High Elevation Sand Retention Following the 1996 Spike Flow

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Abstract

In the spring of 1996, the Bureau of Reclamation conducted a historic event: an experimental manmade flood event was released from Glen Canyon Dam through Glen and Grand Canyons. This high flow experiment was conducted in order to test a number of hypotheses relating to the long term management of natural and cultural resources along the Colorado River. As part of this research, the Hopi Tribe examined the effectiveness of the high flow to elevate sediment into the mouths of four ephemeral arroyos that drain the margin deposits along the River. At three out of the four study locations, sediments were deposited in the mouths of the arroyos; the fourth site, received no deposition. The current study re-examines the arroyos that received sediment deposition and evaluates the maintenance of sand since it was originally deposited.

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Introduction

In the spring of 1996, the Bureau of Reclamation conducted a historic event: an experimental manmade flood event was released from Glen Canyon Dam through Glen and Grand Canyons. This high flow experiment was conducted in order to test a number of hypotheses relating to the long term management of natural and cultural resources along the Colorado River. These hypotheses centered around the ability of planned, high flows to redistribute sediment for such management purposes as maintaining beaches, maintaining or enhancing wildlife habitats, and stabilizing cultural resource locations. In order to evaluate the effectiveness of the high flow to achieve these management objectives, an intensive scientific effort surrounded the high flow experiment and as part of these studies, the Hopi Tribe conducted research aimed at identifying the effectiveness of the high flow to elevate sediment into the mouths of ephemeral arroyos that drain the margin deposits along the River. These arroyos have been identified as one of the contributing sources to the erosion of cultural resources along the Colorado River (Burke et al. 1998, Hereford et al. 1993).

Four arroyo systems were studied by the Hopi Tribe as part of the evaluation of the high flow experiment (Yeatts 1996:4-7). One was located in the Glen Canyon geomorphic reach of the Colorado River, and three in the Furnace Flats geomorphic reach (Schmidt and Graf 1988:2, 8). The arroyo studied in the Glen Canyon reach is located in the area of Lees Ferry; those in the Furnace Flats reach are near Palisades Creek and opposite Cardenas (Figure 1). The rationale for selecting these sites as well a discussion of their physical characteristics and locational information is presented in the original report discussing the results of the high flow experiment (Yeatts 1996) and will not be repeated here.

The original study showed that the high flow was successful in depositing sand into the mouths of all arroyos examined in the Furnace Flats geomorphic reach. The arroyo in the Glen Canyon reach remained essentially unchanged morphologically by the high flow, neither gaining nor losing sediment.

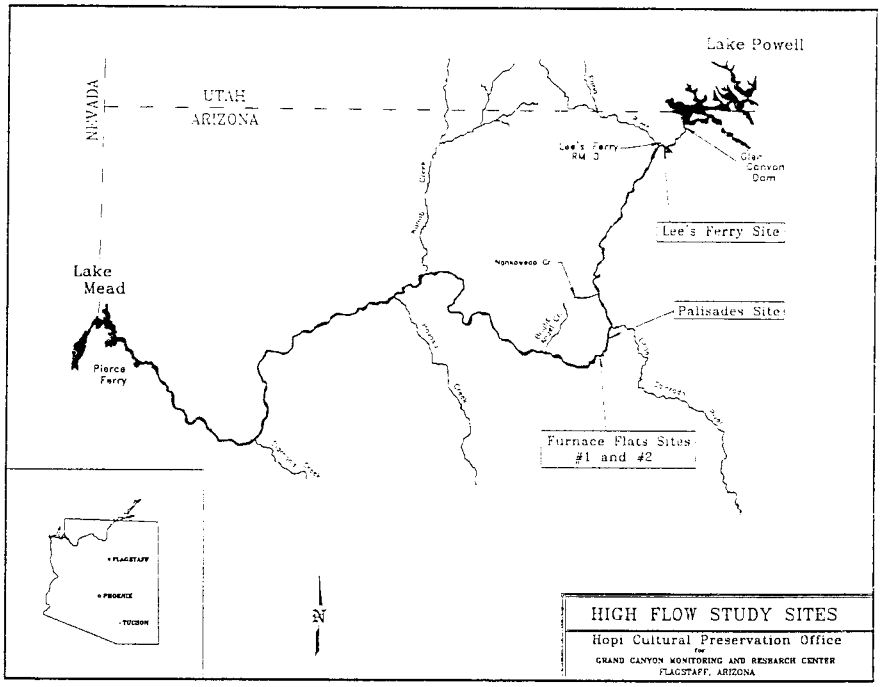

Figure 1. Locations of study sites.

The original work focused on the question of whether sand would be elevated into the arroyo mouths during the high flow experiment. Additionally, secondary hypotheses were advanced that addressed the role these new deposits might play over a longer temporal span for archaeological site stabilization. Specifically, these hypotheses dealt with the duration that the deposits would be retained in the arroyos and the effect that this would have on the erosion rates of the terraces and archaeological sites contained within them (Yeatts 1996:3).

The current report details the results of a repeat mapping episode undertaken about a year after the original spike flow and qualitative observations that have taken place since. While still not a long enough period to fully address the secondary hypotheses posited in the original study, particularly with regards to rates of erosion, the repeat mapping and observations provide some additional supportive evidence for the effectiveness of planned high flows to achieve cultural resource stabilization and suggests some processes acting on the margin deposits that may influence their longevity and effectiveness at reducing terrace erosion rates. Further, the repeat mapping is used to examine effects of the 1996-1997 flows, which were maintained at a relatively high level (+20,000 cfs), on the 45,000 cfs sand deposits.

