San Acacia Diversion Dam: Fish Passage Study

San Acacia, New Mexico

Report Prepared by:

Travis R. Bauer, Hydraulic Engineer
Sedimentation and River Hydraulics Group

Report Peer Reviewed by:

Christi A. Young, Hydraulic Engineer
Sedimentation and River Hydraulics Group

June 2003

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center, Denver, Colorado

1.0 Introduction

This study was intended to be a preliminary assessment of raising the downstream riverbed up to the apron of San Acacia Diversion Dam with several Gradient Restoration Facilities (GRFs) in the San Acacia to Escondida reach to allow fish passage through the dam.

2.0 Background

2.1 Location Information

The study reach for this project is located between San Acacia Diversion Dam and Escondida Bridge. Reach length is approximately 11.5 miles. Figure 1 shows the approximate location of the project.

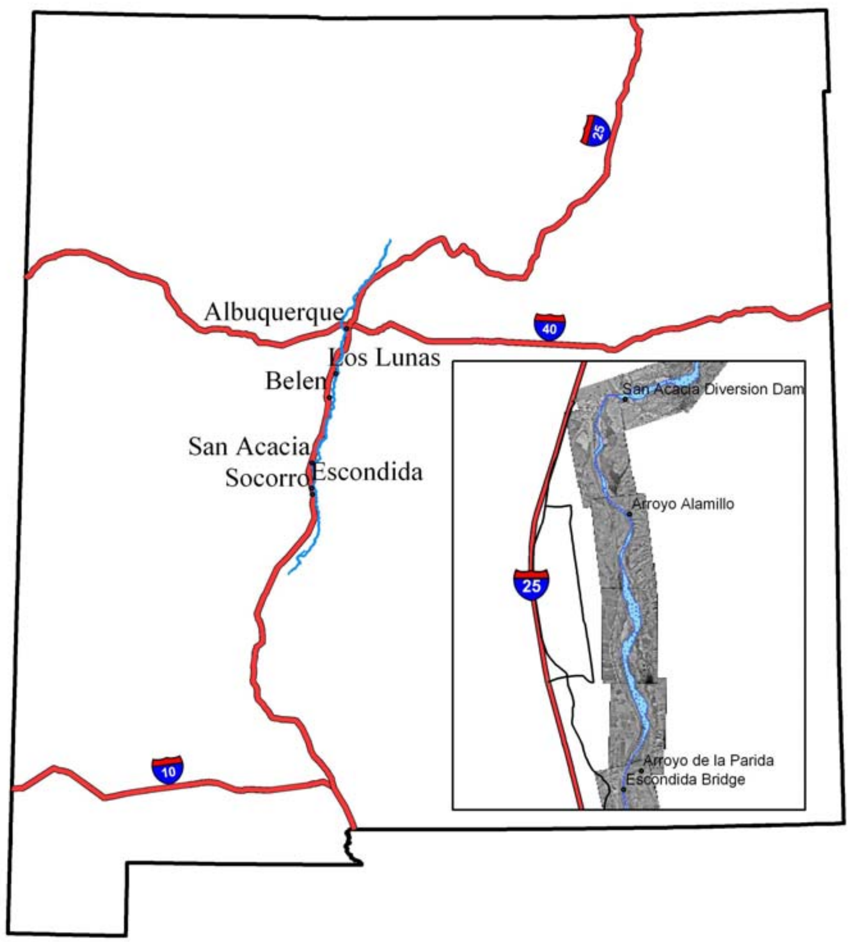


Figure 1. New Mexico map with inset showing the project location between San Acacia Diversion Dam and Escondida Bridge.

2.2 Site Description

Channel elevations downstream from San Acacia Diversion Dam have decreased significantly. Channel incision further downstream, as seen in Figure 2, has resulted in bank heights between fifteen and twenty feet (thalweg to top of bank). The elevation of the dam apron is 4661 feet (NADV 29). In the 1950s, the apron was covered with sediment as seen in Figure 3. By 1972, the thalweg elevation approximately 500 feet downstream from the dam decreased to 4657 feet. By 2002, the thalweg elevation had decreased to 4651 feet.

The San Acacia reach has a wide range of channel widths based on 2001 aerial photography (Oliver, 2002). Widths range from less than 100 feet to over 750 feet. The mean width is 275 feet with a standard deviation of 146 feet. Bed material is predominantly sand and gravel. Several arroyos enter the Rio Grande in and above this reach and act as potential sources of sediment and water. Woody vegetation in this reach includes mixtures of willow, cottonwood, saltcedar, and Russian olive.

Figure 2. Looking upstream at vertical banks downstream from San Acacia Diversion Dam. The distance from the top of bank to the thalweg is between fifteen and twenty feet.

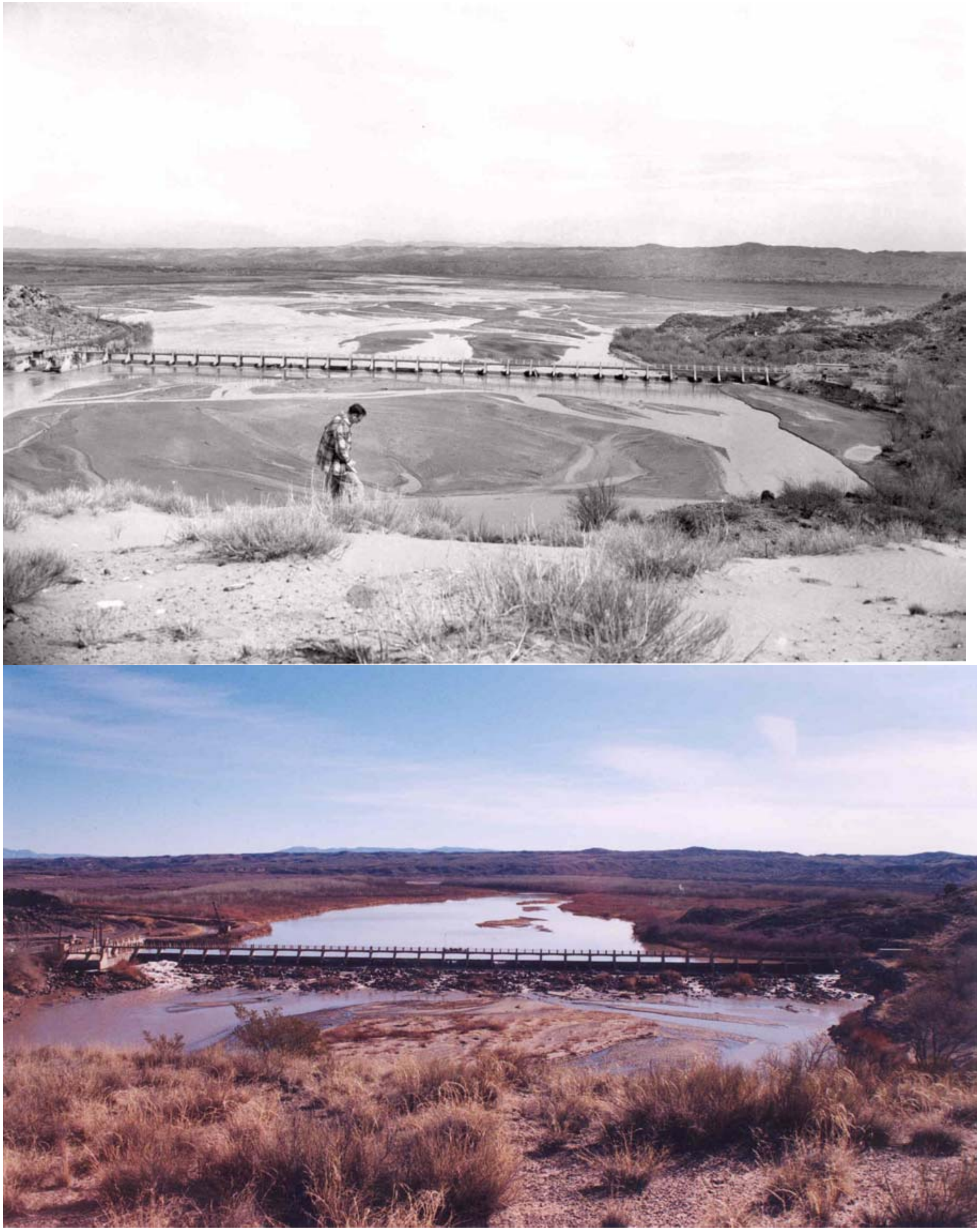


Figure 3. San Acacia Diversion Dam in 1952 (upper photo) and 2002 (lower photo). In 1952, gates are nearly buried in sediment. By 2002, there has been over ten feet of degradation downstream from the dam.

2.3 Geomorphology

Historical channel widths in the San Acacia reach were much wider than present day widths. Figure 4 shows the maximum, 75th percentile, mean, 25th percentile, and minimum channel widths for two sub-reaches of the San Acacia reach. Sub-reach 1, San Acacia Diversion Dam to Arroyo Alamillo, has traditionally been narrower than sub-reach 2, Arroyo Alamillo to Arroyo de la Parida. Mean channel width in sub-reach 1 decreased from over 1,000 feet in 1918 to 200 feet in 2001. In sub-reach 2, mean channel width decreased from over 2,000 feet in 1918 to just over 300 feet in 2001.

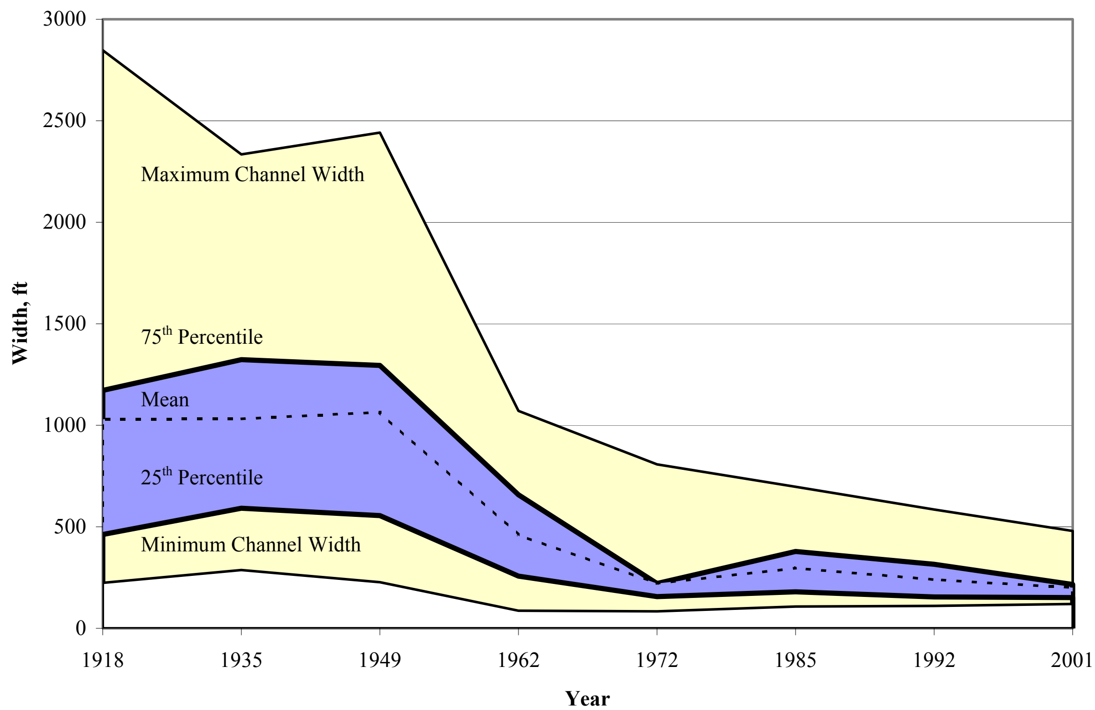


Figure 4. Channel widths from San Acacia Diversion Dam to Arroyo Alamillo between 1918 and 2001.

