CHANNEL CHANGE IN SOUTHERN ARIZONA--
IMPLICATIONS FOR FLOODPLAIN MANAGEMENT

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Frequent changes in morphology and position of alluvial channels of ephemeral streams create uncertainties for floodplain management in the semi-arid southwestern United States. Federal floodplain management regulations, which form the basis for local floodplain management, are primarily concerned with overbank flooding. In the Southwest, however, channel bank erosion and lateral channel migration often present hazards of equal or greater magnitude than overbank flooding, yet they are not adequately addressed in the federal regulations nor often brought to the attention of communities enacting floodplain management programs. Frequent channel changes also lead to erroneous flood hazard delineation, when it is based on standard engineering procedures that utilize rigid channel boundary models. Instability of channel configurations leads to variability in the areal extent of inundation during the 100-year and lesser floods.

This study documents channel change along an alluvial stream system and presents steps taken by one community to regulate urban development adjacent to such stream systems. The Rillito Creek system of Pima County, Arizona, consisting of Rillito Creek and major tributaries Pantano Wash and Tanque Verde Creek, was chosen for study because of severe channel bank erosion in recent years within the rapidly expanding Tucson metropolitan area. Encroachment of urban development onto the floodplains of this stream system has resulted in widespread erosional damage to public facilities, commercial/ industrial structures, and private residences.

The Rillito Creek system drains approximately 934 square miles (2419 square kilometers) of southeastern Arizona (see Figure 1). The watershed consists of large lowland areas surrounded by mountains, with elevations ranging from 2200 feet (690 m) to 9450 feet (2880 m). Vegetal cover varies from the Sonoran Desert communities of creosote bush, desert saltbush, and cacti in the lower-lying basin and foothill areas, to evergreen forest at the