Methodology

The mapping approach followed is identical to that described for the original mapping of the study sites (Yeatts 1996:7-8). A total station was utilized to collect data points at each of the sites in order to generate terrain models with a 0.25 meter contour accuracy. Likewise, the designations of the study sites used in the original report will be retained here. Only those sites where sediments were deposited during the high flow experiment were re-mapped. The Palisades site was re-mapped on April 22, 1997 and the Furnace Flats #1 and #2 study sites on April 23, 1997 using a crew of Chris Brod, Grand Canyon Monitoring and Research surveyor, and Michael Yeatts. In addition, the sites were subsequently re-examined in September, 1997, immediately follow a fairly substantial rain fall which breached many of the check dams at the Palisades sites, and in February, April, and September, 1998.

Results

Data Analysis

As with the survey methodology, the analytic methods for examining the data remained the same as detailed in the original report (Yeatts 1996:9-11). That is, digital terrain models of the land surface were developed from the mapping data at each site and these were used to make volumetric comparisons between separate mapping episodes. This time, three data sets could be examined: the pre-experimental flow state; the post-experimental flow state; and the state one year after the experimental flow. By comparing the 1997 state to that both before and immediately following the high flow, an assessment of the retention and changes that have occurred to the new sand deposits after a year can be made.

For the first step in data analysis, "ratio-of-change" values were calculated at each of the study sites. These values represent a standardized measure of the amount of change occurring and are calculated by dividing the area being examined by the total change (both gain and loss) occurring in the given area and then multiplying the result by 100. The obtained values can be used to compare the relative degrees of change between the different study sites and as an indicator of the amount of change that may be attributable to the inaccuracies inherent in the mapping protocol. For assessing the degree of change that might be attributable to mapping error (which was targeted to be accurate to 0.25 meter contour intervals), the zone above 45,000 cfs between the pre- and post-high flow experiment was assumed to have no actual topographic change and therefore, the ratio-of-change value should reflect the inherent uncertainty due to the mapping protocol. It should also be remembered that the ratio-of-change value includes both positive and negative change, so a high value here may not be reflected in net volume change figures where positive and negative changes will cancel each other out.

Table 1. Ratio of Change.

LOCATION	COMPARISON	BELOW 45,000 CFS	ABOVE 45,000 CFS
Palisades	Pre to Post	15.12	5.43
	Pre to 1997	7.42	6.67
	Post to 1997	11.12	5.89
Furnace Flats #2	Pre to Post	22.25	5.71
	Pre to 1997	22.37	6.23
	Post to 1997	8.42	5.97
Furnace Flats #1	Pre to Post	44.39	5.26
	Pre to 1997	15.95	4.67
	Post to 1997	26.18	3.98

Table 1 provides a breakdown of the ratio-of-change values calculated at each of the sites. The values have been calculated both below and above the 45,000 cfs flow level for the change occurring between the pre-high flow condition and one year later, the post-high flow condition and a year later and for comparison, the pre- to post-high flow change. When calculating these values, it was realized that an error had been made in the original report; the ratio for the pre- to post-high flow was calculated on the net change rather than the total change (Yeatts 1996:9). This error did not result in any change in interpretation of the results however.

From Table 1, it can be seen that most of the change above the 45,000 cfs level falls within the range that potentially is due to limits in mapping precision. The exception is at the Palisades site where examination of the data (discussed later) shows a small, localized deposition that is likely real. Below the 45,000 cfs level, however, there are appreciable changes. They range from a return to the pre-spike state, maintenance of the spike flow sand, and midway between these two extremes. These results will be discussed for each site individual below.

Palisades Site

At the Palisades site, there has been a net loss of the sediment below the 45,000 cfs level since the spike flow experiment (Table 2). Further, the current state of sediment below the 45,000 cfs level is more depleted than is was prior to the high flow experiment; that is, not only was there a loss of the sediment deposited during the high flow experiment, but formerly stable deposits were also removed. It is likely that the sustained high flows following the high flow experiment (+20,000 cfs) figured into this

Table 2. Net volume of change at Palisades study site.

COMPARISON	VOLUME (m^3) Below 45,000 CFS	VOLUME (m^3) Above 45,000 CFS
Pre to Post	+ 77.9	- 4.6
Post to 1997	- 60.2	+ 16.9
Pre to 1997	- 24.3	+ 12.9

additional sediment loss. This loss of sediment is partially, though not entirely, offset by a slight gain in sediment above the 45,000 cfs level (see Table 2). The gain in sediment above the 45,000 cfs level may in part be due to aeolian transport of the high flow sand from lower to higher elevations.

Looking at Figure 2, which shows the areas where sediment has been gained or lost between the post high flow (April 1996) and the April 1997 surveys, it becomes apparent that most of the activity occurred below the 27,000 cfs level. Cutting occurred throughout this zone, with the exception of one area that had been scoured during the high flow experiment and has since been filled. The zone between 27,000 and 45,000 cfs has remained very similar in its condition to that existing immediately following the high flow experiment. Throughout the area above the 45,000 cfs level, there are areas of deposition which reflect gains seen in Table 2.

