

FIELDNOTES

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*Doing What
Comes Naturally*

THE "FLOODS" OF OCTOBER 1983

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Figure 1. Raging waters of the brimful Santa Cruz River. Looking upstream to the south from St. Mary's Bridge. Photo taken on October 2, 1983 by Peter Kresan.

INTRODUCTION

Excerpts from *The Arizona Daily Star*, Tucson:

Sept. 10, 1987:

About 2 o'clock yesterday morning, it started to rain hard and poured unceasingly until after daylight, flooding many parts of the city and causing great loss to railroad east and west of Tucson. . . . Mr. Hancock's apiary was two feet under water. . . . Mr. Wetmore told a *Star* man yesterday that there was 9.5 feet of water in the river and that trees and other articles were floating with the current at a very brisk rate. . . .

Dec. 23, 1914:

WORST FLOOD FOR GENERATIONS. . . . LOSS OF SEVERAL LIVES UP THE VALLEY. . . . BELOW MARANA AND CORTARO, TRACK OF MAIN LINE INUNDED FOR ABOUT 4 FEET; 25 MILES OF TRACK WASHED OUT. . . . TWO PEOPLE BELIEVED DROWNED AT SAHUARITA; 25 PEOPLE MAROONED ON HOUSETOPS AND WINDMILLS. . . .

Dec. 24, 1965:

FLOOD PERIL CONTINUES AS SEWERS WASH OUT; STATE ASSISTANCE SOUGHT. . . . FLOWING WELLS AREA STUNNED BY WILD RILLITO. The roiled, brown waters of the flooding Rillito Creek tore into two trailer parks in the Flowing Wells area yesterday, demolishing two trailers. Residents bitterly termed it a disaster and scorned public officials for apathy about their plights. . . .

Dec. 31, 1965:

RUNOFF CRISIS REPEATS ITSELF. Rain and rapidly melting snow in the Catalinas swelled the Rillito River again yesterday. . . .

Excerpts from *The Tucson Citizen*:

Oct. 3, 1983:

FLOODS RAM TUCSON. . . . ROARING RIVERS EAT AWAY BRIDGES, HOMES. . . . MARANA IS SUBMERGED; RESIDENTS EVACUATED. . . . HOMES, LIFE POSSESSIONS SWALLOWED BY SANTA CRUZ. . . . 4,000 ARIZONANS EVACUATED IN FACE OF MASSIVE FLOODS. . . .

Oct. 4, 1983:

ONLY TWO IN MARANA HAD FLOOD INSURANCE. Only two national flood insurance policies were issued in the Marana area before flooding inundated the whole area, because town officials "didn't believe it floods there," a flood insurance official said. . . .

RIVERS' CURVES FIGHT CITY'S STRAIGHT LINES. . . . Where the rains had collided with roads, houses, and power lines, the flood ripped, swallowed, and snapped. . . .

Excerpts from *The Arizona Daily Star*, Tucson:

Oct. 17, 1983:

THE FLOOD OF '83 — A SPECIAL REPORT:

THE BIG ONE. This was the flood we'll remember. This was the flood our children and grandchildren will be told about time and again as we warn of the awful power of the area's normally dry rivers. At least 10,000 Arizonans were at least temporarily homeless when flood dangers forced evacuation of

entire communities. Other areas were cut off for days as the rivers toppled bridges and blocked roads. . . .

CLIFTON'S BEST PREPARATIONS FAILED. Clifton knows floods. . . . Most of the city's 4,200 residents were evacuated. Over 600 homes and 86 of Clifton's 126 businesses were damaged severely. . . .

LOSSES TOTAL HUNDREDS OF MILLIONS. . . .

If experience is a great teacher, then repetitious experience should be doubly effective as an educator. Teaching is ineffective, however, if the pupils aren't paying attention. In October 1983, nature taught many Arizonans a lesson that they will not soon forget. Certainly, the natural events that occurred during that time inspired many questions, and questions inevitably must precede answers. Local reaction varied from one of tragedy among those who were directly affected to one of glee among those who enjoyed watching nature "do its thing," even at the expense of humankind. Engineers learned a great deal and are already applying their newly acquired experiences and insights.

