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HYDROLOGY OF ARAVAIPA CREEK

INTRODUCTION

A fish barrier has been proposed for Aravaipa Creek in Southeastern Arizona to help protect against exotic species migrating upstream into the watershed. Seven native species are currently found in the basin, and all are listed as endangered on either the State or Federal lists. It is felt that the proposed barrier is a critical step toward the maintenance of these native fish populations. The purpose of this report is to document the general hydrology and hydraulics of the Aravaipa watershed and to develop hydrologic and preliminary hydraulic design criteria.

GENERAL HYDROLOGY AND HYDRAULICS OF ARAVAIPA CREEK

HYDROLOGY

Streamflow data for Aravaipa Creek has been collected for the years 1920-1921, 1932-1942, and 1967 to present. The USGS stream gage is located 6 miles upstream from the confluence of Aravaipa Creek and the San Pedro River(sec. 9, T. 7 S., R 17 E.). The drainage area above the gage is 541 square miles. There are diversions for irrigation of several hundred acres above the station(USGS gaging station data).

The stream length is 55.4 miles and the average channel slope is 45.7 feet per mile. Gradients range from less than 15 feet/mile near the source, to greater than 130 feet/mile within Aravaipa Canyon, and to 50 feet/mile near the USGS stream gage(Minckley, 1981). The watershed is at a mean elevation of 4530 feet above sea level, with the highest point in the watershed being 8441 feet and the lowest point being 2160 feet. The watershed is about 25% forested(USGS gaging station data and Ellingson,1979).

Groundwater discharge from the upper basin water-table aquifer system in Aravaipa Valley is the primary source of water for the Creek. The aquifer is recharged by snowmelt mountain-front recharge, rainfall and direct streambed infiltration. Annual recharge is estimated at 10500 acre-feet. At the Eastern entrance to Aravaipa Canyon, groundwater is forced to the surface because of the restricted crossectional area available to subsurface flow. It has been estimated that 80% of the flow in Aravaipa Creek originates from groundwater discharge from Aravaipa Valley during times of no surface water runoff(Ellingson, 1979).

Rainfall in the Aravaipa watershed ranges from near 20 inches per year in the Galiuro and Santa Teresa Mountains to 14.1 inches per year at the Klondyke rain gage. The mean annual precipitation for the watershed is 16.2 inches. It has been experimentally established in smaller, but similar basins in Southern Arizona that between 2.0 and 2.7% of a rainfall event appears as runoff at the outlet of the basin. The Aravaipa watershed appears to be even more effiecient at producing runoff from a given storm, yielding 3.2%(Ellingson, 1979). The increased efficiency is attributed to the fact that most of the basin

is impermeable to infiltration, especially along the margins of the basin. Also the high mean relief and narrowness of the basin may be contributing factors, enhancing runoff.

Base flow in Aravaipa Creek is about 7400 acre-feet per year(Ellingson, 1979), which is equal to the quanity of groundwater runoff being contributed to the Creek's streamflow. The mean flow of Aravaipa Creek is almost 25,000 acre-feet per year(USGS gaging station data).

CHANNEL HYDRAULICS AND STREAM MORPHOLOGY

The Aravaipa stream channel width is quite variable. The stream begins in the low gradient broad plain of Aravaipa valley, transitions into the higher gradient narrow gorge of Aravaipa Canyon in the mid-section of the basin, and then again decreases in gradient and increases in channel width in the lower-most section of the basin. The severe channel constrictions within the gorge result in rapid changes in flood stage with proportionately smaller changes in discharge than is the case in the upper and lower portions of the basin. Most of the lower portion of the basin, where the fish barrier is proposed to be located, has much less stable channel boundaries, being composed of alluvium rather than bedrock as is found in the canyon. This fact allows for major changes in crossectional area at given locations as was illustrated at the USGS gaging site during the flood of 1983. The hydraulic analyses of the effects of the proposed fish barrier on upstream and downstream water surface profiles can only be evaluated for the channel crossections as they are today. Future floods will surely alter these crossections, and therefore the upstream and downstream effects of the fish barrier as well.