When Figure 3, which compares the pre-high flow topograpy to the April 1997, is examined, several of the trends seen in Figure 2 are clarified. The reworking of sediment below 27,000 cfs has essentially returned the site to the topography that existed prior to the high flow experiment. There has been some additional degradation to the sediment at the northern end of the study area and what appeared as an area of deposition of Figure 2 is in fact the filling of a scour zone back to the pre-high flow level. Between 27,000 and 45,000 cfs, there are areas of both gain and loss of sediment when compared to what existed before the high flow experiment, and looking back at Figure 2 shows that the changes were almost all due to the high flow itself. The areas where high flow sediment has been retained are in the two arroyos that traverse this study location and at the peak stage elevation of the high flow. This indicates that the arroyos themselves serve as sediment traps and that the farther from the normal river edge sediment can be deposited, the better it is retained.

An interesting aspect at this study location is the net gain in sediment above the 45,000 cfs zone since the high flow experiment. The mapping following the high flow showed a small decrease in the amount of sediment volume within this zone (see Table 2). By the 1997, not only had this small lost been offset, but there had been a net gain in sediment, to greater levels than existed following the high flow experiment. The probable mechanism leading to the net gain in sand above the 45,000 cfs zone is aeolian transport The reworking of the high flow deposits by wind may also be partially responsible for maintaining the fill in the arroyos when the surrounding areas are eroded.

Furnace Flats #2

This site has witnessed virtually no change in the overall sediment volume since the high flow experiment (Table 3). Below 45,000 cfs, the net gain of 35.4 m^3 of sediment realized during the high flow experiment has been retained, as seen in the 1997 remapping of the site (see Table 3, Pre to 1997). This result is confirmed by noting the lack of volumetric change between the post flow net volume and 1997 remapping. Similarly, there has been virtually no net change above the 45,000 cfs zone since the high flow experiment.

Table 3. Net volume of change at Furnace Flats #2 study site.

COMPARISON	VOLUME (m^3) Below 45,000 CFS	VOLUME (m^3) Above 45,000 CFS
Pre to Post	+35.4	- 4.0
Post to1997	+ 0.1	+ 2.5
Pre to 1997	+35.9	- 2.0

While there has been no significant change in the overall volume of sediment retained at this site since the high flow experiment, there has been changes in where the sediment is located. Since the high flow experiment, there has been an

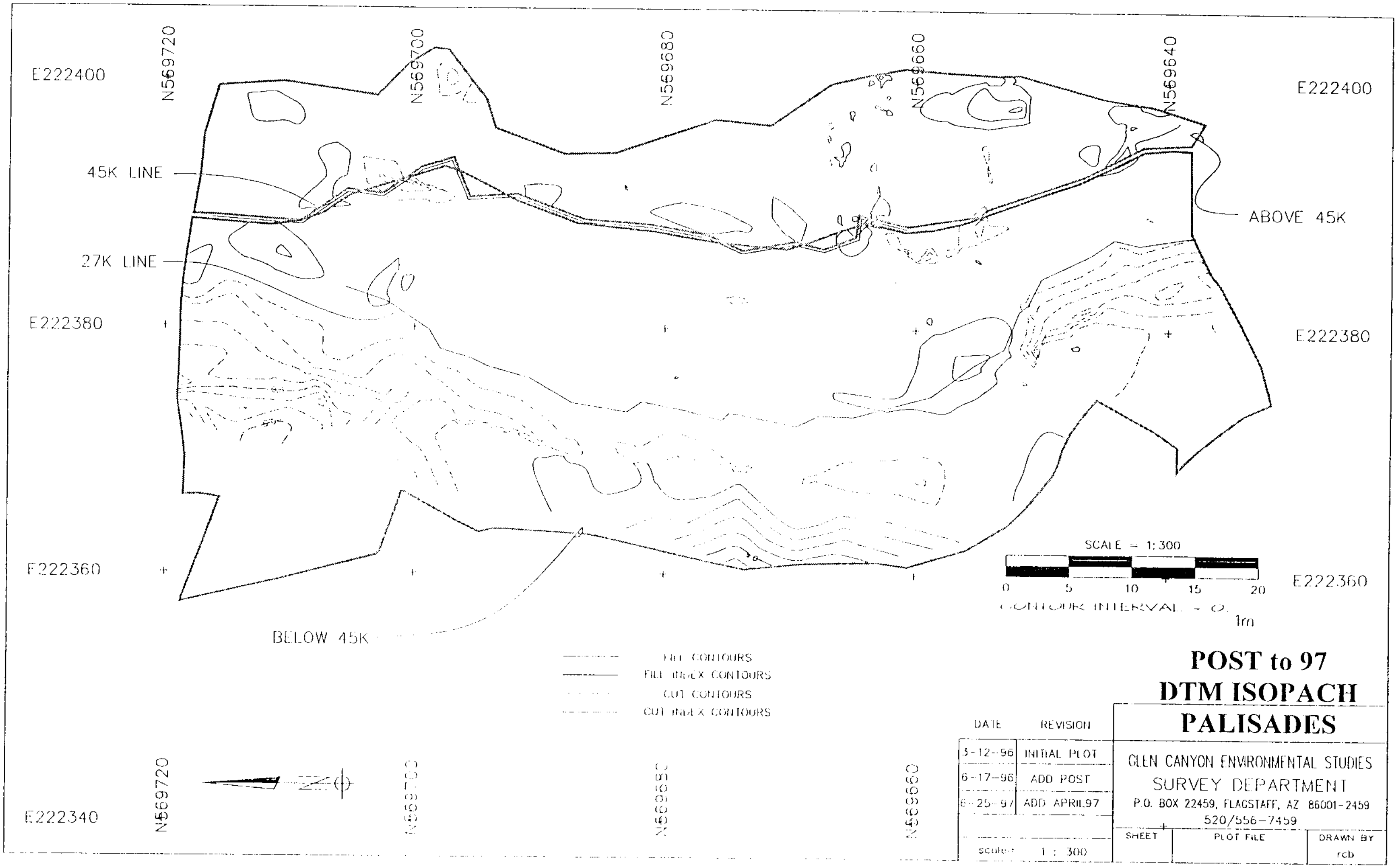

Figure 2. Cut-fill map for the Palisades site comparing the post-high flow topography to the 1997 topography.