The dynamics of the hydrologic event can be analyzed in detail and are probably among the easiest aspects of the event to discuss. There would be no concern about the event itself, however, were there not direct social, economic, and political impacts and implications. Where there is an interface with human activity, some natural earth processes can be both hazardous and damaging. In the desert country of southern Arizona, processes associated with water runoff are the dominant natural hazard.

The events of October 1983 provide the incentive for this brief and basic review of the nature of the runoff hazard in this desert region. Although all of the examples are from the Tucson area, the principles involved are generally applicable to other desert regions.

DYNAMICS OF DESERT RIVERS

The network of natural drainageways in the desert country of southern Arizona is exceedingly intricate. The integrated network is a part of the larger Gila and Colorado River systems, which are naturally designed to carry surface waters toward the Sea of Cortez. Although most of the network occupies valleys and foothills, the headwaters are in the higher reaches of adjacent mountain ranges. Many of these ranges are a mile or so higher than the desert valleys and are, therefore, subjected to much higher precipitation rates. The excess precipitation in the mountains is conveyed to the valleys, where drainages are naturally enlarged to accommodate the total flow.

Within an integrated drainage network, the size of any particular flow or runoff event is proportional to the area receiving precipitation. Only at times of regional rainfall is it possible to activate all of the existing drainages. Such was the case in October 1983. Regionally, the land surface had been well-wetted by previous rains; then, in 2 days, aided by tropical storm Octavo, about 6 inches of rain fell. More rain fell in the mountains, swelling waterways even further.

Those who witnessed one or more of the major drainages in action were reminded of the frightening power of rushing, roily water (Figure 1). A flow rate of 25,000 cubic-feet-per-second (estimated for Rillito Creek) is about equivalent to an 800-ton mass moving past a given point each second. (An 800-ton mass weighs more than two 747 Jumbo Jets, which weigh 775,000 pounds each.)

A basic law of physics states that any mass, once in motion, will continue in a straight line until acted upon by an outside force. What happens when a mass of moving water is "asked" to flow around a bend in a channel? The only way the moving water can be made to turn is if the outside bank exerts enough force to redirect the flow. If the banks are relatively weak, as they tend to be in southern Arizona (Figures 2a-d), there will be a compromise: the river will continually "chew" at the bank in its effort to flow in a straight line, but will eventually turn in response to the resistance that the wasting bank will offer. This "chewing" causes banks at curves, and thus the curves themselves, to migrate downstream. The amount of land removed is a function of bank strength; radius of curvature; rate, amount, and duration of flow; etc.

There are, therefore, two measurements used to describe the extent of bank alteration: (1) the amount of straightening in the direction of river flow; and (2) the distance between old and new bank, measured perpendicular to the direction of flow. For the large historical runoff events, these measurements ranged from near zero to about 1,500 feet, and from near zero to about 600 feet, respectively, for a single bank. In other words, an area as large as 10 acres is known to have been transposed from riverbank to river bottom. Losses of up to 5 acres occurred at several sites along the Rillito last October.

The vulnerability of banks to destruction is also a function of geometric position at any given time. Like a cue ball, rapidly flowing water literally bounces from one side of a stream to the other, wherever there are curves in the channel. Unless they are adequately stabilized, these curves will not remain steadfast for long.

Flood vs. Flow Event

It is conceptually important to distinguish between flood and flow events in a desert region. Much confusion has arisen because of a lack of appreciation for the contrasting processes involved in these two types of runoff. A flood occurs when discharge exceeds the capacity of an active channel to contain the flow. In other words, a true flood refers to distinct overbank flow, called flood flow. If there is no flooding, the runoff event is simply a flow event. Flooding may locally occur, but elsewhere along the same drainage, runoff may be totally contained within well-defined banks. Flooding is an unusual flow condition, whereas confined flow is the norm.

