Channel responses to artificial stream capture, Death Valley, California

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ABSTRACT

Artificial capture of Furnace Creek Wash by Gower Gulch in 1941 caused channel responses in three separate reaches of this integrated ephemeral stream system: (1) upper Furnace Creek Wash, (2) Gower Gulch channel, and (3) Gower Gulch fan. At the diversion point, vertical erosion had lowered the brink of a 25-m nickpoint by approximately 3.2 m by 1974. Upstream from the nickpoint, Furnace Creek Wash had responded with headward dissection for 2.7 km and removal of debris at a mean rate of about 4×10^3 m^3/yr. The mean slope of the Gower Gulch channel had been lowered throughout by erosion due to drastically increased discharge, producing debris at a mean rate of about 2×10^3 m^3/yr. Dissection of the upper part of the Gower fan to a maximum depth of 5.7 m and production of debris at a mean rate of about 0.4×10^3 m^3/yr are attributed to high stream velocities and increased discharge. In the absence of further intervention, evolution of the system during the next few hundred years is likely to be characterized by the following: (1) increasing depth and extent of headward dissection in Furnace Creek Wash and its tributaries upstream from the diversion point and (2) readjustment of the Gower fan profile in response to accumulation of coarse diverted debris.

INTRODUCTION AND SETTING

What appears, in retrospect, to have been an ill-advised flood-control measure was initiated near Zabriskie Point, Death Valley, California, in 1941 with the man-made diversion of the ephemeral Furnace Creek Wash into a branch of Gower Gulch (Fig. 1). The diversion created a nearly right-angle change in the course of Furnace Creek Wash and shortened its route to the floor of Death Valley by about 2 km. The effective drainage area of Gower Gulch was instantaneously increased from about 5 km^2 at low altitudes to about 440 km^2 at intermediate to high altitudes. This artificial stream capture drastically increased the discharge delivered to Gower Gulch and altered its bed load from mainly fine-grained material (silt to pebbles) derived from the Pliocene Furnace Creek Formation to predominantly coarse-grained debris (pebbles to boulders) from the Paleozoic sedimentary sequence of the Funeral Mountains to the northeast.

In assessing the environmental impact of the diversion, Troxel (1974) described the character and degree of channel responses in several parts of the Furnace Creek Wash–Gower Gulch system. He recognized that natural stream capture was imminent at the time of diversion and reported channel adjustments including the following: (1) dissection of the Gower fan, (2) erosion of the Gower Gulch channel throughout its length as evidenced by hanging tributaries, (3) rapid vertical erosion of fine-grained sedimentary rocks of the Furnace Creek Formation at the diversion site, and (4) deep, headward-working dissection of upper Furnace Creek Wash. Although the diversion has reduced flood hazards to buildings and roads on and near the largely abandoned fan of Furnace Creek Wash, repeated damage to California 190 near the diversion point and to National Park Service Route 1 (California 178) on the Gower fan makes the diversion of dubious economic advantage.

Channel adjustments listed above are interpreted as the response of the system to a natural-scale experiment initiated by the diversion in 1941. Field observations indicate that basic principles of stream behavior have resulted in three distinct types of channel response in three separate reaches of the system, as follows: (1) headward-working vertical dissection of Furnace Creek Wash immediately above the diversion site, (2) vertical erosion throughout the Gower Gulch channel to produce a lower mean gradient, and (3) deep dissection of the upper part of the Gower fan to produce an incised channel roughly 500 m long, succeeded by deposition on lower reaches of the fan.

