Arroyos and Environmental Change in the American South-West

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irrigation ditches along the river, and they also recorded that floods frequently destroyed diversion dams and canals, and that as entrenchment progressed some canals had to be abandoned or deepened (see also Newell, 1905). Unfortunately it is not clear whether any of these canals acted as loci for entrenchment. Also in some areas dikes were constructed to protect fields, canal intakes, and railroad embankments and these may have served to concentrate flow.

In attempting to explain the discontinuous trenching along the San Pedro Valley it is necessary to distinguish between entrenchment that occurred before 'white' settlement and that which followed it. It is unlikely that the early entrenchment was caused by human activity, except in so far as Sobaipuri irrigation or cattle on the Spanish land-grant areas may have caused some damage. Alternative explanations are therefore necessary. Perhaps the most likely is that channels were formed at morphologically or hydrologically appropriate locations in the system – in steeper reaches or downstream of cienegas, for example. These possibilities are considered in more detail below (pages 90–94). Alternatively, early entrenchment could have been the result of climatic-vegetation-runoff changes. The first hypothesis does not require environmental *change* to cause channelling, the second does.

After about 1880 the possible causes of entrenchment multiply. Drainage concentration could have been a factor. Climatic change might have played a role. There were severe floods during the last two decades of the century, and these may have initiated entrenchment. Finally, there is a strong possibility that vegetation changes resulting from overgrazing within the watershed (especially south of Benson), cattle damage along trails and the river, and deforestation of some catchment areas for mining timber may have promoted entrenchment.

Evidence of vegetation change is extensive and conclusive.[19] It is recorded on numerous photographs reproduced in Hastings and Turner (1965). Rodgers (1965) reviewed the evidence in the southern San Pedro Valley. He argued that, as there appears (in his view) to be no evidence of a climatic change before or after 1885 and yet there was significant alteration of the drainage system after that time, vegetation disturbance is the most probable cause of increased runoff and erosion. Perhaps the most important alteration was the exploitation of woodlands in the higher, wetter areas of the Dragoon, Mule, Whetstone, and Huachuca mountains, for this change may have very significantly augmented runoff. In addition, the rangelands were also being transformed. Between 1885 and 1900 much of the range was given over to cattle, and Rodgers (1965) estimated that the range was overstocked for all but three of these years; and there had been 'drought' conditions for ten of these fifteen years. Another event that may have been of importance was a major brush fire that followed the earthquake of 1887. Destruction of the grasslands was reported to have been very extensive,[20] and as it coincided with a time of great grazing pressure, grassland recovery may have been impossible.

This combination of environmental changes led to disasters and to further changes. In 1893, for instance, 40–60 per cent of all cattle in the area died. Grazing capacity was seriously reduced. Grass and woodland were succeeded by shrub vegetation. Floods may have increased in size and frequency, and entrenchment may have been associated with them.

Arroyos along the Santa Cruz Valley

The Santa Cruz River rises in Arizona, flows south into Mexico, and then flows north across the border. The river valley covers over 8,600 square miles and may be divided into two main sections. In the southern section, which extends north to the neighbourhood of Redrock, landforms are similar in general to those in the San Pedro Valley – the river runs in an 'inner valley' created within broad, dissected pediments and alluvial plains and flanked by mountains – and it is fed by several major tributaries (Bryan, 1925b; Tuan, 1959). Terraces flank the inner valley in places, and their variability in number and altitude probably reflects local tectonic activity in this basin-range country. North of Redrock the topography changes abruptly: the river flows into a broad plain, uninterrupted by mountains, that extends to the Gila River and is confluent with plains emerging from the Altar and Aguirre valleys. This contrast may be seen as reflecting a fundamental distinction within the system between the headwater zone where erosion is predominant and the downstream zone where deposition is dominant.

Entrenchment within the valley is confined to the southern section except for an arroyo west of Redrock (see below), and a 5-6-mile-long trench that extends south from the Gila River and probably resulted from headward erosion following downcutting of the main river (Bryan, 1925b). Entrenchment in the southern zone is not continuous, and indeed it never has been. It is most pronounced between San Xavier and Tucson. Elsewhere the course of the river is marked by a broad, vegetation-free channel with low or poorly developed banks. And there are still places where the course of the river is ill-defined as it is, for example, south of the Papago Reservation at San Xavier.