Channel narrowing has often been accompanied by channel incision and terrace formation. For a given flow, a narrower channel will also have higher depths and velocities than a wide channel. Data show that the channel is narrower and deeper now than in 1962. There is also less overbank flooding and velocities in the channel are higher. Terraces in the San Acacia reach formed after channel incision are no longer flooded with normal spring runoff (USBR, 2002). Figure 5 shows the progression of channel incision in the San Acacia reach. Mean bed elevations steadily decrease downstream from San Acacia Diversion Dam between 1936 and 1962. Beginning in 1972, the rate of channel incision increases and progresses further downstream. The highest rate of channel incision is between 1992 and 1999.

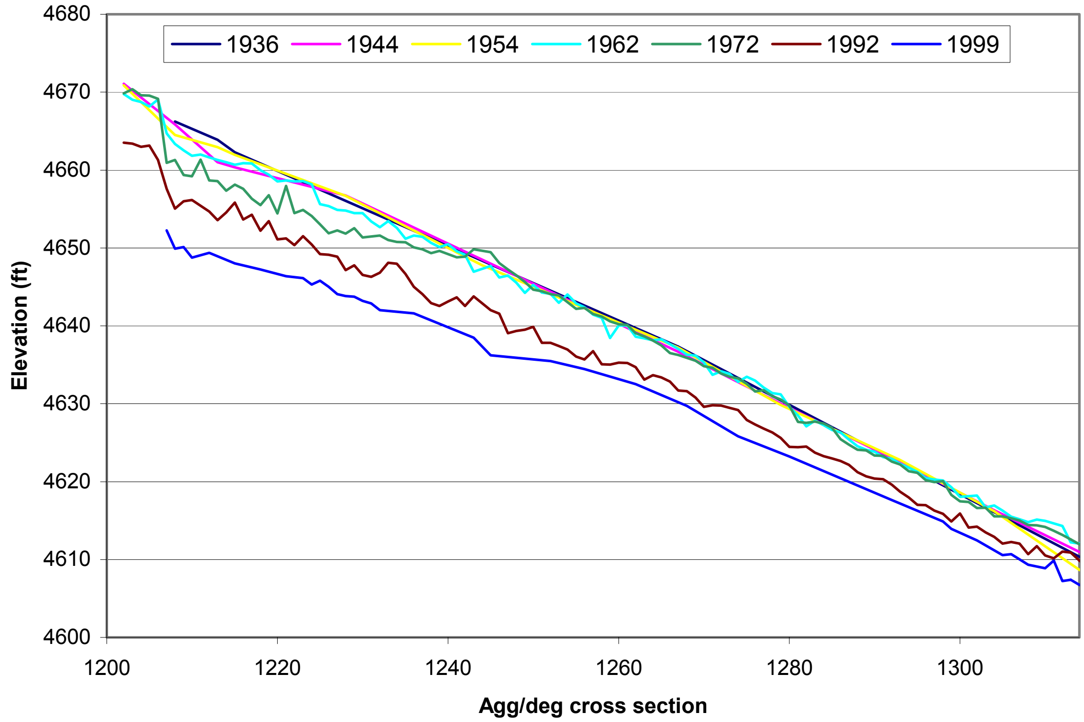


Figure 5. Mean bed profile over time between San Acacia Diversion Dam and Escondida Bridge.

2.4 Project Objectives

- Determine the number of GRFs needed to raise the riverbed up to the apron of San Acacia Diversion Dam.
- Perform hydraulic analysis to assess channel conditions with the proposed structures.
- Estimate preliminary construction quantities.

3.0 Data/Model Setup

3.1 Geometric and Topographic Data

3.1.1 Cross-section Data

Several data sources were used to create a 3-D surface as a base for modeling. Sources include: 1992 agg/deg photogrametric cross sections and the 1999 and 2002 field surveyed data for the San Acacia range lines (SA) and Socorro range lines (SO). There has been a significant amount of vertical and lateral change in the river channel since the 1992 data were collected so these data were used only in overbank areas. Channel data from 1999 were only used for cross sections that were not surveyed in 2002.

3.1.2 TIN Generation

Cross-section data were converted from station/elevation (x,y) format to northing/easting/elevation (x,y,z) format. Cross-section endpoint coordinates and the distance between points were used in a simple trigonometric conversion to obtain the northing, easting and elevation for all cross-section data used. The point data were then imported into Arc View GIS 3.2 and used to make a triangulated irregular network (TIN). After first inspection, the TIN did not have sufficient detail to satisfactorily model the channel. The detail near existing data was sufficient, but the long distances between some cross sections resulted in unrealistic elevation values between cross sections. Several bends were also not shown in the TIN because there were no existing cross sections in these areas. To gain detail in bends and between measured cross sections, interpolated data were manually added to the TIN. Interpolated data were generated by first creating a HEC-GeoRAS export file in Arc View that sufficiently described the channel geometry. The export file included cross sections at or near existing data and included cross sections where more detail was needed.

Cross sections generated from the TIN were adjusted in HEC-RAS to reflect actual conditions. These adjustments relied on existing data to help determine the shape and elevation of cross-section features. For cross sections that were not in bends, bed elevations were estimated from the closest upstream and downstream surveyed cross sections. For a cross section in a bend, the thalweg elevation was estimated from elevation of the Low Flow Conveyance Channel (LFCC). Previous field work in this reach indicated that the thalweg elevation in the bends at river miles 114, 113, and 111 were approximately equal to the elevation of the bed in the LFCC. Once all cross sections were adjusted, additional cross sections were interpolated in HEC-RAS with spacing of 50 to 100 feet to add more data to the TIN. Cross-section data were then exported to Arc View and added to the TIN. This process was repeated several times until there were enough points to represent bend curvature and areas between surveyed cross sections.

3.2 Hydraulic Data

Model calibration at high flow was not possible because the TIN was a composite of various data sources each having measured water surfaces collected at low flow. Low flow conditions are much different than high flow conditions. A much greater percentage of the bed may be mobilized at high flow and the channel position will often change as flows increase.

Uniform roughness values were assigned to all cross sections. For unvegetated channel areas, a Manning roughness value of 0.024 was used. This value was used on previous model runs in this reach and is supported by normal depth calculations based on field data. All vegetated non-channel areas were assigned a Manning roughness value of 0.045. This value is meant to account for young vegetation growing on low bars and banks. There are areas that are more densely vegetated that should have higher roughness values, but these areas are not flooded with the flows simulated in this model.

3.3 Hydrologic Data

Four flows were used in model runs but the spacing of the GRFs was based only on the average winter flow for the past ten years, 1,100 ft^3/s. Other flows included to evaluate channel properties were 100, 3,000, and 5,000 ft^3/s. These flows are the summer low flow, effective discharge, and channel forming discharge respectively.

3.4 GRF Layout

3.4.1 GRF Spacing

Setting the spacing and height of the GRFs was a trial and error procedure. The GRF design was based on the USBR Santa Ana GRF, which has a 'V' shape and rises 2 feet from downstream to upstream (Figure 6) and from the center to the bank (Figure 7). Elevations, widths, and original ground details shown in Figures 6 and 7 are for the Santa Ana GRF and are not applicable to the GRFs proposed downstream of San Acacia Diversion Dam. Layout for this series of GRFs started with the upstream-most GRF. The proposed GRF locations are in relatively straight reaches to avoid adverse channel characteristics. Consideration was also given to the proximity of competent high ground to tie the GRFs into to prevent flanking. The height of the upstream-most GRF was adjusted until the backwater from the GRF raised the water level at least 1 foot above the apron of San Acacia Diversion Dam at 1,100 ft^3/s for fish passage through the dam. The 500-foot design length of the GRFs was set to mimic natural riffles in the Santa Ana reach. For convenience in this study, GRF lengths for the study were determined from existing cross-section spacing, which were often approximately 500 feet apart. Downstream GRF locations were also selected assuming that the backwater effects of each GRF would extend upstream for about one mile submerging the downstream end of the upstream GRF for fish passage.

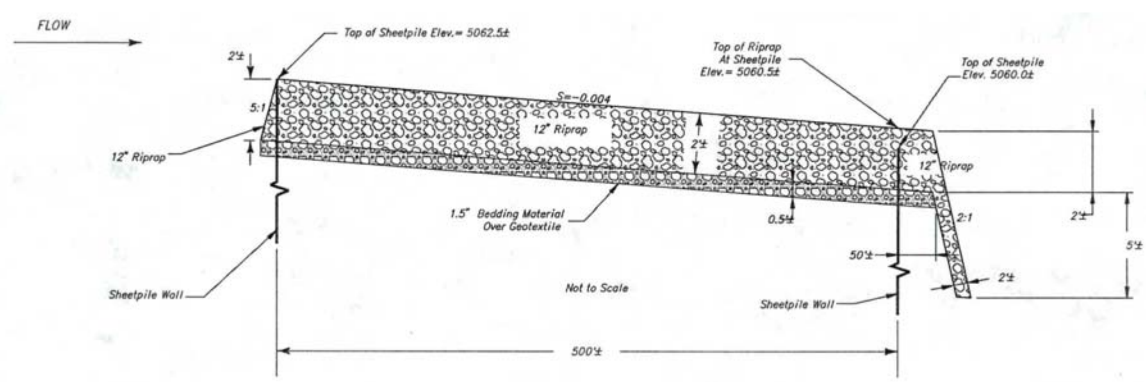


Figure 6. Profile of USBR Santa Ana GRF showing a 2 foot decrease in elevation from upstream to downstream.

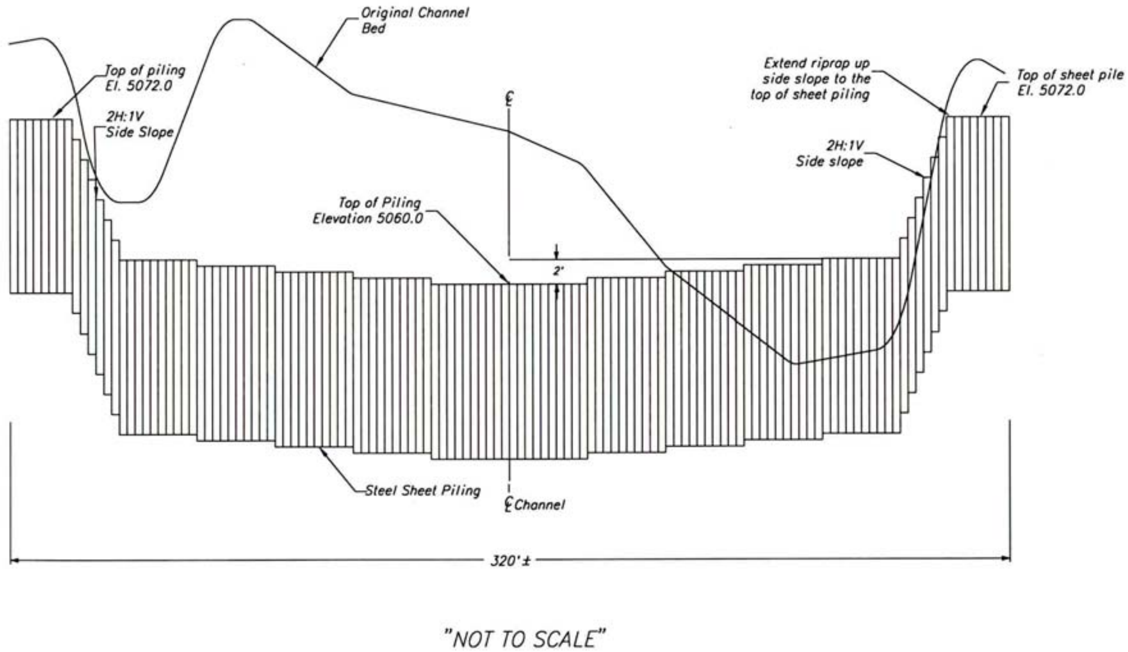


Figure 7. Cross-section schematic of the USBR Santa Ana GRF showing sheetpile tiebacks and 2 foot rise from the center of the channel to the toe of the bank.

