger on average and visually dominated by boulders, the largest of which are approximately four feet in diameter. Third, development begins to encroach onto the floodplain of Rodger Creek, although it is limited to two houses and related fill. There are also four at-grade road crossings through Rodger Creek in Reach 2. Fourth, the channel capacity increases markedly in Reach 2 from Reach 1, but the calculated discharge nearly doubles as well. Fifth, cutbanks are more common than in Reach 1. The floodplain in Reach 2 is well vegetated, with multiple armed saguaros, which usually indicate stable surfaces, found in close proximity to the main low flow channel. Overbank channels are non-existent or poorly manifested throughout the reach, adding credence to the hypothesis of stability inferred by the presence of the multi-armed saguaros.

Figure 4. General view of Reach 2, looking downstream.

- *Reach 3 – Approximate 17th Street alignment to New River Road.* Reach 3 is dominated by a tributary, single-channel drainage pattern, except for a relatively short reach beginning approximately 1400 feet upstream from New River Road and ending approximately 800 feet upstream of New River Road where the channel splits into low flow and high flow channels. Reach 3 is distinctive from other reaches in the large amount of bedrock exposed in its banks and bed, which places limits on lateral erosion and scour (Figure 5). The channel width and channel capacity are greater than in Reach 2, and discharge also increases slightly. The channel width and depth in Reach 3 averages about 30 feet and five feet, respectively. Well-defined terraces or hillslopes bound the floodplain, which is well vegetated. There is currently no encroachment by development into the floodplain in Reach 3, although plans for Greer Ranch development exist. Channel banks are moderately well vegetated and do not appear to be subject to significant lateral erosion, except near development where the banks have been disturbed and the bank vegetation has been removed.

Figure 5. General view of Reach 3, looking downstream. Note bedrock exposed on right bank.

- *Reach 4 – New River Road to 3rd Street.* The main stem of Rodger Creek narrows dramatically downstream of New River Road, from 30 feet on average upstream to 10 feet on average downstream (Figure 6). Bank heights range between two and five feet. Commensurate with the decrease in channel capacity, the frequency of multiple channels sections and overbank channels is greater in Reach 4 than in any other reach. Channel banks are well vegetated, and do not appear to be subject to significant lateral erosion, except at localized cutbanks. Encroachment of structures into the floodplain is most significant in this reach. Just downstream of New River Road there are structures wholly in the floodplain and very close to the main channel. In other locations, encroachment is generally up to the edge of the floodplain. At-grade road crossings include 3rd Street and 7th Street.

Figure 6. General view of Reach 4, looking downstream.

- *Reach 5 – 3rd Street to Skunk Creek confluence.* Rodger Creek returns to a single channel pattern and widens to between 20 and 30 feet in Reach 5 (Figure 7). Bank height increases in the downstream direction, from 2-3 feet near the boundary with Reach 4 to about 5 feet near the Skunk Creek confluence. Cutbanks are most common in this reach, and in some cases are approximately 13 feet high where Rodger Creek flows directly adjacent to a terrace (Figure 8). Banks are moderately well vegetated. There is no encroachment of structures into the floodplain or road crossings in Reach 5.

Figure 7. Overall view of Reach 5, looking downstream.

Figure 8. Caliche cliffs on left bank in downstream section of Reach 5.

Limitations and Assumptions

Any technical analysis is limited by the data available, the contracted scope of services, and the assumptions of the methodologies used. For the Rodger Creek erosion hazard assessment, the following general limitations apply:

- Hydrologic Data. No stream flow gauging data were available for the study reach. Estimates of the 100-year discharges were obtained from Floodplain Delineation Studies (FDS) performed by others.[1] Gauged stream flow data for Rodger Creek and its tributaries would improve the accuracy of the erosion hazard evaluation.

- Hydraulic Modeling. Hydraulic models were prepared by others for the purpose of delineating the 100-year floodplain and floodway.[1] No additional modeling of more frequent flood events was part of this analysis.

- Geotechnical Data. No geotechnical data were available for the study area. Predictions of the existing lateral erosion hazards could be refined if extensive

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[1] Michael Baker, Jr., Inc., 1990, Technical Documentation Notebook and Workmaps for Rodger Creek Floodplain Delineation Study, Flood Control District of Maricopa County.

geotechnical investigations of bank and floodplain stability were completed along the stream corridor.

- Level of Detail. The erosion hazard setbacks determined for this evaluation are based on observations made during field reconnaissance, interpretation of historical aerial photographs and topographic maps, consideration of data and mapping from previously published reports, and the SSA 5-96 Level 1 Methodology. It is possible that the recommended erosion hazard setbacks could be refined by applying more detailed methodologies, such as those used in the District's Watercourse Master Plans.[1,2] This study is roughly equivalent to the SSA5-96 Level 3 Analysis.

- Additional Erosion Hazards. Riverine erosion and flood hazards exist along the entire watercourse. In addition, erosion from slope processes will occur on steep slopes within the study area. This study is limited to evaluation of riverine erosion hazards on the main stem of Rodger Creek.

Methodology

The following procedures and methodologies were used to define erosion hazards along Rodger Creek:

- Field inspection
- Interpretation of aerial photographs
- Comparison of channel position on historical aerial photographs
- Interpretation of detailed soils maps
- Interpretation of surficial geology maps
- Interpretation of regional geology
- Analysis of longitudinal profile
- Application of allowable velocity criteria
- Application of State Standard SSA 5-96 Level 1 Methodology

Field Inspection. Field visits were conducted in the study reach on November 28th, December 8th, and December 19th, 2000, and February 15th, 2001. The objective of the field visits was to document existing channel and floodplain conditions. The types of field data collected included the following:

- Evidence of recent and historic channel erosion
- Location and extent of cut banks
- Location and extent of caliche or bedrock outcrops

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[1] JE Fuller/ Hydrology & Geomorphology, Inc., 1999, Cave Creek/Apache Wash Watercourse Master Plan Report – Lateral Stability Analysis, Draft. Report to the Flood Control District of Maricopa County.

[2] JE Fuller/ Hydrology & Geomorphology, Inc., 1999, Skunk Creek Watercourse Master Plan Report – Lateral Stability Analysis, Draft. Report to the Flood Control District of Maricopa County.

- Location, height and boundaries of stream terraces
- Channel conditions at bridge, culvert, and road crossings
- Photographs of typical channel sections, erosion features and structures

Field data were marked and collated on 1:2400 scale aerial maps, and were later digitized in AutoCAD on a semi-rectified aerial photograph base map. Field photographs and photographs logs are provided in Appendix A. CAD data were provided digitally.

The following general conclusions are supported by the data collected during the field reconnaissance visits:

- Typical Cross Section. The typical cross section for Rodger Creek varies significantly within the study reach, as illustrated in Figures 9 to 14. Channel width and depth in Reach 1 (Figure 9) generally increase in the downstream direction, but average about four feet and two feet, respectively. In Reach 2 (Figure 10), channel width increases to approximately 15 feet on average. Bank heights range between two to five feet deep and there is no trend to increase or decrease in the downstream direction. The channel cross section in Reach 3 (Figure 11) is similar to that of Reach 2, but the width increases to 30 feet on average. Channel bank heights range from 2 feet to 10 feet near scour holes and cut banks. Channel width and depth in Reach 4 averages ten feet and three feet, respectively. The typical cross section in Reach 4 includes a low flow main channel and high flow overbank channels (Figures 12 and 13). The channel in Reach 5 is typically 20-30 feet in width with bank heights of three to five feet, increasing in the downstream direction (Figure 14). Occasional caliche cutbanks in Reach 5 are approximately 13 feet in height (Figure 21).

Figure 9. Typical cross section in Reach 1, view upstream.

Figure 10. Typical cross section in Reach 2, view downstream.

Figure 11. Typical cross section in Reach 3, view downstream.

Figure 12. Typical cross section of main channel in Reach 4, view downstream.

Figure 13. An overbank channel on the left bank floodplain in Reach 4.

Figure 14. Typical cross section in Reach 5, view downstream.

- Floodplain Dimensions. A natural floodplain (Figures 15, 16, 17) is present adjacent to the main channel throughout the study area. In all reaches except Reach 1, the floodplain is generally confined by terraces and hillslopes. In Reach 1 the edge of the floodplain generally falls on the gradual slope of the relict alluvial fan surface on which Rodger Creek flows. The floodplain stays relatively constant in its width from Reach 2 through Reach 4. The floodplain widens in Reach 5 as Rodger Creek flows into Skunk Creek. The height of the floodplain relative to the main channel is lowest in Reach 1, from less than one to two feet. In other reaches the floodplain generally varies from two to five feet above the main channel bed. As the height of this natural floodplain above the main channel increases, the frequency of flow on the floodplain decreases, and the erosion potential of the main channel bank increases due to the relatively higher flow depths and velocities along the main channel bank, as illustrated in Figure 18. Where field evidence suggests more frequent overbank flow on the floodplain, the potential for avulsive channel change increases.

Figure 15. Right overbank floodplain in Reach 4. Note caliche cliff face in background.

Figure 16. Left overbank floodplain in Reach 4.

Figure 17. Right overbank floodplain in Reach 4. Note transition from floodplain to older surface in background.

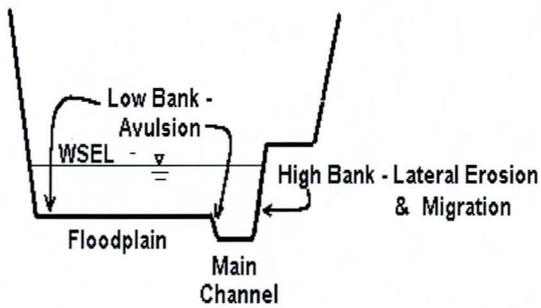

Figure 18. Erosion processes on floodplains.

- Floodplain Soils. The soil materials underlying the natural floodplains adjacent to the main channels appear to be comprised of erosive, unconsolidated sand and gravel. A roadcut exposing portions of the soil profile is shown in Figure 19.

Figure 19. Exposed floodplain soil profile at road cut.

- Caliche. Laminate carbonate-rich soil layers (a.k.a. "caliche") were observed in the bed of Rodger Creek in Reach 1 (Figure 3). Caliche is also exposed in cut banks where the main channel intersects the margins of older geomorphic surfaces in Reaches 3 and 5 (Figures 20 and 21; Table 3). While the caliche layers themselves are more resistant to erosion than the non carbonate-cemented soil layers, field data suggest that the carbonate layers have been eroded by recent stream flows, including overhanging layers and exposed roots. The carbonate layers erode primarily by undercutting the non-cemented underlying layers (cantilever failures), but also by direct shear and impact forces on the carbonate layers themselves (Figure 22). Locations of caliche outcrops observed in the field are shown on Figures 23a to 23d.

Figure 20. Exposed caliche cutbank on right bank in Reach 3. Note exposed palo verde roots indicating active lateral erosion.

Figure 21. Caliche bank in Reach 5 created by Rodger Creek eroding into old terrace.

