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APPLICATION OF ERTS-1 MULTISPECTRAL IMAGERY TO MONITORING THE PRESENT EPISODE OF ACCELERATED EROSION IN SOUTHERN ARIZONA

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Abstract

An episode of accelerate` arroyo-cutting and sheet erosion commenced about 1890 in southern Arizona, following several thousand years of generally sluggish erosion. For a 17,000-square-mile study area, ERTS-1 images, supplemented by ultrahigh-altitude (U-2 and RB-57) airphotos, are proving effective for producing the first comprehensive maps showing the distribution and seriousness of the post-1890 erosion features, for monitoring new erosion changes, and for assessing the effectiveness of ameliorative measures. Such data are essential for understanding and controlling the accelerated erosion, a key environmental problem in this region.

ERTS-1 project 182 is evaluating the usefulness of ERTS-1 imagery of southern Arizona for identifying and mapping the effects of an episode of accelerated erosion that began about 80 years ago. This project is under the EROS Program of the Department of the Interior and is funded by NASA.

Before I tell you about the results from the ERTS imagery, let me explain what the modern erosion is like and why it is a serious problem.

Before the Civil War, the larger streams in southern Arizona and their main tributaries flowed sluggishly in shallow channels through grass-choked flood plains dotted with pools. Archeologic and geologic data indicate that this situation had existed for at least two thousand years, broken only by relatively brief and minor erosional episodes. After the Civil War, a boom in ranching led to a dramatic increase in the numbers of cattle and sheep. Within a few years, floods began to be much larger than formerly. By about 1890, severe entrenchment, catastrophic in places, was underway on all the main streams. Arroyo-cutting subsequently worked its way far upstream and back along the various tributaries, stopping the former natural irrigation of the grassy flood plains and causing much of the grass to die. The most productive parts of the rangelands were thereby ruined, as was much irrigated farmland.

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Figure 1. View of a typical post-1890 arroyo (Railroad Wash, near Duncan, Arizona about 36 miles east of Safford) showing headcuts on a moderately well-grassed and nearly level flood plain. As headcutting continues upstream, excellent pastureland will be converted into a barren badland.

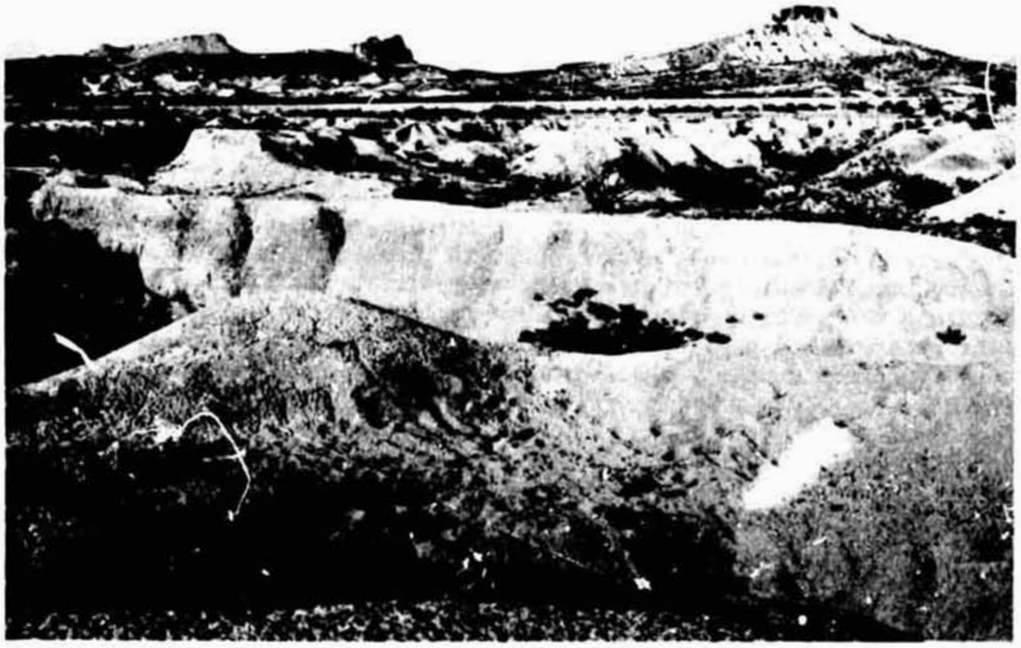

Figure 2. View several miles downstream along the same wash, showing the type of badland that has resulted from the modern trenching of this wash. Sixty years ago this area was a lush pasture and was regularly cut for hay.