Most of the damage to humankind within the Tucson metropolitan region has been done under *nonflood* conditions by the collapse and erosion of river banks, especially on the outside of meander bends.

If nonflood runoff alters banks enough to undercut "flood-protected" buildings, regulations that require construction above a certain elevation on a floodplain will not spare buildings from disaster. Many of the more dramatic pictures taken along Rillito Creek, Tanque Verde Wash, Pantano Wash, and the Santa Cruz River, on or after October 2, 1983, were related to nonflood bank-cutting and bank collapse (Figures 2a-d). Even so, adequate setback regulations have been slow in coming. In recent times, each new experience with severe nonflood runoff damage has led to more stringent setback regulations, especially in areas where there is inadequate bank protection. Because of the October 1983 experience, Pima County engineers now consider "inadequate" any bank protection that is not the relatively new soil-cement type. At the present time, 500-foot setbacks are required where banks are not protected by soil cement. A land user, however, can request a variance if the request is adequately supported by engineering studies. A 500-foot setback might seem large, but at selected times and places on Rillito Creek, bank erosion from a single runoff event has exceeded this amount.

Actual flooding did take place where channel capacity was not able to contain runoff. The Marana area was the most dramatic example. Marana is down-

Editor's Note: Related articles on desert-runoff hazards and flood-plain management have appeared in the following issues of *Fieldnotes*: Vol. 2, No. 3 (Sept. 1972); Vol. 5, No. 1 (March 1975); Vol. 10, No. 4 (Dec. 1980); and Vol. 11, No. 1 (March 1981). These issues are available from the Bureau for \$2.00 (\$1.00 covers postage and handling; \$1.00 covers reproduction costs for the March 1975 issue, which is out-of-print).

NONFLOOD BANK-CUTTING AND BANK COLLAPSE

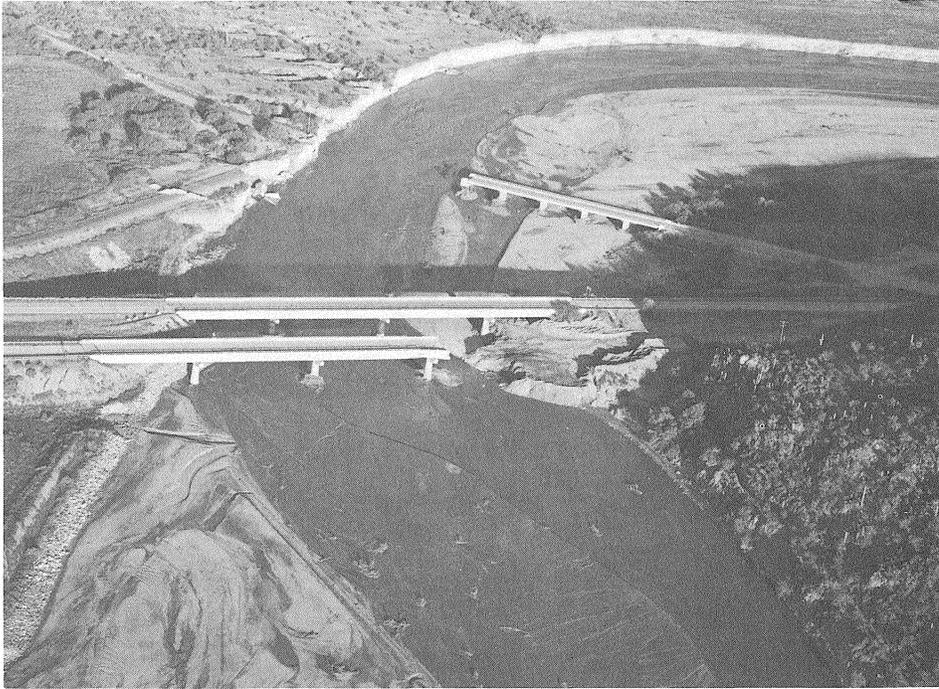


Figure 2a. Severe bank-cutting along the Santa Cruz River near I-19 and San Xavier Road. Looking northwest. Bridge segment nearest viewer collapsed when support washed out. Bridge in distance did *not* fail. Bank retreated from west end of bridge to present position. Distance between bank and midstream end of bridge is measure of amount of bank erosion that occurred. Photo taken on October 9, 1983 by Peter Kresan.