Following this procedure, eight GRFs were needed to raise water levels up to San Acacia Diversion Dam. Heights of the GRFs varied from 2 to 10 feet, and decreased in the downstream direction. The eighth GRF had a height of two feet so no additional GRFs were considered downstream. No bed or channel changes were assumed in the reach below the last GRF. The proposed location for this downstream-most GRF matches a GRF location proposed for another project.

3.4.2 GRF Upstream Slope

Crest elevations of the GRFs followed a nearly constant slope between the downstream GRF and the diversion dam. The bed upstream from each GRFs was filled to match assumed post-construction conditions. Knighton (1998) points to studies showing bed slopes upstream from obstructions having a limited length of effect and ranging from less than 30 percent of the pre-dam slope immediately after construction to less than 83 percent of the pre-dam slope at equilibrium. Because the time required for the reach to evolve to near equilibrium conditions is unknown, if ever, a conservative estimate of 50 percent of the original slope was used to project bed changes upstream. The existing slope is 0.0008 ft/ft, therefore the bed was assumed to be filled from the crest of each GRF upstream at a slope of 0.0004 ft/ft. Figure 8 shows the approximate layout of the GRFs and the assumed future bed slope.

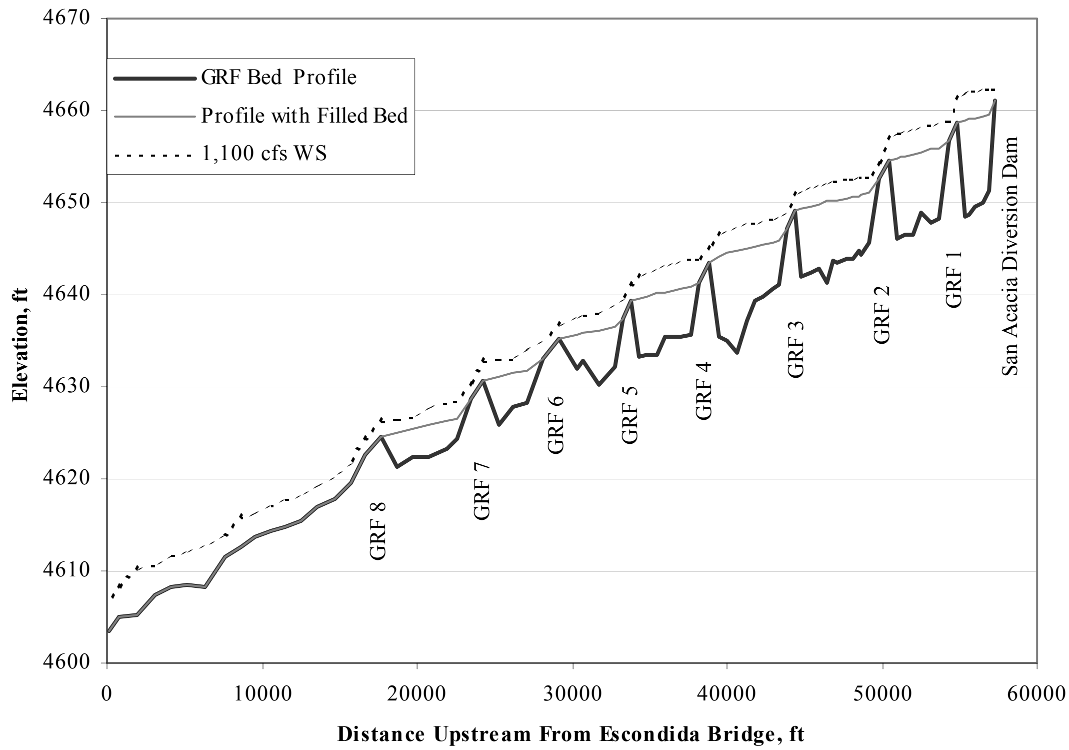


Figure 8. Bed profile between San Acacia Diversion Dam and Escondida Bridge showing GRF locations and bed fill upstream from the GRFs. GRF height decreases as distance downstream from San Acacia Diversion Dam increases.

4.0 Results

General analysis for hydraulic properties, sediment transport capacity, and slope (particle) stability were performed for the 5,000 ft^3/s channel forming flow for both the existing and the assumed future GRF filled conditions. The San Acacia reach was divided into two sub-reaches, San Acacia Diversion Dam to Arroyo Alamillo, sub-reach 1, and Arroyo Alamillo to Arroyo de la Parida, sub-reach 2 (Figure 9). Depth and velocity distribution analyses used shorter reaches and additional flows to more specifically identify areas that might need more attention.

4.1 Average Hydraulic Properties

The hydraulic properties for both existing and future conditions were analyzed using HEC-RAS. Hydraulic properties were numerically averaged by sub-reach. Table 1 shows the reach-averaged hydraulic properties at 5,000 cfs. The most notable changes are the increases in width and average water surface elevation. In both sub-reaches, the average width increases over 100 feet after adding GRFs, which raise the water surface up to portions of the floodplain that have not been inundated in many years.

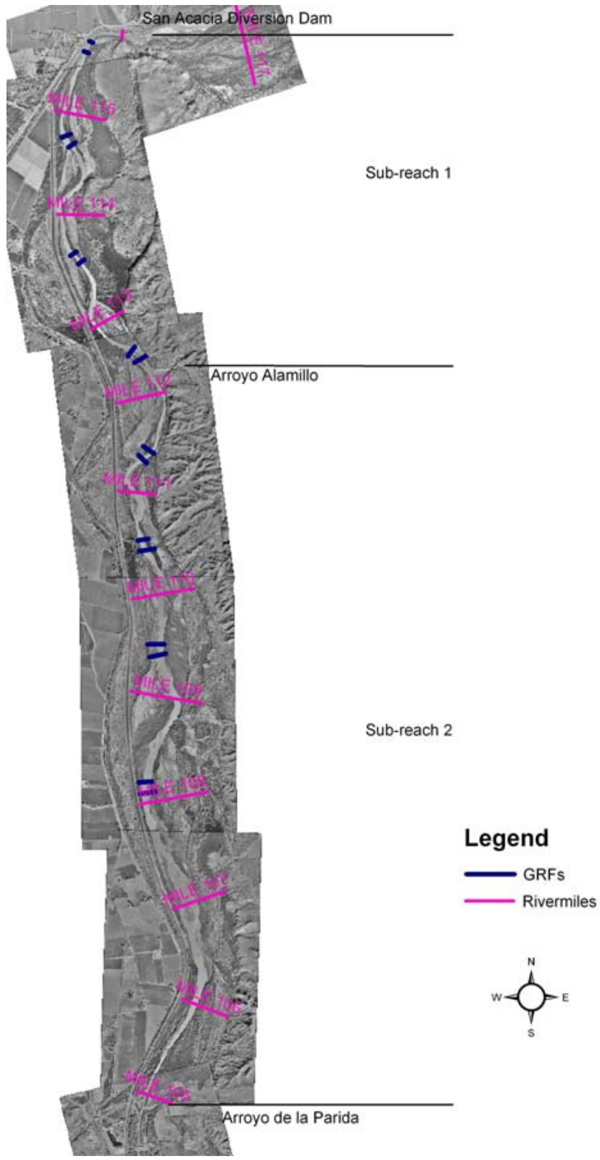


Figure 9. Plan view of the study reach showing the potential sites of the GRFs and the sub-reaches used for general analysis.

Table 1. Reach-averaged hydraulic properties at 5,000 cfs.

Sub-reach	Alternative	Width, ft	Depth, ft	Velocity, ft/sec	Sw	WSEavg
1	Existing	250	5.7	4.8	0.000860	4651.4
1	GRFs	383	4.8	4.5	0.00098	4656.5
2	Existing	502	4.3	4.1	0.000839	4629.6
2	GRFs	610	3.7	4.0	0.000939	4630.8

Average water surface elevation increased over 5 feet in sub-reach 1 and over 1 foot in sub-reach 2 when GRFs are added. Reach-averaged depth values decrease in both sub-reaches when GRFs are added. In sub-reach 1 average depth decreased 0.9 feet and in sub-reach 2 average depth decreased 0.6 feet. The decrease in depth is mostly due to fill that was added in the model upstream from the GRFs. Fill was added across the incised channel creating a wider flatter bottom.

Reach-averaged velocity values show a slight decrease in sub-reaches 1 and 2 when GRFs are added. The slight reduction in velocity values is likely due to increased top width with additional overbank flooding and reduced bed slope.

4.2 Sediment Transport Capacity

Sediment transport was analyzed for sand and gravel sizes to determine if sand can stable in the study reach and if gravel could be transported down the river. Sand-sized surface bed material samples collected during the 1999 cross-section surveys were averaged to form a single composite sample (d_{50} = 0.3 mm, medium sand). A gravel sample was taken from the fan deposit at the mouth of Arroyo de la Parida in the summer of 2001. This sample has a smaller d_{50} (5 mm, fine gravel) than many of the armor layer samples collected from the riverbed in the spring of 2001 (USBR, 2002) but is more representative of potential gravel sources. This size range is more likely to be transported downstream than the coarser material found in the armor layer. The same gradations were used in the analysis of both existing and future conditions.

The results of the sediment transport capacity analysis indicate that both sub-reaches are in disequilibrium. Total load calculations between 1993 and 1999 at the San Acacia gauge were used to determine the incoming sand load. Rating curves based on regression analysis of the sand and gravel portion of the total load, calculated using the Modified Einstein Procedure (Colby and Hembree, 1955 and Lara, 1966), indicate that the incoming bed material load at 5,000 cfs is approximately 23,000 tons/day. Table 2 shows the results from sediment transport calculations using the Yang (1973) unit stream power equation for sand. To account for gravel sizes in the bed, the equation was modified to include gravel sizes. Each sub-reach has a sediment transport capacity that is greater than the incoming bed material load. Using the average water surface slopes and average bed material gradations for each sub-reach, estimates of sediment transport capacity are greater than the incoming load. Based on these results, sand is not stable in this reach even with the addition of GRFs, once filled.

Table 2. Sediment transport capacity at 5,000 cfs.

Sub-reach	Alternative	Sand tons/day	F. Gravel tons/day
1	Existing	33,311	5948
1	GRFs	36,194	6524
2	Existing	25,404	4368
2	GRFs	29,242	5135

Sediment transport capacity for gravel-sized material is much less than for sand-sized material. Sediment supply rates from the arroyos and upstream sources are not known at this time but the data indicate that the river is capable of transporting gravel downstream. Based on these calculations it is likely that after deposition or fill has reached the assumed future bed profile, bed material in the San Acacia reach will continue to coarsen and more gravel will be moved through the reach.

