RECOMMENDATIONS REGARDING
BANK PROTECTION, UTILITY CROSSINGS,
AND MAINTENANCE ANTICIPATED
FOR CHANNELIZATION BETWEEN
I-10 AND THOMAS ROAD

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RECOMMENDATIONS REGARDING BANK PROTECTION, UTILITY CROSSINGS, AND MAINTENANCE ANTICIPATED FOR CHANNELIZATION BETWEEN I-10 AND THOMAS ROAD

Submitted To

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EXECUTIVE SUMMARY

The Flood Control District of Maricopa County has contracted Simons, Li & Associates, Inc. (SLA) to conduct a system analysis of the Agua Fria River from its confluence with the New River to its confluence with the Gila River. The system analysis included an assessment of existing conditions, which were documented in the report entitled "Hydraulic and Geomorphic Analysis of the Agua Fria," and an assessment of proposed flood-control projects between Camelback and Buckeye Roads, which were documented in the report entitled "System Analysis and Conceptual Design of Channelization in the Agua Fria River." SLA was contracted to discuss recommendations regarding bank protection, utility crossings, and maintenance anticipated for channelization between I-10 and Thomas Road, which is documented in this report. SLA was also contracted to provide design plans and specifications for a flood-control project between Camelback Road and Thomas Road.

Included in this report are discussions concerning levees and protection of levees between I-10 and Thomas Road, structural measures necessary in the channelized portion of the river, analysis of utility crossings and their present adequacy, suggested gravel mining limitations for instream and flood plain operations between Camelback and Buckeye Roads, and inspection programs necessary to periodically identify levee problems.

Levees

Suggested channelization in the Agua Fria between Thomas Road and I-10 includes a trapazoidal channel with an 1,100 foot bottom width between Thomas and McDowell Roads transitioning to a 1,410 foot bottom width at I-10. The recommended side slopes of the channel are 3:1 if protected with riprap and 1:1 if protected with soil cement.

Bank protection is necessary to provide a stable channel between Thomas Road and I-10. Average velocities in the reach for the 10- and 100-year floods are 6.7 and 10.4 feet per second, respectively. For sandy type material found on the banks and with velocities of this magnitude, the banks will need protection.

Toe-down depths for bank protection of eight feet below the equilibrium bed profile are necessary to prevent undermining of the levees due to (1) the formation of a low-flow thalweg, (2) the bed forms on the channel bottom, and (3) impingement scour caused by meandering of the low-flow thalweg. The toe down depth around the west (outside) bend of the Agua Fria from 1,200 feet upstream of the I-10 to 2,000 feet below I-10 should be fifteen feet below the equilibrium bed profile to account for the increased flow velocity and scour potential.

Structural Measures

Recommended structural measures in the channel between Thomas Road and I-10 include two four-foot drop structures located 2,200 feet upstream of the proposed McDowell Road Bridge and 200 feet downstream of Thomas Road, gabion protection of transmission towers located within channel banks, riprap blanket protection of I-10 bridge piers, and integration of the I-10 collector channel drainage into the Agua Fria.

Utility Crossings

The local scour around supports during the 100-year flood would undermine the three Salt River Project and five Tucson Electric Power Company transmission towers located within the proposed channel banks between Thomas Road and I-10. Gabion protection of these towers is needed.

Two pipelines cross the Agua Fria at Thomas Road. The city of Avondale has a 16-inch water line and the Southern Pacific Pipeline, Inc. has a six-inch high-pressure gas line that cross at Thomas Road. Approximately 600 feet of the water line needs to be lowered near the west bank. It is suggested that a minimum ten feet of soil cover be provided over the top of the pipe. The depth of burial of the gas line will have to be field verified before comments about its adequacy can be made. Special measures may be needed to be taken beneath the levees to protect the lines during construction.

Gravel Mining

No instream gravel mining is recommended between Camelback and Buckeye Roads, unless it is for the removal of bars or islands that may develop.

Between Camelback and Indian School Road Bridge (ISRB) floodplain gravel pits should be limited to 25 feet in depth and located 500 feet from channelization, dikes and levees. This assumes periodic maintenance is done to prevent lateral migration of the channel. It may be possible to increase the depth of pits between Camelback and ISRB if certain management practices are followed such as construction of berms, continuous backfilling of pits, and controlled flooding schemes for filling the pits without headcuts developing.

Between ISRB and Thomas Road, a settlement was reached between gravel miners and the Maricopa County Attorney's office to provide a 50-foot buffer zone between the back of the levee and gravel pits. It is recommended that a berm be placed between the levee and gravel pit to reduce headcut potential if floods overtop the levees.

Between Thomas and Buckeye Roads it is recommended that floodplain gravel pits have a 200-foot buffer zone behind levees, and that a 500-foot buffer zone be provided near bridge crossings. Only a 200 foot buffer is necessary because the levees contain the 100-year flood, unlike the alternative between ISRB and Camelback Road where the water flows uncontained until it funnels through the bridge.

Inspections

Periodic inspection of levees once every two months and after flood flows is necessary to assess if repairs are needed. The inspector should report if excessive vegetation is present, if rodent burrows are a problem and if vandalism or flood damages have occurred. The inspections should be documented and kept in files for future reference.

I. INTRODUCTION

To fulfill the requirements of Task 4 of contract number FCD 83-7; Simons, Li & Associates, Inc. (SLA) is presenting this report regarding recommendations of bank protection, utility crossings and maintenance anticipated for channelization between I-10 and Thomas Road. The bulk of the work for Task 4 was completed and documented in the report "System Analysis and Conceptual Design of Channelization of the Agua Fria." The above referenced report should be consulted before reading this report.

1.1 Scope of Work

To accomplish the objectives of Work Task 4 the following scope of work was completed.

1. Recommended dike protection to contain the 100-year flood in the Agua Fria between I-10 and Thomas Road, including toe-down depths, side slopes, filter requirements if riprap protection is used, and levee shapes.

2. Recommended structures that were needed, including drop structure locations.

3. Estimated the expected maintenance intervals with and without the protection of dikes. This involved examining the lateral migration tendencies of the banks without protection and estimating costs of maintaining them in a desirable fashion.

4. Recommended inspection programs for the dike system. Inspection intervals pertinent to the channel and dikes for vegetation control, rodent control, levee repair after floods, and vandalism were recommended.

5. Determined local scour at all transmission towers within the proposed channelization.

6. Determined if the burial of the water and gas lines at Thomas Road was adequate.

7. Recommended sand and gravel mining limitations within the channel banks and on the flood plain between Camelback and Buckeye Roads.