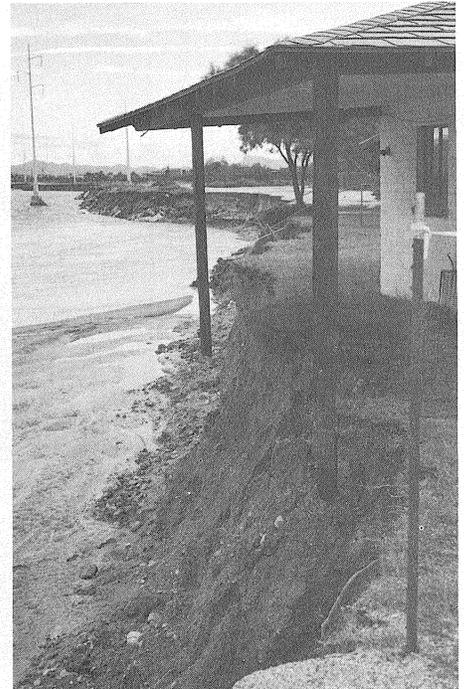


Figure 2b. Bank-cutting along north bank of Rillito Creek at N. 1st Avenue. Looking downstream. Photo by Peter Kresan.

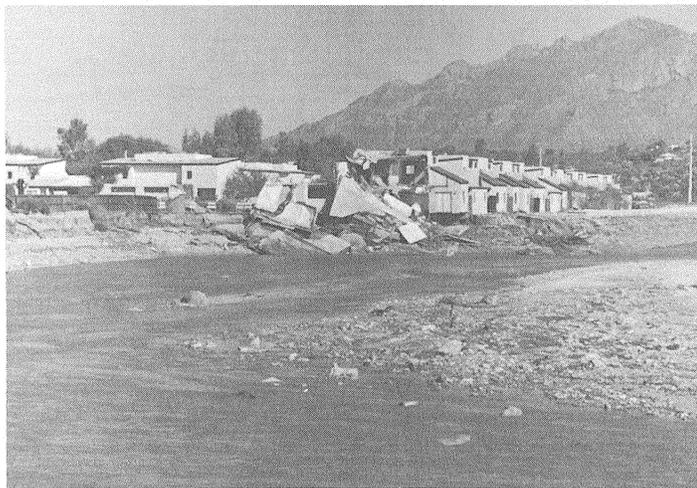


Figure 2c. Bank-cutting on outside of bend along Rillito Creek. Looking downstream near Prince and Country Club Roads. Photo by Tad Nichols.



Figure 2d. Bank erosion along north bank of Rillito Creek. Looking downstream. Photo by Ken Matesich.

stream from the confluence of Rillito Creek and Canada del Oro with the Santa Cruz River. Water spread out laterally over a distance of 4 or 5 miles, causing a true flood. The channels through the city of Tucson, on the other hand, are deeply entrenched and barely managed to contain the October runoff within their banks. Nevertheless, this "saving grace" did not prevent the turbulent waters from damaging bridges, roads, buildings, vehicles, utility lines, crops, livestock, certain bank-protection devices, etc. (Figures 3a-d).

Because almost every drainageway in Arizona was activated by the rainfall from the large storm system, runoff ef-

fects were widespread. Small washes scoured their banks and bottoms, often finding things of man to damage (Figure 4).