4.3 Slope (Particle) Stability

Slope stability calculations were performed to determine the potential for additional degradation in the reach and to assess gravel movement through the reach with and without GRFs. Calculations were performed according to USBR guidelines (Pemberton and Lara, 1984) with the same bed material sample data used in the sediment transport analysis. Results in Table 3 show that for the sand sizes found in the reach to be stable, the slope generally has to be reduced by 90 percent or more. Stable slope calculations for the gravel sample indicate approximately a 50 percent reduction in slope for sub-reach 1. Slopes in sub-reach 2 would need to be reduced by approximately 25 percent for fine gravel to be stable. The data indicate that the existing slope of 0.0008 ft/ft is too steep to maintain a sand bed with the current sediment supply. The data also indicate that the fine gravel brought in by the arroyos and from upstream is not large enough to fully stabilize the bed and stop degradation. Fine gravel will continue to be moved downstream until the slope is sufficiently reduced. Adding GRFs may sufficiently reduce the slope to temporarily stop gravel movement. Long-term gravel movement past the GRFs will depend on the ultimate equilibrium slope of the riverbed upstream from the GRFs. In the short term, the slope should be flat enough to stop gravel migration and stabilize the bed.

Table 3. Reach-averaged stable slope calculations (ft/ft).

Sub-reach	Alternative	Sand	F. Gravel
1	Existing	0.000089	0.000396
1	GRFs	0.000109	0.000503
2	Existing	0.000124	0.000589
2	GRFs	0.000144	0.000683

4.4 Equilibrium Width

Estimates of equilibrium width were calculated using the Chang width equation (Chang, 1988). This equation uses both grain size and water surface slope to calculate width in sand bed rivers. In a previous analysis of the Socorro area, this equation has matched trends and predicted reasonable widths (Makar and Strand, 2002).

Based on results from the Chang equilibrium width equation, the channel width could vary from 60 to 350 feet depending on slope and bed material size. Figure 10 shows the range of possible widths depending on slope and grain size. The large black oval on the plot represents the range of widths for slopes between 0.0004 and 0.0008 ft/ft and bed material between medium sand and fine gravel. Future slope will depend on the size of material that fills in upstream from the GRFs. These boundaries are based on existing bed material sizes and slopes. The lower boundary for slope is based on the 0.0004 ft/ft slope projected upstream from the GRFs and represents the conditions likely to seen in the short term after construction of the GRFs.

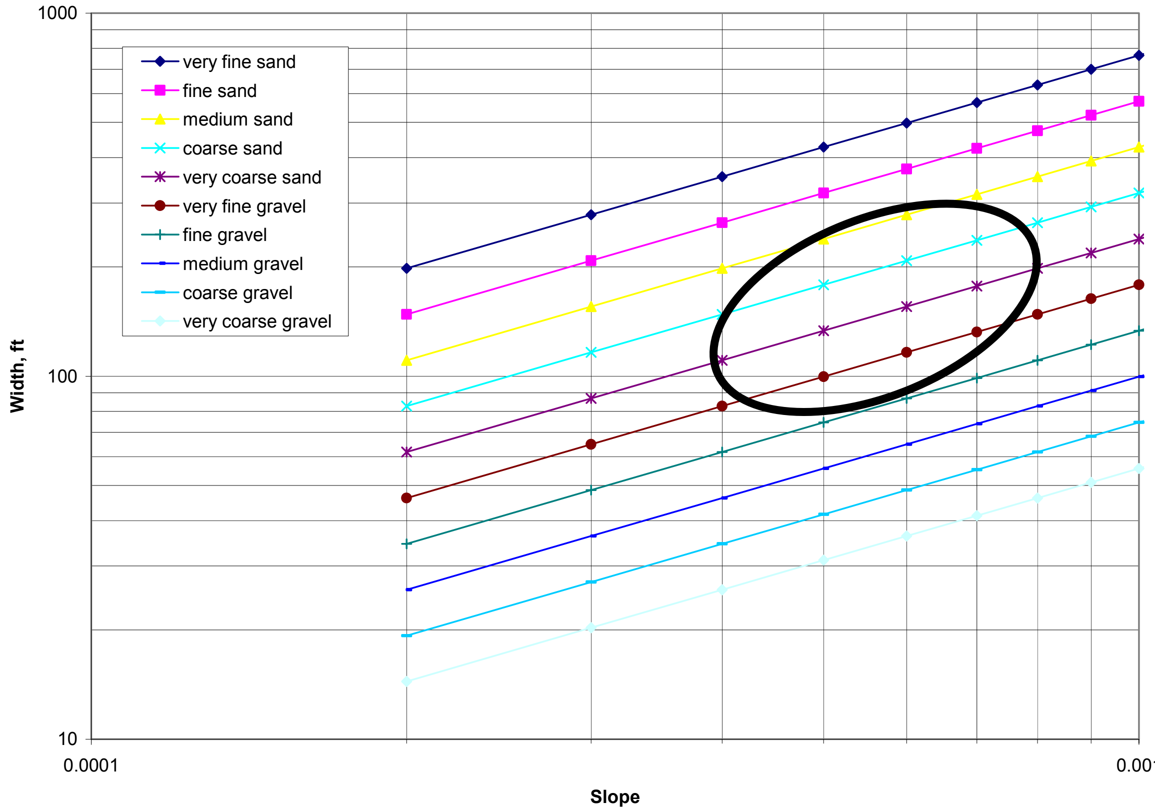


Figure 10. The range of equilibrium widths based on possible future grain size and bed slope are shown in this plot. The black oval is highlighting the range likely to be seen in the San Acacia reach.

4.5 Depth and Velocity Distributions

HEC-RAS output was used to assess velocity and depth distributions for each cross section. Depth and velocity distributions were calculated for flows of 100, 1,100, 3,000, and 5,000 cfs. Low flows were represented by 100 cfs. Analysis of San Acacia gauge data shows that during the non-irrigation season (November through February) the average mean daily discharge since 1990 is approximately 1,100 cfs. Previous studies on this reach have also determined that at 3,000 cfs, the sand bed material becomes fully suspended and that the channel forming discharge is approximately 5,000 cfs (USBR, 2002). Data was sorted by sub-reach to show total wetted surface area, surface area with depth less than 2 feet, and surface area with velocity less than 2 ft/sec (see Tables 4, 5, and 6). Shorter reaches were used in this analysis to get more detailed habitat information. Reach delineations, see Figure 11, are based on GRF locations and extend from the downstream end of one GRF to the downstream end of another GRF. San Acacia Diversion Dam is the upstream-most boundary and Arroyo de la Parida is the downstream-most boundary.

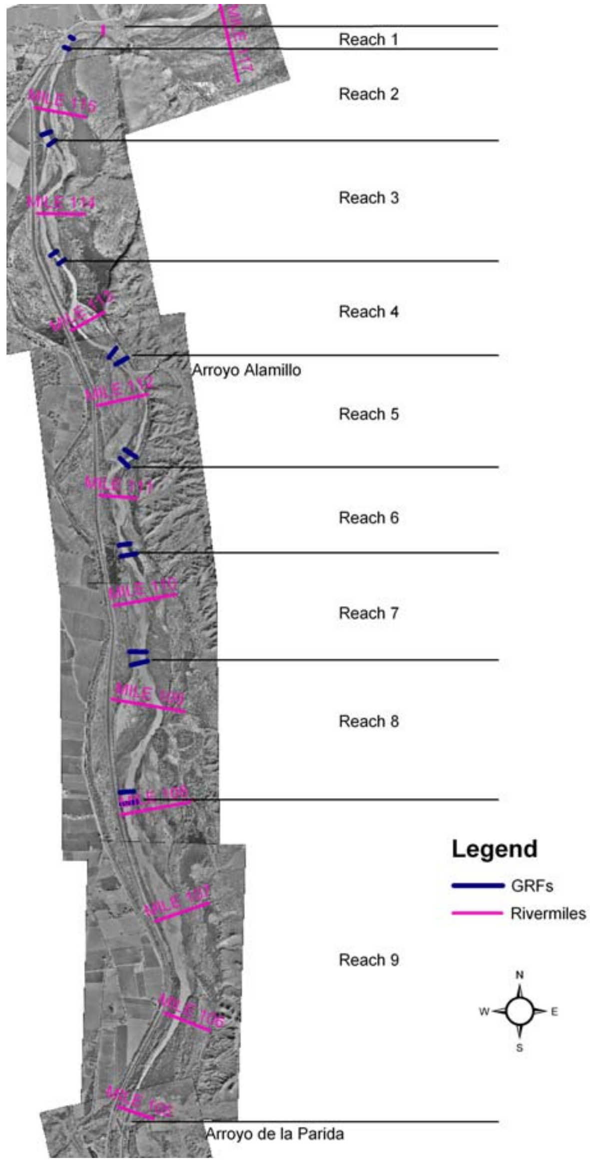


Figure 11. Plan view of study reach showing the location of GRFs and the shorter sub-reaches used for habitat analysis.

Recent physical modeling results with Rio Grande silvery minnow and rock flume fishways indicate that silvery minnow are able to pass through a slope of 1% and velocities less than 1.25 ft/s (Mefford, USBR, pers comm., 2002). Other information on the silvery minnow suggests that the preferred habitat of the minnow is in areas less than 1 foot deep with velocities less than 1.3 ft/sec. Limits for low velocity and low depth were assumed to be 2 ft/s and 2 feet respectively.

At all flows with the GRFs, there is more surface area and except for a few reaches, there is more slow velocity, slow depth area. The few exceptions to this general rule are in reaches that are highly incised. For flows of 1,100, 3,000, and 5,000 ft^3/s there is more low depth surface area in reach 1 for the existing conditions than with GRFs. In the existing conditions, the channel has developed some overbank areas within the incised channel. After the GRFs are added, these areas are filled and there really isn't any accessible overbank in this reach leading to higher depths. The same trend can be seen in reaches 4 and 5 for velocity. Fill levels are less in these reaches than in reach 1, but they have the same effect of covering previous overbank areas within the incised channel. The main difference in reaches 4 and 5, however, is that as flow levels increase to 5,000 ft^3/s, the river gains access to new overbank that had previously been disconnected.

Table 4. Change in low-velocity (<2 ft/s) wetted surface area, in acres, with and without GRFs.

Reach	Flow, cfs	Existing	With GRFs	Percent Change
1	100	8	15	95
2	100	9	14	50
3	100	13	37	194
4	100	14	21	53
5	100	10	16	58
6	100	12	28	127
7	100	11	36	225
8	100	17	51	192
9	100	40	42	4
1	1100	4	12	182
2	1100	2	2	7
3	1100	11	41	276
4	1100	9	9	-8
5	1100	5	10	91
6	1100	10	30	202
7	1100	25	75	202
8	1100	38	51	36
9	1100	40	43	6
1	3000	4	11	191
2	3000	1	2	126
3	3000	9	42	361
4	3000	7	7	-9
5	3000	3	8	145
6	3000	8	22	170
7	3000	39	82	114
8	3000	49	53	9
9	3000	48	44	-7
1	5000	3	13	282
2	5000	1	3	169
3	5000	16	37	130
4	5000	4	13	218
5	5000	4	9	104
6	5000	12	16	36
7	5000	51	85	67
8	5000	46	60	33
9	5000	65	64	-2

Table 5. Change in low-depth (< 2 ft) wetted surface area, in acres, with and without GRFs.

Reach	Flow, cfs	Existing	With GRFs	Percent Change
1	100	9	16	83
2	100	10	15	47
3	100	14	40	180
4	100	14	22	62
5	100	11	17	54
6	100	12	30	153
7	100	12	39	216
8	100	20	51	155
9	100	45	46	2
1	1100	7	7	-7
2	1100	5	6	43
3	1100	11	33	202
4	1100	7	11	47
5	1100	5	10	127
6	1100	18	36	107
7	1100	23	83	262
8	1100	31	80	153
9	1100	60	64	8
1	3000	4	2	-36
2	3000	2	5	213
3	3000	8	24	204
4	3000	2	7	193
5	3000	2	9	370
6	3000	12	23	93
7	3000	37	71	89
8	3000	41	59	42
9	3000	58	58	0
1	5000	4	3	-25
2	5000	2	5	180
3	5000	9	16	68
4	5000	2	10	407
5	5000	3	9	165
6	5000	14	16	13
7	5000	53	69	31
8	5000	44	51	16
9	5000	66	65	-2

Table 6. Change in total wetted surface area, in acres, with and without GRFs.