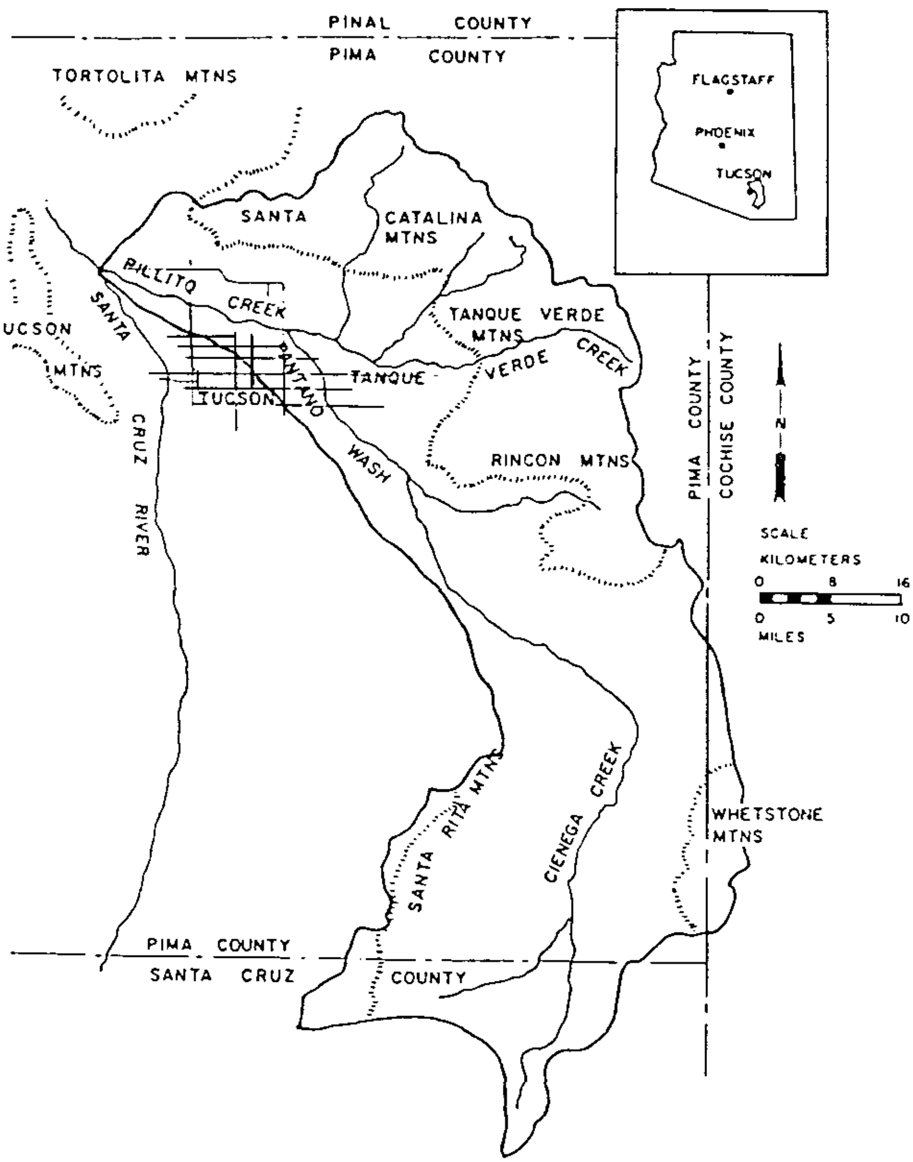


FIGURE 1. Map of the Rillito Creek watershed.

highest elevations (Schwalen, 1942; Turner, 1974). Mean annual precipitation increases with elevation, ranging from approximately 10.5 inches (267 mm) to 37.5 inches (953 mm) (Grove, 1962).

There is usually rainfall during two distinct seasons, summer and winter, separated by dry periods. Summer storms typically consist of thunderstorms of limited areal extent that result from surges of moist tropical air from the Gulf of Mexico and the Pacific Ocean (Durrenberger and Wood, 1979; Sellers and Hill, 1974). Winter rainfall, which tends to cover larger areas and be of longer duration, originates from low-pressure systems and cyclonic storms from the Pacific Ocean. Remnants of tropical storms also drift northward into Arizona in August, September, and early October, and occasionally produce large amounts of precipitation and sizable floods (Durrenberger and Wood, 1979).

Streamflow Characteristics

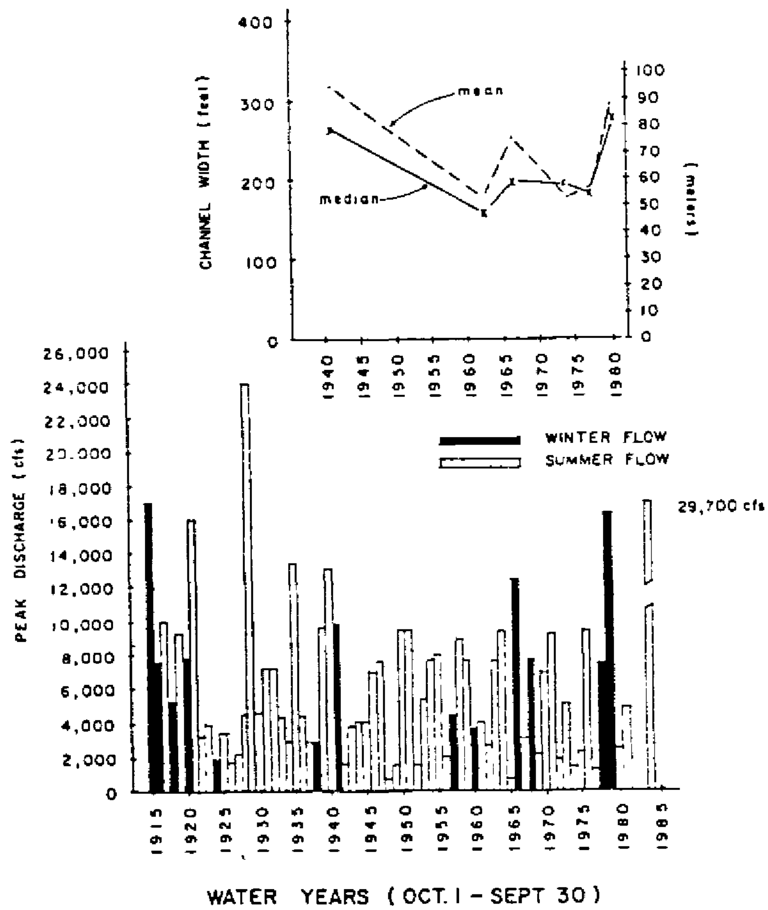
As in all semiarid regions, streamflow in the Rillito Creek system is extremely variable, due primarily to differences in watershed topography and to the temporal and spatial distribution of rainfall. Annual peak flow records are generally dominated by low flows with a few years of high flows (see Figure 2).