When the Water Is Gone

After the last vestiges of runoff have seeped into the sand, vertical channel banks remain. That banks can migrate hundreds of feet during flow events is testimony to their lack of resistance. Banks fail because of undercutting and collapse, and this tendency does *not* disappear when the water does. Collapse of banks on the verge of failure could be triggered by any destabilizing

mechanism. Vibrations of any sort, loading at the top by even one person, and undercutting by cave-making youngsters could cause a bank to collapse, with potentially tragic results (Figure 5).

There are many miles of banks along major drainages that course through the Tucson metropolitan area. Some of these banks are more than twice as high as two average-sized adults. Most were modified during October 1983 and left in various states of instability.

Consequently, when the water is gone, there is still reason for concern about dry drainages. Although they are in their normal state, dry drainageways continue to be hazardous to the unaware.

MISCELLANEOUS DAMAGE



Figure 3a. Ina Road undercut by water from adjacent Santa Cruz River. Looking northeast. Photo by Ken Matesich.



Figure 3b. Wipeout of bridge and utility tower at Sunset Road crossing of Santa Cruz River. Looking southeast. Photo taken on October 2, 1983 by Steve Reynolds.



Figure 3c. Same area as Figure 2d. Looking upstream at water well that was on left side of bank before erosion. Photo by Ken Matesich.



WHAT CAN BE LEARNED?

The events of October 1983 reinforced the belief that the worst regional runoff events tend to associate with the large tropical systems that invade the State during the fall months. Because these tropical systems can be repetitious, they can set the stage for large-scale runoff by first saturating the ground.

A general survey conducted by the authors revealed how fortunate many residents were that the next scheduled tropical storm failed to materialize in southern Arizona. Many buildings and objects, more numerous than those that were toppled, were poised for undermining when the flows of early October abated. Since then, the southern part of the State has been in a dry spell. This respite is buying time for the community

Figure 3d. Wipeout of northern approach to Dodge Boulevard Bridge over Rillito Creek. Looking south. Photo by Peter Kresan.

to complete various repairs and add some protection prior to the anticipated summer rainy season.

Local residents might expect a future rash of aggravating maintenance work where utilities were buried along and beneath foothill washes several years ago. In some cases, various lines, buried until 1983, were uncovered by wash-bottom scour and broken at least three times in the latter half of the year (Figure 4). Many more lines are now closer to the surface because of erosion above them.

Considerable experience was gained about various methods of protecting banks. Almost anything will protect a bank, as long as the protective device is not tested too severely. A recently developed technique, which involves the use of soil cement, received its baptism in October. Except for minor problems, the technique tested well (Figures 6a and 6b). On the other hand, some of the more classic protective measures failed during the big October test (Figures 7a and 7b). For regulatory purposes, Pima County now recognizes only one type of bank protection: soil cement. Several soil-cement projects, funded by Federal monies, are underway at the places deemed to be most critical.

The October runoff event demonstrated how difficult it is to protect works of man that encroach upon major drainages. The largest drainages, such as Pantano Wash, Rillito Creek, and the Santa Cruz River, reached man-made structures that had been built many years ago. The runoff event was large, powerful, and persistent enough to cause hundreds of feet of lateral bank migration in several places. The areas where the soft banks would be cut away were predictable (Figure 8 with inset); the *size* and *power* of the runoff event, however, were *not* anticipated.

Because the channels, banks, and adjacent flood plains along major drainages are usually privately owned, it has not been possible to treat these systematically. A shopping-center owner can afford to invest more heavily in protection than can an average home or trailer-park owner. The result is "piecemealing," a condition that a raging flow of water will test in search of a weakness. Bank protection devices necessarily end at property boundaries, a situation that leaves the devices especially vulnerable at their points of termination. This is also true of soil cement. Water can erode the efficacy of any protective device if it gets behind the upstream end or overtops the structure (Figure 9). Selective application of soil cement is itself a form of "piecemealing" that will leave unprotected banks free to migrate (Figure 9). How this migration will eventually affect the protected parts remains to be seen.