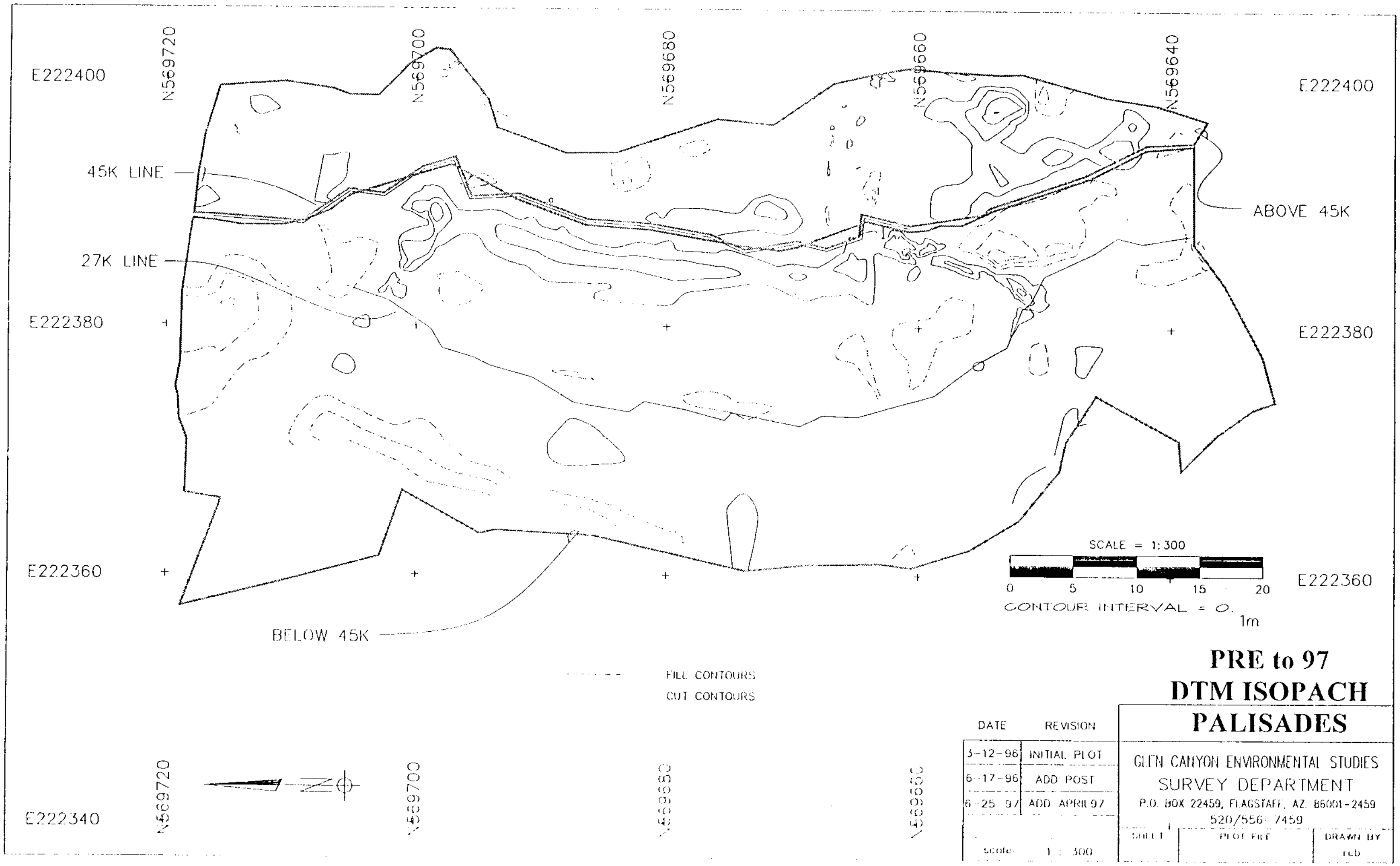

Figure 3. Cut-fill map for the Palisades site comparing the pre-high flow topography to the 1997 topography.

erosion of sediment below the 27,000 cfs level at the upstream end of the study location and deposition at the downstream end (Figure 4). Between the 27,000 cfs and 45,000 cfs levels, the terrain has remained fairly consistent since the high flow experiment. However, above the 45,000 cfs level, there has been some changes. The edges of the arroyo have in places collapsed, widening the arroyo and lessening the slope of the arroyo walls. The material that has fallen into the arroyo has been retained as it has filled in behind the 45,000 cfs sand deposits, which are blocking the arroyo flow.

When the 1997 sediment distribution is compared to that which existed prior to the high flow experiment (Figure 5), the gains that resulted from the high flow experiment are readily visible, particularly those filling the arroyo mouth. Below the 27,000 cfs level, there is one area in the eastern part of the study location that has been eroded so as to be more depleted than prior to the high flow experiment; the remainder of the zone contains deposits not present before the high flow experiment. While it is tempting to posit that the sediment below the 27,000 cfs level is being replenished from the 45,000 cfs flow deposits perched above, there has been no loss of the deposits in the 27,000 to 45,000 cfs flow range. In fact, the degree to which deposits have been retained throughout the entire zone below 45,000 cfs is clearly seen in Figure 5.