8. Documented all findings in this draft report.

1.2 Sources of Information

The bulk of the information used to write this report comes from the two reports entitled "System Analysis and Conceptual Design of Channelization in the Agua Fria River" and "Hydraulic and Geomorphic Analysis of the Agua Fria River" Both were prepared by SLA for the Flood Control District. These reports should be consulted for specific sources of information.

II. LEVEES

The suggested channel bottom width in the Agua Fria from Thomas Road to the proposed McDowell Road Bridge is 1,100 feet, transitioning to 1,410 feet at the I-10 bridge. Levees are necessary to contain flood flows within the proposed channelization.

Levee heights were sized to contain the 100-year discharge plus the freeboard heights required by the Federal Emergency Management Agency (FEMA). Figures 2.1 and 2.2 show levee heights for the east and west banks, respectively, between Thomas Road and I-10.

A minimum three feet of freeboard above the 100-year water surface was maintained throughout, except at bridge crossings and around bends where the sum of one-half the bed form and superelevation is greater than three feet.

At the proposed McDowell Road Bridge and I-10 bridge crossings the freeboard height was extended to four feet above the 100-year water surface. On the west bank of the Agua Fria from approximately 1,200 feet upstream of I-10 bridge to 2,000 feet downstream of the I-10 bridge a severe bend exists. The levee on the west bank was extended eight feet above the 100-year water-surface elevation in this reach due to the sum of the superelevation of flow and one-half the antidune height being eight feet.

Suggested channel shape is trapezoidal with levee side slopes of 3:1 if protected with riprap and 1:1 if protected with soil cement. A crown width of fifteen feet for the levees is recommended to allow vehicles to travel on the levees.

2.1 Bank Protection

The average flow velocity for the 10-year and 100-year discharges of 31,000 cfs and 95,000 cfs, respectively, are 6.7 and 10.4 feet per second. For sandy material found on the banks and with velocities of this magnitude, the banks will not be stable without protection. Two alternative forms of bank protection are recommended, including riprap and soil cement.

Riprap was sized using the Factor of Safety Method presented in Simons and Senturk (1977). For velocities encountered in the reach between Thomas Road and I-10 riprap of two-foot thickness with the following gradation will be adequate except around the bend on the west bank near I-10.

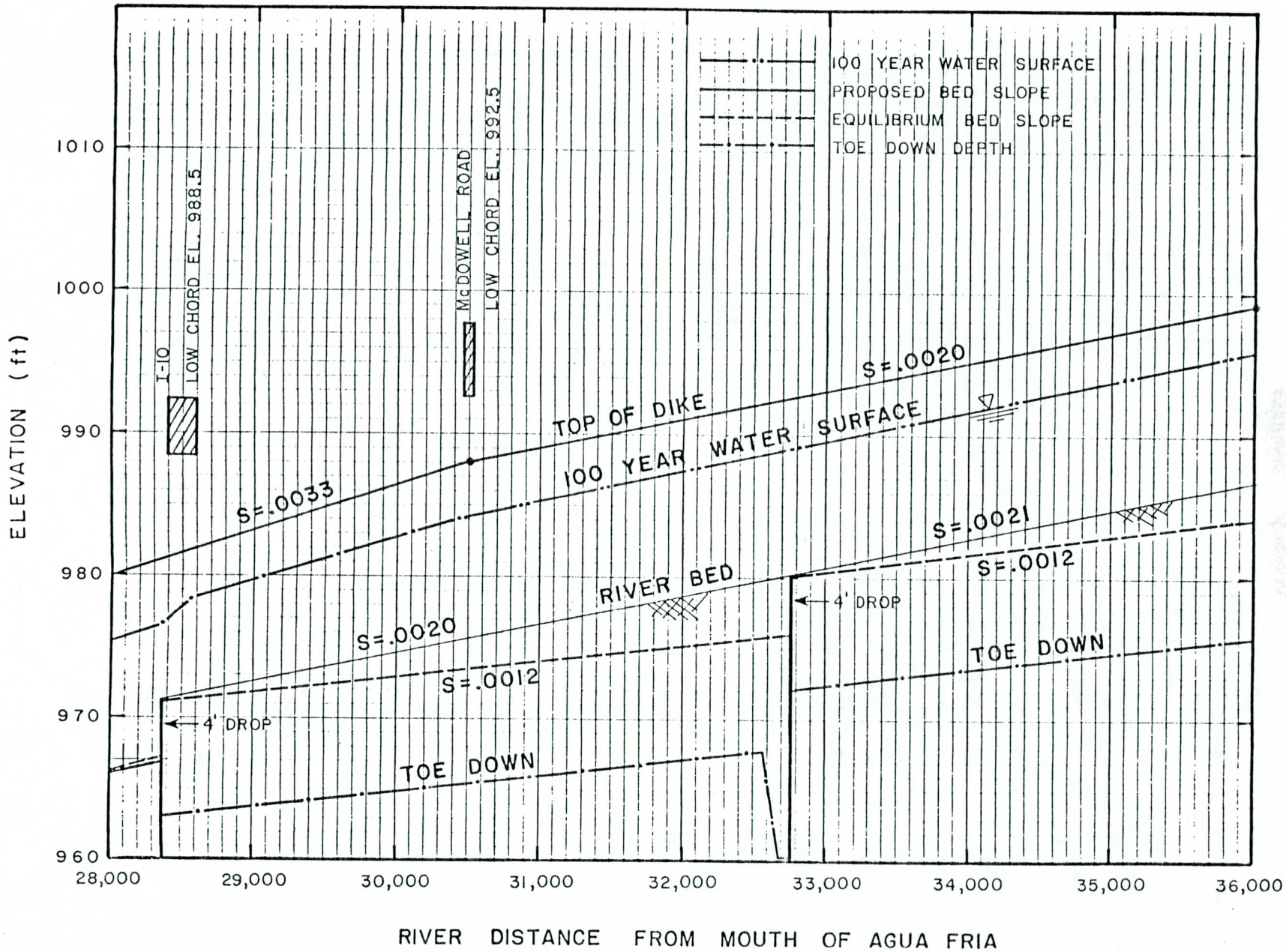

Figure 2.1. Proposed bed profile, equilibrium bed profile, levee heights and toe down depths between I-10 and Thomas Road for east bank.