The causes of the post-1890 erosion are not fully understood. Four principal causes have been considered: overgrazing, climatic change, control of range fires, and increase in rodents and jack rabbits. Researchers generally agree that overgrazing and climatic change are the the two chief factors, probably acting together to trigger the modern erosion episode. Furthermore, photographs and other records show that these factors have produced a fundamental change in the vegetation balance of the whole region: grass has steadily declined in abundance and shrubs have markedly increased on the desert plains and foothills.

The geologic result of this drastic vegetational change is of great human significance because the geologic consequences are practically irreversible. The former condition of "landscape stability," without much stream erosion or deposition, which had lasted several thousand years, has been replaced by an episode of accelerated erosion whose end is not in sight. The areas now undergoing the most erosion are the valley lowlands whose fine-textured alluvium was deposited during the last 10,000 radiocarbon years or so. This young alluvium is a legacy of a delicate balance between rainfall and runoff that was maintained by a vigorous desert grassland ecosystem in both uplands and lowlands. The well-grassed uplands held most of the rainfall and released the runoff slowly and so flood peaks and stream erosive powers were lower than today. The stream channels were narrower and shallower than now, and the seasonal floods regularly overflowed them, inundating the flood plains, irrigating the grass and depositing fine sediment. Now the whole system has changed -- the grassland has deteriorated, runoff is less retarded, flood crests are higher, and erosive powers of the streams have become much greater. The former flood plains are especially vulnerable because, with loss of much of their grass cover, conditions have been reversed from those favoring accumulation of fine sediment to those in which such sediment is actively eroding.

The erosion progresses in three stages. The first is vegetative stress, as a result of overgrazing and/or adverse climatic change. Deterioration of grass cover is especially significant because grass is the most effective type of vegetation for retarding runoff, preventing erosion, and trapping sediment. The second stage is sheet erosion of areas with little or no grass cover. The third stage, gullying or arroyo-cutting, is the spectacular one.

A step toward highlighting the seriousness of the erosion problem is to inventory the modern gullies, arroyos, and sheet-eroded areas. Although they have been mapped in a few small areas, the modern erosion features have not been mapped comprehensively and extensively in southern Arizona. Our project is attempting to do this for a 17,000-square-mile area that represents all the important environments in the region in terms of topography, geology, climate, soils, and vegetation (Fig. 3). For this mapping, we are utilizing both the broad overview capabilities of the ERTS-1 images and the closer looks provided by U-2 and RB-57 aerial photographs. We are using the ultrahigh airphotos to map representative parts of the study area in considerable detail, combined with some fieldwork, in order to have a basis for assessing the mapping done from the ERTS images.