Reach	Flow, cfs	Existing	With GRFs	Percent Change
1	100	9	16	81
2	100	10	15	47
3	100	15	40	168
4	100	15	22	45
5	100	11	17	54
6	100	13	30	129
7	100	13	39	194
8	100	20	51	155
9	100	45	46	2
1	1100	14	18	35
2	1100	14	20	44
3	1100	26	55	110
4	1100	22	30	36
5	1100	17	25	51
6	1100	27	45	66
7	1100	35	87	146
8	1100	52	80	54
9	1100	88	91	4
1	3000	15	20	38
2	3000	16	22	41
3	3000	34	69	104
4	3000	25	35	38
5	3000	19	31	60
6	3000	36	57	57
7	3000	60	108	80
8	3000	81	106	31
9	3000	131	132	0
1	5000	16	23	44
2	5000	17	24	43
3	5000	43	74	73
4	5000	27	43	61
5	5000	22	35	58
6	5000	46	59	29
7	5000	88	121	37
8	5000	98	122	25
9	5000	167	167	0

4.6 GRF Fill and Quantities

Because this was a preliminary analysis of raising the riverbed to the apron of San Acacia Diversion Dam, exact quantities cannot be determined. If this project is to be implemented, detailed information will be needed and it is likely that changes will be made to the design and location of GRFs. Estimates for channel fill and GRF sheetpile and riprap based current assumptions are given in Table 7.

The amount of channel fill was estimated by comparing two TINs, the existing condition and the channel after GRFs were added and the bed was filled. The two surfaces were created using the same breaklines and clip polygons. The surfaces reflected bed elevations before and after the GRFs were added. Cross-section plots showing the existing conditions and the assumed conditions after GRF installation along with location maps are shown in Appendix A. The volume difference between the two surfaces was calculated using the Spatial Analyst extension in ArcMap. Figure 12 shows estimates of fill depths in feet calculated from the two surfaces. Fill depths are greatest upstream and decrease in the downstream direction except for a few scour holes in bends further downstream. Approximately 1.4 million cubic yards of fill may be needed to fill upstream from the GRFs.

If fill is not mechanically placed into the channel, sediment will naturally deposit upstream from the GRFs. The annual sediment loads at San Acacia were estimated between 1991 and 2001 from a rating curve at the San Acacia gauge as discussed previously. Annual sediment loads were averaged to account for wet and dry hydrology. The length of time required to deposit this material depends on the trap efficiency and bulk density of the deposited sediment. By assuming that all material sand size and larger will be trapped upstream from the GRFs until they are filled and an *in situ* unit weight of 100 lb/ft^3, it could take a year or 2 to deposit the 1.4 million cubic yards of sediment depending upon the range of flows. This assumes that nothing but silt and clay sized material would pass downstream from the GRFs for one to two years. If silt and clay sized sediment were also deposited, the fill time may be less.

Quantity estimates for sheetpile and riprap were calculated directly from ArcMap. The length of each sheetpile wall across the river was determined from direct measurement on aerial photos. An attempt was made for each row of sheetpile to extend into high ground to contain high flows within the GRF and prevent potential flanking. Additional analysis will be needed to determine the height and embedment depths for each sheetpile wall. The area for each GRF was based on existing channel alignments and did not consider moving or widening the channel. Riprap volume was calculated by first measuring the area of the GRF footprint, which spanned between the riverbanks and the sheetpile walls and then assuming a two-foot riprap depth. Sheetpile walls were placed 500 feet apart. Additional riprap is needed to protect the banks of the GRFs as well as upstream and downstream keys and aprons.

Table 7. Estimated quantities for channel fill, sheetpile, and riprap.

Item	Quantity
Channel Fill (cubic yards)	1,365,000
Sheetpile (linear feet)	7,300
Riprap (cubic yards)	150,000

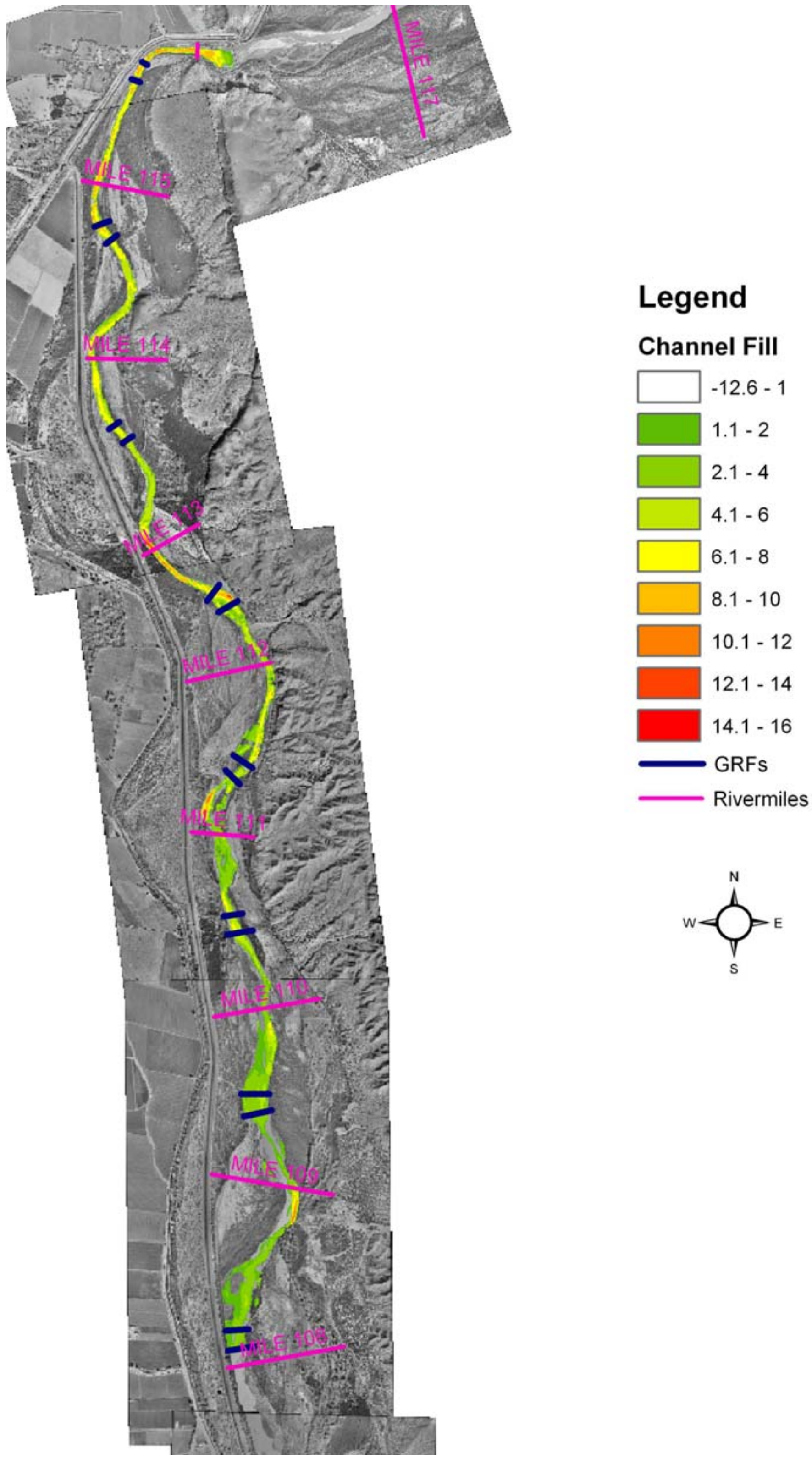


Figure 12. Plan view of study reach showing the location of the GRFs used in the analysis and estimates of the depth of channel fill in feet after the GRFs are placed in the channel.

5.0 Conclusions

In order to raise the riverbed up to the apron at San Acacia Diversion Dam, eight GRFs area needed. The height of each GRF varies but the downstream-most GRF has a height of only two feet. The incoming sediment load for the San Acacia reach is approximately 23,000 tons per day at 5,000 cfs. The sediment transport capacity using a sand-sized sample exceeds the incoming sediment load. The sediment transport capacity of fine gravel also indicates that bed material of this size can move through the reach. Stable slope analysis indicates that the existing slope is too steep for both sand and fine gravel to be stable. With the addition of GRFs gravel may be temporarily stabilized depending on the long-term equilibrium slope. This suggests that the GRFs will not cause long-term aggradation in the reach. Adding eight GRFs to the San Acacia reach increases the amount of wetted surface area and raises water surface elevations. With the exception of a few reaches, the amount of low depth and low velocity area also increases at all flow levels. Estimates indicate that over 1 million cubic yards of sediment could be deposited upstream from the GRFs trapping all sediment for up to two years if fill is not placed into the channel. If tall terraces in incised reaches could be used as a source of fill, less time will be needed to fill behind the GRFs. Excavated terrace surfaces could also create additional low depth, low velocity area during high flows.

References

Colby, B.R. and C.H. Hembree. 1955. Computations of total sediment discharge, Niobrara River near Cody, Nebraska. USGS WSP 1357.

Chang, Howard H. 1988. Fluvial Processes in River Engineering. John Wilely & Sons Inc., pp. 277-281.

Knighton, D. (1998). Fluvial Forms and Processes. Arnold, London, England, 383 p.

Makar, Paula W., and Robert I. Strand. 2002. Draft – Geomorphic Assessment of the Rio Grande: Escondida Bridge to near Fort Craig. U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, Denver, CO.

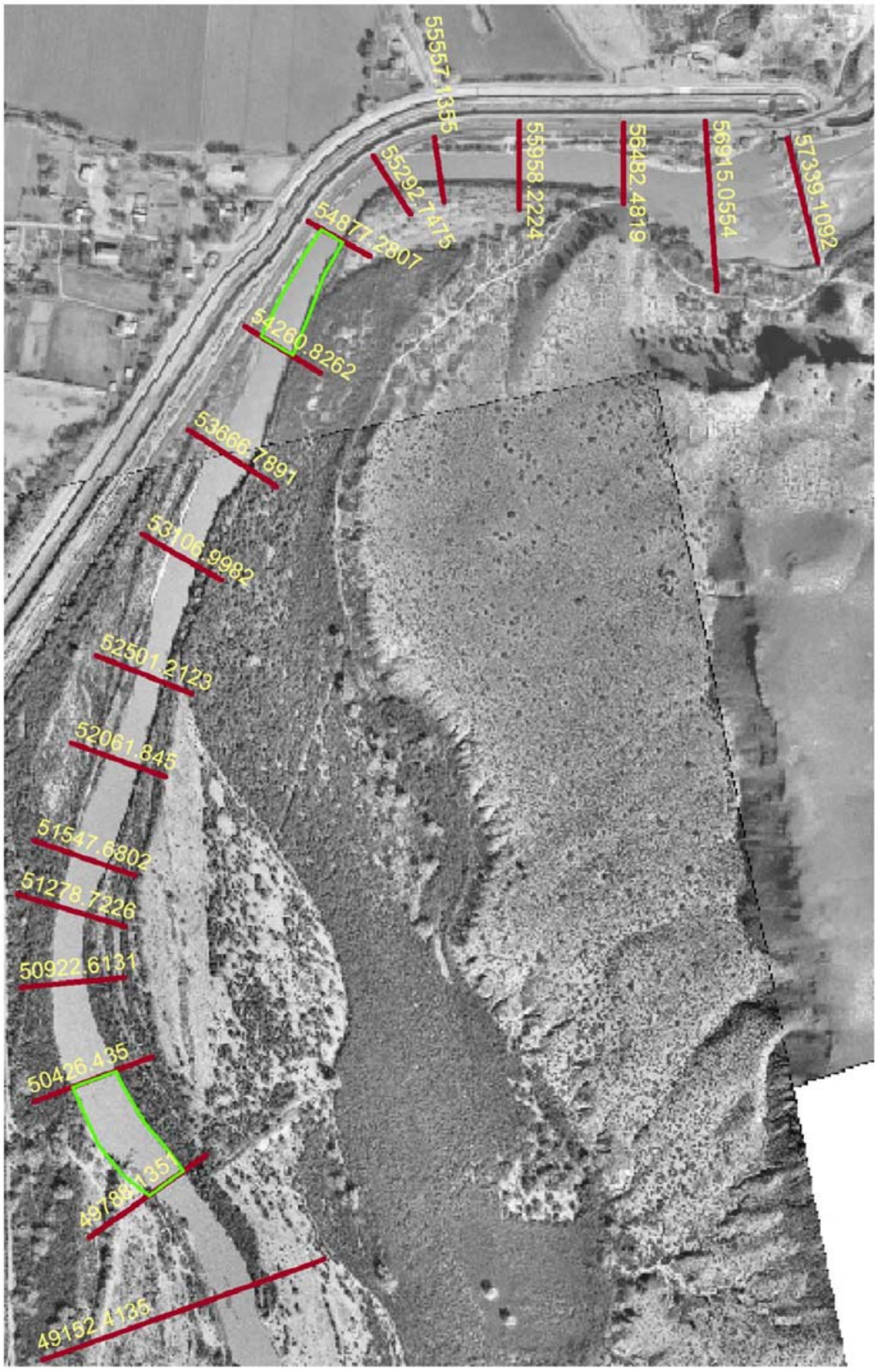
Oliver K.J. 2002. Middle Rio Grande 1918 - 1992 Geomorphology Study for Cochiti Dam to the Narrows of Elephant Butte Reservoir. U. S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Remote Sensing and GIS Group, Denver, CO.