At least two distinct flow regimes are present in the Rillito Creek system. Summer flows are characterized by high peak discharges and short durations. Winter flows are usually of lower peak discharge but longer duration. Pantano Wash flows primarily in response to intense local summer thunderstorms and carries sediment loads consisting mainly of fine grain sizes from the large sedimentary basin areas that it drains (Saarinen et al., 1984). In contrast, Tanque Verde Creek conveys more winter flow that includes snowmelt runoff and coarser sediment sizes from the predominantly mountainous areas of its watershed. The more equitable distribution of summer and winter flow and coarse sand load of Rillito Creek are the result of the combined contributions of the Pantano Wash and Tanque Verde Creek drainages. Extreme flow events resulting from summer tropical storms or extended periods of heavy winter precipitation, typified by high peak discharges, prolonged durations, and high sediment loads, may constitute a third flow regime (Keith, 1981).

Historical Channel Change

Channel change within the Rillito Creek system since 1941 has been characterized by prolonged periods of channel narrowing interrupted by abrupt episodes of locally severe channel bank erosion and general channel widening

FIGURE 2. Variations in the mean and median widths of Rillito Creek from 1941 to late 1979 (upper graph) correlated with annual peak flows recorded at the Rillito Creek near Tucson gauging station (lower graph).



(Pearthree, 1982). Aerial photographs taken from 1941 through 1983 were utilized to investigate historical channel change in addition to longitudinal streambed profiles, annual peak flow records, climatic records, and historical observations. Variability of channel width along this stream system from 1941 to late 1979 is summarized in Table 1, and Figure 2 illustrates the correlation between directions of change in channel width and magnitudes of streamflow for the same time period.

Rillito Creek, Pantano Wash, and Tanque Verde Creek consist of wide sandy channels with near-vertical banks cut into alluvium. Channel bank heights increase progressively in the downstream direction to as much as 15 feet (4.6 m). The present channel system began to evolve in the late 1800's and early

Table 1. Variations in mean and median channel width and standard deviation, from 1941 to 1979, of Tanque Verde Creek (a), Rillito Creek (b), and Pantano Wash (c). Channel width was measured at 22 cross-section locations along Tanque Verde Creek, 35 along Rillito Creek, and 31 along Pantano Wash.

(a)

Year	Mean Channel Width		Median Channel Width		Standard Deviation		Time Period	Percent and Direction of Change in Channel Width	
	(ft)	(m)	(ft)	(m)	(ft)	(m)		mean	median
1941	231	70	211	64	76	23			
							1941-1963	-26	-36
1963	171	52	136	42	92	28			
							1963-1967	+36	+40
1967	233	71	191	58	98	30			
							1967-1974	-19	-22
1974	189	58	149	45	81	25			
							1974-1978	+14	+29
1978	215	66	192	59	80	24			
							1978-1979	+24	+34
1979	266	81	258	79	104	32			

(b)

Year	Mean Channel Width (ft)	(m)	Median Channel Width (ft)	(m)	Standard Deviation (ft)	(m)	Time Period	mean	median
1941	321	98	262	80	179	55			
							1941-1963	-45	-40
1963	178	54	158	48	91	28			
							1963-1967	+41	+25
1967	250	76	197	60	167	51			
							1967-1974	-29	- 3
1974	180	55	190	58	99	30			
							1974-1978	+ 7	- 3
1978	192	58	184	56	97	30			
							1978-1979	+49	+46
1979	285	87	269	82	126	38			

(c)

Year	Mean Channel Width (ft)	(m)	Median Channel Width (ft)	(m)	Standard Deviation (ft)	(m)	Time Period	mean	median
1941	569	173	558	170	226	69			
							1941-1963	-22	-16
1963	446	136	467	142	184	56			
							1963-1967	-16	-29
1967	377	115	330	101	157	48			
							1967-1974	-13	-10
1974	327	100	298	91	126	38			
							1974-1979	-14	- 9
1979	280	85	271	83	106	32			

1900's when arroyo-cutting prevalent throughout the Southwest initiated channel entrenchment (Cooke and Reeves, 1976). Prior to 1941, the Rillito Creek system exhibited braided channel patterns resulting from extended periods of drought followed by one or more wet years (see Figure 3). Between 1941 and the early 1960's, single channel patterns developed in response to low-magnitude summer flows.