Above the 45,000 cfs level, the pattern seen in Figure 4 is also confirmed in Figure 5. That is, the arroyo is widening and the materials that are falling in are being retained behind the plug of 45,000 cfs flow sand. This is an example of the sediment from the high flow experiment effectively maintaining a higher base level in the arroyo than existed prior to the high flow.

Furnace Flats #1

Significant erosion of the high flow sediment deposits has occurred at this location since the high flow experiment (Table 4). Below the 45,000 cfs level, 1/3 of the sand that was deposited has been lost. The net result however, is that there is still more sediment at this site than existed prior to the high flow experiment. The relatively large changes in volume are the result of the loss of a large dune that was formed just off shore during the high flow experiment and subsequently reworked back into the river.

Table 4. Net volume of change at Furnace Flats #1 study site.

COMPARISON	VOLUME (m^3) Below 45,000 CFS	VOLUME (m^3) Above 45,000 CFS
Pre to Post	+147.0	+ 2.2
Post to 1997	- 49.9	-10.2
Pre to 1997	+40.4	- 7.9

The area that this dune was located can be seen as the large cutting zone in Figure 6, which shows the change in sediment from just after the high flow experiment to April 1997. The entire area below 27,000 cfs has been reworked, losing sediment in almost all portions except for an area adjacent to the edge of this zone. The area of gain was a small return channel during the high flow experiment and was in a scoured condition immediately following the high flow experiment; this scoured area has since been filled, resulting in the deposition seen in Figure 6. The zone between 27,000 and 45,000 cfs is relatively unchanged since the high flow experiment. There are areas of slight building, possibly due to wind reworking of sediments from lower elevations. Also, there is a slight cut where water flowing in the arroyo has removed some of the high flow deposits. Above the 45,000 cfs level, relatively minor changes are noted and these are below the range of mapping accuracy (see Table 1).

When the comparison between the pre-high flow topography and the April 1997 topography is

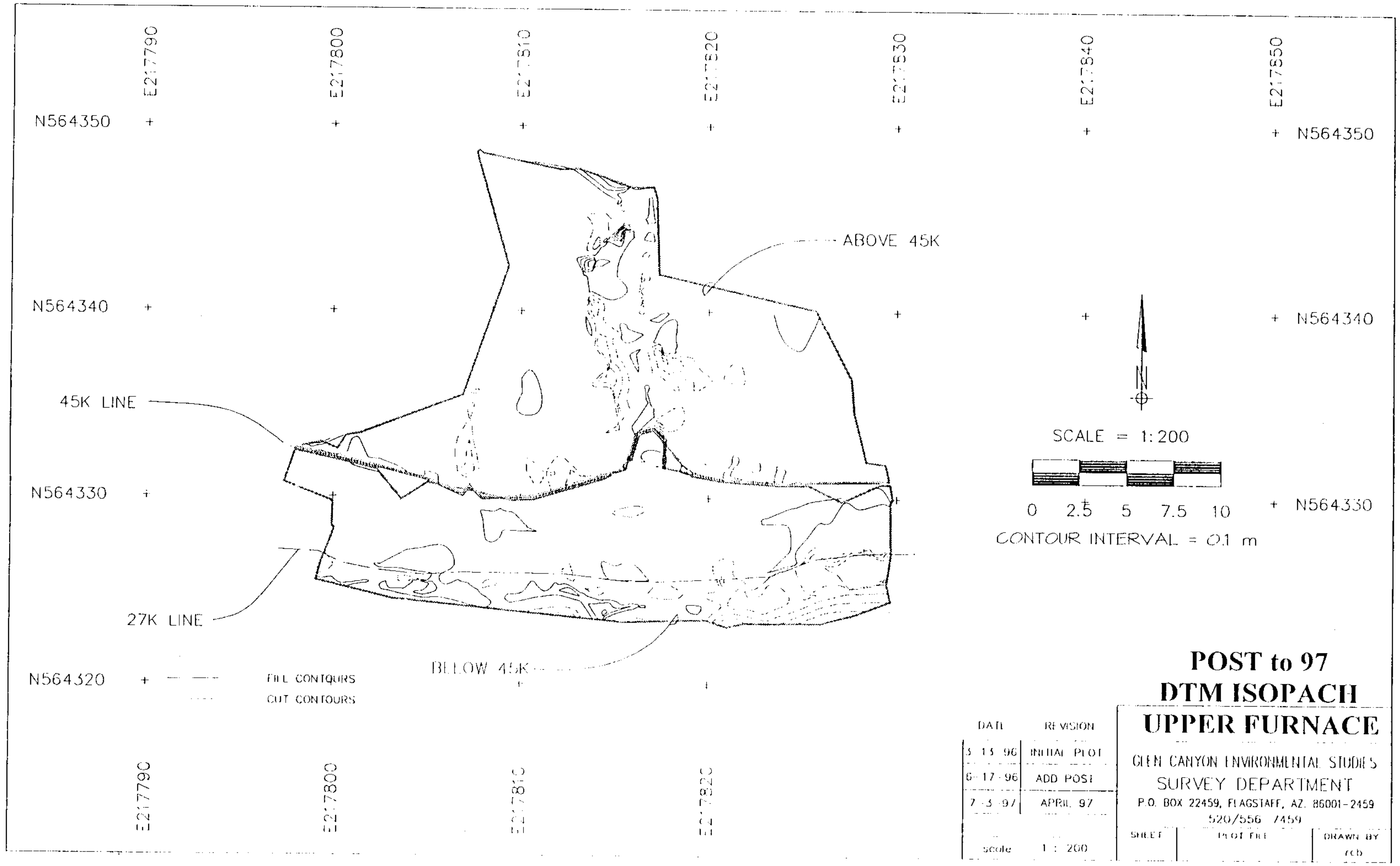

Figure 4. Cut-fill map for the Upper Furnace Flats site comparing the post-high flow topography to the 1997 topography.