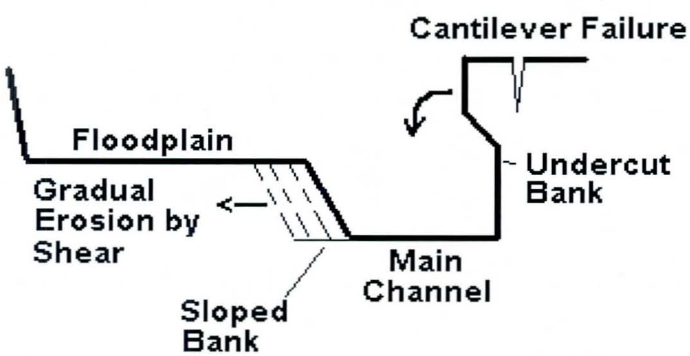

Figure 22. Erosion processes impacting caliche banks.

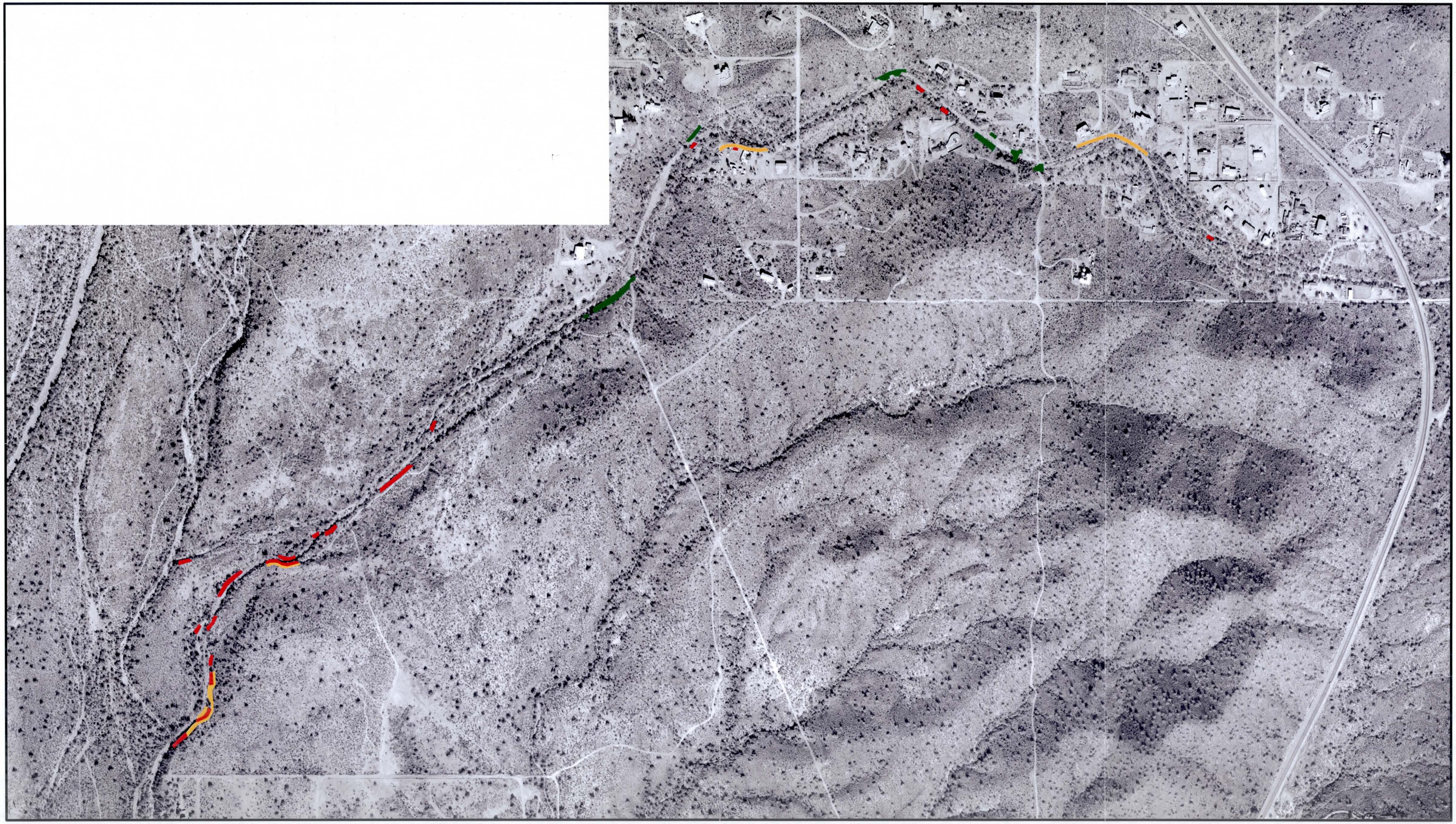

Figure 23a. Bedrock, Caliche, and Cutbank Locations on Rodger Creek (Reach 5 and Reach 4)

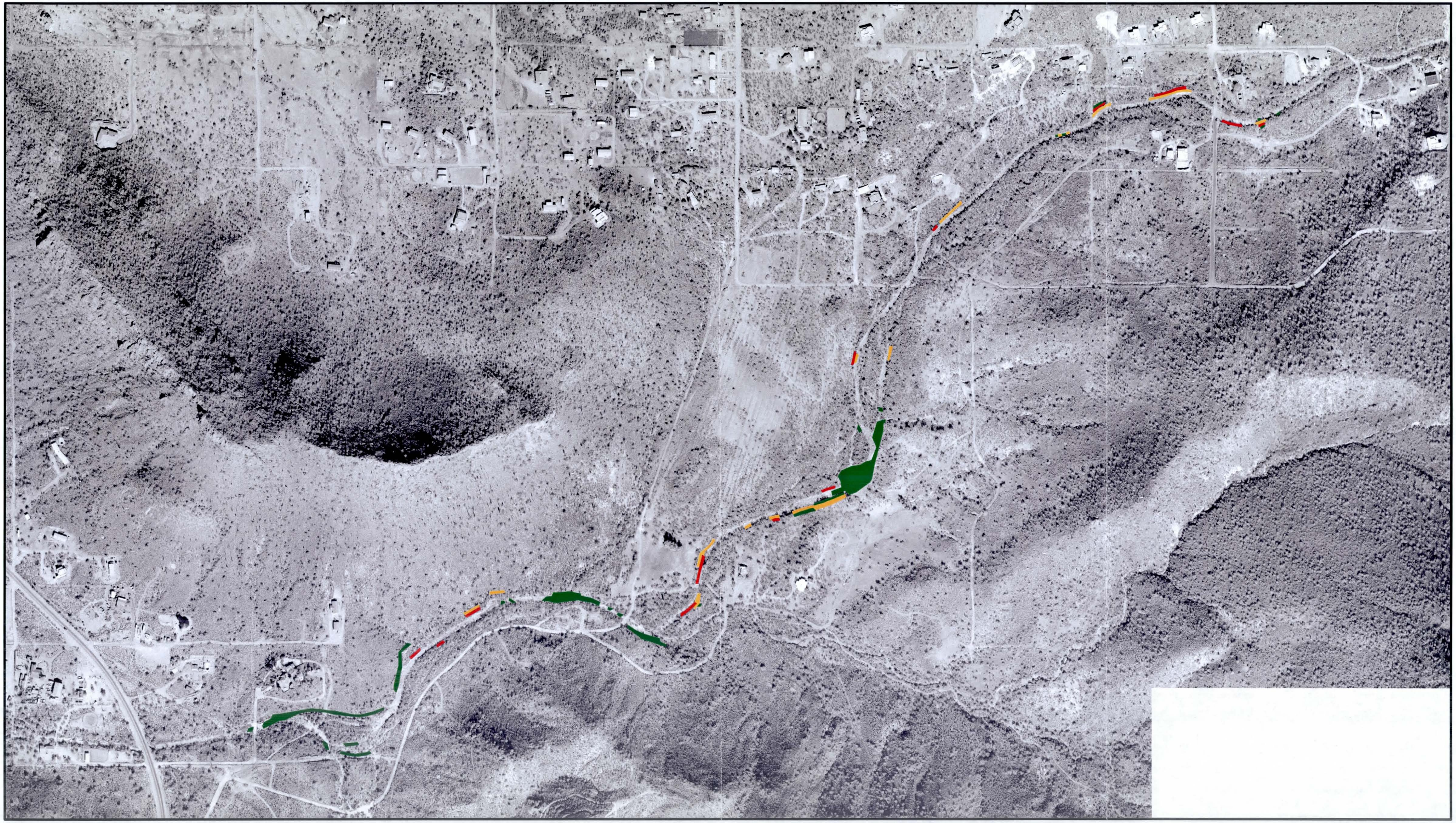

Figure 23b. Bedrock, Caliche, and Cutbank Locations on Rodger Creek (Reach 3 and Lower Reach 2)

Figure 23c. Bedrock, Caliche, and Cutbank Locations on Rodger Creek (Upper Reach 2 and Lower Reach 1)