In the early 1960's, the behavior of Pantano Wash began to diverge from that of Rillito Creek and Tanque Verde Creek. From 1963 to late 1979, Pantano Wash steadily incised as the channel narrowed and the streambed degraded. Mean channel width decreased from approximately 570 feet (173 m) to 280 feet (85 m), and the streambed dropped locally as much as 12 feet (3.7 m). However, severe local channel bank erosion ranging up to 375 feet (114 m), produced by occasional meandering low and by significant flow events in 1958, 1970, and 1971, accompanied this narrowing trend.

In contrast, Tanque Verde Creek and Rillito Creek have widened and narrowed in cyclical fashion (Figure 3). In December, 1965, the fourth storm in a series of five consecutive winter storms produced a flow event with an estimated recurrence interval of 27 years in Tanque Verde Creek and 16 years in Rillito Creek (Aldridge, 1970). Runoff was augmented by snowmelt from the higher elevations of the watershed. Extreme channel bank erosion ranging up to 680 feet (107 m) occurred along both stream channels in conjunction with general channel widening (Figures 3 and 4), resulting in 1.25 million dollars in damages (Arizona Daily Star, 1965). The largest increases in channel width were produced by erosion of the concave banks of channel bends, which migrated in the downstream direction. Following this event, many of the eroded areas recovered naturally through sediment deposition and growth of vegetation or were reconstructed artificially with fill material and bank stabilization measures such as rock riprap and wire fence revetments.

In December of 1978, Rillito Creek and Tanque Verde Creek once again widened extensively (see both Figure 2 and Table 1). As in 1965, a winter storm over the Tanque Verde Creek watershed produced streamflow that included snowmelt. Little sediment was readily available for transport within the channels, having been removed by previous flow in March, 1978 (T. Maddock, Jr., University of Arizona, written communication, 1980). As a result, this flow eroded up to 190 feet (57 m) of the channel banks, and the streambed of Rillito Creek aggraded locally as much as 7.5 feet (2.3 m). The recurrence interval of this event was estimated at 22 to 24 years in Tanque Verde Creek and 20 years in Rillito Creek (B.A. Aldridge, U.S. Geological Survey, verbal communication, 1981). Channel recovery and reconstruction also followed this event.