SOME REMAINING QUESTIONS

Desert drainage systems are complex, interwoven, dynamic, and vital, characteristics that combine to test engineering and management skills. On the one hand, there is a demand to stabilize banks, especially around houses, businesses, and bridges that carry daily traffic. On the other hand, major drainages play a vital role in recharging the only indigenous water supply in southern Arizona: ground water. Replenishment of ground water depends on the maintenance of the sand "sponge" that usually occurs along drainage bottoms. What would cause the removal of this "sponge"? What would save it?

In the ideal solution to this two-sided problem, viable bank protection would be added *and* the necessary conditions for effective ground-water recharge would be maintained. Realization of this plan requires a basic understanding of the dynamics of the system, appropriate engineering techniques, and adequate financing. Appreciation and understanding of regional drainage dynamics is critical to the management of major drainages. Research into the cause-and-effect relationships within this drainage system should be encouraged and supported.

Proper management of drainageways involves several questions: What combinations of circumstances would cause channel-bottom scouring (removal of the important sand-gravel "sponge") or sand-gravel accumulation? How does urbanization of the desert floor affect these processes? Certainly the paving and development of square-mile-after-square-mile prevents transport of normal sediment loads to the major drainages. This leads to clear-water runoff, which, in turn, encourages scour (sediment transport) within the main drainages. If the banks of these drainages were totally protected, the most immediate sediment source would be the loose bottom materials that must be maintained to aid ground-water replenishment. Structural modifications would be required to prevent large drainages from scouring and to promote ground-water recharge. The enhancement of recharge should be a continuing goal of research.

Other questions concern the quantitative influence of urbanization on desert runoff. How does urbanization - paving, smoothing, packing, channeling, vegetative removal, etc. - affect runoff amounts and rates? Is the natural drainage system, at least near urban centers, being asked to carry a larger burden than it



Figure 4. Sewer line, buried for 11 years, uncovered by erosion along bottom of Finger Rock Wash in foothills of Santa Catalina Mountains. Smaller pipe is natural gas line, also exposed by erosion. Looking upstream toward the northwest. Photo by H. Wesley Peirce.

would otherwise? How does this increase in urbanization, over time, affect drainage predictability and planning for the future? How can urbanization of the Tucson Basin be planned to minimize the impact? Because of this evolving factor, how reliable are past studies and the regulations based upon them?

THE FUTURE

Runoff in the Southwest desert is a natural process that is vital to life in general, but injurious in specific cases of encroachment. That the process will continue is assured. Because the frequency and severity of future events are unpredictable, it behooves citizens to look to themselves for protection by



Figure 5. East bank of Pantano Wash collapsing after flow ceased. Scene depicts instability of banks and attendant hazard. Photo by H. Wesley Peirce.

SOIL-CEMENT BANK PROTECTION



Figure 6a. Same area as Figure 1 after passage of major flow. Right bank with railing is undamaged soil cement. Photo by Peter Kresan.

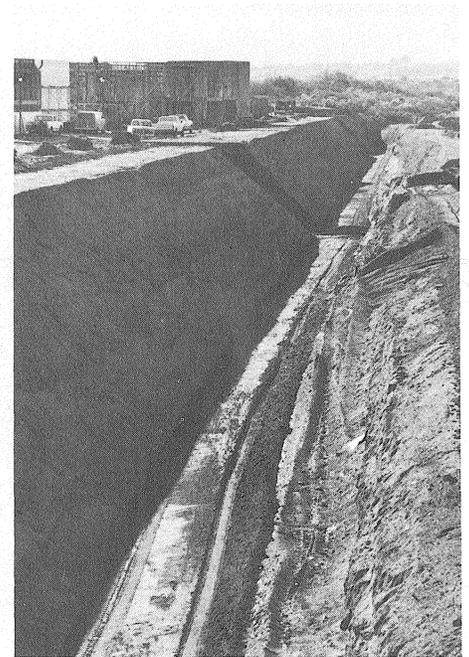


Figure 6b. Pantano Wash bank undergoing soil-cement process. Photo by Ken Matesich.

exercising judgment about things that they can directly control. Most adults have some say about where they choose to live. If one is aware of the general desert-water hazard, there should be no excuse for placing oneself in a grossly vulnerable situation.