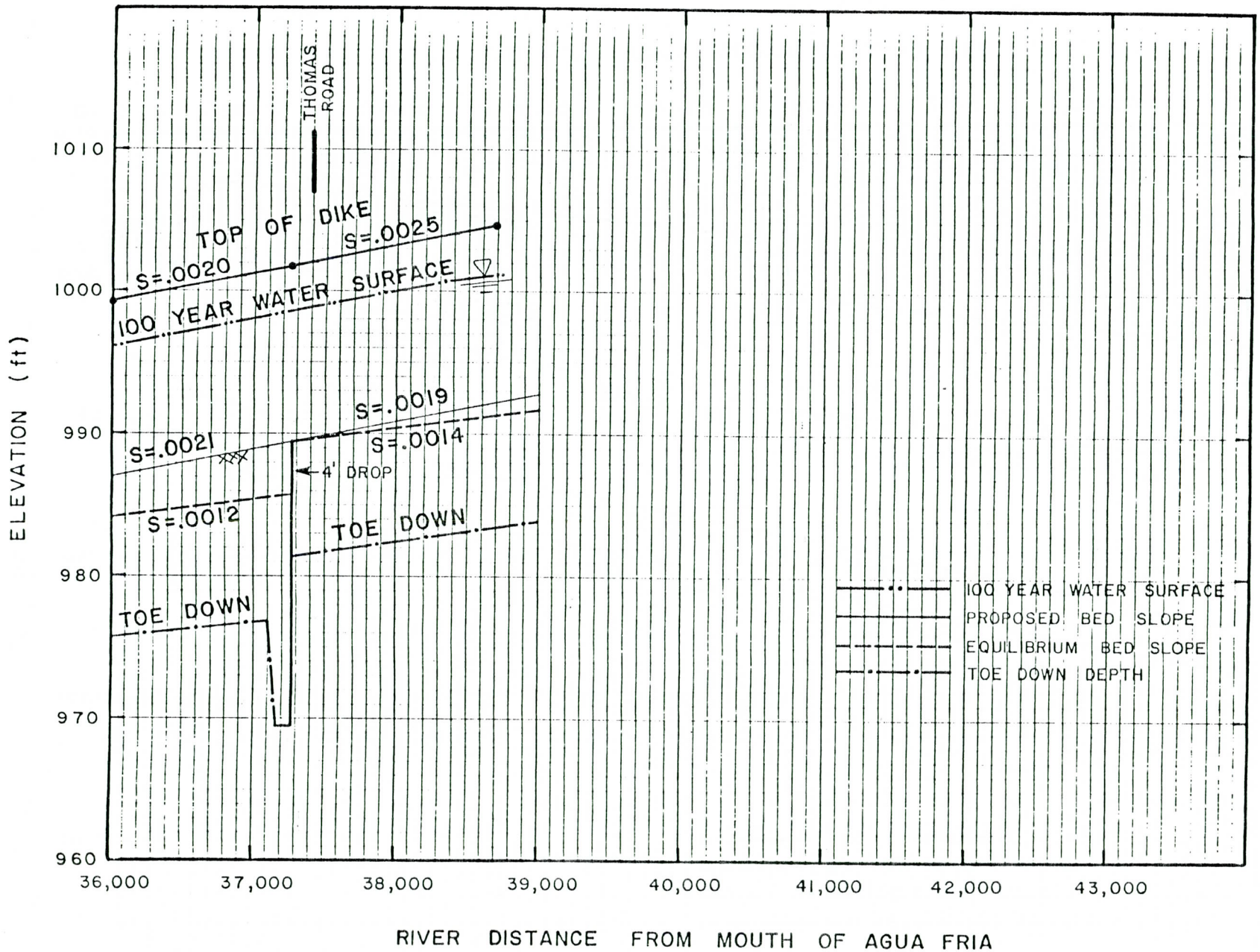

Figure 2.1. (Continued)