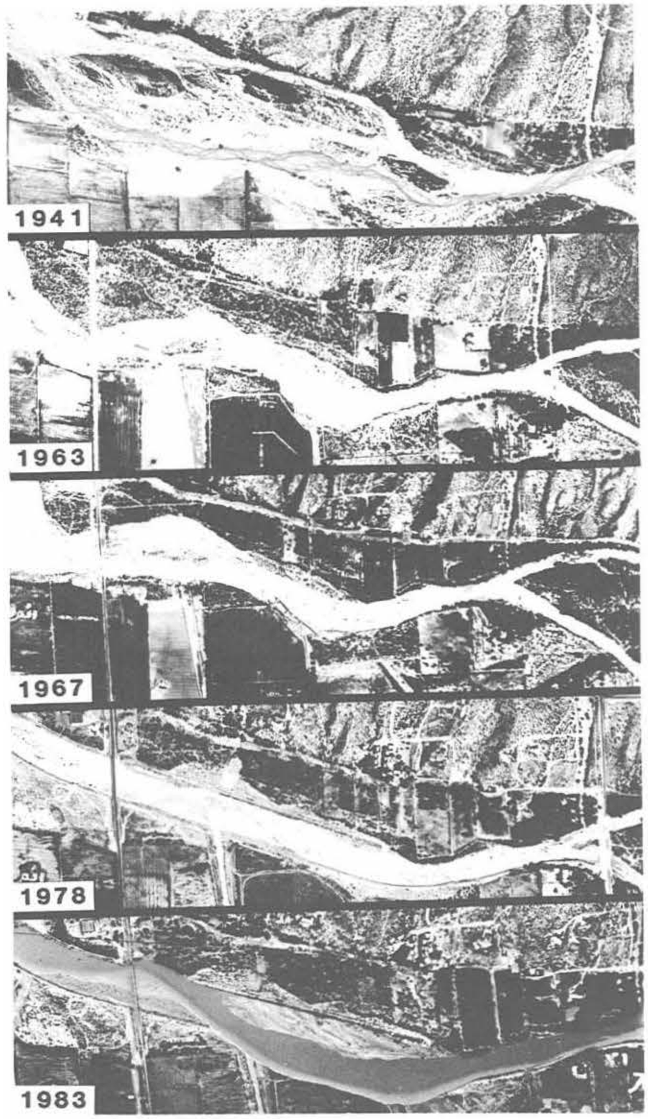


FIGURE 3. Channel change along Rillito Creek from 1941 to 1983 downstream of the confluence of Pantano Wash and Tanque Verde Creek from Craycroft Road to Swan Road. Note the change in plan-view pattern from 1941 to 1963. Extreme channel bank erosion resulting from the December, 1965 flow event is shown in the 1967 photograph. The 1978 photograph shows a smooth channel alignment produced by channel excavation and protection of the banks primarily with wired rock riprap, which failed in the October, 1983 flood event.

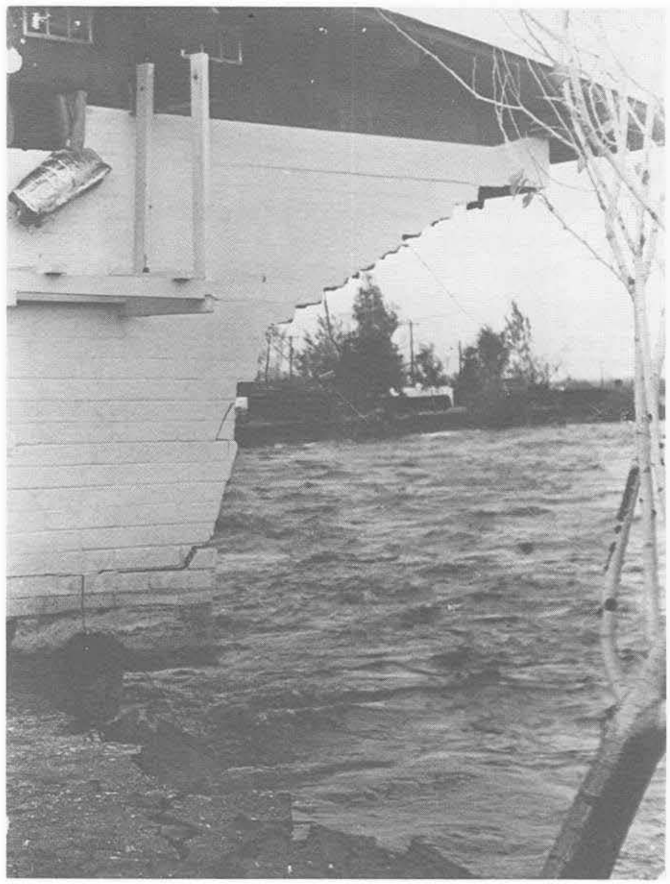


FIGURE 4. House being undercut by Rillito Creek in December, 1965. Photograph taken by L.O. "Pat" Henry, courtesy of Special Collections, University of Arizona Library.

On October 1 and 2, 1983, the most severe channel bank erosion and lateral channel migration seen to date along the Rillito Creek system was produced by a flow event provisionally estimated to have a recurrence interval between 50 and 100 years in Rillito Creek, 10 to 25 years in Pantano Wash, and 10 to 50 years in Tanque Verde Creek (Hjalmar Hjalmarson, U.S. Geological Survey, verbal communication, 1985). Between September 28 and October 2, southeastern Arizona received 6.7 to 10.5 inches (170 to 267 mm) of rainfall produced by a surge of tropical moisture that traveled northeastward from the Pacific Ocean off the coast of Baja, California (Saarinen et al., 1984). Bank erosion was the most severe hazard produced along the more incised stream channel reaches (see Figure 3), although some overbank inundation also occurred. As described by Baker (1984), the Rillito Creek system displayed channel bank erosion that followed existing meander patterns and alternated between stream banks, as allowed by bank protection (Figures 5 and 6). Severe bank erosion also occurred at the downstream terminus of protected channel banks along Rillito Creek, implying that non-continous bank stabilization measures locally concentrate bank erosion as well as protect channel banks and adjacent structures.