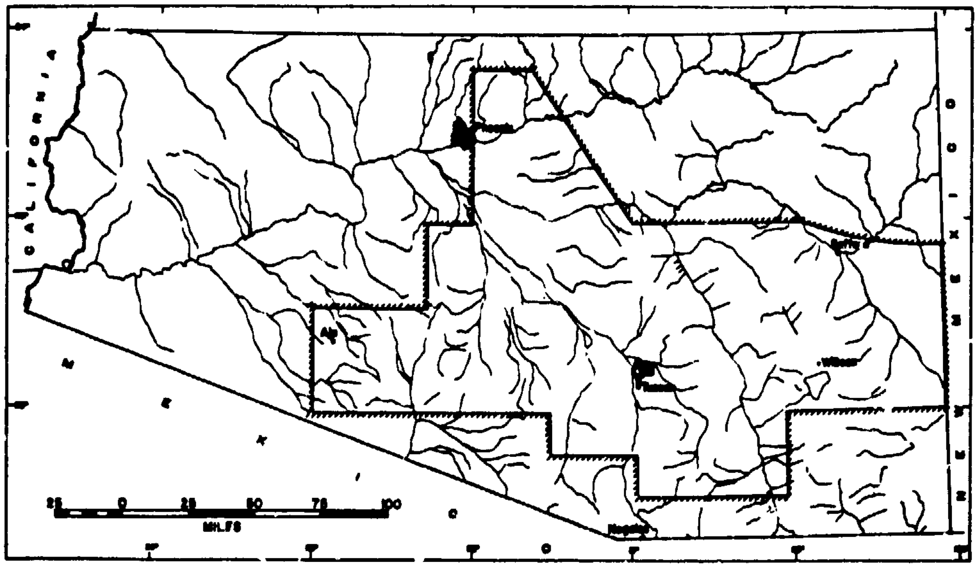

Figure 3. Outline map of the study area in southern Arizona

In addition to the gullies, arroyos, and sheet-eroded areas that have developed since 1890, we also map the areas of modern wind erosion and deposition (which are tiny in this region), and other data pertinent to the erosion problem, such as the distribution of the more erodible types of soil.

We view the 70-mm and 9 x 9-inch positive transparencies of the MSS images under various magnifying devices. We received full coverage of the study area by 9 x 9-inch transparencies during late February (before that we had only one of them), therefore, most of our interpretations have been made from the 70-mm transparencies. For viewing these, a binocular microscope, using 9 times magnification, has been very convenient. To reduce glare and improve contrast, we commonly insert colored Diazochrome sheets between the light source and the image. The multispectral bands of a few frames have been viewed using an I^2S Mini-Addcol additive color viewer. We also have used negative enlargement prints at about 1:1,000,000 scale, made from positive 70-mm transparencies. We have ordered 1:250,000 scale enlarged prints but have not yet received them. We believe it will be most efficient and productive to view the 9 x 9-inch transparencies under a zoom transferscope and plot our interpretations onto either USGS 1° x 2° maps or onto the 1:250,000 scale enlargements of the ERTS images.

Figure 4 shows all the arroyos within the study area that have been identified from the ERTS images. We find that the "red" MSS band 5 gives the sharpest definition of modern arroyos. As linear features, the arroyos can be distinguished when their width is about a tenth of the minimum width for recognition of equidimensional features. On the best images that we have received, we can distinguish modern arroyos as narrow as 150 to 200 feet in reaches where their contrast with adjacent areas is only moderate, and as narrow as 60 to 75 feet in reaches where their contrast is high. High contrast is produced by dark riparian vegetation against light-toned arroyo beds and soils of former flood plains that now are bare of vegetation. Both the red and infrared bands (bands 5, 6, and 7) show differences in soils and vegetation. In the late fall and winter images, band 7 generally is the most useful for mapping the more erodible soils.

The resolution of many images is degraded by atmospheric haze (including smog and smelter smoke haze), especially in the lower parts of the intermontane basins and near Phoenix and Tucson. All bands of the images taken in summer were overexposed in the desert areas because of the high reflectivity of the light-toned soils. This seriously hampered interpretation. The late fall and winter images are correctly exposed for the desert areas because the lower sun-elevation angle has reduced the reflectance. In these images, shadowing also has improved the contrast of some reaches of the deeper arroyos. Dark shadows begin to be distinguishable in arroyos deeper than about 30 feet when sun elevation angles are less than 30°. Near the winter solstice, sun-elevation angles in the study area are around 27°.

Figure 5 is an example of the more detailed mapping possible with the ultrahigh airphotos. In this case, we used 9 1/2 x 9 1/2-inch color infrared positive transparencies (EK 2334 film) taken last August by NASA's U-2 aircraft with a Wild RC 10 metric aerial camera at about 62,500 feet above ground, giving a photo scale of about 1:125,000. We are extremely pleased with the resolution-detectability and spectral sensitivity characteristics of these photographs; they are proving to be valuable research tools. This map shows a 50-mile belt along San Simon Creek, between the towns of San Simon and Solomon in southeastern Arizona, that has been affected considerably by post-1890 erosion. This wash is 75 miles long and has a drainage area of about 2,200 square miles. It has trenched its channel commonly 20 feet and, in places, 40 feet since 1905. The solid black lines show the channels and narrow flood plains that have formed since 1905, and the three types of patterns show the areas that are severely gullied, severely sheet-eroded, and moderately sheet-eroded. We plan to prepare similar maps for sizable parts of the study area to represent all the important soil, climatic, vegetational, and geomorphic-topographic conditions, and also the areas most affected by post-1890 erosion.