The channel realignment which occurred at the USGS gaging station during the flood of October 1983 resulted in significant erosion along the northern(left) bank, increasing the channel width about 100 feet. The left bank of the stream is a terrace deposit composed mostly of unconsolidated silt and sand. The right bank, which remained relatively unchanged through the flood is composed of conglomerate rock(USGS,1983).

Southwest-flowing tributaries to Aravaipa creek have rather small catchments and excessivley high gradients. They have not kept pace with downcutting in the mainstream, instead having developed many series of falls as they drain into Aravaipa creek. The north-flowing tributaries on the other hand exhibit a stream morphology more closely related to Aravaipa creek. Their catchments are longer and likely receive more rainfall than the southwestern tributaries. These tributaries have high, but more uniform grades and have generally kept pace with downcutting in the main channel(Minckley,1981).

The reach of Aravaipa creek which is being considered for a fish barrier flows primarily through broad alluviated areas. In general the channel width is about 100 feet and ranges up to 200 feet. The available data suggests the alluvium to be poorly sorted sand and gravel, plus a small percentage of cobble and boulder. The minimum depth of these alluvial deposits is on the order of several tens of

feet. Limited well log data and geophysical measurements indicate thicknesses of 100-130 feet in some areas(Ellingson,1979). Deposition of the sand and gravel component of recent alluvium is primarily from the surface deposits of the relatively broad plain of Aravaipa valley. Large amounts of materials are transported to and through the system when floods originate in the valley portion of the catchment. However, when floods originate in the upper basin bedrock canyons, large boulders and cobbles are moved through the system. Some of the tributary canyons have developed alluvial fans at their confluence with the mainstream and can in some instances "dam" the creek with alluvial wash deposited during a flash flood. Brandenburg Wash has historically "dammed" the mainstem of the creek with alluvium deposited after a flash flood, for example, in the spring of 1977 (Minckley, 1981).

HYDROLOGIC DESIGN CRITERIA

FLOW-DURATION DATA FOR ARAVAIPA CREEK

The mean daily dishcharge in Aravaipa Creek is rarely above 350 cubic feet per second(cfs), usually being closer to 15 cfs. The minimum flow in the creek is rarely below 2 cfs. Flow-duration data for Aravaipa Creek is given in Table 1 below.

TABLE 1

MEAN DAILY DISCHARGE, IN CFS, WHICH WAS EQUALLED OR EXCEEDED FOR INDICATED PERCENT OF TIME

1%	5%	10%	15%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%
357	82	46	34	30	22	18	15	12	10	8	5	4	2

USGS, 1989, Statistical Summaries of Streamflow Records in Arizona through 1986.

Streamflow on a monthly basis for Aravaipa creek is given in table 2 below. The wettest month is October, which is toward the end of the irrigation season and is also during the flood season. The driest month is June, which is at the peak of irrigation diversions.

TABLE 2

MEAN MONTHLY DISCHARGES(CFS)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN. MEAN
37	61	56	18	13	11	25	32	25	62	23	49	34

USGS, 1989, Statistical Summaries of Streamflow Records in Arizona through 1986

The primary effect of the proposed barrier on the channel at mean flow rates will be a slight lowering of the stream gradient in the immediate upstream area of the barrier due to alluvial backfilling. As a consequence, the average water velocity just upstream from the barrier may decrease slightly. Also, because of backfilling behind the barrier, the water surface elevation upstream from the barrier will increase slightly. This effect will be felt for a short distance upstream of the barrier, that distance probably being no more than a few hundred feet. Downstream of the barrier there may be some limited increased erosion, but a concrete apron below the structure should minimize the potential for the development of a plunge pool.

