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

to 1,300 feet wide (Figure II.10). The only precise evidence concerning the arroyo in this very poorly documented area comes from the notes of the first survey made by a well-known local surveyor, George Roskruge, in 1886.[28]

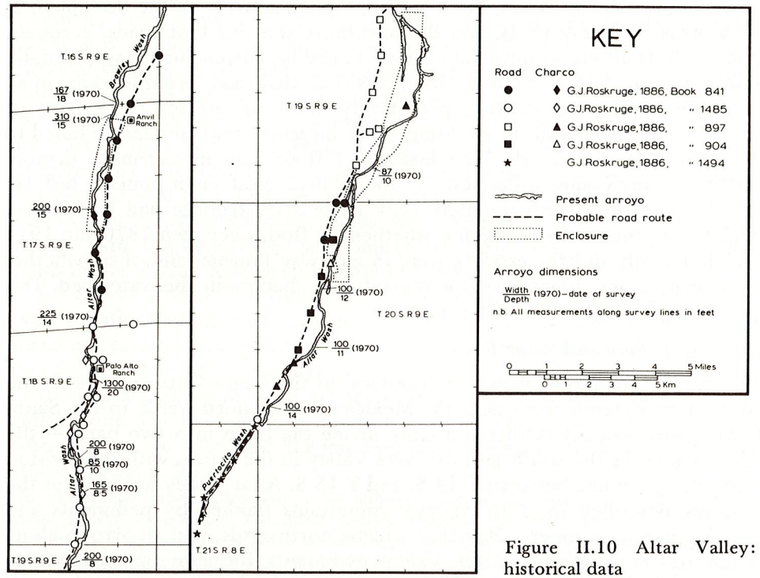

Figure II.10 Altar Valley: historical data

It is quite clear that there was no entrenchment in 1886 (Figure II.10). But there is evidence of three features on the narrow, grassy floodplain that may have been loci for subsequent erosion.

Firstly, there were several roads on the valley floor, including the main wagon road from Tucson to Altar (Mexico). The present arroyo follows the lines of these roads in several places, especially along Puertocito Wash (Figure II.10, T.21 S., R.8 E.) and near Palo Alto Ranch (T.18 S., R.9 E.).[29] There are places where the 1886 road and the present arroyo are not coincident. Field investigations revealed traces of the old road in locations given by Roskruge: the old road is relatively free of vegetation and is incised into the floodplain by several feet. These two observations confirm previous deductions (in the San Simon Valley, for instance).

A second feature of the 1886 record is two enclosures along the valley floor (Figure II.10). Both enclosures are now entrenched. A possible clue to the cause of entrenchment in the southern of these two enclosures is contained in a note by Roskruge (Book 904, T.20 S., R.9 E., 1886):

Through the center of this Township running N & S there is a large body of fine bottom land, susceptible of raising almost any kind of crop, if properly watered. In secs 4,5,8,9,

& 17 there is a post and wire fence enclosing about 600 acres of this land, the fence being the property of A. Hemme. I am informed that Mr. Hemme intends to conduct water on to this land by iron-pipes laid from Arivaca Creek a distance of 7 or 8 miles.

It is not known if this irrigation scheme materialized but if it did it probably would have provided a concentrated supply of water along the axis of the enclosure. Equally, grazing of animals or even cultivation of crops within the enclosed area might have promoted erosion.

A third feature of interest is the *charco*, of which nine are mentioned (Figure II.10). Charcos are hollows in generally undissected floodplains that contain water from time to time (Bryan, 1920). The origins of these features are varied, but mainly they are either natural depressions eroded, for example, by scour on the outside of meander bends, or they have been excavated by man. In either case they contain pools of water after a rainfall or flood and provide watering-places for cattle and horses. Bryan, who studied the features throughout the Papago country (1920 and 1925b), made several pertinent comments on them.

in places where the [flood] current is exceptionally swift, part of the mud laid down by past floods is removed and a relatively large channel is formed. It is characteristic of these channels that they begin with a series of little cliffs, 6 inches to 18 inches high, which lead down to numerous small channels and rill marks which collect together into a single channel which pursues a somewhat sinuous course in the direction of the drainage, and finally ends more or less abruptly. In many instances the channel ends in a vertical wall 3 to 5 feet high. It is evident that concentration of the current of a flood normally spreads in broad sheets over the flat, digs the original channel, and movement of water into this channel toward the end of the flood or during minor floods causes erosion of the fan-like set of miniature canyons at the upper end.

In this passage (Bryan, 1920, p.204) a natural origin is envisaged, but the current could be 'exceptionally swift' or 'concentration' could be increased due to irregularities created by man. In either case, the result is a depression below the level of the floodplain in which water collects.

Speaking of smaller charcos in grassy flats, Bryan (1920, p.205) continued:

Channel cutting of the kind previously described sometimes takes place in these flats, and many of the smaller charcos seem to be due to a breaking of the grass cover which allows erosion to take place over a very small area. Other holes seem to be due almost wholly to the activities of animals, both wild and domestic, which come to feed in the flat immediately after the rain. Very shallow pools of water attract them: they drink the muddy water, roll in the mud, and trample and compact the bottom. Thus a somewhat deeper hole is formed . . . The maximum depth below the surface attained by this process seems to be about two feet.

Whatever the origin of charcos they could have served to concentrate floodwater flow and promote erosion. In Altar Valley nearly all the charcos of 1886 were sites of subsequent entrenchment.