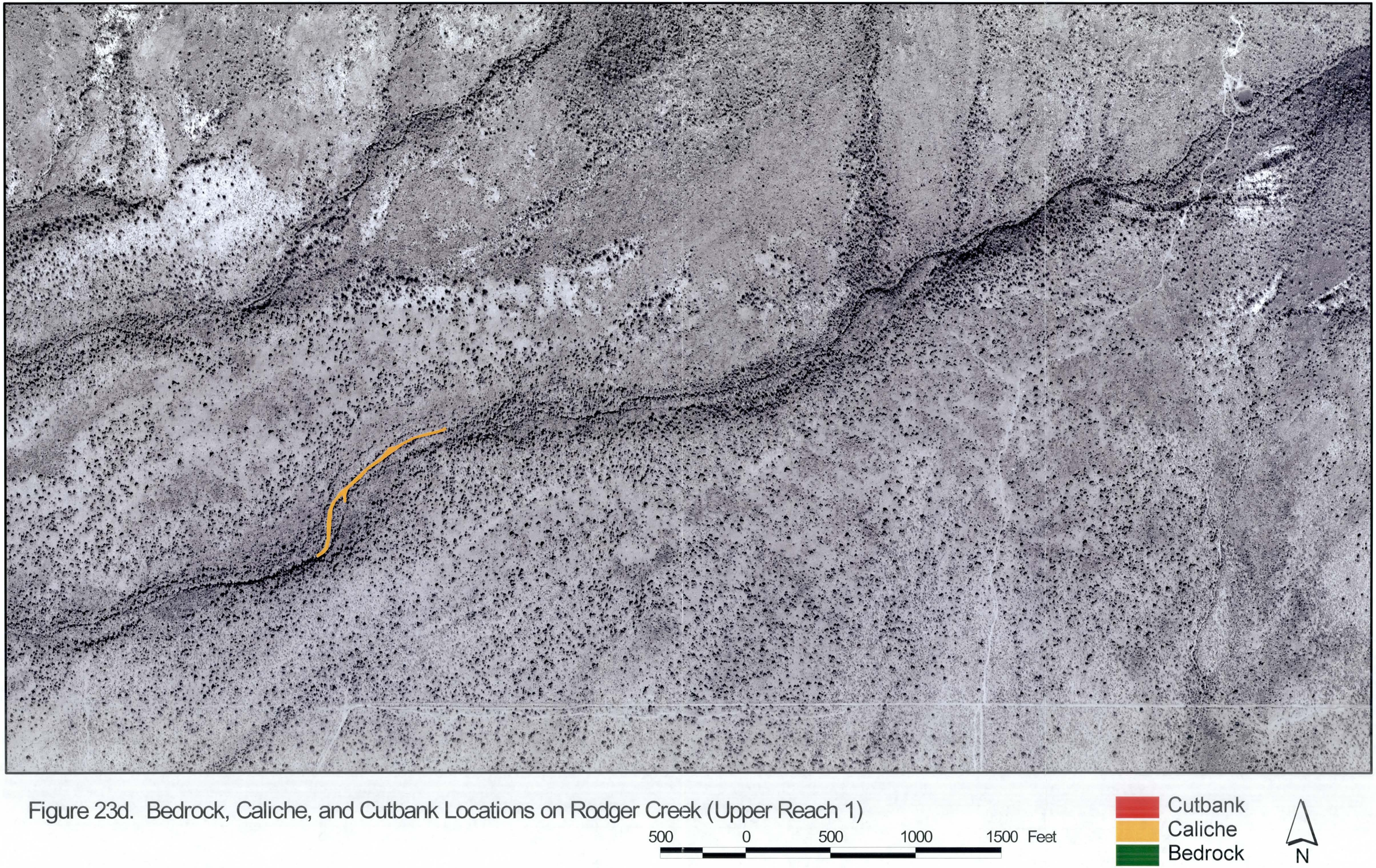

Figure 23d. Bedrock, Caliche, and Cutbank Locations on Rodger Creek (Upper Reach 1)

- Bedrock. Lateral erosion is effectively prevented by bedrock. Bedrock is present along the banks and in the channel bed at many points along the course of Rodger Creek. Bedrock outcrops are especially prominent in Reach 3, limiting both lateral erosion and scour (Figures 24 and 25). Locations of bedrock outcrops observed in the field are shown on Figures 23a to 23d.

Figure 24. Bedrock exposed in channel bed and on right bank in Reach 3, view upstream.

Figure 25. Large field of exposed bedrock in upstream portion of Reach 3, view downstream.

- Long-term scour. No evidence of extensive and significant historical long-term degradation on Rodger Creek was observed in the field. Field evidence of long-term scour typically includes undercut bank vegetation, leaning or fallen bank vegetation, high or multiple terraces, abundant cut banks, headcutting, armoring, perched channels, and excessive erosion at structures. The only feature of this type observed was a headcut in Reach 4 (Figure 26), the upstream expansion of which is ultimately limited by the presence of bedrock approximately 2400 feet upstream. However, the New River Road culvert is located between the headcut and the upstream bedrock. The hypothesis of no significant long-term scour is supported by the comparison of longitudinal stream profiles from 1964 and 1997 discussed later in this memorandum (Figure 45).

Figure 26. View upstream at 2' deep headcut in Reach 4. Note also exposed roots on left bank (photo right).

- Local scour. Scour holes up to three feet deep were observed at some channel bends or where natural obstructions such as trees, boulders, or bedrock partially block the main channel (Figure 27). The size of the observed scour holes indicates a moderate potential for severe local scour, especially at bends or obstructions in the creek. The scour holes are created when cross currents erode sediment from the inside of the bend and then deposit the sediment on the outside of the bend when the velocity decreases. Alternately, turbulence created by the obstructions in the creek also contribute to sediment scour adjacent to the obstruction. The size of the scour holes also reflects the moderate flood velocities and peaks that occur in the wash.

Figure 27. Scour hole approximately 3' deep in Reach 4.

- Structure impacts. Few structures for which structure impacts could be assessed exist within the study area. In general, the potential for lateral erosion increases near structures due to flow constriction, flow acceleration through the structure, and inability of the stream to adjust its boundaries within the structure in response to changing flow conditions. The impacts from structures observed in the field are summarized below.

    - New River Road culvert. The only significant structure impacting Rodger Creek is the New River Road culvert. The culvert is a stonework structure that spans the width of Rodger Creek. Two 7.5 feet-diameter corrugated metal pipes are positioned in the creek to allow throughflow (Figure 28). Bed material upstream of the culvert is larger than the material downstream. The solid nature of the bridge restricts the flow of Rodger Creek, backing up water and widening the floodplain. Several bank protection measures have been constructed near the culvert. Chain link fence backed by rounded stream cobbles line the banks on the upstream side of the bridge, providing a degree of bank protection (Figure 29). Downstream of the culvert, wire-reinforced concrete protects the left bank. Apparently recent flow has severely undermined the concrete protection (Figure 30).

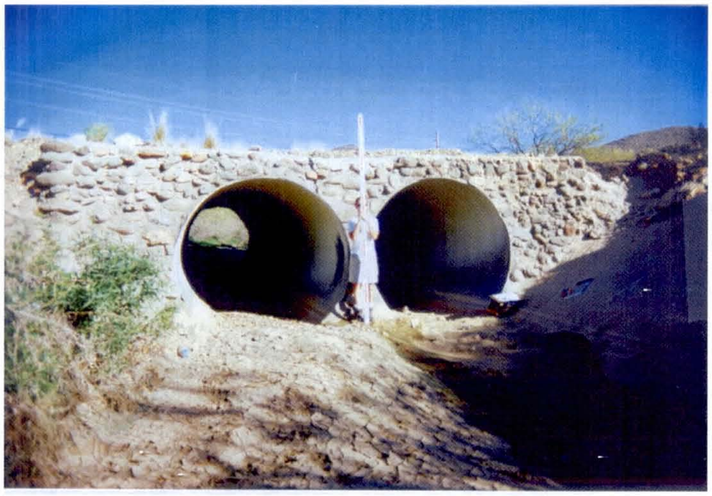

Figure 28. Downstream face of New River Road culvert.

Figure 29. Bank protection on left bank just upstream of New River Road culvert. Culvert abutment is visible at extreme right of photo.

Figure 30. Undermined concrete bank protection on left bank downstream of New River Road culvert.

- Road Dip Crossings. Most at-grade crossings of the dirt roads that cross the streams in the study area have minimal impact on the streams, aside from trapping fine-grained sediment in the road section during flow events (Figure 31). However, there are two examples of road crossings in the study area that potentially impact the creek in greater ways. First, at the 22nd Street crossing, the grading for the road has disrupted the continuity of the floodplain on the right bank (Figure 32). The constriction has the potential to concentrate flow into the main channel, increasing the likelihood of erosion against the left bank. Second, the creek bed has been disturbed downstream of the 20th Street crossing, creating an area that is probably prone to ponding. The disturbance may be an attempt to mitigate the energy associated with a large flood events (Figure 33 and 34).

Figure 31. 3rd Street at-grade road crossing, view downstream.

Figure 32. 22nd Street road crossing, view at right bank. Road fill interrupts existing floodplain.

Figure 33. Disturbance of creek bed downstream of 20th Street road crossing, view upstream.

Figure 34. 20th Street at-grade road crossing, view downstream.

- Fences. Fence crossings are limited to two occurrences, both associated with at-grade road crossings. (Figures 35 and 36). The fences are made of barbed wire and are generally poorly anchored. These fences will tend to trap debris, increasing local scour immediately surrounding the fence, and ultimately causing failure of the fence. More importantly, the fences will trap flood debris and divert water from the main channel into the floodplain, increasing the likelihood of avulsions or scour in the floodplain.

Figure 35. Barbed wire fence downstream of road crossing at Reach 2/Reach 3 boundary.

Figure 36. Barbed wire fence upstream of 24th Street at-grade road crossing.

- Bridges. No bridges span Rodger Creek. Pilings for an aborted bridge construction project remain in place in the creek bed approximately 500 feet downstream of New River Road (Figure 37). According to the property owner, the private project was discontinued when the channel aggraded to a point where the banks were traversable. The pilings present an obstruction around which scour is possible, however field observations indicate minimum scouring at present.

Figure 37. Home built partially in floodway of Rodger Creek downstream of New River Road, view upstream. Note Abandoned bridge pilings in creek bed.

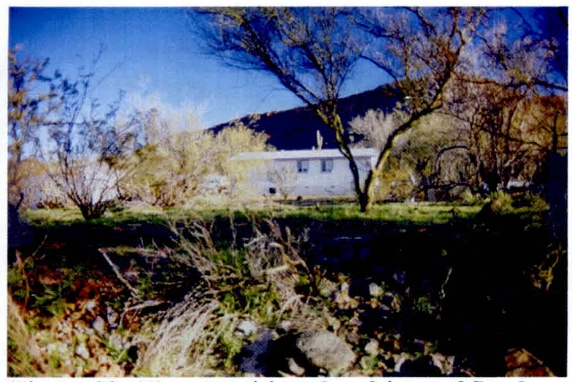

Figure 38. Home positioned at fringe of flood-plain.

- Homes. Residential development is minimal along Rodger Creek except in Reach 4. Only one home appreciably encroaches into the floodway of Rodger Creek and is located within several feet of the main channel banks, just downstream from the New River Road Bridge, (Figure 37). Several other structures associated with the home, including corrals and storage sheds, are located in the floodplain. Other homes, structures, and associated fill, generally located at the fringe of the floodplain, are at risk of flood damage and erosion (Figure 38).

- Cut banks. The locations of cut banks observed in the field are plotted on Figures 23a to 23d. The presence of cut banks indicates that active lateral erosion can occur within the stream systems in the study area regardless of bank vegetation, soil lithology, and soil composition (Figures 39 and 40).

Figure 39. Cut bank in Reach 5.

Figure 40. Cutbank in Reach 3.

The incidence of cut banks observed in the field generally increased in the downstream direction, coinciding with the increase in discharge (Table 1). Cutbanks are often associated with the presence of caliche, which provides the bank with the cohesiveness to stand at a higher angle. There is not a direct correlation between the two, however. While cutbanks are quite variable in frequency from reach to reach in Rodger Creek, the amount of caliche remains fairly constant.

Table 1. Rodger Creek Erosion Hazard Analysis
Percent Caliche, Bedrock, & Cut Banks by Reach

Feature	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Overall
Bedrock	0%	6%	50%	10%	10%	7%
Caliche	13%	14%	20%	17%	13%	15%
Cut Banks	0%	6%	13%	3%	29%	8%

- Bank vegetation. In most locations, the upper banks are well vegetated with mesquite, palo verde, and dense brush (Figure 41). The bank vegetation generally covers the upper portion of the bank slope, and includes deep rooting riparian species that enhance bank stability.[1] Where the upper bank is heavily vegetated, there is a definite water line below which flow is more common and vegetation is limited. The following two aspects of the bank vegetation enhance bank stability: (1) roots which holds soil material in place, and (2) branches, leaves, and debris trapped in the vegetation which lower the velocities at the bank line and prevent high-velocity floodwaters from flowing directly on the soils that comprise the bank. The presence of mature bank vegetation, including multi-armed saguaros near the banks, throughout much of the study area indicates that the average rate of lateral erosion has been slow in the past 50 years or more (Figure 42). That is, the average rate of lateral erosion is less than the average growth rate of the vegetation on the banks.