HEADWARD DISSECTION OF FURNACE CREEK WASH

Troxel (1974) noted that the diversion of Furnace Creek Wash into Gower Gulch immediately created a nickpoint roughly 25 m high and concentrated strong erosive force at the diversion point. Subsequent modification by running water has converted this nickpoint into a succession of normally dry cas-

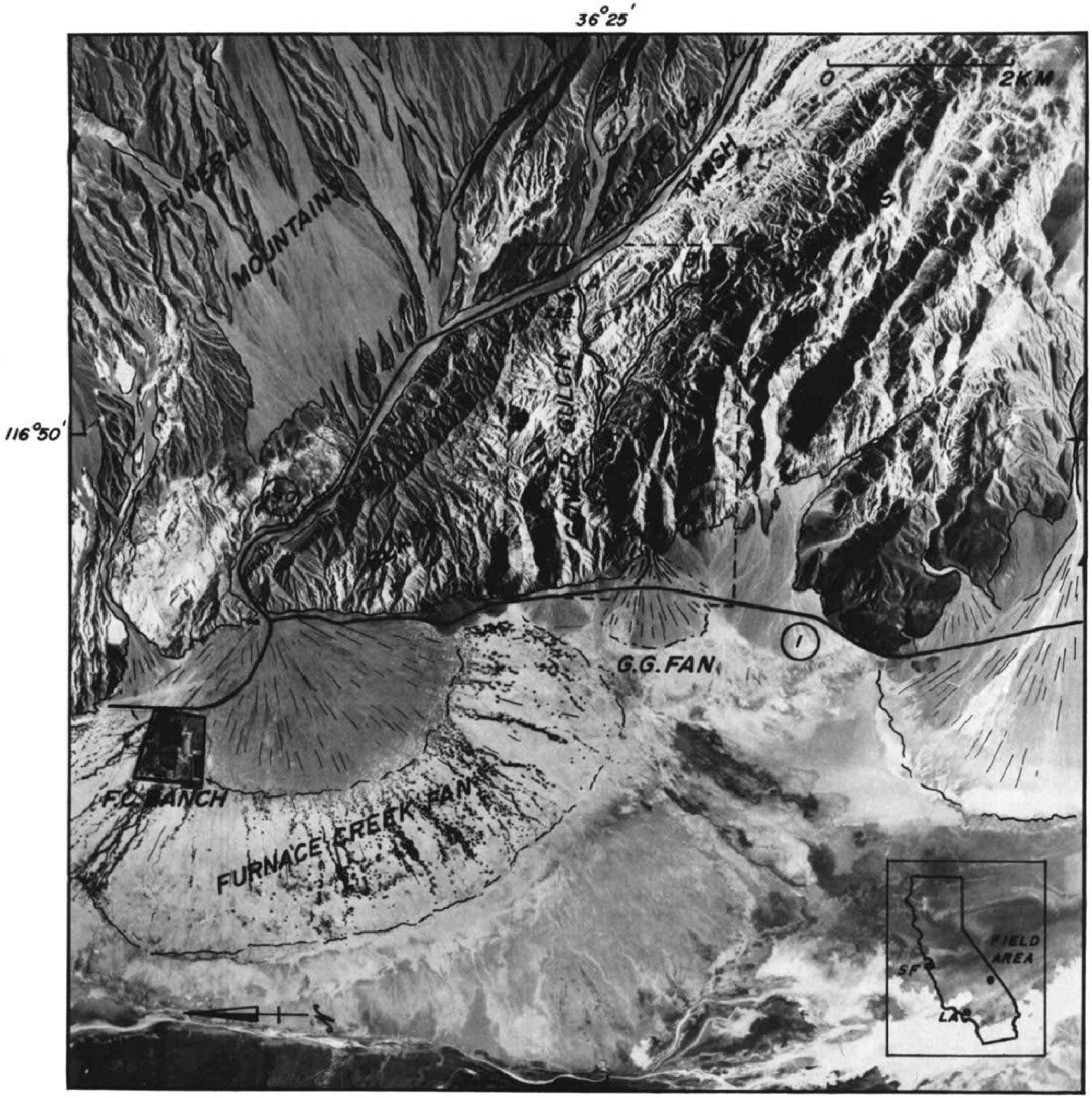

Figure 1. Aerial photograph of Furnace Creek Wash–Gower Gulch area near Zabriskie Point (Zab. Pt.) in central Death Valley, California. Letters A to E are endpoints of channel profiles presented in Figure 3. Dashed line encloses diversion point (A), Gower Gulch (AD), principal southern branch of Gower Gulch (BC), and dissected part of Gower fan (below D). Photograph was taken in 1948 and is courtesy of Glen A. Miller of the U.S. Geological Survey.