Subsurface flow in the alluvium should not be materially affected by the proposed barrier. While the structure will marginally decrease the subsurface crossectional area available to flow, the groundwater velocities should adjust upward enough to mask any affects the structure's piles have on flow paths. The net effect on the downstream shallow alluvial aquifer should be imperceptable.

ANNUAL PEAK FLOWS FOR ARAVAIPA CREEK

The design of the proposed fish barrier will be affected more by the peak flow rates the Creek receives. The barrier must be able to structurally withstand infrequent, but very high flow rates. Below is a table of the recorded annual peak discharges.

The annual peak flow occurs most often in August, but any of the fall or early winter months are likely times of the year for high flows in the creek. Over the period of record, on only six years have the peak flows been over 10,000 cfs. Of these six, all have been in the range of 10-25 year peak flows. The only exception is the 1983/1984 flood peak which is about a 50 year flow.

TABLE 3

ANNUAL PEAK DISCHARGES(CFS)

WATER YEAR	ANNUAL PEAK DISCHARGE	WATER YEAR	ANNUAL PEAK DISCHARGE
1919	20,000	1969	1,800
1920	7,400	1970	5,560
1921	12,600	1971	1,780
1931	4,700	1972	1,830
1932	6,300	1973	8,200
1933	9,340	1974	2,100
1934	3,100	1975	836
1935	10,200	1976	1,120
1936	6,500	1977	2,560
1937	3,380	1978	5,100
1938	3,600	1979	16,200
1939	6,450	1980	2,460
1940	5,480	1981	2,460
1941	9,600	1982	1,620

1965	4,480	1983	3,920
1966	6,340	1984	70,000*
1967	2,340	1985	1,330
1968	15,300	1986	1,060

* CALCULATED BY SLOPE AREA METHOD, A THEORETICAL ESTIMATION TECHNIQUE. FIELD MEASUREMENTS OF HIGH WATER MARKS INDICATE A PEAK OF 27,000 CFS.

USGS, 1989, Statistical Summaries of Streamflow Records in Arizona through 1986

FLOOD FREQUENCY DATA AND FISH BARRIER DESIGN FLOW

The frequency of flooding in Aravaipa Creek is a primary concern in the design of a fish barrier. It has been decided the barrier will be designed to withstand the 50 year flood. Below is the flood frequency curve developed by the USGS. There is some disagreement in the professional community with these values, because the USGS includes their estimate of 70,000 cfs for the October 1983 flood. Other analyses conducted by the University of Arizona indicate a peak of only about 27,000 cfs for that flood.(Roberts, 1987) The University's flood frequency curve is given in figure 1. Differences between the two curves are not significant for barrier design purposes. Generally the values calculated by the University are somewhat higher.

TABLE 4

DISCHARGE, IN CFS, FOR INDICATED RECURRENCE INTERVAL, IN YEARS, AND EXCEEDANCE PROBABILITY, IN PERCENT

2 50%	5 20%	10 10%	25 4%	50 2%	100* 1%
4,100	8,190	11,800	17,400	22,300	28,000

* RELIABILITY OF VALUE IN THIS COLUMN IS UNCERTAIN, AND POTENTIAL ERRORS ARE LARGE.

USGS, 1989, Statistical Summaries of Streamflow Records in Arizona through 1986

As indicated in the table above the 50 year flood is estimated at 22,300 cfs; an analysis by the University of Arizona places the 50 year flood at about 27,000 cfs. At either of these flow rates the barrier will be submerged and therefore the difference should not materially affect the barrier design. For practical purposes either flowrate is suitable as a design flow.