[1] Bank vegetation enhances the stability of the bank materials, but does not preclude the possibility of bank erosion, as indicated by the presence of cut banks.

Figure 41. Well-vegetated bank. Note distinct channel line along bank.

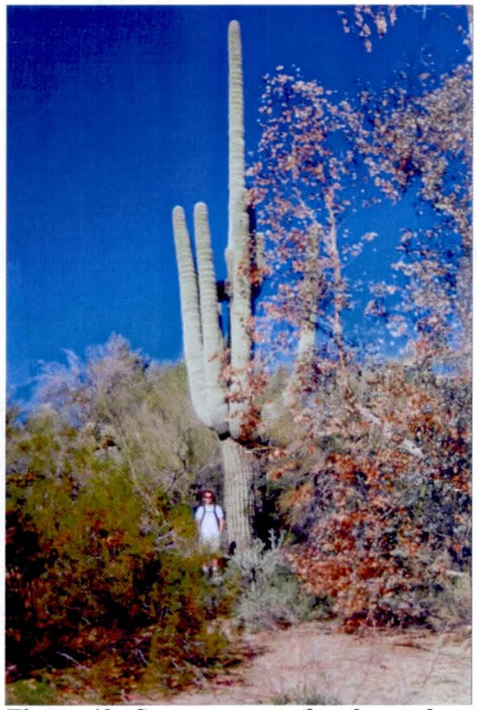

Figure 42. Saguaros are often located near the banks of Rodger Creek suggesting a relatively stable floodplain.

- Sediment Transport. The channel beds consist primarily of cobbles and small boulders with interspersed sand and gravel sized sediment (Figure 43). The floodplain soils typically consist of finer sand and gravel deposits. The difference in composition between the floodplain and channel indicates that fine sediment is transported through the main channels without being deposited. The main channel sediments are moderately well sorted, indicating that they have been transported by recent flows, and are not primarily derived from slope processes

Figure 43. Typical large caliber bed material found in the upper reaches of Rodger Creek.

acting on the banks and hillslopes. The creek bed does not appear to be in danger of armoring. Flows in the creek are of insufficient duration to winnow away completely the small sediment in the creek bed. Sediment supply from the upstream reaches is also sufficient to replenish losses of the small-sized sediment. The limited likelihood of armoring reduces the chance of increased bank erosion since the flow energy will have a chance to expend itself transporting the loose bed material rather than attacking the banks.

- Channel Pattern. The dominant channel pattern of Rodger Creek in the study area is a straight, single channel pattern. At several locations upstream of the New River Road Bridge, however, the channel branches into a multiple channel pattern, with a definite low flow main channel and a high flow channel. Downstream of the New River Road Bridge, where the channel decreases in size, a significant volume of flow is diverted onto the floodplain where overbank channels are prone to form.

- Avulsions. Where the main channel becomes small, the potential for high volumes of flow in the floodplain is high. That is, if the elevation of the overbank floodplain is low relative to the main channel, the floodplain will convey frequent flows of sufficient volume and peak to cause new channels to form. With time, these floodplain channels can capture the main channel and cause an avulsive shift of the main channel into the floodplain channel, resulting in a sudden relocation of the active channel from one side of the floodplain to the other. Potentially incipient avulsive channels were observed on the floodplains in Reach 4 and Reach 5.

- Flood High Water Marks. Flotsam observed along the banks of the main channel in Reach 4 indicates that at least one flood has recently filled the channels and inundated portions of the floodplain. The depth of flow as indicated by the flotsam was approximately 4 to 5 feet deep in the channel (Figure 44).

Figure 44. Flotsam observed slightly above bank level in Reach 4. View downstream.

- Human Impacts. Impacts associated with human occupation of the study area are limited, but include the following:

    - Road crossings and fences (Figures 31 through 36)
    - Construction of homes in floodplain and floodway (Figures 37 and 38)

  In general, human activities have had little impact on the erosive hazards on Rodger Creek.

Interpretation of aerial photographs. The erosion hazard along Rodger Creek was also evaluated by interpreting surficial characteristics visible on aerial photographs. The age of stream terraces adjacent to the main channels provides information on past stream bed elevations and positions that can be used to forecast where the stream may be located in the future. Geomorphic surface characteristics were used to compare terraces within the study limits to surfaces in the local area previously evaluated by the Arizona Geological Survey.[1] Those characteristics included the following:

- Soil development
- Surface color
- Desert pavement
- Desert varnish
- Topographic relief
- Vegetative characteristics

Individually, these age-indicating characteristics provide a relatively low degree of confidence in age estimates. Considered together, the characteristics provide a higher degree of confidence. The physical characteristics of a surface give clues as to its depositional history, stability, and flood potential.

If a land surface ceases to receive new deposits, it will begin to age. As it ages, the surface begins to develop distinctive physical and chemical characteristics indicative of its age. As the soil develops, its structure, color, and content change. Soils become redder with increased age due to oxidation of iron, a process called rubification. Clay and carbonate also accumulate as a soil ages, causing the soil to develop structure (clay), and become whiter and more cemented (carbonate). Soils with high clay and carbonate content are generally more resistant to erosion. As they age, surfaces may also develop gravel lag coverings known as desert pavement. The large clasts on the surface, if they contain sufficient ferromagnesian minerals, will develop a dark black patina called desert varnish on their tops and an orange coating underneath. Surfaces free from new

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[1] Leighty, R.S., and Holloway, S.D., 1998, Geologic Map of the New River SE 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-21.

Leighty, R.S., 1998, Compilation Geologic Map of the Daisy Mountain 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-22.

deposition will also begin to erode and develop new tributary channel networks, creating a greater degree of relief between the channel bottoms and the ridges that separate them.

Because many of these characteristics take thousands of years to develop, it can be concluded that surfaces that exhibit well-developed soils, red color, significant carbonate development, desert pavements composed of strongly varnished gravels, and tributary drainage networks have been relatively free from flooding and erosion for thousands of years. Therefore, without external disturbance, it can be assumed that the flood and erosion hazard potential in the future will remain low.

Digital black and white aerial photographs provided by the District were used in conjunction with field observations to distinguish older, more stable surfaces from younger, more active surfaces near the stream channels using the principles described in the preceding paragraphs. These data were used to estimate the potential for future lateral erosion; i.e. the youngest surfaces were considered most prone to erosion.

Comparison of channel position on historical aerial photographs. The position of the main channel thalweg of Rodger Creek was digitized from readily available historical aerial photographs and from the 7.5 minute USGS topographic quadrangles for the study area. A list of the historical aerial photographs used is shown in Table 2. The historical aerial photographs were scanned to create digital images that were then semi-rectified using AutoCAD 2000 software and the digital USGS quadrangles as the map base. A plot of the historical channel position in 1962 and 1999 is shown in Figure 45. In general, the channel position has not significantly changed during the approximately 40-year period of record. Two short reaches, one located between the 16th Street and 18th Street alignments and the other downstream of New River Road, exhibit movement of the thalweg over a braided, multiple-channel area. Comparison of the historical thalwegs in Reaches 4 and 5 does not indicate any past avulsive movement despite the presence of potentially avulsive overbank channels at present.

Table 2. Rodger Creek Erosion Hazard Evaluation
Historical Photographs and Maps

Year	Description	Scale	Source
1962	Black & white aerial photo (9-15-62)	1:24,000	USGS
1964	7.5 minute USGS topographic map	1:24,000	USGS
1971	Black & white aerial photo (7-23-71)	1:40,000	Landis
1988	Black & white aerial photo (12-12-88)	1:40,000	Landis
1992	Black & white aerial photo (9-6-92)	1:40,000	NAPP
1999	Color aerial photo (7-31-99)	1:20,000	AMC/FCDMC

Interpretation of detailed soils maps. Detailed soils mapping of the study area is available from the Soil Conservation Service (SCS).[1] Brief descriptions of the mapped soil units near Rodger Creek are provided in Tables 3 to 5. Engineering characteristics of the soils are listed in Table 5. Note that all of the soil units in the study area were

[1] Camp, P.D., 1986, Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona.

designated as fan terraces or hillslopes, and none were considered representative of drainageways or floodplains. In addition, as shown in Table 4, the soil classes for the units near Rodger Creek are typically associated with surfaces of early Holocene age (7-11 ka[1]). The relationship of surface age with soil class is supported by the presence of clay and caliche in the soil profiles as noted in Table 4. The portion of the SCS soils map near Rodger Creek is reproduced in Figure 46.

Designation of the soils in the study area as fan terraces might be erroneously interpreted to indicate that the erosion hazard outside the main channel is slight. However, the designation of fan terrace for these surfaces is probably more of a reflection of the macro-scale of the SCS mapping and unit descriptions than a precise interpretation of the existing surficial processes. Field evidence and the District's 100-year floodplain mapping clearly indicate potential inundation of a much broader surface than is designated by the SCS map units. The degree of soil development recorded by the SCS (Tables 3 to 5) does indicate that erosion of the areas outside the main channel corridor has been relatively rare during the past 7,000 years, and has generally been confined within the floodplain for the past 250,000 years.

SCS soil unit boundaries are provided in digital format with the AutoCAD deliverable for this study. The SCS soil unit boundaries and surficial geology units mapped by the Arizona Geological Survey are complexly intertwined. Differences between the two maps are probably due to the extent of exposed bedrock and multiple terraces along Rodger Creek, the scale of mapping, the different objectives of mapping by AZGS and SCS, and interpretation by the mapper.