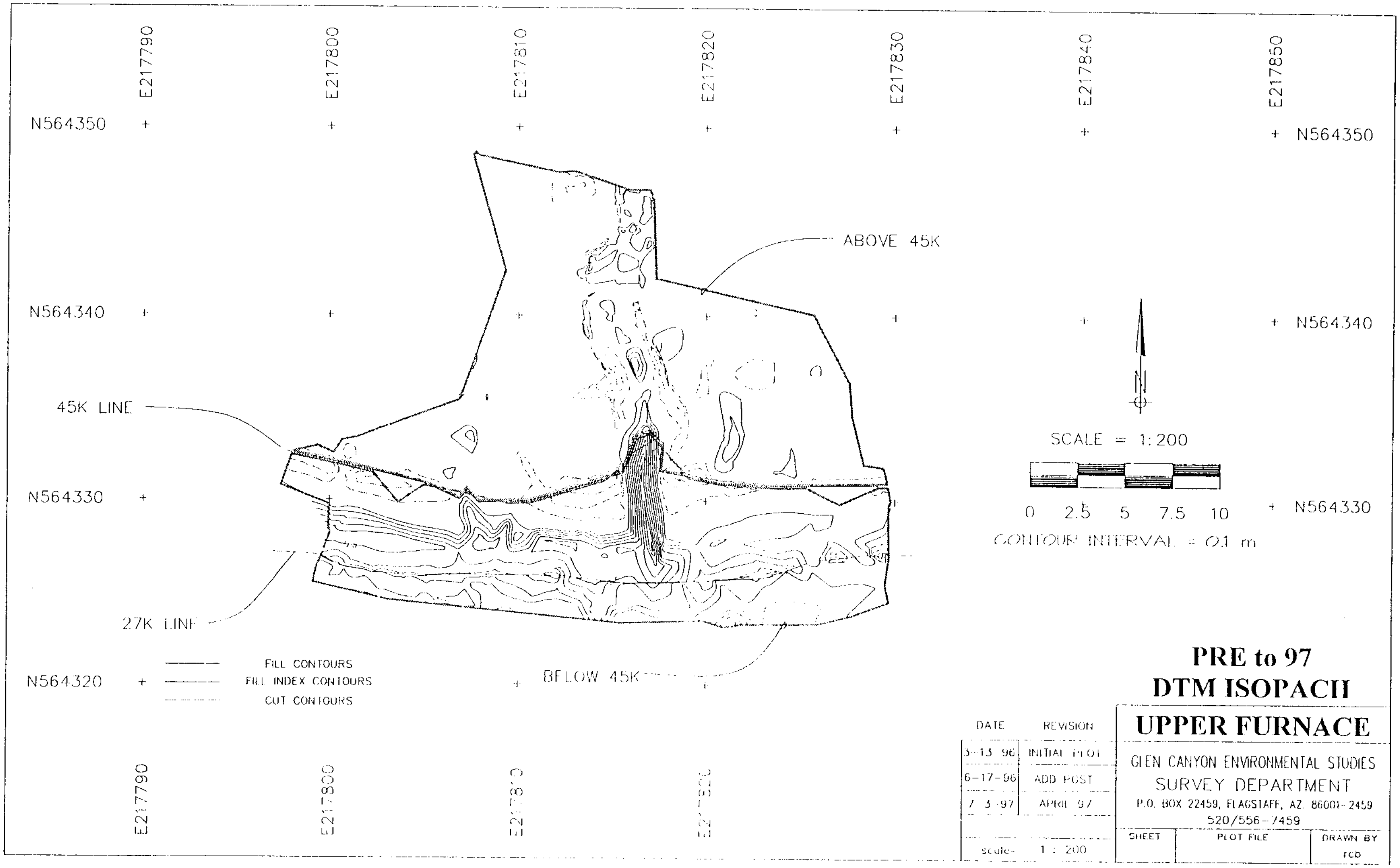

Figure 5. Cut-fill map for the Upper Furnace Flats site comparing the pre-high flow topography to the 1997 topography.