As the investigation progresses, we will utilize the repetitive ERTS-1 imagery and ultrahigh aerial photography to monitor erosional changes. We also are utilizing aerial photography back to 1935, to prepare detailed maps of the evolution of the modern erosional features. Thus, we hope to determine the rates of headward growth, widening, deepening, or aggradation of the gullies and arroyos. We will also monitor the erosional effects of highway construction, stream channelization, and urban and suburban developments. An ultimate objective is to develop a quantitative understanding of the factors that have caused the modern episode of accelerated erosion, as an aid to planning and implementing ameliorative measures.

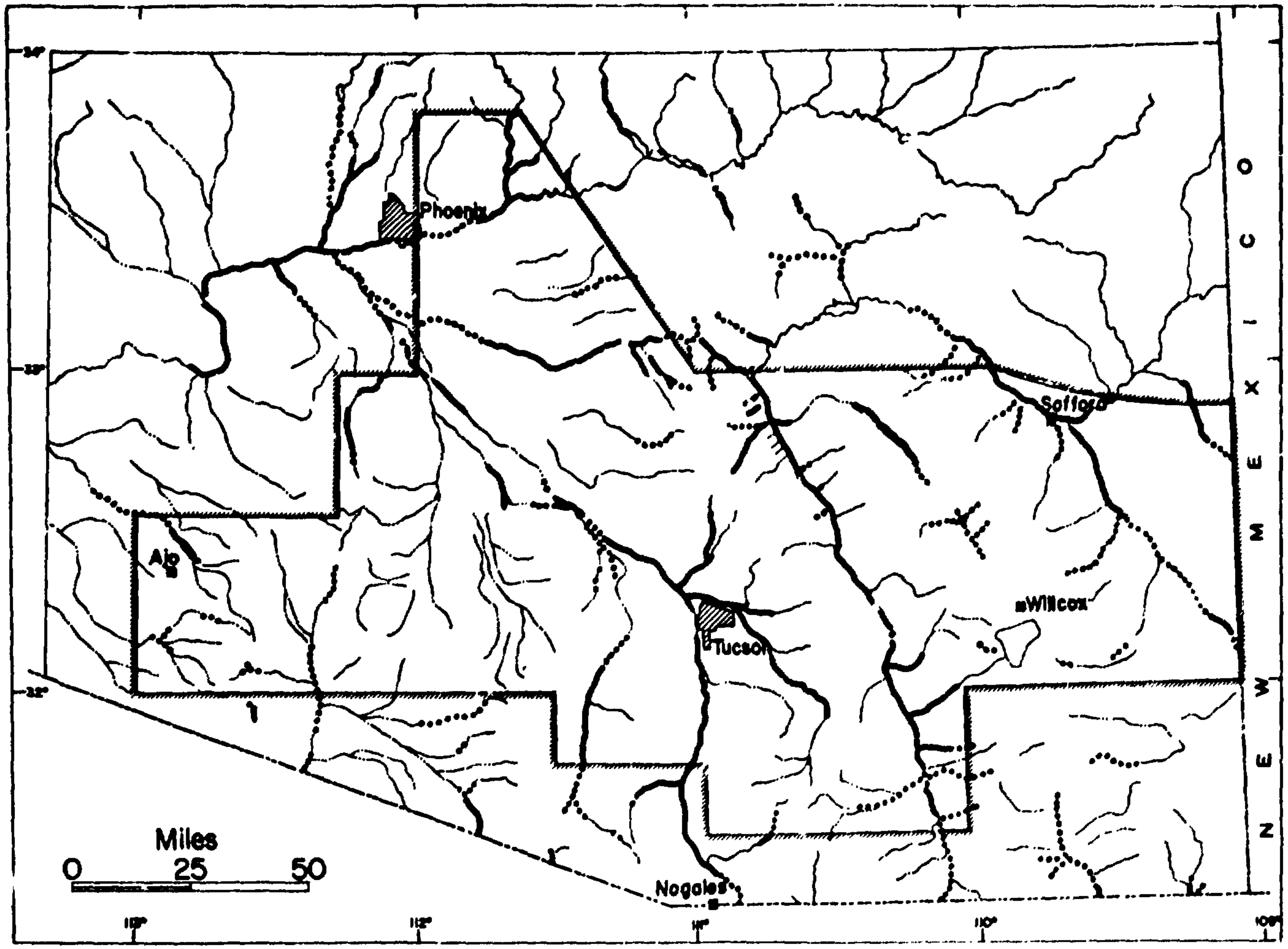

Figure 4. Modern arroyos in south central and southeastern Arizona that are detectable from ERTS-1 imagery (shown as heavy lines where continuously detectable, dotted lines where intermittently detectable).