Today, as in the past, there are areas where water is near to the surface. Early records refer to several cienegas including those near Arivaca Junction, at San Xavier and Tucson, and north of Rillito, but today most of them have been trenched and drained. The water-table is still relatively near the surface at these places, but it has fallen in recent years due to pumping (Arizona Bureau of Mines, 1969; Clyma and Shaw, 1968; De la Torre, 1970). Flow along the valley is largely ephemeral, although there is perennial baseflow near Nogales, in Sonoita Creek, and in Pantano Wash (De la Torre, 1970). It appears that flow was normally ephemeral in the past, too, because the earliest surveyors' notebooks[21] often refer to the 'dry bed of the Santa Cruz River'. Floods, especially those in July, August, and September, are a regular

feature of the hydrological history of the Santa Cruz River. They are usually recorded in the local newspapers (Grove, 1962), in reports concerning the Indian Reservations (e.g. Berger, 1898, 1901), and in most other records of activity on the valley floor. It is interesting to note from such records that, although the summer floods were certainly responsible – and were seen to be responsible – for arroyo cutting, floods were not universally regarded as a bad thing. For example, the *Arizona Weekly Citizen* stated on 5 August 1893: 'The floods in the Santa Cruz will do immense good in developing the big flows of water a little below the surface. The floods cut down and developed good flows for the Allison brothers, Sam Hughes and Buckalow's ranch. The good done by the waters more than compensates the damage.'[22] Similarly, Berger (1898) said of San Xavier Reservation: 'The land is generally overflooded every year in the rainy season, and the floods are continually causing damage to irrigating ditches and to roads and bridges, and in many locations also prevent the planting for the so-called second crop; but otherwise these floods do much good, as the considerable amount of sediment they bring is considered to be, and, as a matter of fact, is, a great fertilizer, and land so overflowed does not need any artificial fertilizing.'

Two other features of the floods are important. Firstly, their lengths of flow along the valley vary greatly, and infiltration into the bed is high: by no means all floods flow the whole length of the valley. Secondly, the percentage of rainfall reaching the stream is extremely small. For example, the average ratio of streamflow to rainfall (in per cent) is only 3·0 at Nogales and 0·6 at Tucson. Ninety-three per cent of flood peaks above a selected base discharge coincide with the summer months when high-intensity rainstorms occur (De la Torre, 1970).

The land-use history of the southern Santa Cruz Valley differs in many ways from that in the topographically similar San Pedro Valley. The Santa Cruz Valley had no Mormon settlements. The Indian settlement along the Santa Cruz was more stable and more persistent. Irrigation has been practised more or less continuously by Indians living near the Spanish missions at Tubac and San Xavier at least since Kino visited the area in 1689 (Bolton, 1936; Dobyns, 1962). Irrigation development by white settlers has also been more extensive, especially near Eloy, than in the San Pedro Valley. The urban development at Tucson, which may have significantly altered runoff into the Santa Cruz and Rillito, has no counterpart in the neighbouring valley. Cattle and sheep were introduced early into the Santa Cruz Valley, by Father Espinoza in 1763 (Dobyns, 1962). (There were Spanish land grants, similar to those in the San Pedro Valley, such as that of San Ignacio de la Cañoa, and descendents of original grantees still live in the area.) Finally, the floor of the Santa Cruz Valley has been a historical routeway for many generations. The major difference between the Santa Cruz and San Pedro valleys, therefore, is that man has used the former more intensively and more successfully. As a result, the documentary evidence