Thus entrenchment in Altar Valley coincides in part with the lines of old roads, the location of charcos, and the area of two enclosures. It is not clear whether these features merely acted as loci of erosion that was certain to occur somewhere, or whether the changes of hydraulic conditions associated

with them caused erosion where there would otherwise have been none. The arroyo was formed after 1886. By 1923 it had banks 2–6 feet high and extended almost to Anvil Ranch (Bryan, 1925b). By 1937 it was up to 20 feet deep and 600 feet wide (Andrews, 1937). And today it extends as far as T.14 S., is up to 1,300 feet wide, and is still no more than 20 feet deep.

There is no doubt about the origin of the arroyo in Avra Valley. When the land was sub-divided in the 1950s for irrigation, the fields were protected

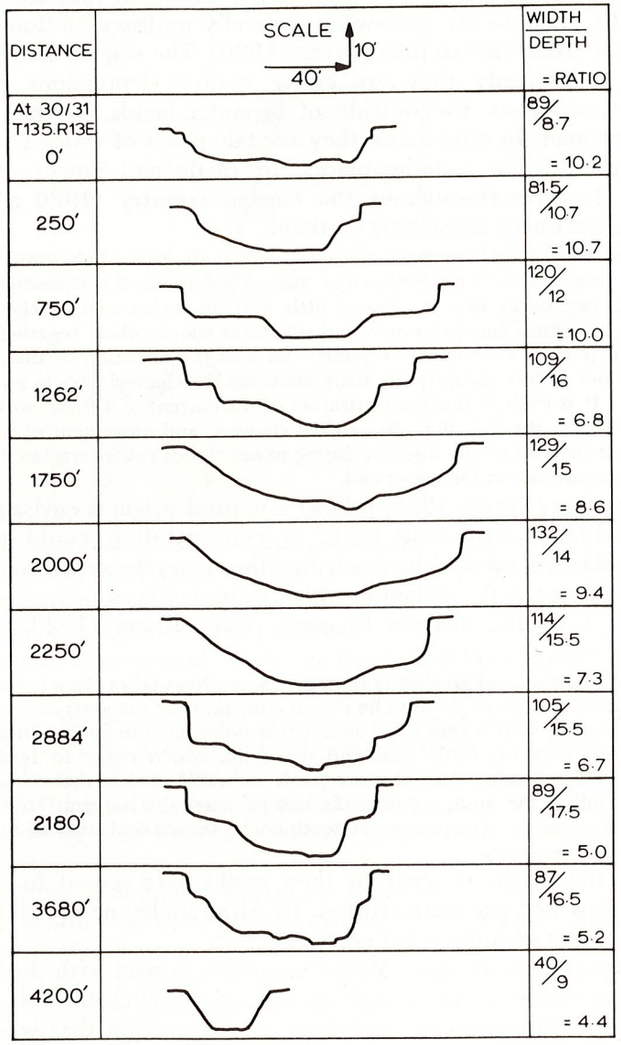

Figure II.11 Avra Valley arroyo: cross-sections, 1970

from occasional flooding by dikes, and floodwater was diverted into flood channels. One of these channels, that in the south of the area and nearest to major floods coming down the valley, was too small to accommodate large floods, such as that of 1962 (Lewis, 1963), and it has been seriously eroded. The dimensions of this arroyo are shown in Figure II.11. It is interesting to note that in places the terrace remnants in this valley are structurally controlled by the resistant B or caliche horizons of the palaeosol referred to elsewhere. The Avra arroyo is unquestionably the result of artificial drainage concentration.

Arroyos in the Papago Country: a Speculation

Beyond the Baboquivari divide lies the Papago ('Bean People') Indian Reservation – a different cultural and natural environment.

The Papago country differs in many ways from the basin-and-range lands to the east. It is dominated by broad, gently sloping alluvial plains and poorly integrated drainage systems. Mountains are fewer and the relief smaller. The area is also drier, although the precipitation regime is still dominated by summer storms. Despite the greater aridity and many years of vegetation modification by man, there remain grassy plains, and broad swaths of riparian vegetation still characterize most valley floors. A further contrast with the basins to the east is that valley-floor entrenchment is less frequent and less spectacular. Nevertheless, there are several arroyos within the reservation (Figure II.1).

It is within this harsh environment that the Papago Indians live. The tribe is generally regarded as an environmentally differentiated group of the Pima Indians (Hackenberg, 1962). Their traditional society was characterized by small groups of peaceful, industrious, and skilled agriculturalists, meagre in equipment, and informal and decentralized in organization (Castetter and Bell, 1942). Traditionally, the Papago response to the harsh desert environment has been a semi-nomadic existence in which kinship groups move between winter and summer occupation sites.The winter settlement ('The Well') was usually in the mountains or their foothills at a permanent source of water; this settlement was the base for hunting by the men and gathering by the women.

The summer village ('The Field') was on the alluvial plains some miles away from the winter settlement. According to Castetter and Bell (1942, p.44): 'Papago agriculture, involving no storage of water, was characteristically of the primitive but efficient *de temporal* "thunderstorm" type; that is, flood-water farming in which seed was planted in moist ground at the mouth of a wash after the first rains, which came in summer.' This agricultural system was reported as early as 1694 and it persists today.[30] Field and documentary evidence indicates that the Papago skilfully directed flood water from the wash on to prepared land by means of canals and dikes. Together with planting, weeding, and harvesting crops such as corn, beans,