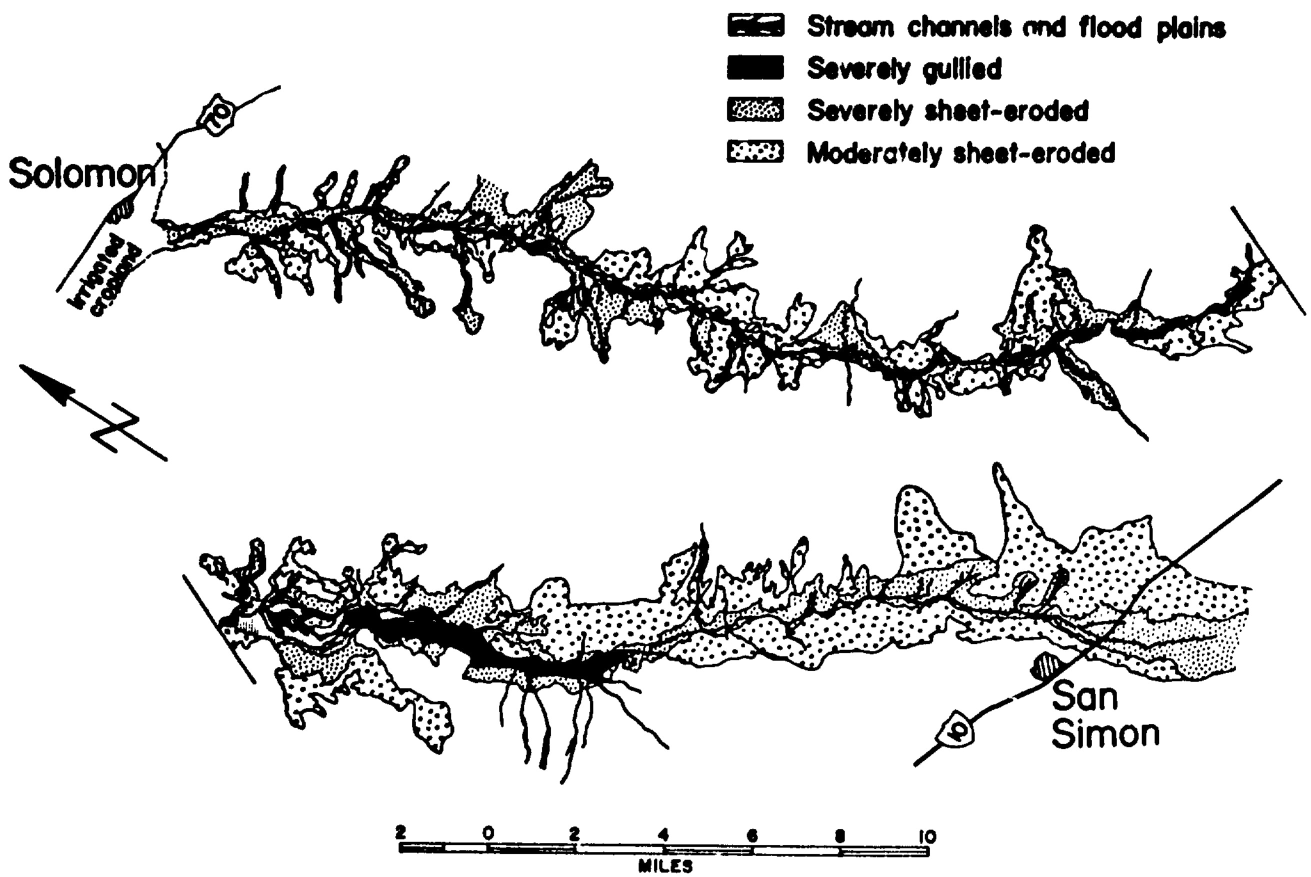

Figure 5. Map of modern erosion features along a 50-mile reach of San Simon Creek, southeastern Arizona. Solomon is 5 miles east of Safford.