Many of the effects of the October, 1983 flood repeated the experiences of the 1965 and 1978 events. In eastern Pima County, approximately 28 bridges, nine flood control projects, and numerous residential, commercial, and industrial developments were damaged by channel bank erosion (Pima County Department of Transportation and Flood Control District, 1985). Power lines were damaged when their support pads were undermined by channel bank erosion or streambed scour, and major utilities were washed out (Saarinen et al., 1984). Erosional damage also occurred at several active and abandoned sanitary landfill sites and at wastewater treatment facilities. The total cost of the flood repair and flood hazard mitigation program prepared by the Pima County Department of Transportation and Flood Control District following this event has been estimated at $105.8 million.

Channel changes observed along the Rillito Creek system are consistent with long-term characteristics of southwestern stream systems (Saarinen et al., 1984). The greatest amounts of bank erosion documented in this study have occurred on the concave banks of channel bends, along unprotected banks where flow has been concentrated by upstream bank stabilization, and at locations where the silt-clay content of the banks and density of riparian vegetation have been minimal (Pearthree, 1982). Lowering of the groundwater table in this century has virtually eliminated riparian vegetation along the middle and lower

FIGURE 5. Damage to the northern (left) abutment of the Dodge Road bridge across Rillito Creek caused by channel bank erosion and lateral channel migration in October, 1983. Note the threat to the electric utility station on the opposite bank downstream. Photograph by Peter Kresan.

FIGURE 6. Damage to the Pima Park Townhomes caused by lateral migration of a prominent meander bend of Rillito Creek. Erosion occurred behind the soil cement bank protection shown adjacent to the townhomes, leading to its failure. Photograph by Peter Kresan.

reaches of Rillito Creek, rendering the channel banks less resistant to erosion. Local sand and gravel operations have also been linked to channel changes by initiating 1) channel bed degradation upstream of excavations, 2) bank sloughing in conjunction with head-cutting upstream of in-channel and overbank operations and from upstream sediment trapping, and 3) bank erosion caused by diversionary structures related to the operations.

Floodplain Management

In compliance with federal regulations under the National Flood Insurance Program, management of floodplains in Pima County has focused on areas potentially subject to inundation by the 100-year flood, defined as having a 1% chance of occurring in any given year. The geomorphic complexity of alluvial stream systems in the Southwest, as illustrated in this study, creates difficulties in administration of federal regulations that are based primarily on flooding. Abrupt channel change, including fluctuations in cross-sectional channel shapes, plan-view patterns, and channel positions, has generally constituted a greater hazard to Pima County than has overbank flooding. Recognition of the threat to the public safety and welfare posed by such channel change has led Pima County to establish building setback requirements for structures from unstabilized channel banks and to begin delineating erosion hazard zones along major watercourses for regulatory purposes.

Much of the damage in Pima County caused by channel bank erosion has been to public and private facilities constructed prior to the establishment of building setback distances. Since 1974, when the first Pima County floodplain management ordinance was adopted by the community, building setback distances along the major watercourses have evolved from 100 feet (30 m) for commercial/industrial structures and residential structures for rent and 300 feet (91 m) for owner-occupied residences, to 500 feet (152 m) for all structures. The latter distance was adopted following the October, 1983 flood.

At this time, the minimum building setback distance of 500 feet (152 m) is required along the Rillito Creek system and other major watercourses in Pima County where no unusual conditions exist. Where unusual conditions do exist, including historical meandering of the watercourse, presence of sand and gravel operations, poorly defined or unconsolidated channel banks, or local changes in directions, quantities or velocities of flow, building setback limits are to be established on a case-by-case basis by the County Engineer. Setback distances ranging from 50 to 250 feet (15 to 76 m) have also been established along smaller watercourses based on the magnitude of the estimated 100-year peak discharge.