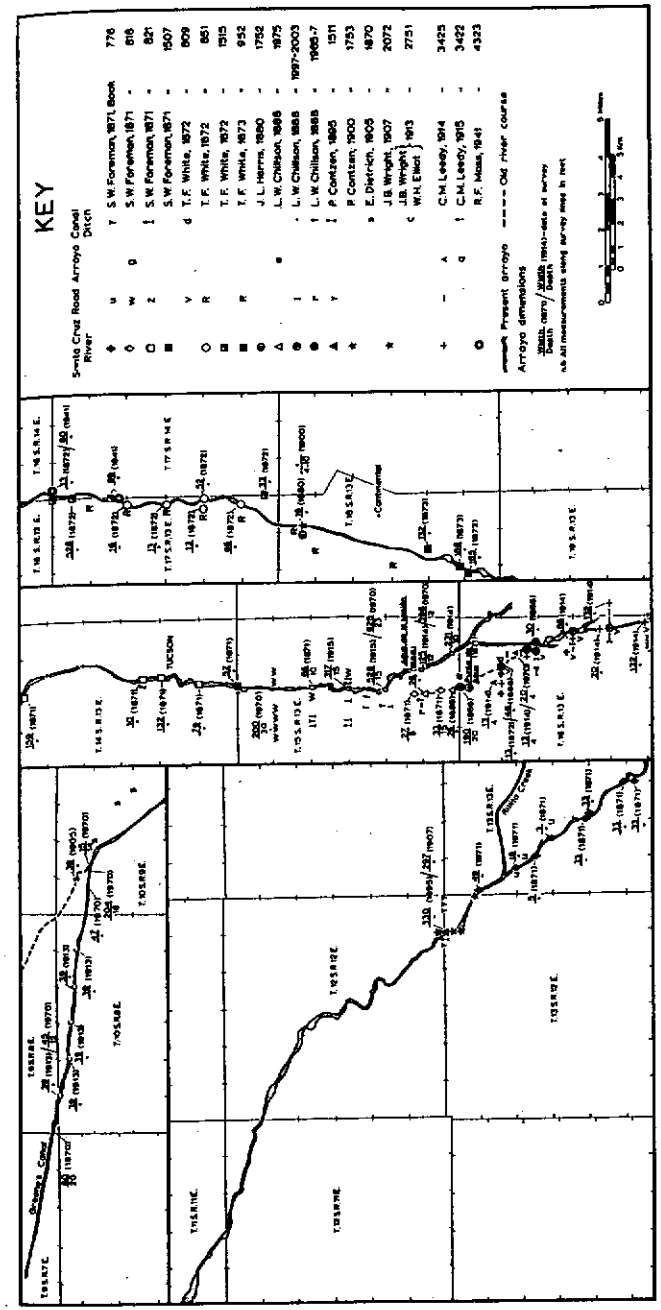

Figure II.8 Santa Cruz Valley: historical data

concerning arroyo development and man's attempts to understand and control hydrological conditions is more extensive and more precise.

The main features of floodplain development can be briefly described. Before about 1880, the valley floor of the southern Santa Cruz Valley was similar to that of the San Pedro. The early surveyors' notebooks often describe the presence of a river channel, in places 'wide and sandy', sometimes with low banks, sometimes without. There was some entrenchment by 1871 (e.g. T.15 S., R.13 E., Figure II.8). In addition, unchannelled, marshy cienegas are mentioned for example near Tucson and San Xavier. In 1857 Silver Lake was created on the untrenched floodplain behind an earth dam south-west of Tucson, and served the needs of milling and, later, recreation (Cusolich, 1953). After 1880, the major changes have been localized entrenchment, headward extension of some arroyos, and widening and deepening of all; the establishment of a continuous vegetation-free sandy swath along the line of flow, and the draining and drying of cienegas.

Entrenchment occurred at the site of Greene's Canal, at Tucson and San Xavier, and near Sonoita and Tubac. Evidence relating to the last two areas is from surveyors' notebooks, and it confirms Bryan's (1922, 1925b) observations. At Tucson, San Xavier, and Greene's Canal the evidence is conclusive and more detailed.

(a) Tucson The pattern of landholdings (reflecting a strong Spanish heritage) and acequias on the untrenched Santa Cruz floodplain at Tucson is clearly shown on the Fergusson map of 1862.[23] Relatively little is known about the acequias at this time and later, but one important type of ditch deserves special mention. This is the infiltration 'ditch' or 'gallery' which was excavated in the floodplain in order to intercept the shallow water-table and thus provide a regular water supply in an area where surface supplies were unpredictable and normally inadequate. The ditches headed into the floodplain upstream and were deepest at their headings. Apparently there were no attempts to protect the headings from erosion. If the water-table fell, the gallery would be extended headward and it would be cut deeper into the floodplain. This type of water recovery was used at least until 1938 (U.S. Dept. Agriculture, 1939). Unintentionally these ditches served to concentrate flood flows and to increase flow depths and erosion velocities. There is no doubt that at Tucson and San Xavier they acted as the loci of entrenchment.