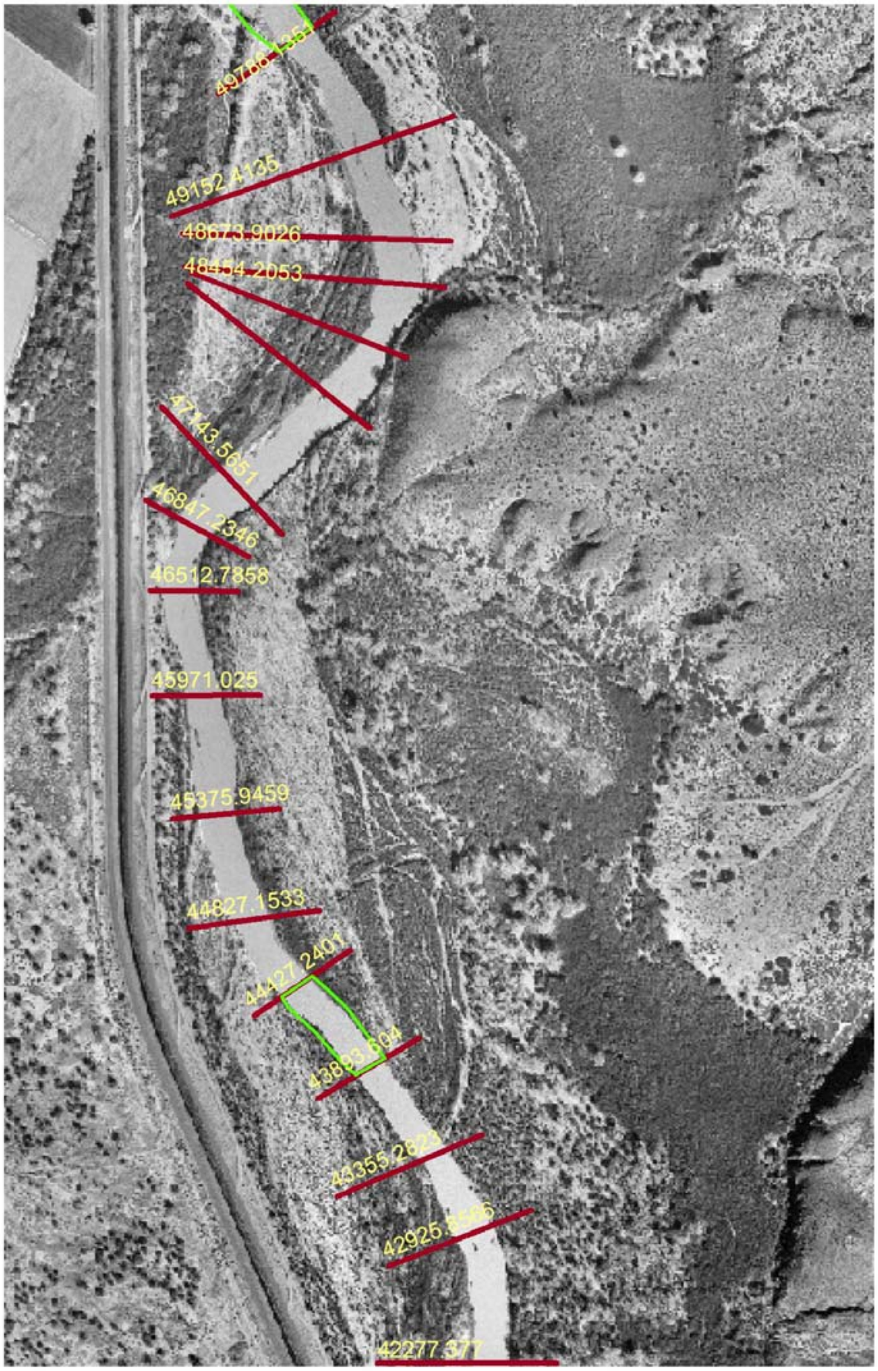
Pemberton, E.L, and Lara, J.M. 1984. Computing Degradation and Local Scour. Technical Guideline for Bureau of Reclamation, Denver, Colorado.

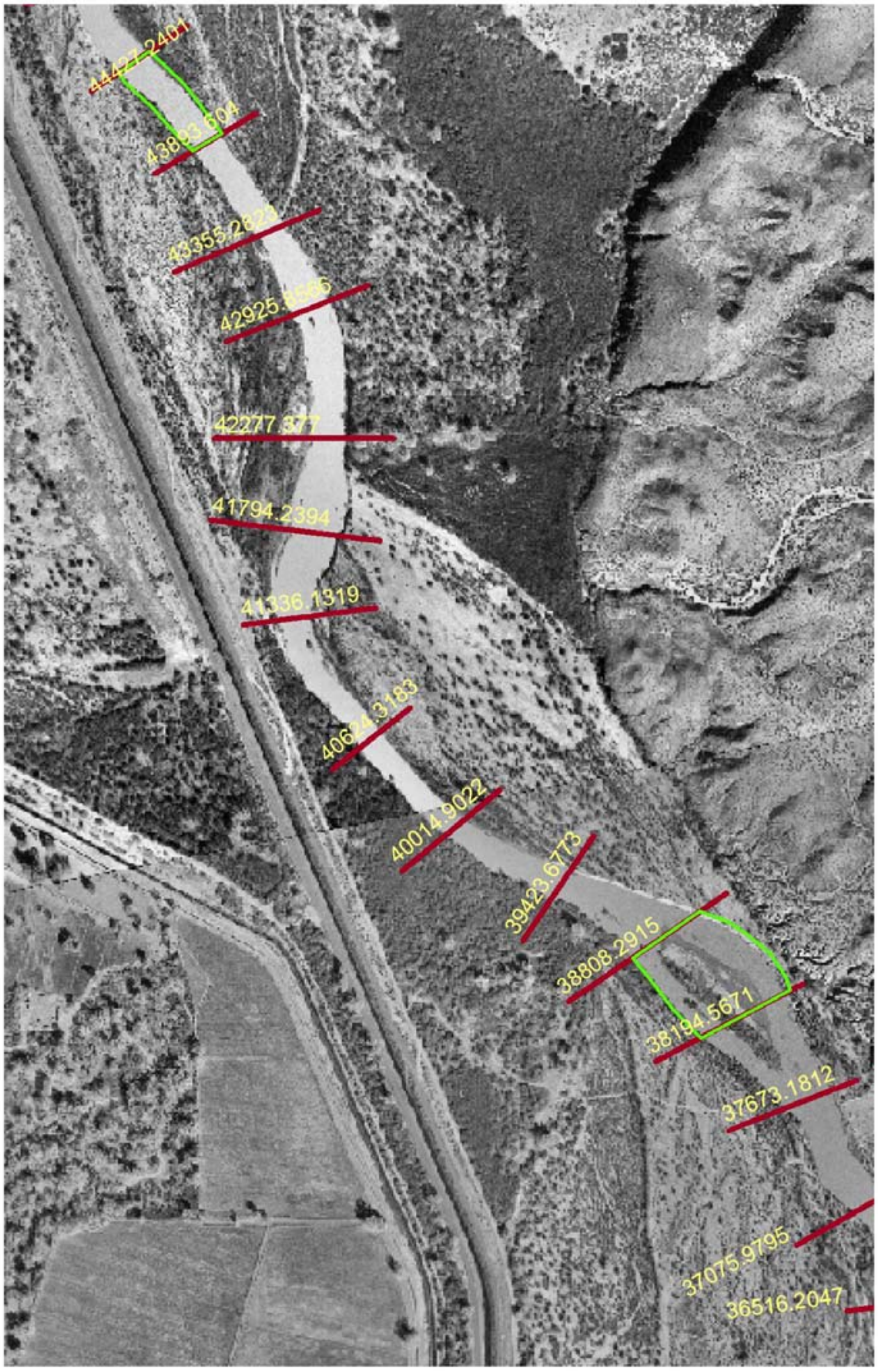
U.S. Bureau of Reclamation. 2002. Geomorphic Assessment of the Rio Grande San Acacia Reach (Draft). unpublished report, Albuquerque Area Office, Technical Service Division, Albuquerque, NM.