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[1] ka = thousand years


Figure 45. Rodger Creek
Historical Channel Position
1962 - 2000
Thalweg - 1962
Thalweg - 1964
Thalweg - 1971
Thalweg - 1988
Thalweg - 1992
Thalweg - 1999
Thalweg - 2000
Skunk Creek
Roads
LIMIT OF STUDY
Rodger Creek
Skunk Creek
Scale
0
2000
4000
1 Inch = 2000 Feet
N

Figure 46. Rodger Creek Soil Distribution

Table 3. Rodger Creek Erosion Hazard Assessment SCS Soils Information: Description, Classification, & Geomorphic Setting				
SCS Map Unit	**Component Soil Series**	**Position/Landform**	**Key Characteristics**	**Subgroup/Order**
Carefree Cobbly Clay Loam (12)	Carefree – 80%	On fan terraces	Calcareous pink surface layer, reddish-brown calcareous subsurface layer Main limitation for development is shrink swell potential	Vertic Haplargid Typic Durargid
Continental Cobbly Clay Loam (26)	Continental – 85%	On fan terraces	Light brown calcareous cobbly clay loam surface layer, light brown to brown calcareous clay subsurface layer Main limitation for development is shrink swell potential	Typic Haplargid
Ebon very Gravelly Loam (44)	Ebon – 80%	On fan terraces	Brown very gravelly loam surface layer, yellowish red very gravelly clay and calcareous very gravelly sandy clay subsurface layer, with white calcareous gravelly loamy sand substratum Few limitations for development, except slow percolation rate	Typic Haplargid
Gachado-Lomitas-Rock Outcrop Complex (52)	Gachado – 45% Lomitas – 20% Rock – 20%	On mountain and hill slopes	Gachado: light brown very gravelly loam surface layer, brown very gravelly clay loam subsurface layer; bedrock at depth of 7 inches Lomitas: brown very gravelly sandy loam, strong brown very gravelly sandy loam; bedrock at depth of 10 inches Rock: andesite, rhyolite, & tuff Main limitation to development is shallow bedrock and slope	Lithic Haplargid Lithic Camborthid
Greyeagle-Suncity Variant Complex (66)	Greyeagle – 55% Suncity Variant – 30%	On fan terraces	Greyeagle: pink calcareous very gravelly loam surface layer, brown calcareous gravelly sandy loam subsurface layer; hardpan at depth of 10 inches Suncity Variant: brown calcareous very gravelly sandy loam surface layer, brown calcareous gravelly clay loam subsurface layer; hardpan at depth of 9 inches. Main limitation to development is depth to hardpan	Typic Durorthid Typic Durargid
Lehmans-Rock Outcrop Complex (72)	Lehmans – 45% Rock – 30%	On mountain and hill slopes	Lehmans: reddish brown very gravelly clay loam, reddish brown clay and clay loam subsurface layer; bedrock at depth of 20 inches. Rock: basalt, andesite, rhyolite, tuff, & agglomerate Main limitations to development are shrink swell potential, shallow bedrock, and slopes	Lithic Haplargid
Nickel-Cave Complex (93)	Nickel – 50% Cave – 35%	On fan terraces	Nickel: pinkish gray calcareous gravelly sandy loam surface layer, pinkish gray very gravelly loam subsurface layer, with white calcareous very gravelly loamy sand substratum Cave: light brown calcareous gravelly loam surface layer, pinkish gray calcareous loam subsurface layer; hardpan at depth of 14 inches. Main limitations to development are slope and depth to hardpan in Cave soils	Typic Calciorthid Typic Paleorthid

Table 3 (cont.). Rodger Creek Erosion Hazard Assessment SCS Soils Information: Description, Classification, & Geomorphic Setting				
SCS Map Unit	**Component Soil Series**	**Position/Landform**	**Key Characteristics**	**Subgroup/Order**
Pinaleno-Tres Hermanos Complex (96)	Pinaleno – 45% Tres Hermanos – 40%	On fan terraces	Pinaleno: yellowish red very gravelly clay loam surface layer, yellowish red calcareous gravelly clay loam and light brown calcareous gravelly loam subsurface layers, with light brown calcareous loam substratum; buried soil below substratum in some areas Tres Hermanos: reddish yellow gravelly loam surface layer, reddish yellow calcareous loam and yellowish red calcareous gravelly clay loam subsurface layers, with white weakly to strongly lime-cemented very gravelly loam substratum Few limitations for development in Pinaleno soil; main limitation for development in Tres Hermanos soil is shrink swell potential	Typic Haplargid Typic Haplargid
Pinamt-Tremant Complex (98)	Pinamt – 45% Tremant – 35%	On fan terraces	Pinamt: brown calcareous very gravelly sandy clay loam surface layer, brown calcareous very gravelly loam subsurface layer Tremant: reddish yellow gravelly loam surface layer, reddish yellow and yellowish red calcareous sandy clay loam and gravelly clay loam subsurface layer Main limitation for development of Tremant is shrink swell potential; few limitations for Pinamt	Typic Haplargid
Suncity Cipriano Complex (110)	Suncity – 55% Cipriano – 30%	On fan terraces	Suncity: brown gravelly loam surface layer, reddish brown calcareous gravely clay loam subsurface layer. Hardpan at depth of 9 inches Cipriano: brown calcareous very gravelly loam surface layer, brown calcareous very gravelly loam subsurface layer over hardpan Main limitation for development is shallow hardpan	Typic Duragid Typic Durorthid

Table 4. Rodger Creek Erosion Hazard Assessment
General Soil Age & Relation of SCS and AZGS Map Units

SCS Map Unit	Subgroup/Order	Order	Minimum General Age Of Soil Order	AZGS Map Units
Carefree Cobbly Clay Loam (12)	Vertic Haplargid Typic Durargid	Aridisols	Early Holocene (7-11 ka)	Q_{lr} – Late Pleistocene River Terrace (10-250ka) Q_m – Middle Pleistocene Alluvium (250-750ka) T_{sy} – Late Miocene to Pliocene Conglomerate & Sandstone (> 2ma)
Continental Cobbly Clay Loam (26)	Typic Haplargid	Aridisols	Early Holocene (7-11 ka)	Q_m – Middle Pleistocene Alluvium (250-750ka) TQ_o – Pliocene Alluvial Fan Deposits (1-3ma)
Ebon very Gravelly Loam (44)	Typic Haplargid	Aridisols	Early Holocene (7-11 ka)	Q_m – Middle Pleistocene Alluvium (250-750ka) T_{sy} – Late Miocene to Pliocene Conglomerate & Sandstone (> 2ma)
Gachado Lomitas Rock Outcrop Complex (52)	Lithic Haplargid Lithic Camborthid	Aridisols	Early Holocene (7-11 ka)	X_f – Felsic metavolcanics (1600-2500 ma)
Greyeagle-Suncity Variant Complex (66)	Typic Durorthid Typic Durargid	Aridisols	Early Holocene (7-11 ka)	TQ_o – Pliocene Alluvial Fan Deposits (1-3ma)
Lehmans-Rock Outcrop Complex (72)	Lithic Haplargid	Aridisols	Early Holocene (7-11 ka)	Q_{ct} – Quaternary colluvium and talus (<2ma) TQ_o – Pliocene Alluvial Fan Deposits (1-3ma) T_{bl} – Chalk Canyon Formation (17-22ma) X_f – Felsic metavolcanics (1600-2500 ma) X_v – Intermediate to Felsic metavolcanics (1600-2500 ma)
Nickel-Cave Complex (93)	Typic Calciorthid Typic Paleorthid			Q_{mo} – Early to Middle Pleistocene Alluvial Fan Deposits (250ka - 1.6 ma)
Ohaco Gravelly Loam (95)	Typic Durargid	Aridisols	Early Holocene (7-11 ka)	Q_{mo} – Early to Middle Pleistocene Alluvial Fan Deposits (250ka - 1.6 ma) TQ_o – Pliocene Alluvial Fan Deposits (1-3ma)
Pinaleno-Tres Hermanos Complex (96)	Typic Haplargid Typic Haplargid	Aridisols	Early Holocene (7-11 ka)	Q_o – Early Pleistocene Alluvial Fan Deposits (750 ka - 1.6ma)
Pinamt-Tremant Complex (98)	Typic haplargids	Aridisols	Early Holocene (7-11 ka)	Q_{yr} – Holocene River Terrace (< 10ka) Q_{lr} – Late Pleistocene River Terrace (10-250ka) Q_m – Middle Pleistocene Alluvium (250-750ka)
Suncity Cipriano Complex (110)	Typic Duragid Typic Durorthid	Aridisols	Early Holocene (7-11 ka)	Q_m – Middle Pleistocene Alluvium (250-750ka) T_{sy} – Late Miocene to Pliocene Conglomerate & Sandstone (> 2ma)

Table 5. Rodger Creek Erosion Hazard Assessment
SCS Soil Unit Hazards

SCS Map Unit	Building Site Development Restrictions (Table 9)				Sanitary Facility Hazards (Table 10)	Flooding Hazard (Table 15)	Depth to Bedrock or Hardpan
	Shallow Excavation	Dwellings without basements	Local Roads	Lawns & Landscaping			
Carefree Cobbly Clay Loam (12)	Severe - Cemented pan	Severe – Shrink swell	Severe – Low strength, shrink swell	Severe – large stones	Clay; slope, percs slow, large stones	None	> 60 in (bedrock)
Continental Cobbly Clay Loam (26)	Moderate – too clayey	Severe – shrink swell	Severe – low strength, shrink swell	Slight	Percs slow,	None	> 60 in (bedrock)
Ebon very Gravelly Loam (44)	Severe – cut banks cave in	Moderate – shrink swell	Moderate – shrink swell	Severe – small stones	Percs slow, small stones	None	> 60 in (bedrock)
Gachado Lomitas Rock Outcrop Complex (52)	Severe – depth to rock; slope	Severe – depth to rock; slope	Severe – depth to rock; slope	Severe – small stones; slope; thin soil layer	Shallow rock, slope	None	4-20 in (bedrock)
Greyeagle-Suncity Variant Complex (66)	Severe – cemented pan	Severe – cemented pan	Severe- cemented pan	Severe –small stones, droughty, thin layer	Cemented pan, poor filter, large stones	None	4-20 in (hardpan)
Lehmans-Rock Outcrop Complex (72)	Severe - depth to rock, slope	Severe – shrink swell, slope, depth to rock	Severe – depth to rock, low strength, slope	Severe – small stones, slope, thin layer	Depth to rock, slope	None	6-20 in (bedrock)
Nickel-Cave Complex (93)	Severe – cut banks cave in, slope, cemented pan	Severe – slope, cemented pan	Severe – slope, cemented pan	Severe – slope, thin layer	Cemented pan, slope, seepage	None	4-20 in (hardpan)
Ohaco Gravelly Loam (95)	Severe – cemented pan	Severe – shrink swell	Severe – low strength, shrink swell	Moderate – small stones, thin layer	Cemented pan, percs slow	None	20-40 in (hardpan)
Pinaleno-Tres Hermanos Complex (96)	Slight	Slight to moderate – shrink swell	Slight to moderate – low strength, shrink swell	Moderate to severe – small stones, droughty	Percs slow, seepage, slope	None	> 60 in (bedrock)
Pinamt-Tremant Complex (98)	Slight	Slight to moderate – shrink swell	Slight to moderate – low strength; shrink swell	Moderate to severe – small stones	Percs slow, small stones	None	> 60 in (bedrock)
Suncity Cipriano Complex (110)	Severe – cemented pan	Severe – cemented pan	Severe – cemented pan	Severe – small stones, thin soil layer	Cemented pan, small stones	None	4-20 in (hardpan)

Interpretation of surficial geology maps. The surficial geology of the Rodger Creek watershed was mapped previously by the Arizona Geological Survey (AZGS).[1] A portion of the AZGS surficial mapping near Rodger Creek is provided in Figure 47. The AZGS mapping distinguishes the following eleven geomorphic surfaces and five exposed bedrock units in the vicinity of Rodger Creek.