Spalding (1909, p.9) reported that in about 1889 'Certain old settlers undertook to "develop water" at a point about two miles down the river, where there were springs, and in order to accomplish this most easily, cut a channel for a little distance, expecting the river when it rose to do the rest. Their expectations were fully realized, for the river scoured out the cut and carried on with its work.' This comment may be important because it suggests that the settlers *deliberately* intended floods to enlarge their cuts and thus provide better flows of groundwater. Unfortunately, the floods did more damage than was anticipated. Hastings (1958–9) collected from the

Arizona Daily Star of 1890 the contemporary descriptions of arroyo initiation and rapid development in the irrigation ditch at Tucson dug by Sam Hughes:[24]

> 5 August 1890. The flood yesterday washed a deep cut across the hospital road, so that the road now is not only impassable but extremely dangerous for teams or travel as the embankment of the cut is perpendicular and the water below deep, and pedestrians might easily endanger their lives.
>
> 6 August. Another flood . . . It is thought that the washout in the Santa Cruz, opposite this city, will reach Stevens Avenue this morning.
>
> 7 August. The channel or cut being made by the overflow of the Santa Cruz river, is now one mile and a half long, by from one to two hundred yards wide – in other words – it extends from the smelter to about two hundred yards this side of Judge Satterwhite's place.
>
> 8 August. More than fifty acres of land which has formerly been under cultivation in the Santa Cruz bottom, has been rendered worthless by being washed out so as to form an arroyo.
>
> 9 August. The single channel which was being washed out through the fields of the Santa Cruz by the floods, resulted in considerable damage but this damage has been greatly increased from the fact that the wash or channel has forked at the head, and there are now several channels being cut by the flood, all of which run into the main channel. If the flood keeps up a few days longer there will be hundreds of acres of land lost to agriculture. As these new channels or washes are spreading out over the valley, they will cut through and greatly damage the irrigating canals.
>
> 13 August. The raging Santa Cruz continues to wash out a channel and the head of it is now opposite town. It may reach Silver Lake before the rainy season is over.

On 15 August 1890 the *Graham County Bulletin* reported that the arroyo was 5–20 feet deep, up to 150 feet wide, and over a mile long. Clearly the major damage was done in 1890, although there are suggestions of an arroyo in the vicinity of Tucson before this time (e.g. *Arizona Weekly Citizen*, 5 August 1893; the *Arizona Daily Star*, 10 September 1887 refers to 'the arroyo'). Floods along the river in 1890, 1891 and 1892 (Cusolich, 1953; Turner *et al.*, 1943) breached the dam of Silver Lake and soon the arroyo extended into the drained floor of the lake. As Warren Allison (Odom, no date) explained: 'The summer of 1890 was a very wet summer and there were many big floods. The Santa Cruz didn't have a channel before that; this channel that is down there now was made in 1890 and those floods took lake out, fish and all.'

According to Olberg and Schanck (1913) the arroyo was 18 miles long by 1912, having been extended by numerous floods (Figures II.8, II.9). It is possible that the railroad, which crosses part of the floodplain on an embankment near Tucson, also served to concentrate floods; certainly it was washed out from time to time (e.g. in 1887).

Drainage from tributary channels was recognized as being an important contributor to the floods. A trench was therefore cut along the west side of the floodplain to trap tributary flow and keep it away from the growing arroyo. Flood also transformed this trench into an arroyo.