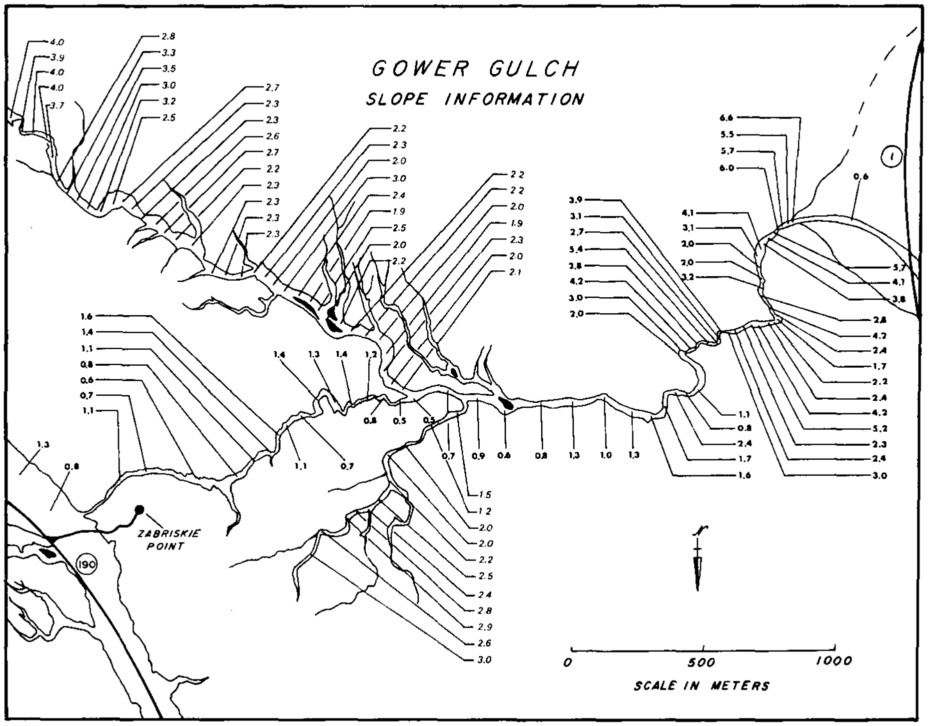

Figure 2. Slope information in degrees for Furnace Creek Wash, southern branch of Gower Gulch, and central channel of Gower Gulch.

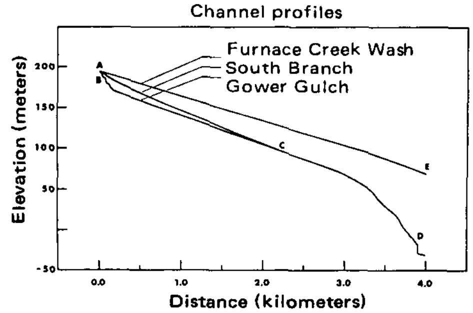

Figure 3. Channel profiles derived from slope information presented in Figure 2. Endpoints A to E are indicated in Figure 1.

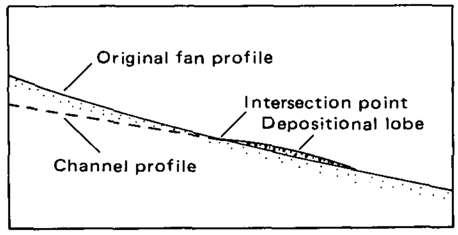

Figure 4. Typical radial profile of fan with entrenched stream channel, after Hooke (1965).

cades and waterfalls that effectively isolate upstream Furnace Creek Wash from downstream influences below the nickpoint. Since the diversion 33 yr ago, vertical erosion has lowered the brink of the original nickpoint by approximately 3.2 m, thereby lowering the effective local base level for upper Furnace Creek Wash, which has responded by lowering its bed at the nickpoint by that amount and with headward-working dissection now extending 2.7 km upstream (Troxel, 1974, Fig. 2). This dissection is the result solely of nickpoint lowering, because neither discharge nor load, both upstream factors, has changed in this reach of Furnace Creek Wash as a result of the diversion. The shortened route to ultimate base level caused by diversion cannot be responsible, because the nickpoint at the diversion site isolates upstream Furnace Creek Wash from such downstream influences.