Along the Santa Cruz River, to which Rillito Creek is tributary (Figure 1), preliminary erosion hazard boundary maps have been compiled based on qualitative and quantitative analyses of channel bank erosion and lateral channel migration (see Figure 7). These analyses have included investigations of historical channel positions and erosional sites seen on aerial photographs, and have considered present channel patterns, locations of sand and gravel operations, landfill sites, and existing and planned bank stabilization measures. When adopted by the Pima County Floodplain Management Board, these maps will be used to restrain urban development within zones determined to have a high potential short-term and long-term channel bank erosion and lateral channel migration. Where erosion hazard limits exceed mapped floodway and 100-year floodplain limits, the erosion hazard limits will form the basis for regulating development adjacent to the stream channels, as these represent estimated worst possible flooding and erosional conditions.

Conclusions

Floodplain management practices that account for the geomorphic complexity of alluvial channels of ephemeral streams will continue to evolve in the Southwest as it is increasingly recognized that semiarid stream systems do not lend themselves to flood hazard regulatory procedures established at the national level. These procedures are incomplete when they fail to account for channel change. Nonstructural floodplain management approaches are recommended to regulate urban development adjacent to these stream channels. The high cost of bank stabilization measures capable of withstanding local streamflow erosional conditions, such as soil cement at approximately one million dollars per mile, discourages implementation of structural flood and erosional control measures on a large scale. Nonstructural floodplain management approaches can save the cost of channel bank stabilization as well as decrease the potential for erosional and flood damages. Through geomorphic research, the complex behavior of alluvial stream systems in the Southwest can be documented, thus providing the data necessary to locally augment federal floodplain management regulations and policies to suit the Southwest.

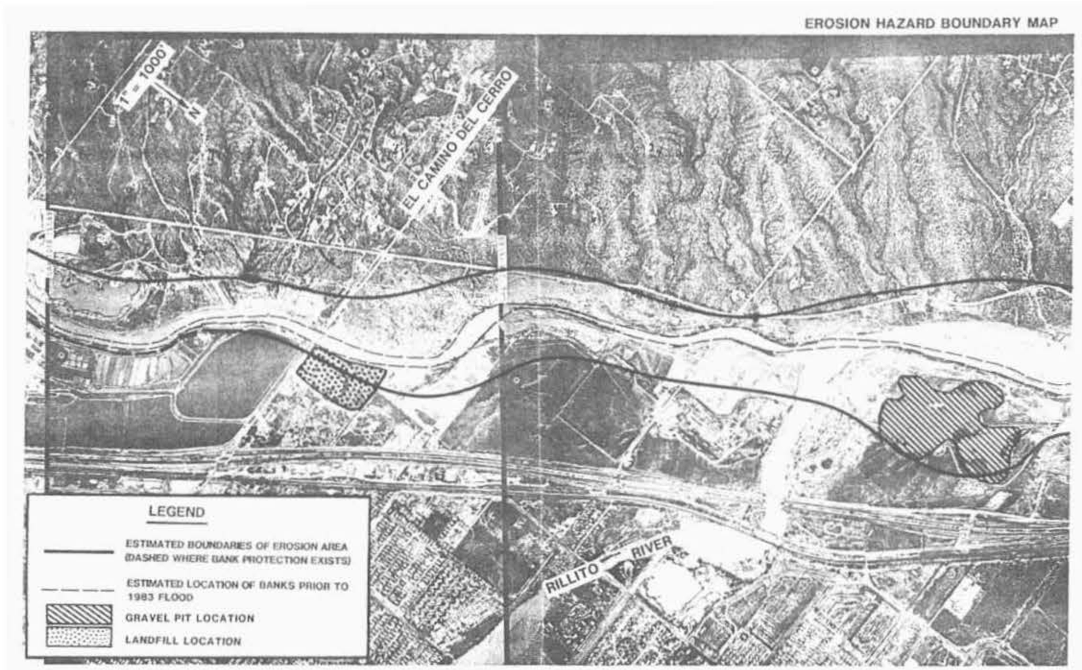


FIGURE 7. Erosion hazard boundary map for the Santa Cruz River at its confluence with Rillito Creek.

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