There will be future damage to existing man-made structures that have been rendered vulnerable by virtue of their location and inadequate or nonexistent bank protection. On the other hand, because of the experiences of October 1983, the security of many bridges and associated features will be enhanced by better bank protection.

Building will continue near the major drainages where banks are judged to be

adequately protected by soil cement. Although great faith is being placed in this form of bank protection, it remains to be seen whether nature, over time, will be able to significantly undo even these man-made attempts to control the natural flow of water toward the sea.

CONCLUSION

Damaging runoff in the deserts of southern Arizona is the rule rather than the exception. The region continues to grow in population and urbanization. It is only logical, therefore, for one to assume that damaging runoffs will occur in the future.

The consequences of large-scale runoffs range from minor harassments to tragic destruction. The "floods" of October 1983 resulted from pervasive tropical systems that affected much of Arizona. Although this natural event may have been the most costly ever inflicted on Arizona, it demonstrated what is possible. This message alone is invaluable; "forewarned is forearmed." More respect is already being given to the important drainages.

Because of the applicability of the laws of physics and geometry, there is no real mystery as to what a flowing mass of water will attempt to do and where it will do it. What are not predictable are the size and frequency of runoff



Figure 7a. Post in foreground marks position of bank-protection device prior to October 1983. South bank of Rillito Creek near N. 1st Avenue. Photo by Peter Kresan.



Figure 7b. Rock-and-wire-mesh bank-protection device breached and overtopped in October 1983. Looking north along Santa Cruz River from bridge at W. Grant Road. Photo by H. Wesley Peirce.