FISH BARRIER DESIGN STORM

Some of the greatest general rainfall and the most severe floods in Arizona have resulted from tropical storms. At least 16 flood events

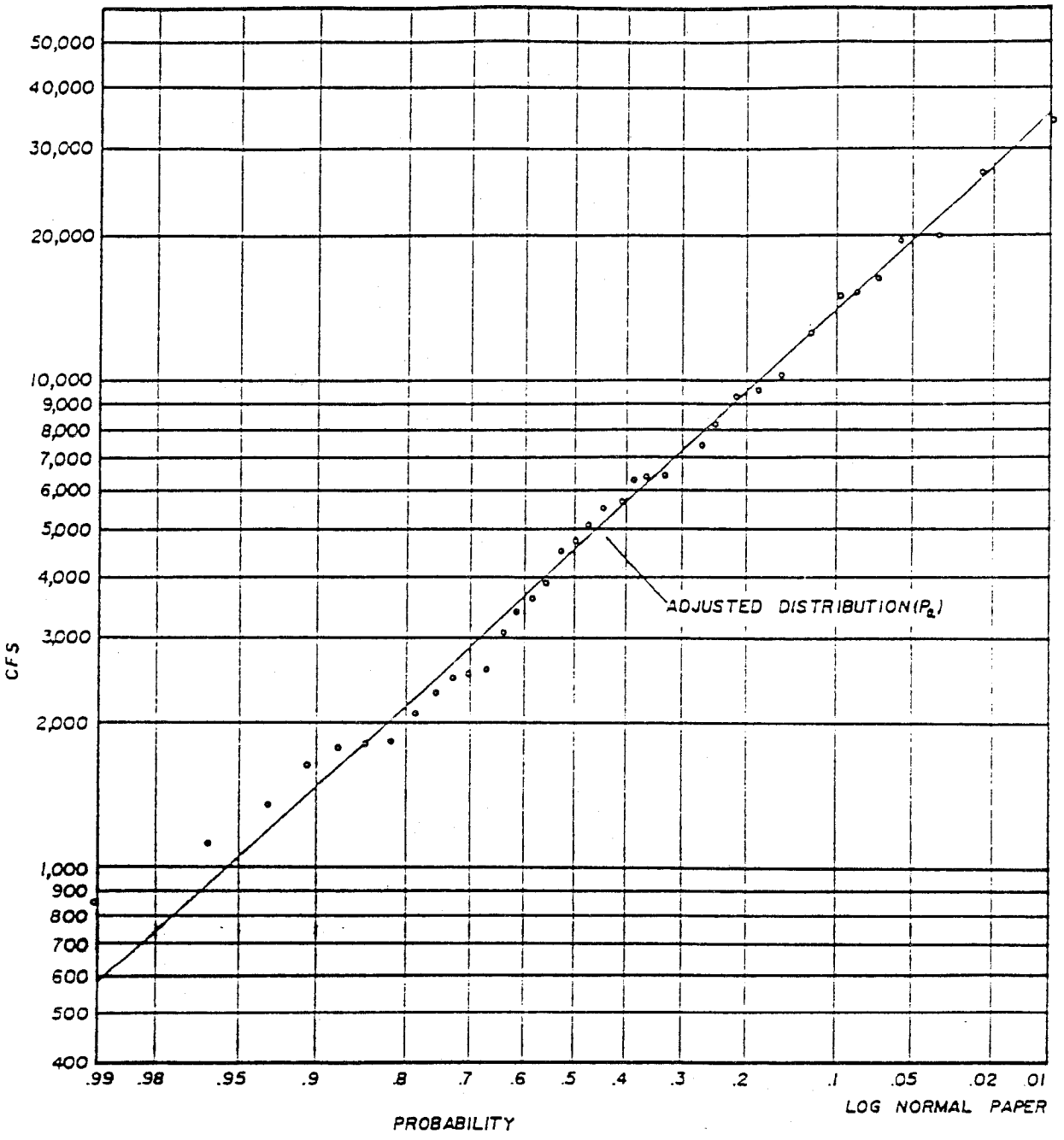

FIGURE 1: Flood frequency curve developed by the University of Arizona

have ocurred since 1926 in the region as a result of this type of weather pattern(USGS 1983). These floods have all occurred between late August and early October.