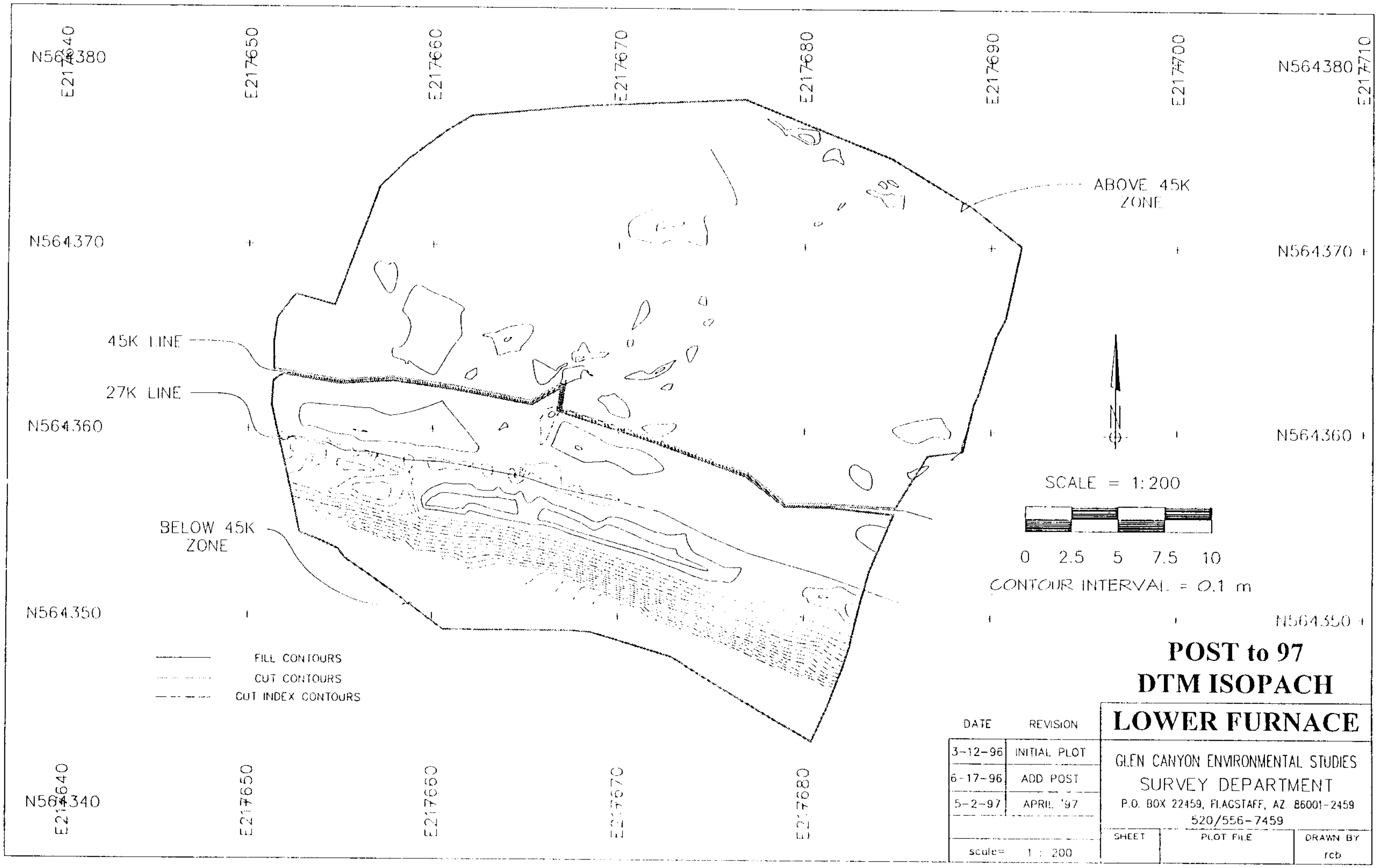

Figure 6. Cut-fill map for the Lower Furnace Flats site comparing the post-high flow topography to the 1997 topography.

made, it becomes obvious that even though there has been considerable erosion below the 45,000 cfs level since the high flow experiment, more sediment has been retained at the site than existed prior to the experiment (Figure 7). This net positive gain is seen both below the 27,000 cfs level and between the 27,000 and 45,000 cfs levels. Of particular interest is the maintenance of sediment in the arroyo channel. Above the 45,000 cfs level, the have been relatively minor changes, likely all within the range of mapping error. In fact, the largest change, the "deposition" adjacent to the 45,000 cfs line in the eastern portion of the study location is in fact an artifact of the mapping between the survey prior to the high flow experiment and the subsequent surveys. This area is highly vegetated and an area of steep slope was not as completely measured in the original survey as in the following ones. This lead to an apparent "gain" of sediment when in fact it was just a more accurate representation of the topography.

Summary and Discussion

At all three sites examined in this study, the arroyos still maintain sediment deposited during the high flow experiment a year following the experiment and this trend continued into the following year. Further, at the two furnace flats sites, there remains a net gain in sediment above that which was present prior to the high flow. The Palisades site, however, has less overall sediment below the 45,000 cfs level than existed prior to the spike flow. This can likely be attributed to the flows that were seen through much of year following the high flow experiment which were of a greater magnitude than those seen preceding it. At all sites however, sediment has remained in the arroyo channels even when it has been eroded in the areas adjacent to them.

The maintenance of sand in the arroyos has positive implications for reducing the erosion rates to archaeological sites. As long as this sand remains, it is in effect reverting the arroyo from a stream-base to a terrace-based system, and thereby resets the erosion state to an earlier condition. Logically, this should decrease the effective erosion rate of the arroyo.

Unfortunately, at the time that the study locations were re-mapped, there had not been any significant rainfall events. This meant that virtually all of the changes seen were due to either river or wind effects. Following the re-mapping, however, some significant rainfall events did occur. In September, 1997, the Furnace Flats reach received a considerable amount of precipitation, particularly at the Palisades site, and all of the arroyos being studied flowed. If fact, at the Palisades site, many of the checkdams in the upper reaches of the arroyo systems were breached and both arroyos flowed to the river, following their original paths. Examination of the arroyos over the course of the next year (Fall 1997-Fall 1998) is at the basis of the following suppositions.