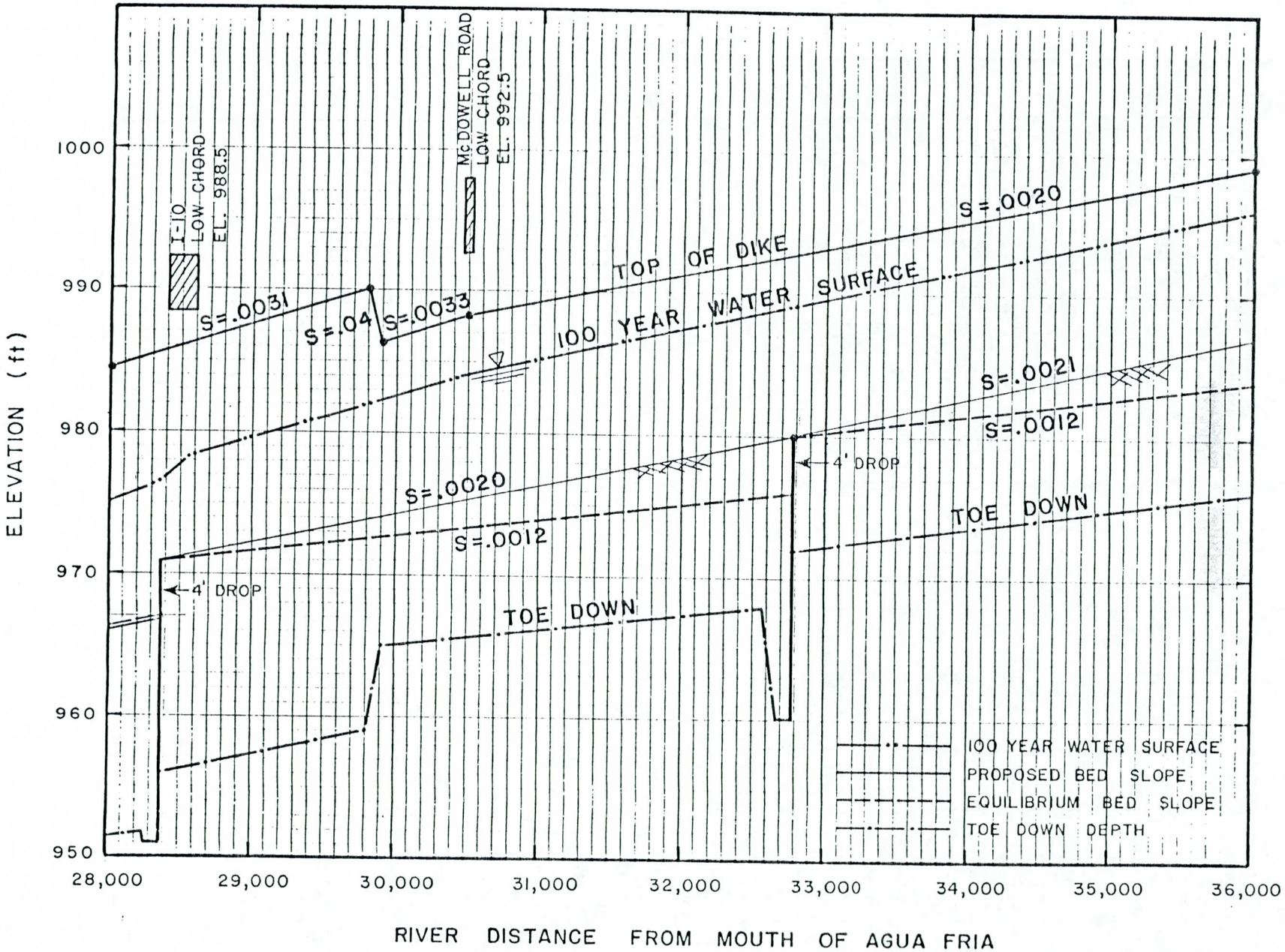

Figure 2.2. Proposed bed profile, equilibrium bed profile, levee heights and toe down depths between I-10 and Thomas Road for west bank.

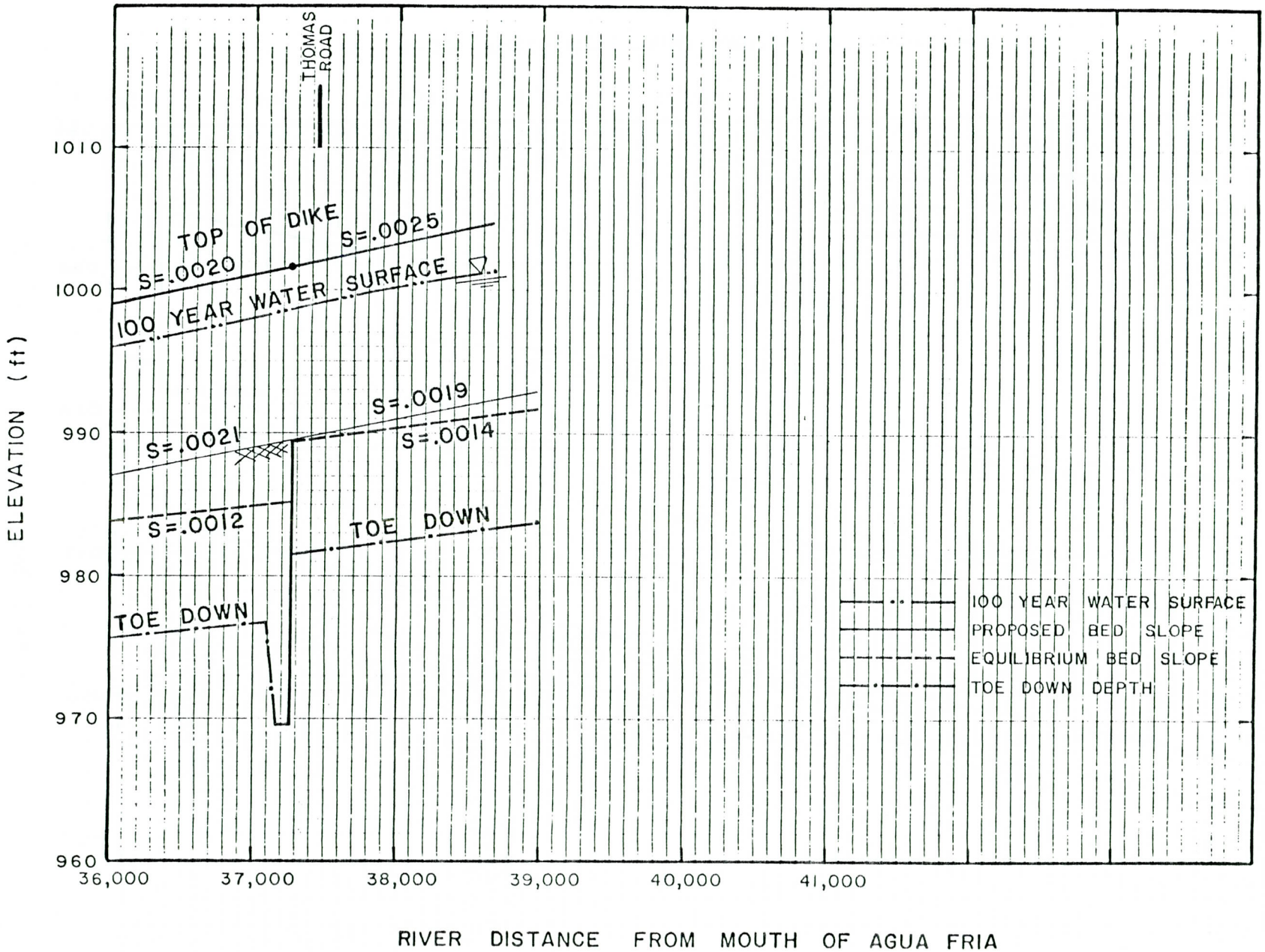

Figure 2.2. (Continued)

Rock Size	Percent Finer
24"	100
15"	50 - 70
7"	15 - 30
3"	0 - 5

For velocities encountered around the outside bend of the channel near I-10, riprap 4.67 feet thick with a D_{50} size of 28 inches and a D_{100} size of 56 inches is necessary.

A filter is recommended to prevent piping of bank material through the riprap. Filter fabric with three to six inches of parent material placed on top of the fabric is needed. Typar 3401 by Dupont, or equivalent, will be adequate.

Soil-cement bank protection is suggested as an alternative to riprap. Soil cement placed in lifts of four to eight inches, nine feet wide on 1:1 slopes is recommended. The volume of soil cement per linear foot of levee is not that much greater than riprap, even though it is nine feet thick because it can be placed on 1:1 side slopes. No filter is necessary for soil cement. The soil cement design shall be such that it has a compressive strength of 750 psi after seven days plus two percent additional cement added for erosion control. The initial mix design should be determined by the project engineer in the field for soils found within the channel reach.