Tropical storm Octave off the coast of Baja California was the main cause of the heavy rains which occurred between September 27-October 3, 1983 over the Aravaipa watershed. Precipitation in and near the Aravaipa watershed averaged about 7 inches over the 8 day period of the storm. Actual measurements at the Klondyke and West Aravaipa raingages were 5.92 and 4.72 respectively. Figure 2 is a isohyetal map of rainfall in the San Pedro basin of which Aravaipa is a tributary.

The above storm is usefull as a design storm for the proposed fish barrier for two reasons. First, rainfall was caused by a tropical storm in the Pacific Ocean and it is this type of weather pattern which produces the greatest flows in the watershed. Second, the storm produced a peak flow rate very close to the 50 year flow rate. These two factors make it a "representative" storm for the area and adequate for design purposes.

FISH BARRIER DESIGN FLOOD

Rainfall had occurred over the Aravaipa basin for almost four(4) days prior to the flood peak reaching the gaging station in the lower part of the basin. One of the important features of this storm is not only the amount of rainfall the watershed received, but also the intensity of the storm. Because this storm lasted for almost a week(most occurring in the first 4 days), the basin was "primed" to produce a large peak flow. That is, rainfall over the first few days saturated the alluvium in the basin so that at the time peak flows were experienced, infiltration was at a minimum. The net result was that the basin was producing runoff very efficiently, with minimal losses. Table 5 below contains the recorded flood flows which resulted from this tropical storm system.

TABLE 5

ARAVAIPA CREEK NEAR MAMMOTH, AZ.

DATE	TIME	DISCHARGE(CFS)	DATE	TIME	DISCHARGE(CFS)
09-29	2400	91	10-01	0645	144
09-30	0500	216	10-01	0730	414
09-30	0700	200	10-01	0830	926
09-30	0800	170	10-01	0930	1,730
09-30	1000	336	10-01	1015	2,600
09-30	1300	340	10-01	1100	5,460
09-30	1500	1,140	10-01	1200	7,440
09-30	1700	1,310	10-01	1300	7,920
09-30	2000	1,020	10-01	1400	9,040
09-30	2400	336	10-01	1800	27,000*
10-01	0300	273			