Approximately 1.4×10^5 m^3 of debris have been removed from Furnace Creek Wash since the diversion, at a mean rate of 4×10^3 m^3/yr. Somewhat less than 10 percent of this total now forms a veneer less than a metre thick along the entire length of Gower Gulch. The remainder resides on lower reaches of the Gower fan and on the floor of Death Valley.

LOWERING OF THE GOWER GULCH CHANNEL

The artificial capture of Furnace Creek Wash served to increase drastically the volume of water and the amount and caliber of debris delivered to Gower Gulch. Its bed load changed from mainly fine-grained silt and sand to material ranging in size from pebbles to boulders some tens of centimetres in diameter. Hanging tributaries along the entire length of Gower Gulch are evidence for significant vertical erosion in response to this change in regimen.

The principal southern branch of Gower Gulch (Fig. 1) drains a slightly larger basin than did the prediversion central branch now followed by diverted water and debris. Both branches originally drained similar parts of the Furnace Creek and Artist Drive Formations and presumably transported bed loads similar in type and caliber of debris. The southern channel was presumably adjusted to a gradient at least as gentle as that of the prediversion central channel.

Longitudinal profiles of both branches (Figs. 2, 3) indicate that the central branch has now developed a still gentler gradient throughout the upper 75 percent of its length. Significant vertical erosion, implied by hanging tributaries, is presumably the cause of this lower gradient in the central channel. The effect of increased discharge in this narrow, confined channel has outweighed the effects of an increase in amount and caliber of load. Assuming that the profile of the prediversion central channel was similar to that of the southern channel, the amount of eroded material is about 0.7×10^5 m^3, corresponding to a mean erosion rate of 2×10^3 m^3/yr.

The newly established upper Gower Gulch channel and incised Furnace Creek Wash channel are comparable in both width and gradient, presumably reflecting identical discharge and debris loads. Steepening of the gradient along the lower 25 percent of the Gower Gulch central channel (Figs. 2, 3) occurs exclusively within the Artist Drive Formation (McAllister, 1970) and is presumably lithologically controlled. In contrast to the upper reach of the channel, this section is characterized by numerous small nickpoints as high as 2 m associated with cross-strike flow over relatively resistant sedimentary beds. There is no evidence that postdiversion lowering of a 12-m, near-vertical nickpoint at the head of Gower fan has contributed to the increased gradient, which presumably predates the diversion.

DISSECTION OF GOWER FAN

Lack of dissection on nearby fans strongly suggests that the Gower fan was undissected prior to diversion. Subsequent dissection of this fan has created a curving, vertical-walled, flat-bottomed channel roughly 5.7 m deep and 10 m wide at the fanhead, which extends with decreasing depth nearly halfway (500 m) down the fan. Roughly 1.4×10^4 m^3 of material have been removed by dissection and deposited on lower reaches of the fan and on the floor of Death Valley at a mean rate of 0.4×10^3 m^3/yr.

Field measurements indicate that the head of the prediversion Furnace Creek fan had a slightly steeper radial gradient than did the head of the original Gower fan surface, probably because of the coarser debris delivered to the Furnace Creek fan before diversion. The Gower fan now receives essentially the same discharge and debris load as did the Furnace Creek fan before diversion, so dissection of the Gower fan to an even gentler mean gradient seems anomalous.