- Active channel deposits (Q_{ycr}). The Q_{ycr} unit consists of river deposits younger than about 1,000 years found in the small active channels of Skunk Creek tributaries. The unit is characterized by unconsolidated, well-stratified, alluvium dominated by sand and silt with clasts ranging in size from pebbles to boulders. Channel surfaces are modern, but vegetated bars may be several hundred years old. There is no appreciable soil development in the unit's deposits. Q_{ycr} surfaces are prone to flooding.

- Holocene alluvium (Q_y). The Q_y unit consists of river deposits younger than about 10,000 years, and is generally found in small active channels and on low terraces. The unit is characterized by unconsolidated, stratified, poorly to moderately sorted sand, gravel, cobble and boulder deposits along the drainageways. Alluvial surfaces exhibit bar and swale topography, with the ridges typically being slightly more vegetated. Q_y surfaces typically lack desert varnish or pavement, and have a sandy loam mantle. Surface colors are usually light brown to yellowish brown, with slight reddening due to iron oxidation. Q_y surfaces are considered subject to flooding and erosion.

- Holocene river terrace deposits (Q_{yr}). The Q_{yr} unit consists of low terrace deposits that are less than 10,000 years old. The unit is characterized by unconsolidated, moderately to poorly sorted, subrounded to rounded sand and gravel in a silty matrix. The terraces mapped in this unit are typically 1 to 5 meters above active channels, and any fluvial landforms such as gravel bars are subdued. However, portions of these terraces have experienced inundation during historical floods, and margins of the terraces along active channels are prone to lateral migration. Weakly developed soils on the terraces are generally light brown to yellowish brown at the surface with slight reddening in the subsurface. Soil profiles have weak calcic horizons (<= Stage I). Q_{yr} surfaces are considered subject to flooding and erosion.

- Quaternary colluvium (Q_c). The Q_c unit consists of hillslope-covering unconsolidated to moderately consolidated colluvial deposits that are Holocene to Middle Pleistocene in age. The colluvium is variably coarse, subangular to

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[1] Leighty, R.S., and Holloway, S.D., 1998, Geologic Map of the New River SE 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-21.

Leighty, R.S., 1998, Compilation Geologic Map of the Daisy Mountain 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-22.

subrounded, poorly sorted, and weakly bedded. The unit grades into the colluvium-talus unit (Q_{ct}) upslope.

- Quaternary colluvium and talus (Q_{ct}). The Q_{ct} unit is found on steep hillslopes and consists of unconsolidated to moderately consolidated, weakly bedded, subangular to angular, poorly sorted sand and gravel. The age of the colluvium and talus is Holocene to Middle Pleistocene. The unit typically grades into the colluvium unit (Q_c) downslope.

- Late Pleistocene river terrace deposits (Q_{lr}). The Q_{lr} unit consists of moderately old (10,000 to 250,000 years old) terrace deposits of Cave Creek, Apache Wash, and Skunk Creek. The unit is characterized by unconsolidated, moderately to poorly sorted, subrounded to rounded sand and gravel in a sandy to silty matrix. The terraces mapped in this unit are typically 2 to 15 meters above the modern channels. Desert pavement and varnish on Q_{lr} surfaces ranges from nonexistent to moderately developed. Soil profiles as observed have moderate clay accumulation and carbonate development (Stage II), although there is no cementation. The Q_{lr} surfaces are not prone to flooding, but where the surface is adjacent to active channels, lateral bank erosion is possible.

- Middle Pleistocene alluvium (Q_m). The Q_m unit consists of relict alluvial fan and river terraces greater than 250,000 years old. The unit is characterized by tan, sandy to loamy materials with sand- to boulder-sized clasts. Q_m surfaces have generally been eroded into shallow valleys and ridges due to development of an internal drainage pattern. The surfaces typically have moderate to strongly developed desert pavement and varnish, except where surface erosion has removed them, and are brown to reddish brown. The soils are strongly developed with reddened argillic horizons and stage II-IV calcic horizons. Q_m surfaces are generally not flood prone. The unit has been divided into older Q_{m1} and younger Q_{m2} surfaces.

- Middle Pleistocene river terrace deposit (Q_{mr}). The Q_{mr} unit consists of relict river terraces of the New River greater than 400,000 years old. The unit is characterized by unconsolidated, moderately to poorly sorted, subrounded to rounded sand and gravel in a silty matrix. The deposits also include rounded and subrounded basalt boulders up to 1.5 meters in diameter. Soil profiles are clay-rich with well-developed caliche horizons.

- Early to Middle Pleistocene alluvial fan deposits (Q_{mo}). The unit is comprised of alluvial fan and terrace deposits 250,000 to 1,600,00 years old. The unit is characterized by unconsolidated, moderately to poorly sorted, subrounded to rounded sand and gravel in a sandy to silty matrix.

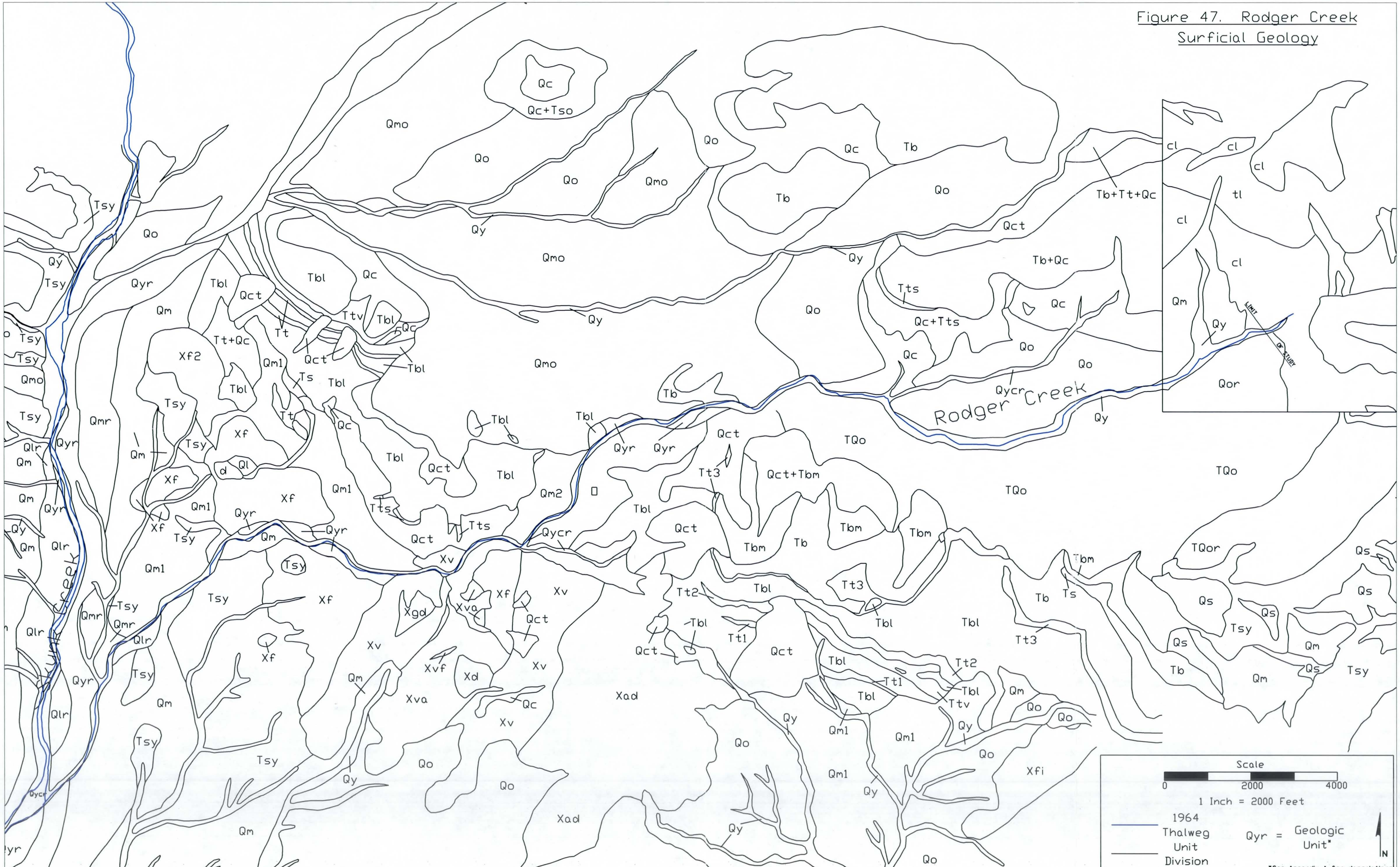

Figure 47. Rodger Creek Surficial Geology

- Early Pleistocene alluvial fan deposits (Q_o). The Q_o unit is comprised of alluvial fan and terrace deposits 750,000 to 1,600,00 years old. The brown, sandy to loamy conglomerates are moderately consolidated and commonly indurated by soil carbonate. Soil profiles on preserved alluvial surface remnants include moderately- to well-developed reddish-brown argillic horizons.

- Pliocene to Early Pleistocene alluvial fan deposits (TQ_o). The TQ_o unit consists of very old alluvial fan deposits approximately one to three million years old. The deposits are sandy and include abundant basalt cobbles and boulders. Soils on the relict fan are generally brown and clay-rich with cemented petrocalcic horizons exposed in beds of shallow gullies (including the most upstream reach of Rodger Creek.)

- Middle to Late Tertiary basin-fill conglomerate (T_{sy}). The T_{sy} unit consists of "basin-fill" conglomerate and sandstone of late Miocene to Pliocene age. Sand- to boulder-sized clasts are arranged in a grussy[1], carbonate-rich matrix. The larger clasts are typically more rounded than the smaller clasts. This unit is generally covered by Quaternary deposits but exposed along drainageways.

- Early to Middle Miocene basaltic rocks, undivided (T_b). The T_b unit is composed of basaltic lava flows intermixed with scoria basalt-related breccia, and volcanic sandstone. The basalt forms resistant hills. The unit is probably correlative with the Chalk Canyon formation (see below).

- Chalk Canyon formation (T_{bl}). The Chalk Canyon formation is composed of dark gray to purplish red basaltic lava flows interbedded with numerous tuff layers. The unit is dated to the Early Miocene (22 to 17 million years old.)

- Felsic metavolcanic rocks (X_f). The X_f unit is composed of red to brick red, medium- to fine-grained felsic metavolcanic rock. This unit is Early Proterozoic in age.

- Intermediate to felsic metavolcanic rocks (X_v). The unit is composed of complex interbedded tuffs and flows of andesite, dacite, and rhyolite. The fine- to medium-grained andesites range in color from green and olive drab to brown and reddish brown. The interbedded rhyolites are typically fine-grained. Occasional thin, fine-grained, tan to reddish layers are probably felsic tuff or sedimentary beds.

AZGS map unit boundaries are provided in digital format with the AutoCAD deliverable for this study. Correlation of AZGS map units and SCS soils map units were discussed above. For the purposes of this study, the Q_y and portions of the Q_l surfaces were

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[1] Gruss is highly weathered bedrock, typically granite, broken into small pebble-sized pieces.

considered to be subject to some risk of lateral erosion, channel avulsion, or erosion by concentration of overbank flooding.