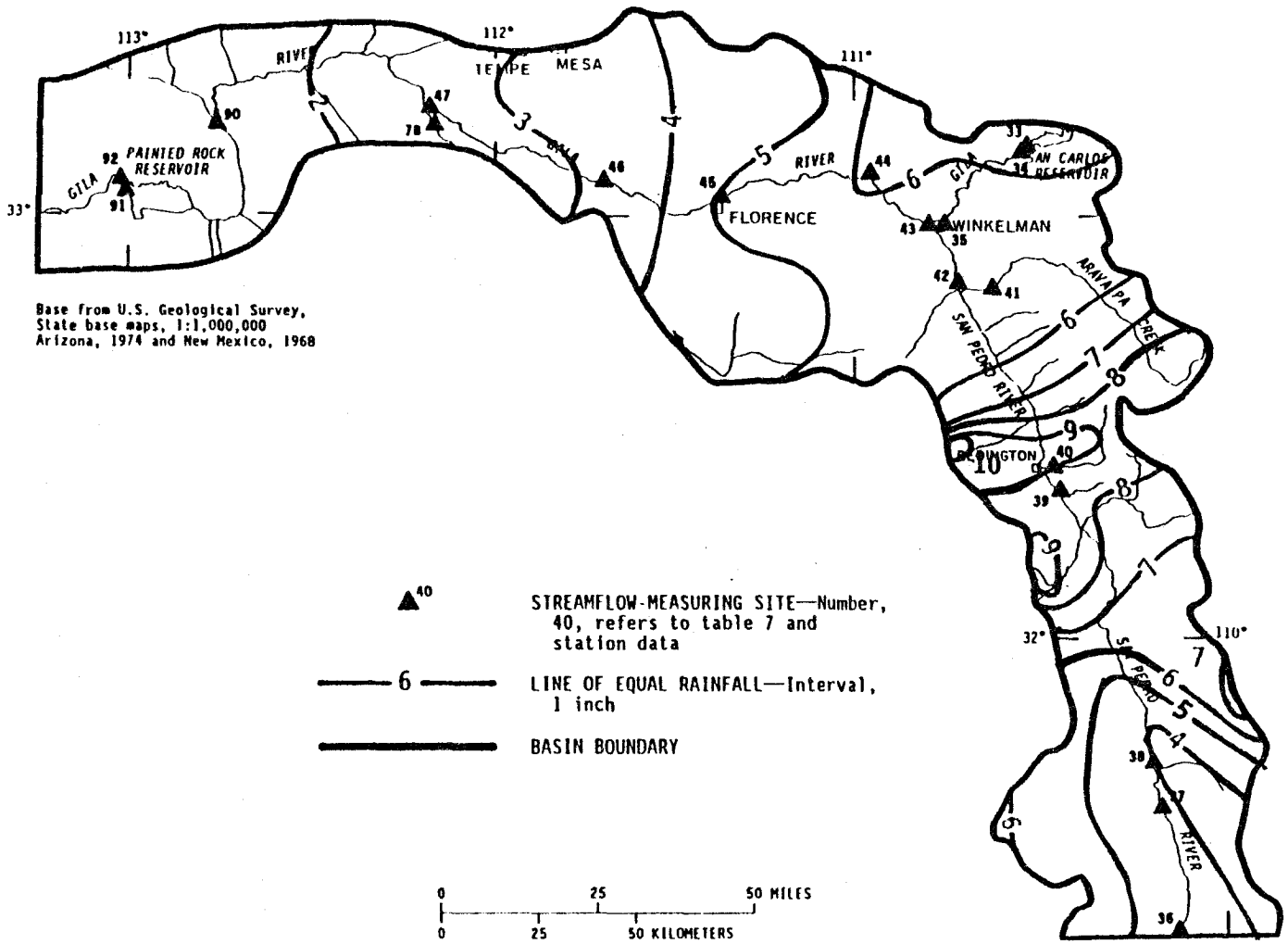

Figure 2: -Total storm rainfall, September 27 to October 3, 1983, and streamflow-measuring sites in San Pedro River and Gila River basins from Coolidge Dam to Painted Rock Dam.

* Gage was damaged at this time. USGS estimates 70,800 cfs flow at 1800. Flow rate given calculated by University of Arizona and thought to be more accurate.(USGS 1983)

One of the main problems with estimating the peak flow rates for a flood of this nature is how to account for the major reconfiguration of the channel crossection at the gage. Figure 3 compares the crossection of the channel before and after the flood. Extreme erosion along the northern(left) bank resulted in such a large increase in crossectional area available to flow that the existing rating table for the gage was rendered very inaccurate. The effects of this flood on the channel configuration illustrates the importance of potential geomorphic changes in the design of the proposed fish barrier. That is, if the barrier is not properly anchored to stable abutments, then lateral realignment of the stream channel during floods may cause flow to go around the barrier.

The difference between the USGS estimated peak flow of 70,800 cfs and the University of Arizona estimate of 27,000 cfs is related to the major change in crossectional area which occurred at the gaging station. The USGS attempted to reconstruct a peak flow rate in the area of the gage using high water marks and an assumed average crossectional area during the flood. With this information, a peak flow can be calculated. The main problem with this technique is the potentially large error that can result from the assumed crossectional area at the time of peak flow.