FAILED BANK PROTECTION

PREDICTED BANK EROSION

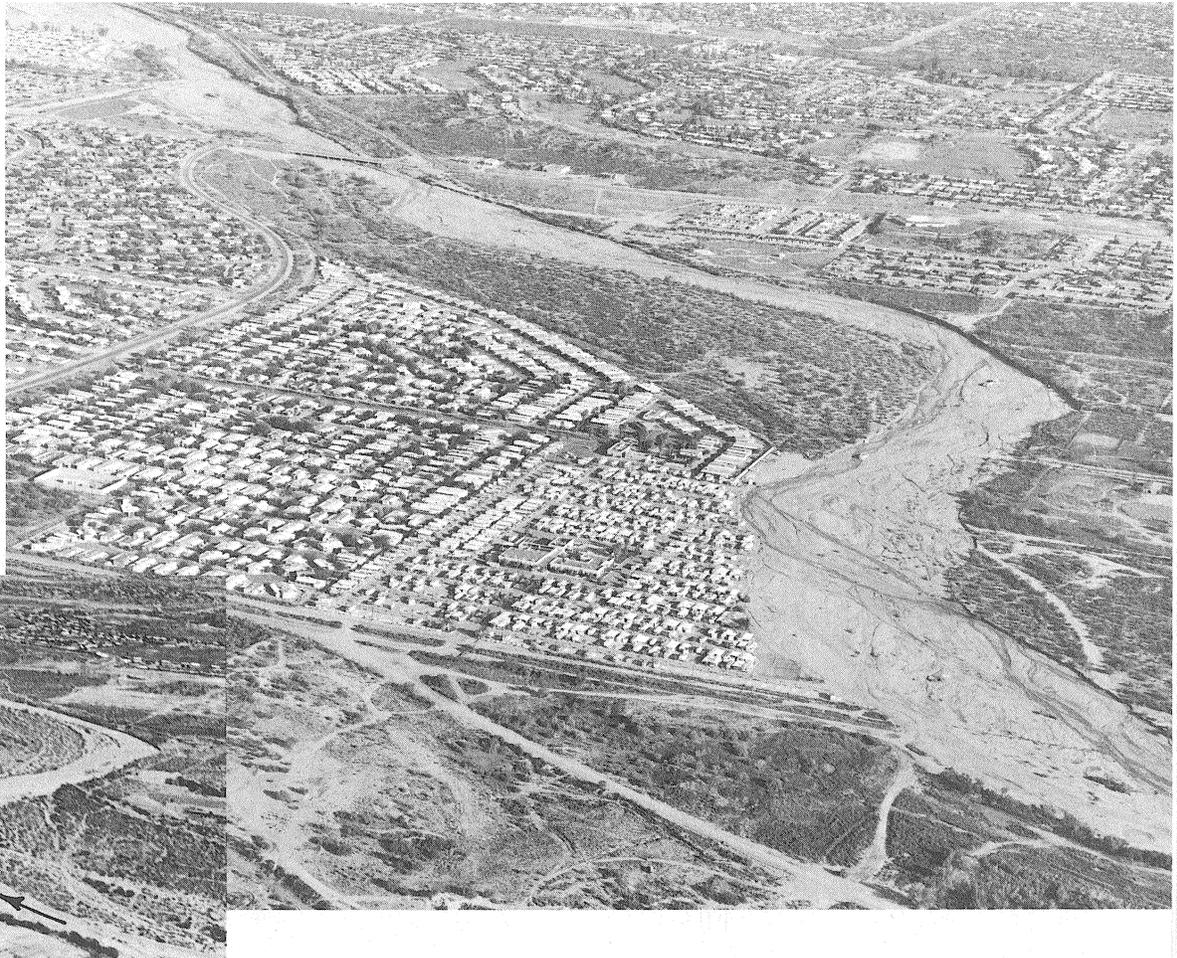


Figure 8. Bank-cutting at outside of bend along west bank of Pantano Wash, south of Golf Links Road. Photo taken on October 9, 1983 by Peter Kresan.

Inset: Same area as main photo, as seen in 1972. Dashed line indicates trend of future bank-cutting, as predicted in *Fieldnotes* in September 1972. Note erosion along predicted trend. Also note expansion of development toward wash. Photo by H. Wesley Peirce.

events for which a community should prepare itself. What constitutes preparedness? How much is enough? How much are citizens willing to spend on the uncertain future? One thing *does* seem certain, however: because of their experience with the October 1983 runoff, Arizonans will be willing to spend more than they otherwise would have. Oftentimes people have to see to believe. Crying wolf too often tends to lower a citizen's level of concern; *seeing* a wolf, on the other hand, heightens his or her awareness. Seeing the "wolf" of October generated enough support that Pima County voters approved a bond sale to redesign and repair the many highways and bridges that were damaged. Included will be bank protection mechanisms that will better withstand high flows, if they are properly designed and constructed.

As more channel control is sought to arrest bank collapse and migration, important questions will arise about the maintenance of stream-bottom stability, the potential for increased bank erosion

along unprotected stretches, and the increased flood potential downstream from highly channelized sections. Major drainages are vital ecological factors: they are linked to the ground-water supply upon which much of southern Arizona depends. A raging torrent of water may appear unfriendly and in need of control; however, some of this torrent, if given the chance, will seep underground and help to restore the level of the water table. The trick to management of drainages is to exert control where necessary, but to encourage and maintain maximum recharge.

High banks continue to be unstable long after they have returned to their normal state of dryness. For wayfarers along the drainages, caution is the watchword, whether the drainages are wet or dry.

Figure 9. Bank collapse after Rillito Creek got behind upstream end of soil-cement protective device and undermined buildings. Flow is from bottom to top. There was no bank protection for buildings in lower left position. Near intersection of Prince and Country Club Roads. Photo taken on October 9, 1983 by Peter Kresan.