Interpretation of regional geology. Surficial geology mapping[1] and field observations were used to make the following preliminary interpretation of the geologic history of the study area. The upper reach of Rodger Creek flows across a relict alluvial fan[2] that was formed during Pliocene to Middle Pleistocene time (250ka - 3 ma) by deposition of sediments derived from the Rodger Creek watershed. The relict fan surface is divided into three distinct surfaces of differing age: Pliocene to early Pleistocene, Early Pleistocene, and Early to Middle Pleistocene.

Downstream of the fan system Tertiary and Early Proterozoic lava flows and metavolcanic rocks confined Rodger Creek laterally, and in some locations vertically. The flow of Rodger Creek between the bedrock confines deposited alluvial material, probably partially derived from the fan surfaces, during Middle Pleistocene times (> 250ka).

During the late Pleistocene (10–250 ka) and Holocene (<10ka), Skunk Creek became incised, which prompted Rodger Creek to adjust to a series of new base levels. The first adjustment resulted in a Late Pleistocene age terrace level currently manifested near Rodger Creek's confluence with Skunk Creek. Subsequently, Rodger Creek entered a depositional phase lasting into the Holocene. A second period of incision and terrace formation occurred during the Holocene. The resulting terraces are located within the bedrock-confined reaches of Rodger Creek.

Present geomorphic features in the downstream reaches of Rodger Creek below New River Road suggest that Rodger Creek is adjusting to a more recent lowering of Skunk Creek. Bank height gradually increases in the downstream direction in the lower reaches, whereas in the upper reaches bank height remains fairly constant on average. Likewise, the presence of headcuts in the most downstream reaches indicates an active adjustment to a lower base level.

Analysis of longitudinal profile. The longitudinal profile is a plot of the channel elevation versus distance along the stream bed (Figure 48). Analysis of the longitudinal profile can be used to identify slope irregularities, over-steepened or over-flattened reaches, headcuts, and areas of natural grade control. The longitudinal profile also provides some information on expected lateral stability. Reaches with lower slopes than adjacent reaches will experience net deposition, and bank erosion associated with

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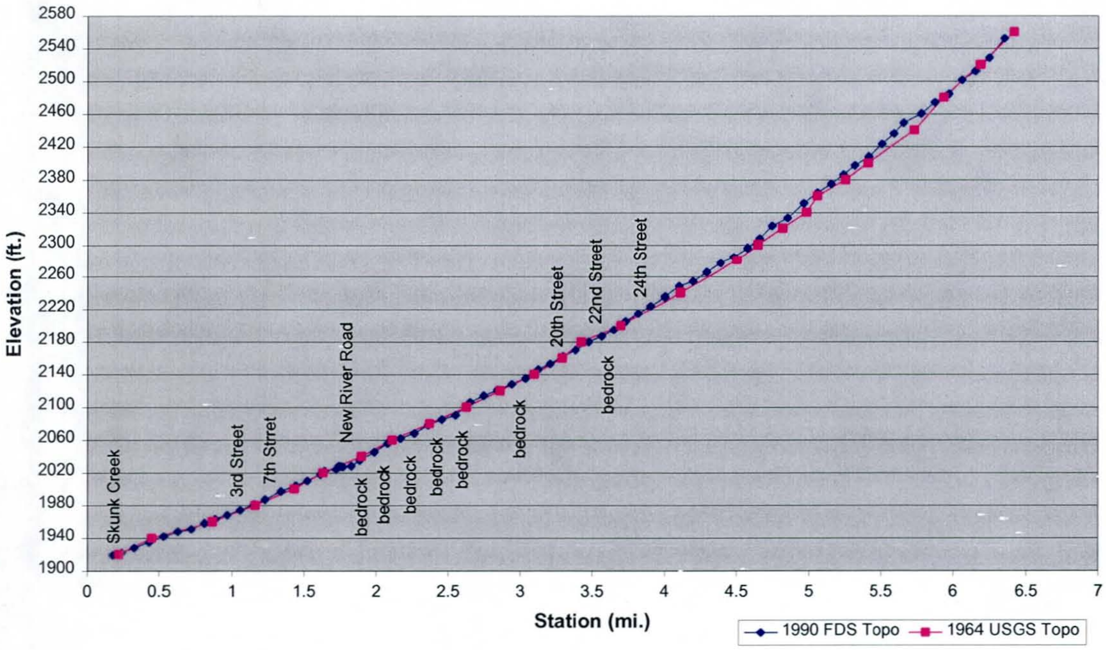
[1] Leighty, R.S., and Holloway, S.D., 1998, Geologic Map of the New River SE 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-21.

Leighty, R.S., 1998, Compilation Geologic Map of the Daisy Mountain 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-22.

[2] The Q_m surface on the AZGS surficial geology maps represents the boundaries of the middle Pleistocene relict fan.

braiding and avulsions. Reaches with steep slopes typically experience high velocities and high rates of sediment transport associated with bank shear or degradation.

Figure 48. Rodger Creek Longitudinal Profile



The following conclusions about lateral stability and erosion hazards can be drawn from the longitudinal profiles of Rodger Creek shown in Figure 48:

- Shape. The Rodger Creek longitudinal profile has concave up shape, which is the typical profile for an alluvial river.

- Profile comparison. Despite the difference in contour interval and map scale, the 1964 and 1990 profiles are nearly identical, except in the reach upstream of 24th Street where the 1990 profile indicates a higher elevation than in 1964. It is not likely that this difference is due only to differences map accuracy, since the discrepancy in bed elevations is slightly greater than the vertical accuracy of the USGS mapping (±10 feet). However, no physical evidence of significant long-term aggradation in this reach was observed in the field. At this time, no completely satisfactory explanation of the elevation differences for the longitudinal profiles of the reach upstream of 24th Street exists. Throughout the rest of the study area, the two longitudinal profiles indicate that no significant long-term aggradation or degradation has occurred, a conclusion supported by field observations.

- Perturbations. There are no significant breaks in the 1990 or 1964 longitudinal profile of Rodger Creek.

Application of Allowable Velocity Guidelines. Allowable velocity criteria have long been used in channel design to estimate the velocity at which channel bed and bank sediments will begin to erode. A variety of allowable velocity data have been published by the Corps of Engineers (1970, 1990, 1995) and the Soil Conservation Service (1977), as well as by many other agencies.

The Corps of Engineers (1970; 1995) has established suggested maximum velocities for design of non-scouring flood control channels of various bank materials, as shown in Table 6. In general, the banks of the streams in the study area are composed of silty fine sand with intermixed cobbles and are covered with brush and woody vegetation. Very few banks were observed to have sufficient grass cover. The average floodway velocities derived from the Michael Baker (1990) FDS maps indicate that the erosive threshold for the bank material will be exceeded during the 100-year event, as shown in Table 7. No information on expected velocities for the 2-, 10- or other recurrence intervals was readily available, but should be included if more detailed erosion hazard evaluations are conducted. Bed sediments observed in the field indicated that up to boulder-sized material is transported during bankfull events.

Table 6. Rodger Creek Erosion Hazard Evaluation
Suggested Maximum Permissible Mean Channel Velocities (USACOE, 1995)

Channel Material	Mean Velocity (ft/sec)
Fine Sand	2.0
Fine Gravel	6.0
Grass-Lined Banks (< 5% Slope, Sandy Silt, Bermuda Grass)	8.0
Poor Rock (Sedimentary)	10.0

Table 7. Rodger Creek Erosion Hazard Analysis
FDS 100-Year Floodway Velocities

Stream Segment	Average Velocity (ft/s)	Maximum Velocity (ft/s)
Reach 1 – Upstream of R-2 Tributary	6.1	8.1
Reach 2 – R-2 tributary to approximate 17th Street alignment	4.6	6.2
Reach 3 – Approximate 17th Street alignment to New River Road	5.4	7.2
Reach 4 – New River Road to 3rd Street	4.5	6.0
Reach 5 – 3rd Street to Skunk Creek confluence	4.2	5.6

The allowable velocity information summarized above indicates that bank erosion should be expected during the 100-year event, particularly where the stabilizing bank vegetation is removed.

Application of State Standard SSA 5-96. State Standards for floodplain management have been adopted by the Arizona Department of Water Resources (ADWR) as the minimum required regulatory policy in the State of Arizona under the authority of Arizona Revised Statutes 45-3605(a). SSA 5-96 (ADWR, 1996), adopted in 1996, describes a methodology for estimating an erosion setback to account for the lateral instability of Arizona streams. The SSA 5-96 Level 1 Methodology is based on the following two equations:

$$SB = 1.0*(Q_{100})^{0.5} \qquad \text{Eq'n \#1}$$
$$SB = 2.5*(Q_{100})^{0.5} \qquad \text{Eq'n \#2}$$

Where SB = Erosion hazard setback distance (ft.)
Q_{100} = 100-year peak discharge (cfs)

According to SSA 5-96, equation #1 is intended for stream segments that are straight or have "minor curvature." Equation #2 is intended for stream segments with "obvious curvature." Obvious curvature is defined as a channel centerline with a radius of curvature less than five times the channel topwidth. Other guidelines and limitations for the SSA 5-96 Level 1 Methodology are summarized in Table 8. In general, the SSA 5-96 methodology is applicable to the streams in the study area.

Table 8. Rodger Creek Erosion Hazard Evaluation
SSA 5-96 Setback Guidelines and Limitation Study Area Condition

SSA 5-96 Assumption	Rodger Creek
Drainage area < 30 mi.^{2}?	Yes. Drainage area = 5.0 mi^2
Significant channel filling?	No. Profile appears stable in recent history
Local mining?	No. No significant in-stream mining
Channel modifications?	Very few. Road crossings, fences
Massive channel shifting?	No. Photos indicate only minor recent shifting
Channelization?	No. Mostly natural channel except at road crossings

For the study area, channel curvature was measured on plots of digital aerial photographs provided by the District. 100-year discharge estimates were obtained from the Michael Baker, Inc., Floodplain Delineation Study for Rodger Creek (1990). The results of the SSA 5-96 Level 1 Methodology for Rodger Creek are shown in Table 9. The SSA 5-96 Level 1 setbacks were applied from the channel bank or the floodway, whichever was further from the channel centerline, as per the SSA 5-96 Level 1 Methodology. SSA 5-96 Level 1 setbacks for each of the three stream segments are shown on Exhibit 2.