Bull (1964) studied alluvial fans in western Fresno County, California, and concluded that upstream alterations in regimen caused by tectonic or climatic changes inevitably result in changes in radial fan profile. In particular, fans associated with progressively gentling stream gradients undergo deposition near the toe of the fan to reduce the gradient to that of the lower reaches of the stream channel. As shown, the Gower Gulch channel has experienced erosion to a lower mean gradient since diversion, but the near-vertical nickpoint at the head of the Gower fan effectively isolates the fan from this upstream slope reduction. Since the coarse debris now transported down Gower Gulch can ultimately be expected to produce a *steeper* gradient than that of the original fan surface, deposition near the toe of the fan is not likely to produce a more gently sloping fan segment. Deposition of diverted debris is now occurring on the Gower fan beyond the end of the incised channel west of National Park Service Route 1, but so far only a thin veneer has been spread, and it conforms to the slope of the pre-existing fan. Total volume of postdiversion debris accumulated on the fan is difficult to estimate in the field, but it presumably accounts for most of the 2.1×10^5 m^3 of material that has been removed upstream and has not accumulated in Gower Gulch.

The dilemma of the present situation is, What caused dissection rather than deposition on the upper half of the Gower fan? The answer is far from clear, but it is suggested that following diversion, flood waters were discharged in such a high-velocity linear stream from the confined, steep lower reach of Gower Gulch that they quickly cut a narrow channel into the original Gower fan surface. Once it was established, this channel was self-perpetuating, because it provided a more efficient channel of flow than did the myriad of small shallow channels on the original fan surface. Curiously, this newly incised fan channel is comparable in width but is of gentler gradient than the incised channel in Furnace Creek Wash. This may reflect the relative reduction of turbulence and increased efficiency caused by introduction of fines from the Furnace Creek Formation to the load discharged onto the Gower fan (Vanoni, 1946).

IMPLICATIONS FOR FUTURE DEVELOPMENT

Consideration of mean adjustment rates for these three reaches of the integrated Furnace Creek Wash–Gower Gulch system suggests that evolution during the next few centuries will be characterized by deepening and continuing headward dissection of Furnace Creek Wash and rapid accumulation of debris on the surface of the Gower fan. Eventually, about 20 to 25 m of vertical erosion will migrate up Furnace Creek Wash as the present nickpoint at the diversion site is eliminated. Although vertical erosion of the nickpoint just above the fanhead and others in the lower reach of Gower Gulch will proceed at a slower rate, it will eventually contribute an additional 15 to 20 m to the net dissection of Furnace Creek Wash. Dissection working up north-side tributaries of Furnace Creek Wash, which drain the Funeral Mountains, will almost certainly undercut sections of California 190 for several kilometres upstream of Zabriskie Point. The incised channel of Furnace Creek Wash is also likely to widen and establish a width/depth ratio comparable to that of the prediversion channel, thus further threatening California 190.

As a consequence of this erosion, debris will be delivered to the Gower fan at a mean rate in excess of 10^3 m^3/yr during the next few hundred years. If channel incision at the fanhead was a temporary disequilibrium event as suggested, deposition is ultimately more likely to modify the morphology of the fan than will further incision. Bull (1964) suggested that incised fan channels eventually backfill if cut to a gradient less than that of the adjacent lower fan segment. This is now the condition on the Gower fan. Hooke (1965) noted that in such situations, material deposited immediately below the intersection point is usually coarser than the average in the incised channel, with the coarser material forming a secondary lobe on the fan surface below the intersection point (Fig. 4). Gower fan conforms to this model, because the incised channel is littered with a veneer of pebbles and cobbles, whereas boulders that are tens of centimetres in diameter compose a significant fraction of the debris deposited immediately below the intersection point. Continuing deposition of large quantities of this coarse debris may in time backfill the incised channel, eventually filling it and allowing discharge of debris directly onto the fan surface, which should result in steepening of the fan profile. This is consistent with the results of a recent small cloudburst that led to the deposition of about 1 m of debris on National Park Service Route 1 above the intersection point (P. Sanchez, 1974, personal commun.). Large slump blocks in the incised channel are evidence that lateral retreat of channel walls also contributes to channel modification and may play a role in ultimate channel adjustment. Long-term viability of National Park Service Route 1 on the upper reaches of the fan is thus questionable. The deterioration of California 190 and National Park Service Route 1 provides an imposing testament to the unhappy results of a natural-scale experiment performed just three decades ago to cure what may have been a lesser evil.

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