2.2 Toe Down Protection

The levees shall be toed down beneath the proposed channel grade to a depth greater than the sum of the components of degradation, which are: general aggradation/degradation response of the bed, low-flow thalweg depth, one-half the bed form height, and any impingement scour of meandering low-flow thalwegs. Figures 2.1 and 2.2 show the proposed toe-down depths for the east and west banks, respectively. Toe-down depths increase significantly around the bend on the west bank of the river near I-10 because of the increased flow velocities and scour potential. Toe-down protection is extended approximately twenty feet below the channel bed on the downstream end of grade control structures to provide local scour protection.

2.3 Lateral Migration

If the channel banks are not protected between Thomas Road and I-10 some lateral migration will occur. Presently the 100-year flood plain averages 5,000 feet. By narrowing the channel to 1,100 feet, average velocities increase in the 100-year flood from 5.7 to 10.4 feet/second, and therefore sediment transport rates increase. Material from bed and banks will be removed as a result of the increased flow velocities, and destruction of the banks will result.

There are approximately 875 acres of land within the 100-year floodplain between Thomas Road and I-10. For proposed channelization the channel right-of-way is 280 acres. If the banks are not be protected, it is recommended that a flow easement be purchased to the present 100-year flood plain to limit the liability of the Flood Control District against future damage claims of property owners behind the levees when the unprotected banks fail.

It is expected that annual maintenance of levees will be rather large. To evaluate annual maintenance costs for unprotected levees a weighted probability cost analysis was used. By associating percent damages to the levees with floods of various return periods, the cost of maintaining the levees in their original design capacities was estimated. For this analysis, based on the velocities associated with each of the floods, it was assumed that the floods with these return frequencies caused the following damages to the levees:

Flood Return Interval	Levee Damage
2 Year	10%
10 Year	25%
25 Year	50%
50 Year	75%
100 Year	90%

These damages are relatively high, but considering the fact that the unprotected levees cannot withstand velocities in excess of four or five feet per second , they are realistic. A 100-year flood would nearly destroy an unprotected levee system.

By incrementally weighting the probability of each flood occuring each year and multiplying it with the damage each event will do the levees, and then multiplying this number by the estimated cost of replacing the levees,

an annual maintenance cost was estimated. For the reach between Thomas Road and I-10, it was estimated the fill for the levees will cost $1,004,000. This is based on fill compaction, and benching of fill costing $5.00 per cubic yard. This is considerably higher than the original common fill cost estimate, because the total quantities associated with the repair are much less and consequently more expensive per cubic yard. Thus, the expected annual maintenance cost for perserving the levees in their original shape is approximately $81,825.

	100-Year	50-Year	25-Year	10-Year	2-Year

$$\text{Annual Cost} = \$1{,}004{,}000\ [(.01)(.9) + (.01)(.75)+(.02)(.5)+(.06)(.25)+(.4)(.1)]$$

The average annual cost of maintaining levees in their original shape, ($81,825), plus purchasing flow easements for the original 100-year flood plain ($2,975,000), more than offset the cost of bank protection between Thomas Road and I-10 ($2,958,365), and therefore bank protection is recommended. With bank protection no lateral migration is anticipated, although some bed degradation may result.

An analysis to evaluate the average annual aggradation/degradation response of the channel bed considering bank protection was performed on all channelized reaches to determine if sediment deposition would reduce the flood carrying capacity of the channel. The procedure involved:

1. Divide the Agua Fria into reaches with similar hydraulic and sediment transport characteristics.

2. Compute the average hydraulic properties for each reach, such as flow velocity, top width and depth for a range of water discharges.

3. Establish sediment rating curves for each reach.

4. Use sediment rating curves to establish sediment transport rates for floods with return intervals of 10, 25, 50, and 100 years.

5. Using a weighted incremental probability method, determine annual sediment transport rates for each reach.

6. Compare the average annual sediment transport rate of each reach with that of the upstream supply reach to determine net deposition or degradation rates per year.

The Agua Fria River was divided into seven reaches as defined in the report "System Analysis and Conceptual Design of Channelization in the Agua Fria River," (SLA, October 1983). They are:

Reach 1	Camelback Road to 2,200' upstream of ISRB
Reach 2	2,200' upstream of ISRB to ISRB
Reach 3	ISRB to RID flume
Reach 4	RID flume to Thomas Road
Reach 5	Thomas Road to I-10
Reach 6	I-10 to Van Buren
Reach 7	Van Buren to Buckeye Road

Average hydraulic properties for each reach were established by using the Army Corps of Engineers HEC-II backwater profile program. Average flow velocity, depth, and top width were established for a range of water discharges in each reach and used in deriving sediment rating curves.

The Meyer-Peter Muller (MPM) bed-load equation in combination with Einstein's integration of the suspended bed material was used to determine the sediment transport capacity of each reach. The sediment transport capacity was correlated with the water discharge to establish rating curves of the following form:

$$Q_s = aQ^b \qquad (1)$$

where Q_s is the sediment transport capacity in cfs, Q is the water discharge in cfs, and a and b are the best fit coefficient and exponent. Table 2.1 lists the coefficients and exponents a and b for each of the seven reaches.

Sediment transport rates for the 10-, 25-, 50-, and 100-year floods were determined by applying Equation 1 to the discretized flood hydrographs. The average annual sediment yield for each reach was then computed using the weighted incremental probability of occurence of floods.

$$Q_{s_{annual}} = (.01)\,(Q_s)_{100} + (.01)(Q_s)_{50} + (.02)(Q_s)_{25} + (.06)(Q_s)_{10} \qquad (2)$$

Table 2.1. Coefficients and exponents of sediment rating curves for each reach of the Agua Fria River.

Reach No.	a	b
Upstream Supply	1.223×10^{-5}	1.545
1	1.102×10^{-9}	2.535
2	1.170×10^{-7}	2.155
3	1.751×10^{-7}	2.046
4	4.643×10^{-7}	1.928
5	2.900×10^{-6}	1.741
6	1.762 X 10-5	1.558
7	5.611×10^{-7}	1.827

Supply Camelback to the confluence with New River
Reach 1 2,200 ft. upstream of ISRB to Camelback Road.
Reach 2 ISRB to 12,200 ft. upstream of ISRB
Reach 3 RID flume to ISRB
Reach 4 Thomas Road to RID flume
Reach 5 I-10 to Thomas Road
Reach 6 Van Buren to I-10
Reach 7 Buckeye to Van Buren

where Q_s is the average annual sediment yield (ft^3) and the 100-, 50-, 25-, and 10-year subscripts are for floods with these respective return intervals.