The University of Arizona also used high water marks to calculate a peak flow. However they conducted their analysis at multiple locations within the canyon itself. By using this reach of the stream, they eliminated the error involved in estimating average crossectional area. The walls of the canyon are stable and therefore the area available to flow did not change throughout the flood. Figure 4 is the water surface profile that the University of Arizona constructed from high water marks and flood deposits observed in the canyon. The profile indicates a maximum water stage of about 23 feet within the canyon, while at the USGS gaging station the same flow yielded a gage height of about 17 feet. In this range of stages the 3 to 5 foot fish barrier will be completely submerged and will have a minor effect on flood stages. More important at these stages is the structural stability of the barrier.

HYDRAULIC DESIGN

TO BE COMPLETED WHEN SURVEY DATA IS AVAILABLE. EFFECTS OF FISH BARRIER ON STREAM HYDRAULICS EXPECTED TO BE MINIMAL.

CONCLUSIONS

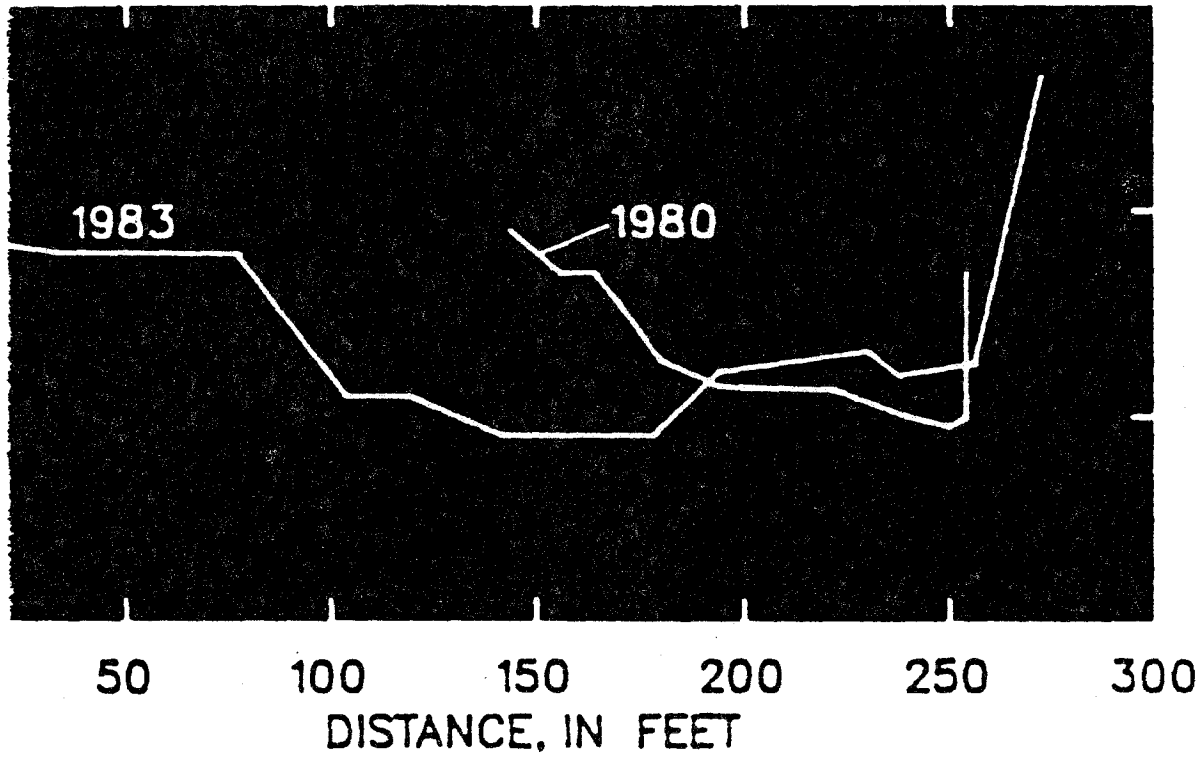

Figure 3: in channel geometry of Aravaipa Creek near Mammoth, (site 41), March 1980 and October 1983.