(b) San Xavier del Bac The long and complex history of irrigation and

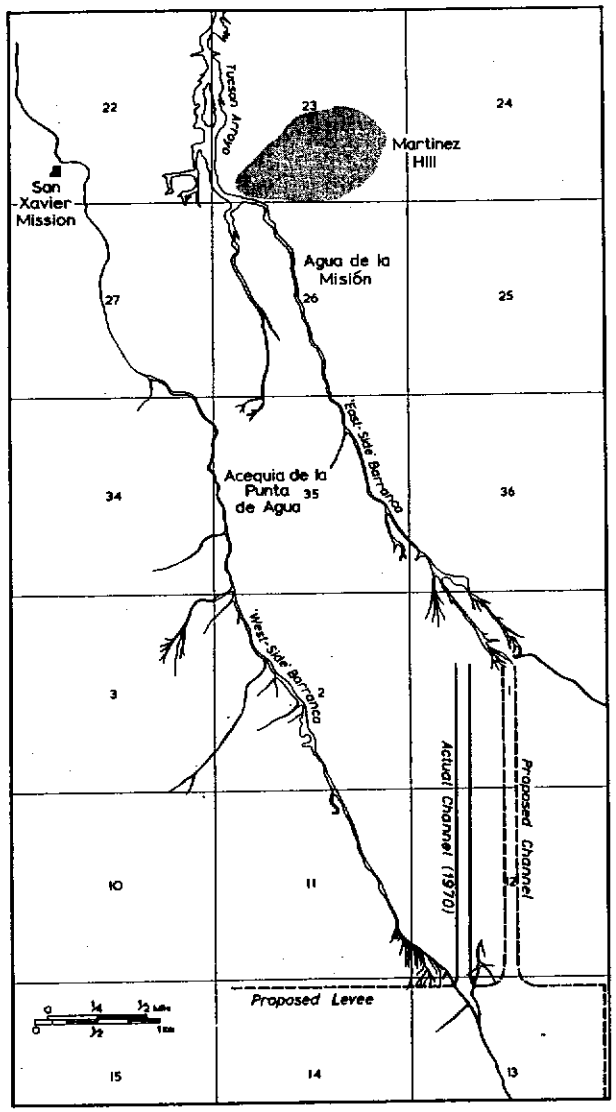

Figure II.9 Santa Cruz Valley: data from Olberg and Schanck (1913)

erosion on the Papago Reservation at San Xavier has been reported in detail by Olberg and Schanck (1913) in a perceptive government document, and it has been reviewed by Castetter and Bell (1942). The Sobaipuri and subsequently the Papago irrigated by flood water (which was diverted in historical times by dikes and brush dams) and by spring water.

There were two main sources of spring water: the *Agua de la Misión* and the *Acequia de la Punta de Agua* (Figure II.9). Springs at the Agua de la Misión were destroyed by an earthquake in 1883 and flow was forced to the surface higher up the valley. Development of this water led to the formation of the East-side *Barranca*, a channel 100–200 feet wide, 15–20 feet deep, and over 2 miles long. The acequia de la Punta de Agua is first mentioned in a Mexican grant of 1851 and is shown on a map of San Xavier dated 1871.[25] Construction of the infiltration gallery resulted in a channel 60–100 feet wide and 6–20 feet deep that came to be known as the West-side Barranca and by 1912 it was approximately 2 miles long. Certainly both arroyos are shown on the Roskruge Map of 1882. The ditches dried up from time to time, and it was necessary to deepen and extend them artificially (Berger, 1901). Thus the two arroyos on the San Xavier Reservation were initiated and extended as infiltration galleries by man, and were exploited by floods.

Meanwhile the Tucson arroyo was being extended by headward erosion during floods (Figure II.8) and by bank caving and piping during low-flow or times of drought. Development of this arroyo was probably helped by concentration of flow *within* it in order to recover water more efficiently for irrigation. Canal irrigation became progressively more difficult as the channel became deeper (Olberg and Schanck, 1913), and flow-concentrating structures such as those for the Farmers' Ditch were frequently washed out. By 1912 the arroyo had reached the Papago Reservation and was about to merge with the arroyo of the Agua de la Misión.

So serious was the threat of erosion on the reservation that a flood-control plan became necessary. Olberg and Schanck (1913) proposed to concentrate flow into a single channel, the East-side Barranca, by diverting flood water eastwards along a dike at the head of the West-side Barranca and directing flow northwards along an artificial channel (Figure II.9). These proposals were accepted, and the new structures effectively prevented further headward extension of the East-side Barranca (although it became much wider and deeper), and stabilized the West-side Barranca. The new flood-control channel has not been seriously eroded. Olberg and Schanck's report marks a turning-point: their successful plan seems to have been the first to be based on a critical evaluation of all available hydrological information.

(c) Green's Canal The only arroyo on the Santa Cruz Plains has been created entirely from the ill-fated Greene's Canal (Figure II.8, T.9 S., T.10 S.). Plans[26] were drawn in 1909 of a canal and reservoir for the Santa Cruz Reservoir Land Co. The plans were changed somewhat, but the enterprise was completed in 1910. The intention was to concentrate flood

water from the Santa Cruz River into the canal (using dikes, brush dams, and embankments), transfer the water along the canal to the reservoir, and distribute it for the irrigation of farm land on the Santa Cruz Plains near Toltec. Unfortunately, the major flood of 1914 destroyed the enterprise (Aguirre, pers. comm., 1970) by breaking the dam, and by damaging the canal and eroding it to a depth of about 12 feet (Turner *et al.*, 1943). Colonel William C. Greene and his colleagues had made the common error of underestimating the size of floods and the erosional effects of drainage concentration. Since 1914, floods have tended to follow the canal, at least for part of its length, and the arroyo has become sinuous, deeper, and wider (Figure II.8). In 1962, for example, flood discharge was estimated at between 17,000 c.f.s. (Rainer, pers. comm., 1970) and 24,100 c.f.s. (Lewis, 1963), the canal overflowed, dikes were breached, and large areas were eroded and flooded (Eloy Soil Conservation District, 1969). Since 1916, lands in the district have been irrigated by well water.