Table 2.2 summarizes average annual sediment yields for each reach and compares the yields with the supply reach to determine net aggradation/degradation response. All reaches display net degradation except reach 7, which shows a very slight aggradation response. The degradation response should continue until an armor control or equilibrium condition develops. Therefore, no major channel excavations are expected after channelization. The channel, however, should be monitored for any development of bars or islands, and any bars or islands that develop should be removed.

Table 2.2. Sediment transport rates for channelization in the Aqua Fria River.

Reach No.	Sediment Transport Rate (ft^3)	Degradation/ Aggradation (ft^3)	Average Depth of* Degradation/Aggradation (ft)
Supply	1,202,000		
1	3,597,000	-2,395,000	-0.4
2	6,672,000	-5,470,000	-1.6
3	3,161,000	-1,959,000	-0.7
4	2,247,000	-1,225,000	-0.3
5	2,157,000	- 955,000	-0.1
6	1,979,000	- 777,000	-0.2
7	1,201,000	181,000	<0.1

Supply Camelback Road to confluence with New River.
Reach 1 2,200 ft. upstream of ISRB to Camelback Road.
Reach 2 ISRB to 2,200 ft. upstream of ISRB.
Reach 3 RID flume to ISRB.
Reach 4 Thomas Road to RID flume.
Reach 5 I-10 to Thomas Road.
Reach 6 Van Buren to I-10.
Reach 7 Buckeye to Van Buren.

* The degradation/aggradation responses are computed for initial conditions, and as the bed responds toward equilibrium conditions the net degradation/aggradation tends toward zero. Therefore, this is just a measure of the direction in which each channel reach will respond.

III. STRUCTURAL MEASURES

Recommended structural measures in the Agua Fria between Thomas Road and I-10 include two drop structures, protection of transmission towers, riprap blanket protection of I-10 bridge piers, and integration of the I-10 pilot channel into the Agua Fria channelization.

Two four-foot drop structures are needed between Thomas Road and I-10. The proposed bed profile as shown in Figures 2.1 and 2.2 is 0.002 for this reach. The equilibrium bed profile in the reach is 0.0012. Thus there is the potential for approximately eight feet of degradation in this 8,700-foot reach.

The proposed drop structure locations are 2,200 feet upstream of the proposed McDowell Road bridge and 200 feet downstream of Thomas Road. A riprap blanket extending 20 feet upstream of the drop structures as well as across the entire width of the channel is recommended to stabilize the channel. The foundation of the drop structure should extend below the local scour hole on the downstream end of the drop as well as the toe down of the levees if a stilling basin or riprap blanket is not provided on the downstream side of the structure. The Schoklitsh*,Jaeger* or Veronese** methods can be used to evaluate the local scour on the downstream side of a drop structure.

The need for protection of transmission towers within the banks of the Agua Fria between Thomas Road and I-10 is discussed in Chapter 4. SLA is proposing an island with gabion protection of the sides extending the depth of local scour for transmission towers upstream of Thomas Road. Figure 3.1 shows a plan and elevation view of suggested protection measures. These measures are recommended for Tucson Electric Power and Salt River Project towers between Thomas Road and I-10.

I-10 bridge piers are buried approximately 23 feet below the proposed channel bed. A grade-control structure is suggested downstream of the bridge to control the general degradation in the area; however, the grade-control structure will not reduce the local scour near the bridge piers. Computed local scour depths for the 100-year discharge of 95,000 cfs, using Shen and

* (Simons and Sentruk, 1977)