The two furnace flats sites were less effected by the September 1997 rainfall event. The new sediments in both arroyos were breached, but in neither case did the channels entrench back to their original depth. What appears to have happened was that even though the flows were successful in reaching the river, the high flow sand was unconsolidated enough so that when a channel was cut through it, the surrounding sand fell back in, once again blocking the channel. If this is in fact the mechanism, then two aspects may impact the future erosion rates of arroyos following a high flow event. First, the magnitude of flow in an arroyo needed to breach a deposit will be directly relate to the length of fill in the arroyo. The sand, being quite porous tends to soak up the water rather than allowing it to run over the surface, at least until a certain flow threshold is reached; the longer the plug of sand, the higher the flow threshold. If flows are below this threshold, there is essentially no increase in erosion rate because the flow drops to zero in the sand. Further, since the river sand deposited in the arroyo is generally more porous than the substrate forming the arroyo walls, the preferred course of flows is in the original channel rather than around the "plug", which is often the case with less permeable obstructions. Therefore, given that increasing stage

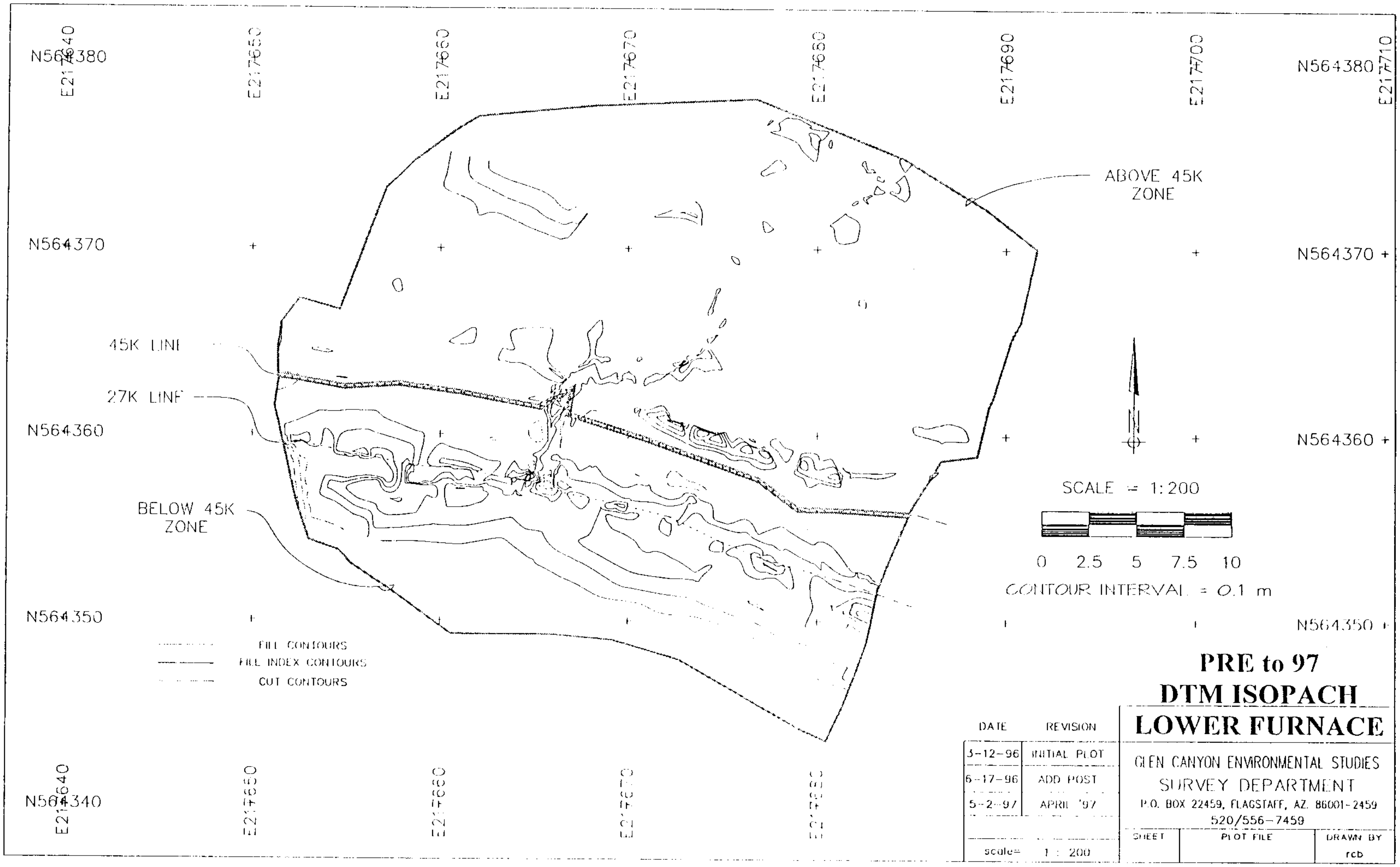

Figure 7. Cut-fill map for the Lower Furnace Flats site comparing the pre-high flow topography to the 1997 topography.

during a high flow event will have the potential to fill in a longer portion of a given arroyo channel, a greater decrease in effective erosion rates should be realized even with small increases in maximum stage.

Second, it appears that even when the threshold is exceeded, a the second process comes into place that again serves to decrease the effective erosion rate; that being the re-infilling of the arroyo by surrounding sand deposits. As sand is removed from the arroyo by flowing water, surrounding sand is available to partially replace that which is carried to the river. The degree to which this happens depends on the immediate availability of surrounding sand as well as the depth of those deposits. The deeper the deposits, the greater the potential for filling in arroyo channels. Further, this sand is available for reworking by the wind.

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