(d) Rillito arroyo The Rillito is a major tributary of the Santa Cruz that was significantly altered between 1858 and 1910. Unlike most other historical arroyos in the Santa Cruz Valley, this arroyo is not associated with conclusive evidence of drainage concentration being responsible for channel erosion although there were acequias (including infiltration ditches) in the valley floor. The only detailed description of the changes is by Smith (1910), who appears to attribute the changes to overgrazing and haymaking. He stated (1910, p. 98):

> [In 1858] The entire valley was . . . an unbroken forest, principally of mesquite, with a good growth of gramma and other grasses between the trees. The river course was indefinite, – a continuous grove of tall cottonwood, ash, willow and walnut trees with underbrush and sacaton and galleta grass, and it was further obstructed by beaver dams. The vegetative covering on mountain slopes, on foothills and plains held the rainfall, causing a large proportion of it to be absorbed into the soil. Such portion as found its way to the river channel was retarded and controlled in its flow, and perhaps not oftener than once in a century did a master flood erode and sweep the river channel.
>
> In the fall of 1872 the United States Army post was moved from the military plaza in Tucson to the junction of the Pantano Wash and the Rillito. There was a great demand for hay and the grass was cut off with hoes to supply the post on large contracts. A few years of such cropping of the grass sufficed to kill it. Cattle were brought in to the country during the seventies and roamed the valley and hills, destroying the root grasses and wearing trails which later became rivulets in time of rain, increasing the runoff of water to the river. New and unusual[27] floods cut out a wide channel . . .
>
> . . . the first real flood to reach the Rillito occurred in 1881, but it was much spread out over the valley and not until the nineties was the present deep broad wash with vertical banks eroded.

Conclusion. The detailed evidence from the three loci of entrenchment along the Santa Cruz Valley point to several important conclusions. Firstly, all three loci are unquestionably characterized by man-made drainage-concentration features. Secondly, entrenchment was initiated at different times in the three areas and, in each case, it was initiated shortly after the drainage-concentration features were established. These two conclusions provide strong support, in these areas, for the 'drainage-concentration' hypothesis of arroyo development. Thirdly, although no direct evidence of drainage concentration has been discovered in other areas of entrenchment in the basin, there has been much activity on the floodplain in such areas for many years, and the possibility remains that roads, acequias, and cattle trails etc. concentrated flow. Fourthly, entrenchment was initially discontinuous, and it still is. Fifthly, it is clear that man, often working in an alien semi-arid environment, persistently tried to control the effects of drought and flood and, in so doing, took measures that frequently failed to accommodate the floods. The history of floodplain management demonstrates an increasing awareness of the hydrological environment, but adequate perception unfortunately only came after damage had been done. Finally, it remains to determine whether the floods between 1870 and 1914 which actually did the eroding were in any way unusual and, if so, whether they arose from climatic and/or vegetational changes in the watershed. This problem is considered in a later section.

Arroyos in Avra and Altar Valleys

The Altar-Avra Basin, which is tributary to the Santa Cruz and lies to the west of it, extends from near the Mexican border northwards to the Santa Cruz Plains. Locally residents usually divide the basin into two parts – the Altar Valley in the south and the Avra Valley in the north, with the division lying along the line between T.14 S. and T.15 S. Altar Valley has most of the features described in other valleys: mountains flanked by pediments and alluvial plains, an inner valley that widens northwards, and an arroyo along much of its length. In Altar Valley pediments form an unusually large portion of the plains and this fact may be of some importance because groundwater aquifers in alluvium are rather restricted, and the proportion of precipitation that runs off may be relatively high. In Avra Valley the plains are broader, pediments are restricted, the groundwater reservoir is extensive, and there is only one short entrenched section.

Land-use history in the region has been rather simple. Andrews (1937) commented that the area was sparsely settled and had been of slight economic interest except for grazing. This seems to have been true for many years mainly because the area has been the western frontier of white settlement and has been relatively remote from the main centres of activity. Cattle grazing certainly was the chief interest in 1886, and in Altar Valley it still is. It was not until 1950 that the groundwater aquifer in Avra Valley was seriously exploited for irrigation, although there was a little irrigation based on imported water before that time (White, Matlock, and Schwalen, 1966).

Entrenchment in Altar Valley has resulted in a well-developed arroyo, known as Altar Wash in the south and Brawley Wash in the north. Although the entrenchment varies in magnitude along the valley, the arroyo is a relatively continuous, meandering feature that is up to 20 feet deep and up