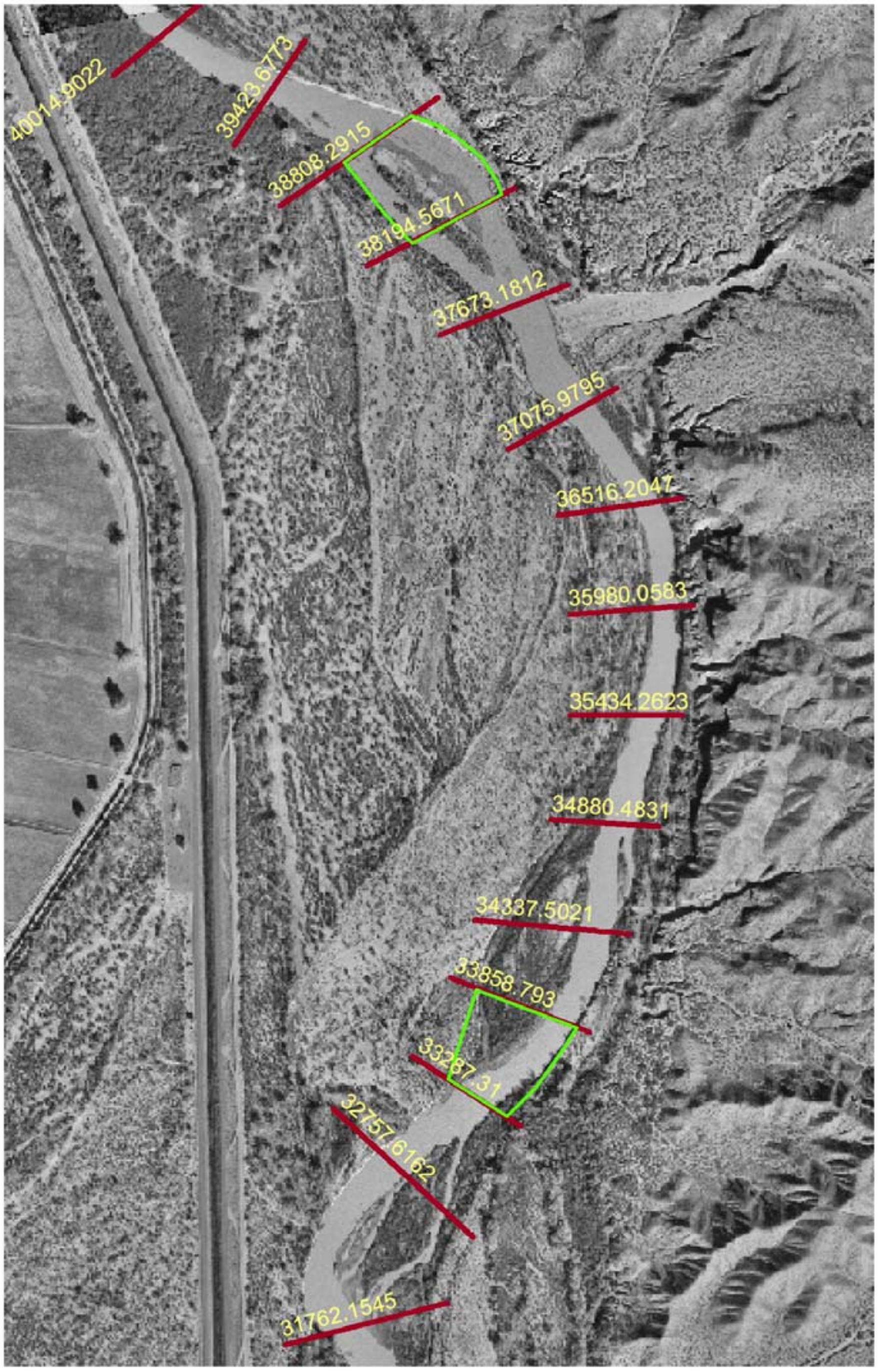
Yang, C. T. 1973. Incipient Motion and Suspended Sediment Transport. Journal of the Hydraulics Division, ASCE, vol. 99, no. HY10, Proceedings Paper 10067.

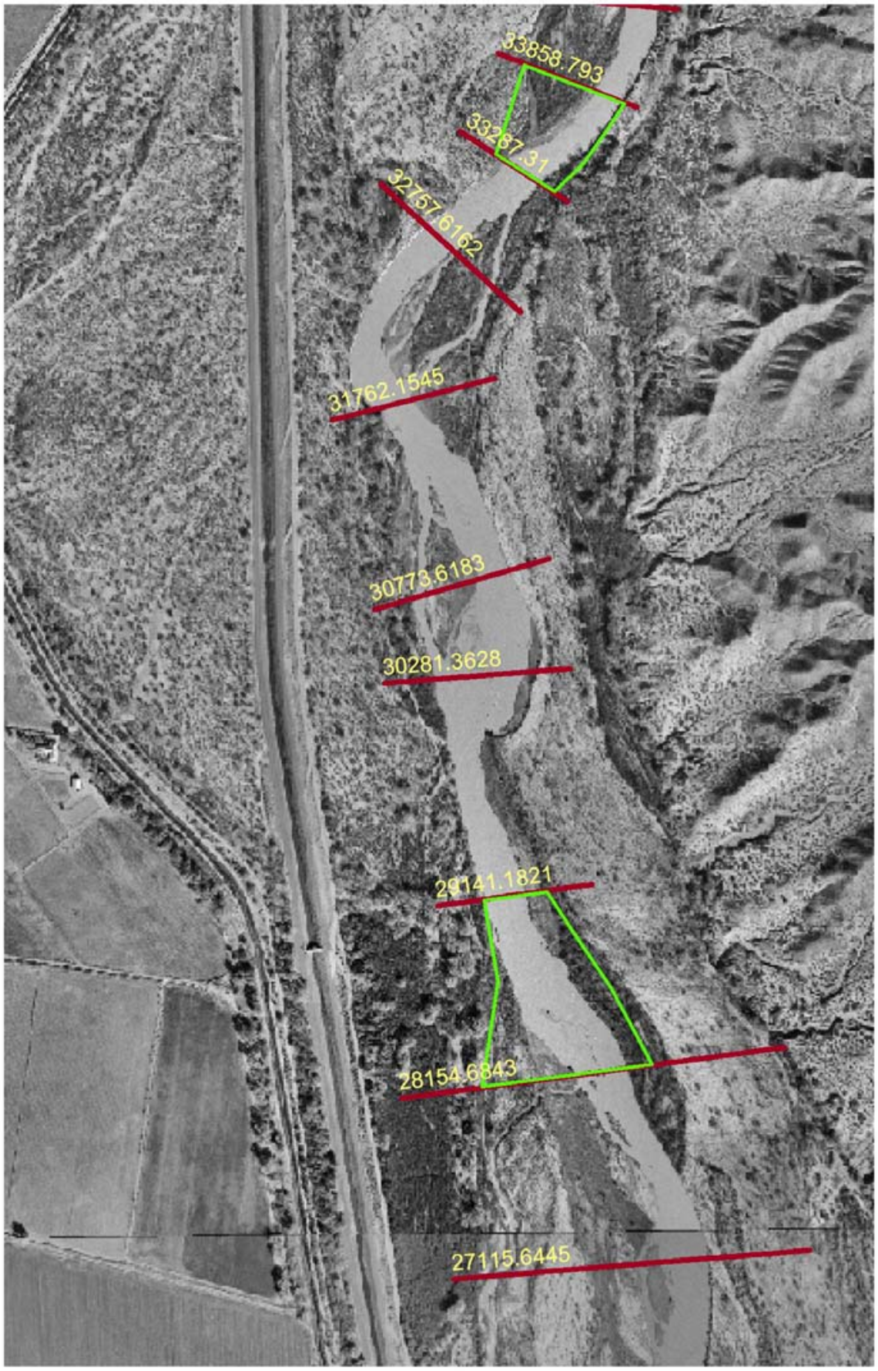
Appendix A: Cross Section and GRF Locations


55557.1355
55292.7475
55958.2224
56482.4819
56915.0554
57339.1092
54877.2807
54260.8262
53666.7891
53106.9982
52501.2123
52061.845
51547.6802
51278.7226
50922.6131
50426.435
49788.1351
49152.4135

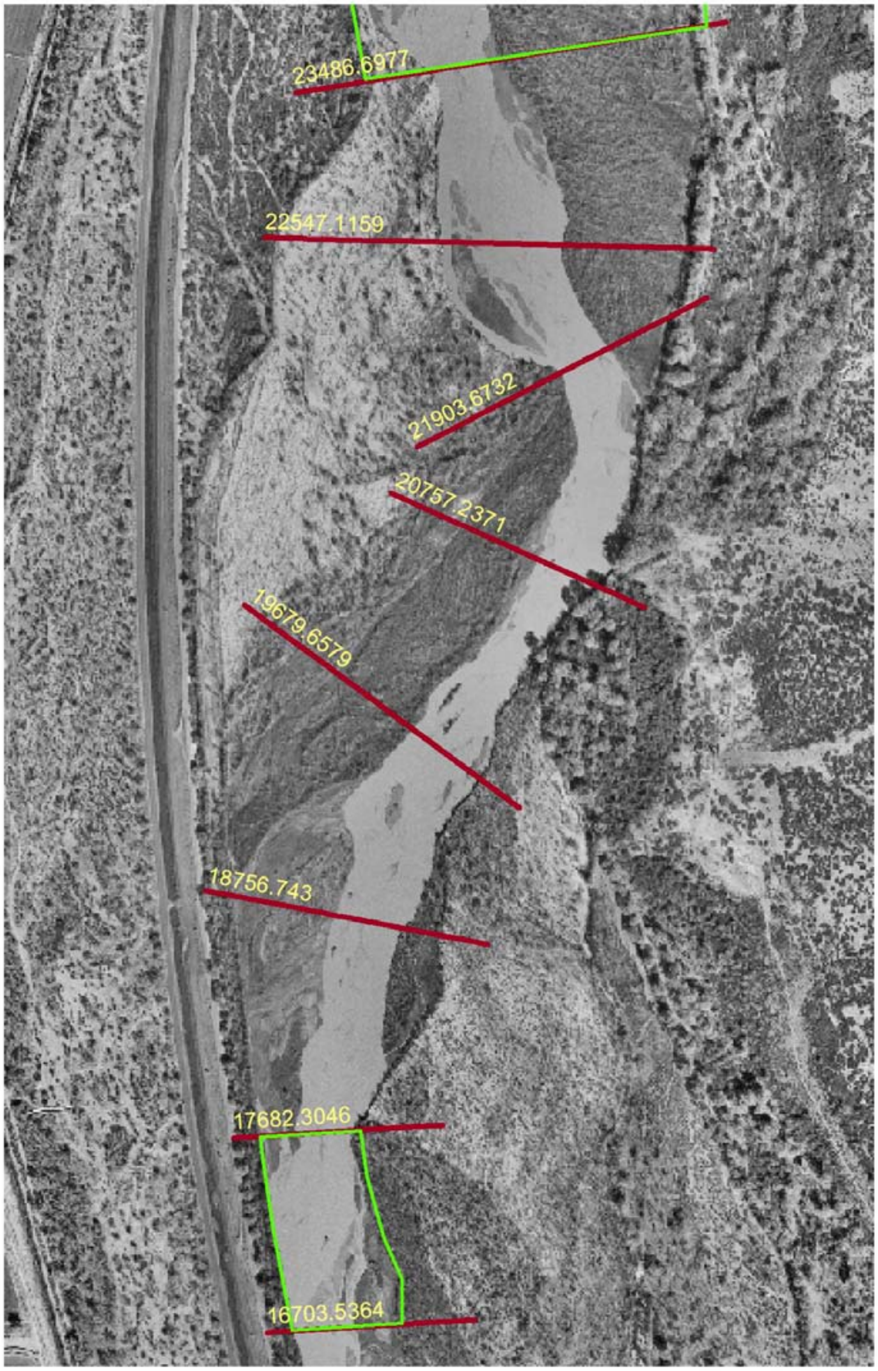

49786.1351
49152.4136
48673.9026
48454.2053
47143.5651
46847.2346
46512.7858
45971.025
45375.9459
44827.1533
44427.2401
43883.604
43355.2823
42925.8566
42277.377