** (Bureau of Reclamation, 1977)

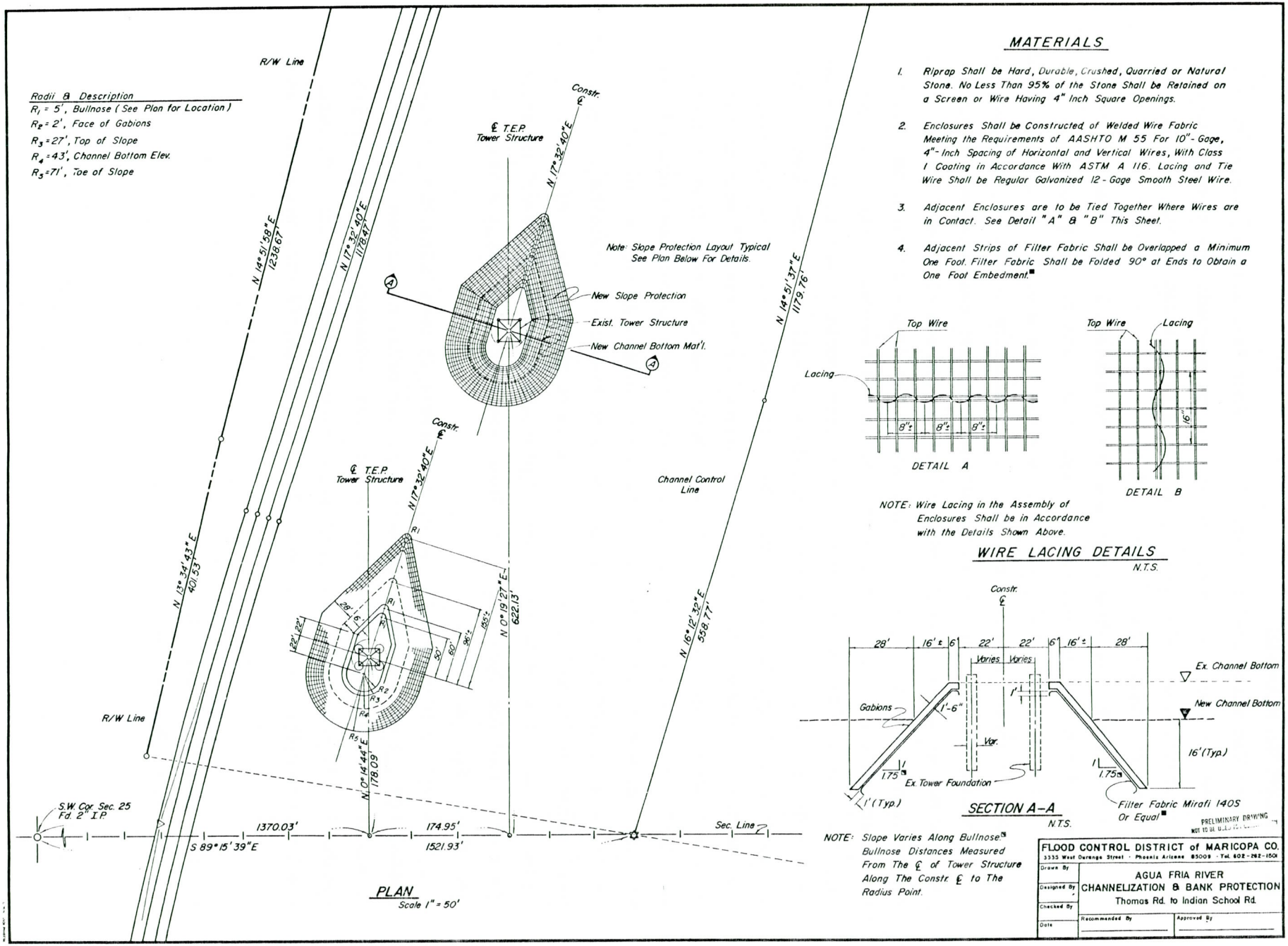

Figure 3.1. Gabion Protection of Transmission Towers.

Neil methodologies were 15.3 feet and 12.9 feet, respectively. The west bank of the I-10 bridge is located on the outside of a rather severe bend. Velocities will increase due to the bend, further accelerating the scour potential. Therefore, riprap blanket protection of I-10 bridge piers is recommended. A blanket extending thirty feet in all directions of the piers, 2.5 feet thick with the following gradation is recommended:

Rock Size	Percent Finer
24"	100
15"	50 - 70
7"	15 - 30
3"	0 - 5

A 12-inch gravel filter meeting the following criteria should be placed beneath the riprap.

$$\frac{D_{50}\ \text{(riprap)}}{D_{50}\ \text{(gravel filter)}} < 40 \qquad (3)$$

$$5 < \frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(gravel filter)}} < 40 \qquad (4)$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{85}\ \text{(gravel filter)}} < 5 \qquad (5)$$

Three alternatives were developed for integrating the I-10 collector channel drainage into the Agua Fria. These include: (1) leave a 200-foot opening between the spur dike north of I-10 on the east bank and proposed levee downstream of McDowell Road, (2) extend the collector channel 2,900 feet into the Agua Fria with levees high enough to contain the 100-year flood from the collector channel and Agua Fria, or (3) provide a siltation basin between the I-10 collector channel outlet and the Agua Fria with a depressed section in the levee on the east bank to allow overflow of large discharges from the collector channel into the Agua Fria. For a further discussion of these alternatives please see the report "System Analysis and Conceptual Design of Channelization in the Agua Fria River."

IV. UTILITIES

With the suggested channelization several transmission towers will be inside the levees between Thomas Road and I-10. Both the Salt River Project and Tucson Electric Power Company have towers that will be subjected to local scour.

Also, several pipeline crossings exist within the levees. The city of Avondale has a 16-inch water line crossing the Agua Fria at Thomas Road. The Southern Pacific Pipeline, Inc. has a six-inch high pressure gas line crossing the Agua Fria at Thomas Road.

The present adequacy of transmission towers and pipeline crossings is discussed in the following sections.

4.1 Transmission Towers

The Salt River Project has a 230 KV line that will have three transmission towers within proposed levees between Thomas Road and I-10. Table 4.1 summarizes for each tower the obstruction width of each footing, the 100-year flow velocity and depth near the footing, the elevation of the bottom of the footing, the 100-year local scour as computed using Shen's and Neil's equations, the adopted local scour, the approximate ground elevation in the vicinity of the tower, and the expected elevation after scour. Plates 2 and 3 in the report "System Analysis and Conceptual Design of the Agua Fria River" show all utility locations. All the towers will require some type of protection, as the scour depths combined with the channelization will undermine all towers.

Tucson Electric Power Company has a 345 KV line that will have five transmission towers within the levees between Thomas Road and I-10. Table 4.2 summarizes local scour depths at the towers, all of which will require protection. Protection measures for the transmission towers were discussed in Chapter III.

4.2 Pipeline Crossings

The city of Avondale and the Southern Pacific Pipeline, Inc. have pipelines that cross the Agua Fria at Thomas Road. The proposed channel bed elevation at Thomas Road is 889.5 feet. Approximately 600 feet of the water pipeline will have to be lowered at the west bank. It is suggested that a minimum of ten feet of cover be maintained above the water line to the pro-

Table 4.1. Local Scour Around Towers - Salt River Project for Channelized Conditions

Tower Number	Obstruction Width	Flow Velocity (ft/sec)	Flow Depth (ft)	Elevation at Bottom of Footing	Shen (ft)	Nell (ft)	Adopted Scour (ft)	Approximate Channelized Ground Elevation	Elevation After Scour
59	3'	9.44	9.45	987'	7.48	9.02	8.3	985.1	976.8
60	3'	9.13	9.34	979'	7.33	8.87	8.1	983.8	975.7
61	3'	9.32	9.25	981'	7.42	8.94	8.2	982.9	974.7

Table 4.2. Local Scour Around Towers - Tucson Gas & Electric Co. for Channelized Conditions

Tower Number	Obstruction Width	Flow Velocity (ft/sec)	Flow Depth (ft)	Shen (ft)	Neil (ft)	Adopted Scour (ft)	Approximate Channelized Ground Elevation	Elevation After Scour
88 (R)	10'	9.30	9.38	15.61	19.57	13.9	984.3	970.4
89 (R)	10'	9.22	9.30	15.53	19.48	17.5	983.4	965.9
90	5'	9.46	9.08	10.27	12.51	11.4	982.2	970.8
94	5'	9.62	8.65	10.38	12.52	11.5	974.0	962.5
96 (R)	10'	10.42	7.38	16.75	19.90	18.3	972.1	953.8

R = Reinforced

posed channel bed. Therefore, it is recommended the top of the pipeline be maintained at an elevation of 879.5 feet in the channel.

The toe-down depth of the levee is approximately eight feet below the proposed channel invert at Thomas Road. Thus only two feet of cover will exist between the top of the pipeline and the levee toe-down protection. The minimum soil cover is likely to be greater than two feet and therefore, the pipe should be lowered, at the intersection with toe-down protection, to meet the minimum soil cover requirements.

The Southern Pacific Pipeline, Inc. has a six-inch high pressure gas line crossing at Thomas Road and the exact depth of burial is not known. The depth of burial will have to be field verified before recommendations regarding relocation are made. It is recommended that ten feet of soil cover be maintained above the pipe in the channel and the minimum soil cover be observed at the intersection with toe-down protection.