Table 9. Rodger Creek Erosion Hazard Evaluation
SSA 5-96 Setbacks

Reach Limits for Q100 Value (Cross Section # on FDS Work Map)	Q100[1] (cfs)	Erosion Setback Distance (ft)	
		Straight Chl	Curved Chl
4.481 – 6.349 Upstream of R-2 Tributary	6170	78	196
2.458 – 4.389	5450	74	185
0.179 – 2.363	2890	54	134

Notes: 1. Source of discharge estimates – FDS work maps (Michael Baker, 1990)
2. The recommended setback is shown in Exhibit 2

Summary

Based on the types of analyses described above, the recommended erosion hazard zone (EHZ) was delineated for Rodger Creek. Within the recommended erosion hazard zone, there is risk of lateral migration, however minimal, as well as erosion caused by overbank flow concentration, diversion of overbank flows, and impact by shallow flooding. It is recommended that no development occur within the recommended erosion hazard zone without engineered bank protection, or without a detailed engineering and geomorphic analysis of the potential impacts of bank protection on adjacent reaches. The recommended erosion hazard zone, shown in red on Exhibit 1, was delineated using the following principles:

- 100-year floodplain. The EHZ generally corresponds to the location of the 100-year floodplain, except where the 100-year floodplain consists only of backwater areas and where bedrock is exposed along the banks.
- Bedrock. The EHZ significantly narrows regardless of the floodplain width where bedrock is exposed along the banks of Rodger Creek.
- Shallow floodplain. The EHZ hazards are greatest where the floodplain terrace elevation is close to the channel bed elevation, and the risk of flood inundation is highest.
- Geomorphic surfaces. The EHZ generally includes the youngest geomorphic surfaces (Q_y and Q_l) and excludes the older geomorphic surfaces (Q_m), except where the main channel abuts an older surface and a cut bank is present. In the latter case, a buffer distance is included within the EHZ.
- Development. The EHZ attempts to include the impact of development in the floodplain. Floodplain development may concentrate or redirect overbank flooding and cause excessive scour.
- Field judgment. The EHZ reflects the judgment of the project geomorphologist's interpretation of the field conditions with respect to future erosion potential.

Appendix A – Surficial Geology Unit Descriptions

Rodger Creek Surficial Geology Unit Descriptions

cl	colluvium and weathered bedrock
d	disturbed area
Qs	alluvium, undivided
Qy	Holocene alluvium
Qycr	Active channel deposits
Qyr	Holocene river terrace deposits
Qc	Quaternary colluvium
Qct	Quaternary colluvium and talus
Ql	Late Pleistocene alluvium
Qlr	Late Pleistocene river terrace deposits
Qm	Middle Pleistocene alluvium
Qmo	Early to Middle Pleistocene alluvial fan deposits
Qmr	Middle Pleistocene river terrace deposits
Qm2	Younger Middle Pleistocene alluvium
Qm1	Older Middle Pleistocene alluvium
Qo	Early Pleistocene alluvial fan deposits
Qor	Early Pleistocene river terrace deposits
Tb	basaltic rocks, undivided
Tbl	Chalk Canyon Formation
Tbm	Hickey Formation
tl	talus deposits
TQo	Pliocene alluvial fan deposits
TQor	Pliocene river terrace deposits
Ts	conglomerate and sandstone
Tsy	'basin-fill' conglomerates
Tt	tuff
Tts	tuff and tuffaceous sandstone
Tt2	Middle Early Miocene tuff
Tt3	Upper Early Miocene tuff
Xad	andesite-diorite complex
Xf	felsic volcanics
Xf2	additional felsic volcanics
Xgd	granodiorite
Xv	intermediate to felsic volcanics
Xva	andesite and basalt volcanics
□	not described

Appendix B – Field Photograph Descriptions

Rodger Ck Erosion Zone Assessment 12/8/00

M. Kenzo + B. Dillard

Starting downstream from New River Rd. Bridge

RC1-1 View Downstream from New River Rd Bridge, note Boulders up to 1.5' diameter well vegetated banks

RC1-2 View D/S Note flotsam line on RB ~3.5-4.0 ft water depth

RC1-3 View D/S from in steeply sloping reach note boulders + cobbles, well vegetated banks

RC1-4 View of LB; 2-2.5' diameter mesquite well vegetated banks

RC1-5 View at RB looking U/S of second channel on right side of flow path, bank ~5.5-6' hi

RC1-6 View D/S in "pool" - finer seds. well vegetated banks ~5' hi

RC1-7 At grade road crossing - not much effect on stream - "pool" U/S ? - old mattress

RC1-8 Second chl encounters main channel - view U/S - overbank concentration?

RC1-9 View D/S of Scour hole - note exposed roots; bank 5-6' high - flotsam at bank level; note ~1' diameter boulders dumped rocks behind B. Dillard

RC1-10 View over right overbank toward house 2-3' above floodplain

RC1-11 Flow path against left side hill

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RC1-20	Old msq. exposed roots, ~5' degrade from orig ground - lateral erosion suggested by roots exposed in chl.
	View of LB main chl, looking somewhat D/S
RC1-21	View U/S at 2' headcut also note exposed roots at photo right
RC1-22	View D/S from headcut note vertical cut? bank on LB
RC1-23	View D/S where splits come together note widening of channel
RC1-24	View U/S at split channel
RC1-25	View at RB caliche cutbank ~7' high; caliche throughout vertical bank, depositional "floodplain" bank in front of vert. wall
RC1-26	View D/S at scour hole ~4' deep
RC2-1	Bedrock on LB and in channel at road crossing
RC2-2	View D/S note encroachment (junk) at right
RC2-3	View U/S at bedrock RB, scour hole
RC2-8	ignore on X-Sec 2 ?
RC2-8	View D/S at road crossing
RC2-9	Weak caliche bank + exposed roots bank to bottom of tree trunk is ~5' high
RC2-10	View D/S Note widening of single chl

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RC2-11	Brooke next to the biggest Saguaro he's seen in his entire life
RC2-12	View D/S of bedrock on LB
RC2-13	View D/S typical straight reach in lower Ck well vegetated banks; boulder bed with sands; banks 3-4' high
RC2-14	View U/S at headcut/scour hole ~3' deep
RC2-15	View D/S typical straight reach
RC2-16	View of RB cutbank; boulders weak caliche? sandy; ~4' high
RC2-17	View of old surface, looking south
RC2-18	View D/S caliche bank on LB
RC2-19	View of RB note cut bank, exposed roots
RC2-20	Caliche at toe of bank provides some grade control, stability against lateral migration
RC2-21	View D/S, caliche in chl bed and LB
RC2-22	View U/S into Rodger Creek secondary chl
RC2-23	View U/S along the RB not much of a channel
RC2-24	View U/S and toward LB House is not more than 3 ft above bed of creek

Talked to guy in home - he says the creek has filled in - agraded - lived here for three years had to sandbag in early November

RC2-25	View U/S toward LB undermined concrete bank protection

p.4 Rodgen Creek

RC3-4	View U/S from New River Rd Bridge note bouldery bed, well vegetated banks RB ~2' hi, LB 5' hi
RC3-5	Well vegetated gently sloping bank bank proper is ~2' tall max elev is ~5' above bed View U/S of RB
RC3-6	Heavily vegetated channel - bad for efficient flow of water - back up? View U/S
RC3-7	View U/S at road crossing; road 1' above to at grade of channel bed; road made of concrete slabs
RC3-8	View U/S of bedrock extending into channel Note water mark on bedrock
RC3-9	View U/S + RB of bedrock cliff ~8-10' tall
RC3-10	View U/S along for LB of Rodgen Creek splits
RC3-11	View U/S at LB of scour hole ~3' deep
RC3-12	View U/S of boulder riffle, note elevation drop and bedrock on RB (photo left)
RC3-13	Cool water marks on boulders

Rodgen Creek M. Henze B. Dilland 12/19/00

RC4-19	Right overbank looking NNE
4-20	View U/S Bedrock dominated chl - bed and RB (photo left)
4-21	View up right bank
RC5-5	View of RB slightly looking U/S on region slope breaks - gradual change to non-welded surface
5-6	View U/S along RB note mature saguaros and scour hole ~2½' deep
5-7	View of RB - caliche cut bank - exposed p.v. roots ~2' lateral change
5-8	View U/S on LOB toward coral (possibly visible) f/p type deposits on overbank - margin w/in photo
5-9	View U/S Bedrock control on bed and RB (photo left)
5-10	View @ RB note mature saguaros
5-11	View U/S at BR outcrop on RB scour hole ~2' deep
5-12	View U/S at LB fairly straight reach, but has scour hole? ~1½' deep
5-13	View D/S heavy veg in chl
5-14	View U/S toward RB note pipeline crossing; small inset floodplain, and proximity of mature saguaros to channel
5-15	View U/S on ROB note rise in background at saguaro evidence of concentrated flow on surface - cobbles

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RC 5-16 View at LB bed (loose) rhyolite breccia under caliche layer

5-17 View U/S at rhyolite breccia bed and LB loose - source of sediment D/S

5-18 Caliche cap over rhyo. breccia. LB ~ 15-20' tall

5-19 View of basalt vein through breccia w/ caliche cap.

5-20 Close up of contact zone

5-21 View D/S in rhyolite breccia zone

5-22 View U/S note saguaros in center of frame just budding its 1st arm; looking U/S into overflow channel - main chl on river right (photo left)

5-23 View U/S note boulder bed, deposition of fines on RB (photo left) ~ 2' high

5-24 View west on ROB looking at margin of deposition and older surface

5-25 View D/S along RB cutbank note tree w/ exposed roots; caliche in bed; cut bank 4.5-5' high

RC 6-1 View D/S at split

6-2 View D/S at fence + at grade road crossing

6-3 View at RB Reinforced bank for road

6-4 View at f/p bank on River left

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RC 6-5 View D/S. Note boulder bed; multi-arm saguaros on RB; RB ≈ 6' hi; thick veg banks

6-6 View at ROB f/p; caliche cliff/hillslope in background

6-7 Close up of house on fill atop caliche cliff

6-8 View U/S at slope break / scour hole

6-9 View D/S at RB caliche cutbank

6-10 View U/S at RB caliche cutbank ~12' high; scour line ~3' hi; note dead saguaro and exposed roots along edge of cutbank

6-11 View U/S at boulder 'dike' d/s of road crossing

6-12 Riprap on D/S side of road crossing, LB

6-13 View D/S of large 4' boulders in bed

6-14 View D/S at "fill (bed veg); house v. close to ck

6-15 View U/S at Road crossing; 3' drop on D/S side; at grade on U/S side

6-16 View U/S; note well-veg banks

6-17 View at Roadcut on LOB older well vegetated surface abandoned f/p?

6-18 View at RB Road fill

6-23 View at RB + D/S note bedrock at base; large boulders

6-24 View U/S at Road crossing; fence u/s of rd

6-25 View D/S at " ; " "

p 8. Rodger Creek

RC7-1	View of surface on LOB
7-2	View U/S @ RB note sag. ~6' above bed
7-3, 7-4	narrow boulder chl View US wide flp
7-5	View U/s toward RB floodplain bank ~2-3' hi
7-6	View D/S on ROB
7-7	View U/S veg chl + well veg banks
7-8	View @ confluence
7-9	View across OB chl towards LB terrace
7-10	View U/S narrow chl ~6-8'; f/p on ROB
7-11	View u/s at confluence trib on photo right is higher than main chl by 2-3'; lots of veg in chl
7-12	View U/S what Creek? trib D/S must contribute a lot of flow; 1.5' dp, 4-6' across at most
7-13	View U/S
7-18	View u/s
7-19	View D/S of caco3 bounds ~2-3' below surrounding surface
7-20	View U/S