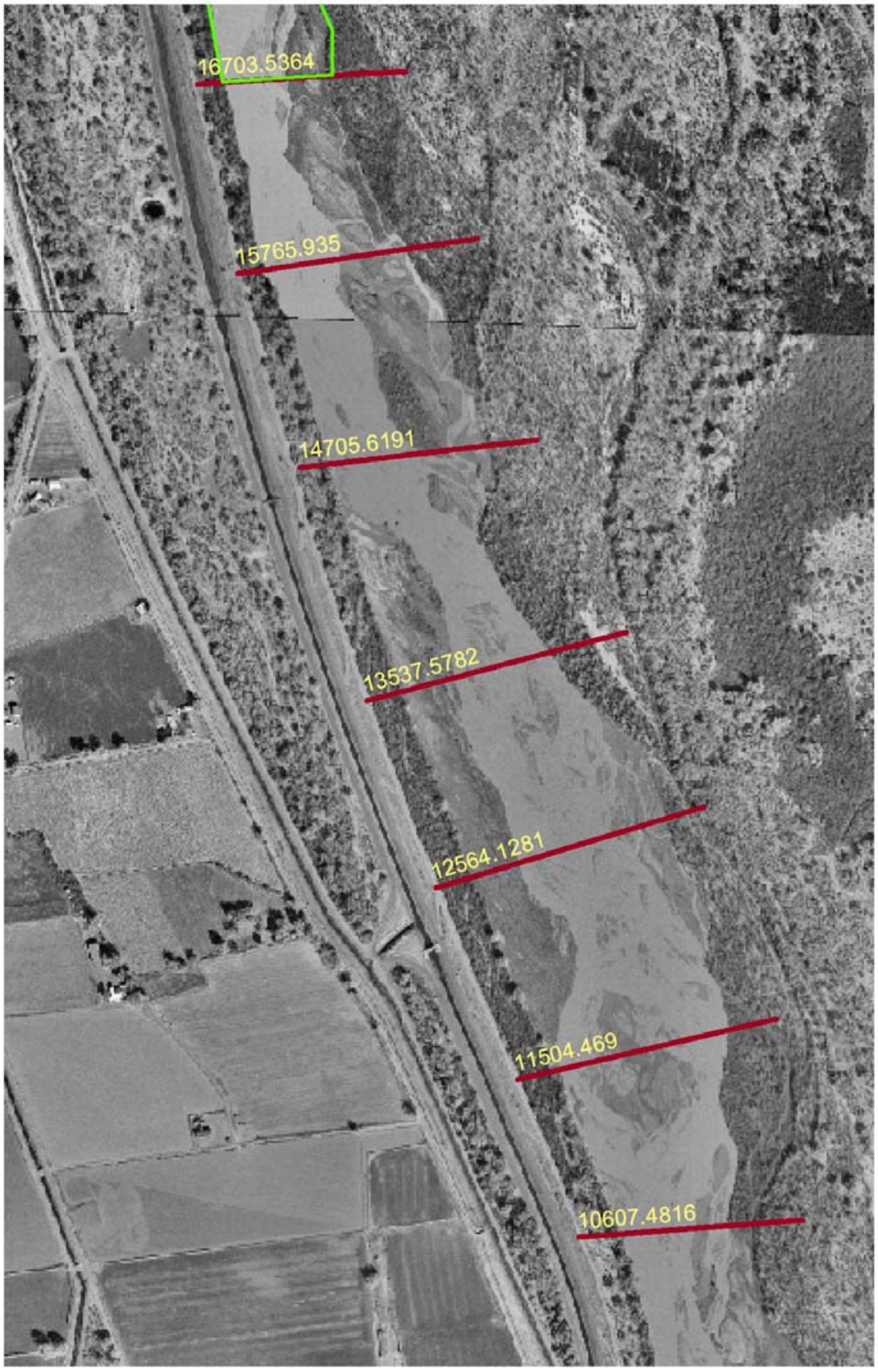

44427.2401
43893.604
43355.2823
42925.8566
42277.377
41794.2394
41336.1319
40624.3183
40014.9022
39423.6773
38808.2915
38194.5671
37673.1812
37075.9795
36516.2047

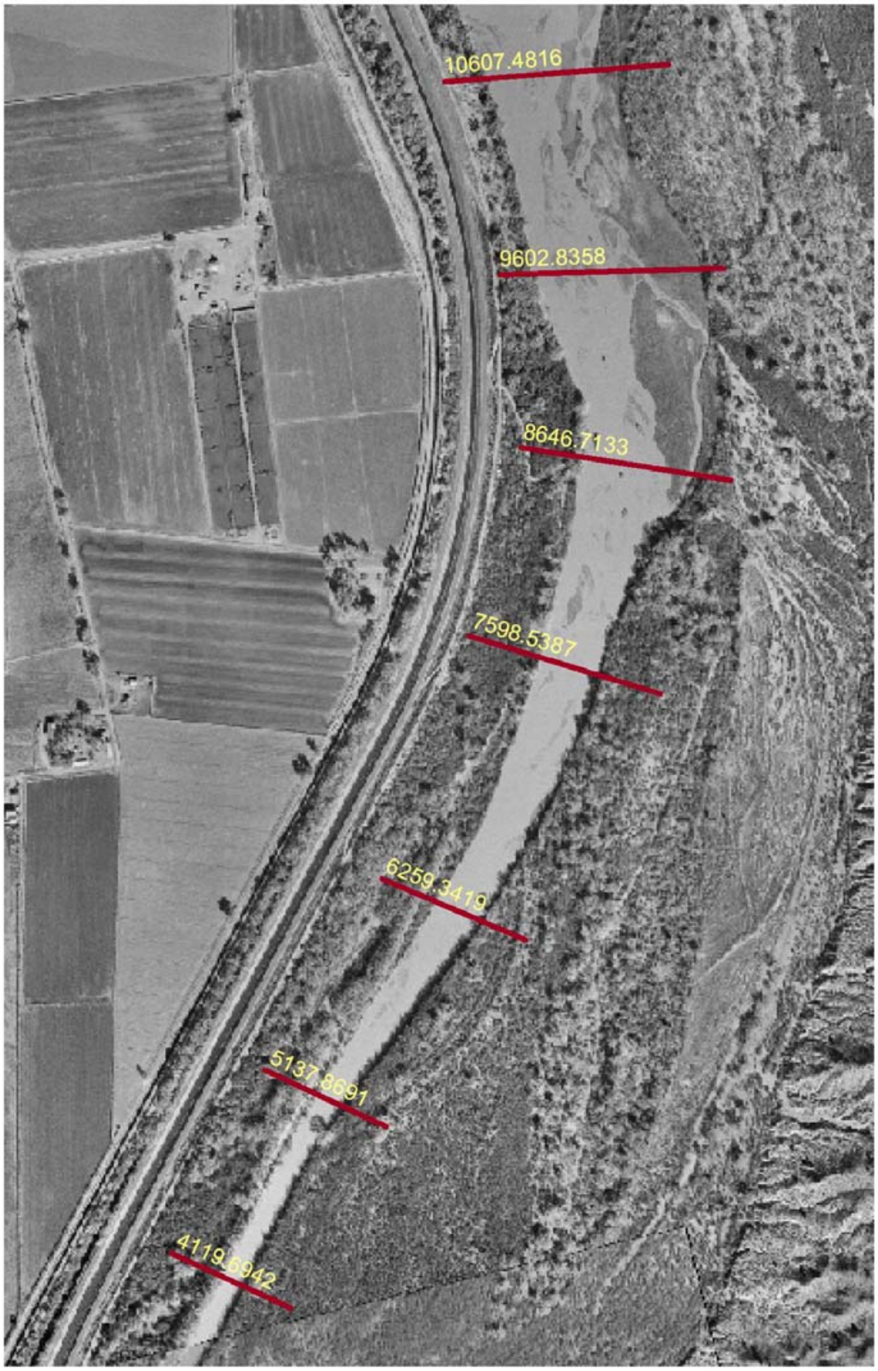

40014.9022
39423.6773
38808.2915
38194.5671
37673.1812
37075.9795
36516.2047
35980.0583
35434.2623
34880.4831
34337.5021
33858.793
33287.31
32757.6162
31762.1545

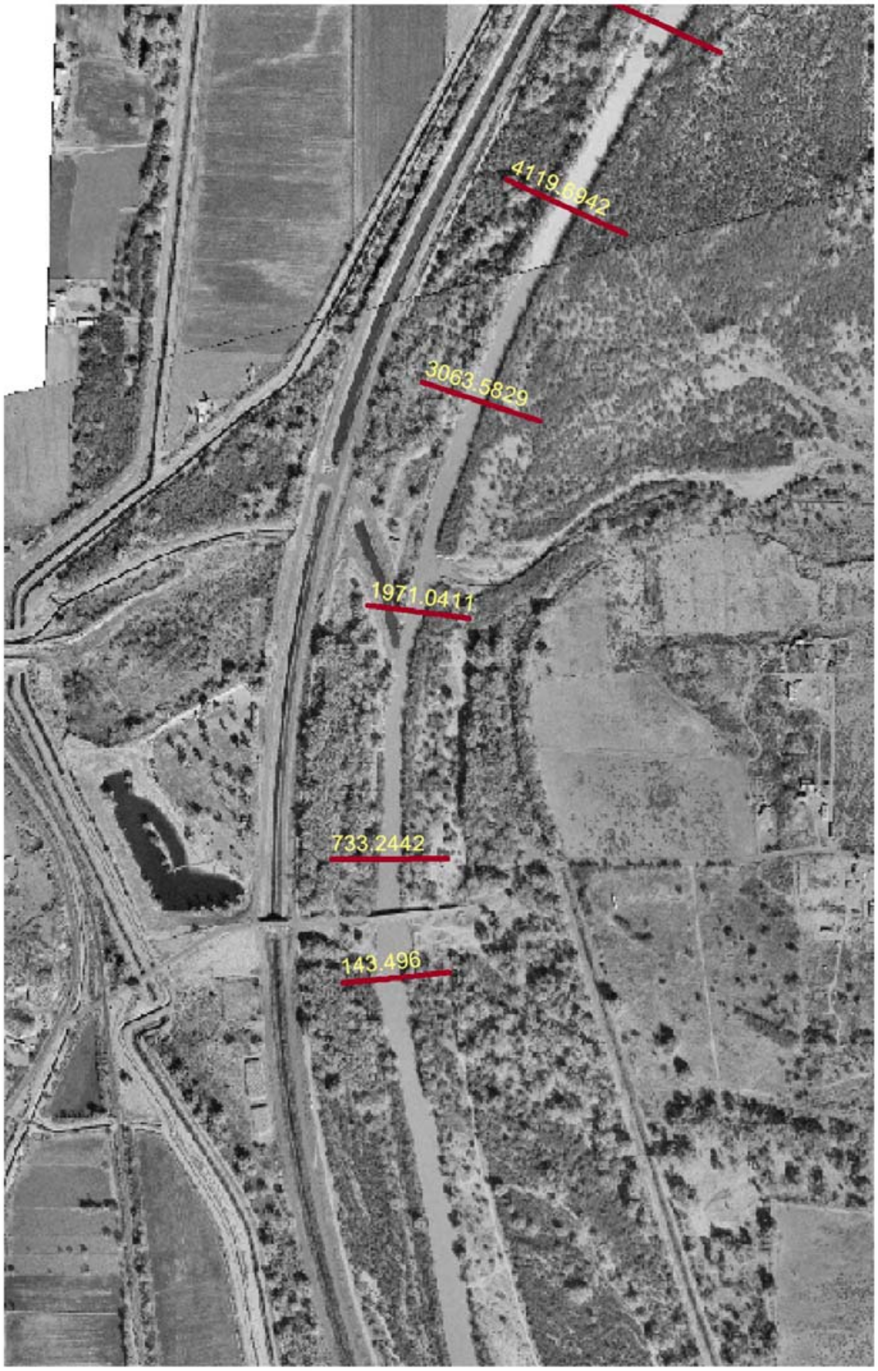

33858.793
33287.31
32757.6162
31762.1545
30773.6183
30281.3628
29141.1821
28154.6843
27115.6445


29141.1821
28154.6843
27115.6445
26233.0922
25320.307
24291.4923
23486.6977
22547.1159


23486.6977
22547.1159
21903.6732
20757.2371
19679.6579
18756.743
17682.3046
16703.5364


16703.5364
15765.935
14705.6191
13537.5782
12564.1281
11504.469
10607.4816


10607.4816
9602.8358
8646.7133
7598.5387
6259.3419
5137.8691
4119.6942


4119.6942
3063.5829
1971.0411
733.2442
143.496