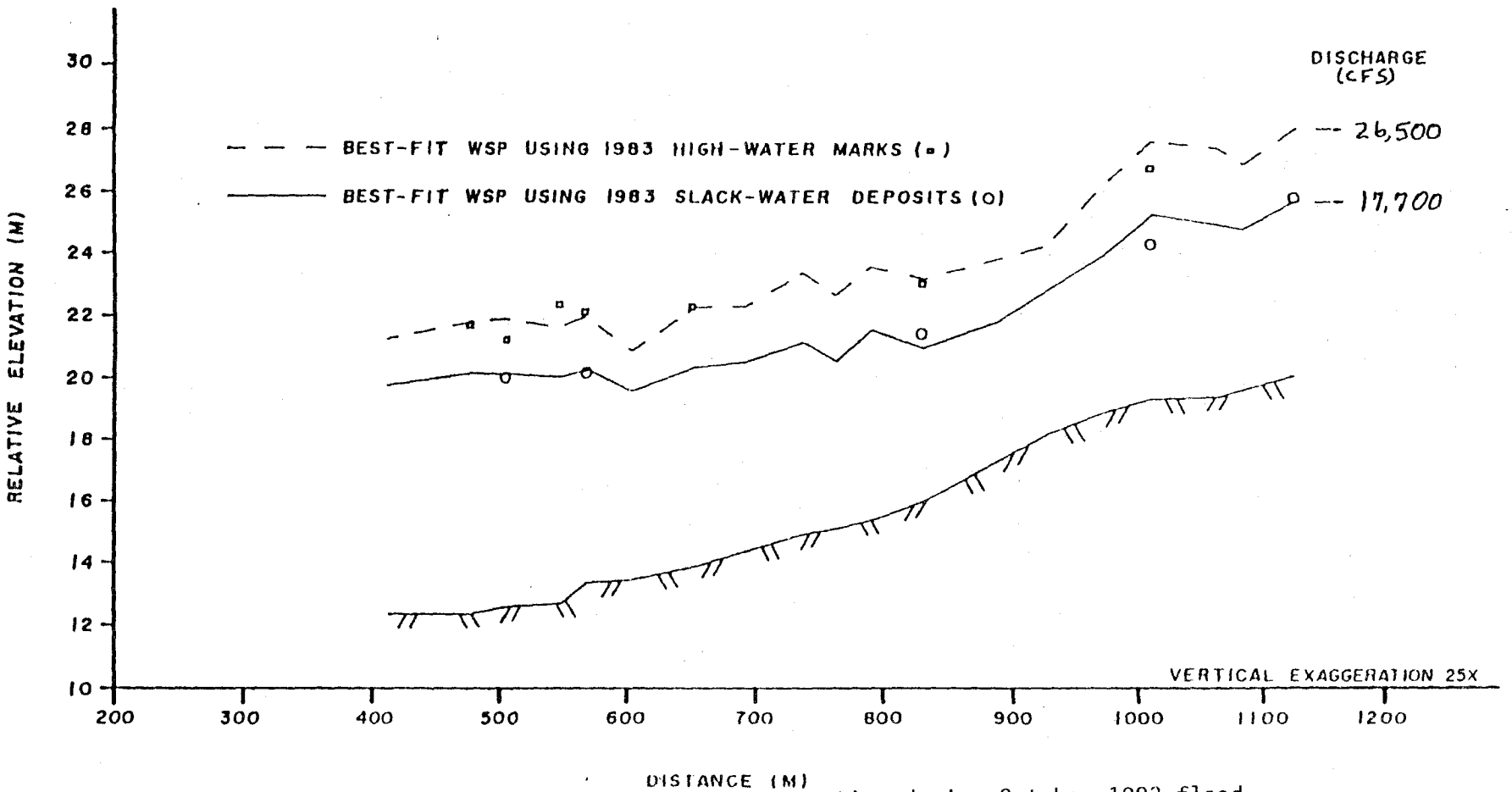

Figure 4: Water surface profile within canyon section during October 1983 flood

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