V. ALLOWABLE GRAVEL MINING

Within the channelized area proposed by SLA between Camelback Road and Buckeye Road no gravel mining is recommended unless it would be for removal of any sand or gravel bars that may form.

An instream gravel pit has impacts on the channel bed both upstream and downstream of the pit. Upstream, the gravel pit adds energy to the system by increasing the water-surface slope, or energy slope. The steeper slope has greater erosive power and can initiate headcutting. Downstream of the pit, degradation can result because of sediment being trapped in the pit, causing a sediment transport inbalance. The accelerated upstream and downstream degradation could result in undermining of levees or other protection measures. Therefore, no instream gravel mining is recommended.

Floodplain gravel pits can also initiate headcuts and cause erosion problems if they are not properly located or protected from overbank flows. Impacts from flood-plain gravel pits are generally restricted to flood and overbank conditions. Water and sediment transport rates are generally reduced due to increased resistance to flow by flood-plain features such as vegetation, plowed fields, etc. As a result, the water in the flood plain has much less bed-material load. Of special concern when this relatively clean water spills over into exposed gravel pits is the potential of eroding a dike or buffer zone designed to separate the pit and active river channel. A headcut and erosion through a buffer zone can affect the stability of a river, and in this case the integrity of transverse dikes and levees. Also, a geomorphically active channel (i.e. migrating laterally) can cause the gravel pits to be captured. In other words, the river becomes rerouted through the pit.

The extent of damage to the system that can result from a headcut induced by sand and gravel mining is a function of volume and depth of the pit, location of the pit, material sizes present, flood hydrographs, and sediment inflow rates and volume. In general, all other factors constant, the deeper the pit and the larger the volume of the pit, the greater the potential for headcutting.

5.1 Flood-Plain Pits Between Camelback Road and Indian School Road

Between Camelback Road and Indian School Road the recommended channelization alternative involves a 1,650-foot-long dike on the west bank north of ISRB terminating in an 800-foot-long transverse dike. On the east bank two

transverse dikes and a spur dike just north of ISRB are needed to direct the flow through the bridge. An erosion analysis was conducted to determine headcut distances for three different pit dimensions and three different pit depths. The three pit dimensions include:

1. 500' X 300'
2. 1,000' X 500'
3. 2,000' X 700'

Pit depths examined were 10', 25', and 50'.

Table 5.1 summarizes the headcut distances and time for inundation of pits for the three cases. From the headcut analysis it is recommended that flood-plain gravel pits between ISRB and Camelback should not exceed 25 feet in depth and should be located 500 feet from suggested transverse dikes, levees and channelization. The 500-foot buffer zone assumes periodic maintenance will be done if lateral migration occurs.

It may be possible to increase the depth of the pit if certain management practices are followed by the gravel miner. For example, the miner can limit the active volume of the pit by continuously backfilling with suitable material to keep the actual volume of the pit, and thus the duration of headcutting, to a minimum. Another alternative would be to protect the area where water spills through the pit against headcutting. Possibilities are soil cement on the pit slopes or constructing terraces with sheetpiling. These types of measures would have to be evaluated on a case-by-case basis by the flood-plain manager.

5.2 Flood-Plain Pits Between Indian School Road and Thomas Road

As part of the settlement between the Maricopa County Attorney's Office and gravel miners on the east and west overbanks between ISRB and Thomas Road, a 50-foot buffer zone is to remain between the back toe of the levee and gravel pits. Further, any gravel pits shall have 2:1 side slopes on the levee side. These requirements were made to insure slope stability on the back side of the levees.

Levees between ISRB and Thomas Road were designed to contain the 100-year flood, therefore overbank flow will not occur until discharges are in excess of 95,000 cfs. The back side of the levees will not have protection and any overbank flow will result in erosion to the backside of the levee. Further compounding the spillage problem will be potential headcuts originating from the gravel pit. To prevent a headcut from progressing from the pit to the

Table 5.1. Headcut distances for various pit dimensions

Pit Size	Depth = 10 ft. Headcut Distance (ft)	Depth = 10 ft. Time to Fill (hrs)	Depth = 25 ft. Headcut Distance (ft)	Depth = 25 ft. Time to Fill (hrs)	Depth = 50 ft. Headcut Distance (ft)	Depth = 50 ft. Time to Fill (hrs)
500'X 300'	130	.3	210	.70	320	1.4
1,000'X 205'	205	.6	310	1.4	510	2.8
2,000'X 700'	285	1.1	500	2.8	720	5.6

levee a berm between the pit and back toe of the levee is recommended. This will prevent overbank flows from entering the gravel pit.

5.3 Flood-Plain Pits Between Thomas Road and Buckeye Road

It is recommended that a 200-foot buffer zone be left between the back toe of levees and any proposed gravel pits between Thomas Road and Buckeye Roads except at bridge crossings where a 500-foot buffer zone should be provided. The levees are designed to contain the 100-year discharge of 95,000 cfs. The 200-foot buffer should provide adequate protection for most overbank flows.

VI. INSPECTION PROGRAMS

To assure proper functioning of the proposed channel and levee systems regular inspection intervals should be allotted to check for vegetation growth, rodent populations, and necessary repair after flooding or vandalism. Each of these tasks is discussed below.

6.1 Periodic Inspection

In order to determine the need for specific maintenance items, routine inspections should be conducted every two months and after any significant flooding. Each inspection would include a written report summarizing findings and recommending repairs which would correct any problems.

6.2 Vegetation Control

Establishment of vegetation on the levee embankment is desirable for increasing the stability of the levee. However, levees with soil cement lining or riprap will not require vegetation protection. The channel bed should be kept free of vegetation to provide a roughness coefficient compatible with the design assumptions.

6.3 Rodent Control

Burrowing animals are capable of perforating a levee to the extent that the structural integrity of the levee may be jeopardized. To alleviate this problem, the rodent population should be kept under control. Rodent problems should be identified during the bimonthly inspections.

6.4 Levee Repair

In order to maintain the structural integrity of the levee, it is anticipated that some repairs will be required after periods of significant flooding. This would include replacement of earth fill along levee embankments and repair and replacement of any damaged sections of soil cement or riprap. Experience has indicated that damage resulting from vandalism, motorcycles and vehicles can also be expected periodically.

VII. SUMMARY AND CONCLUSIONS

Based on the hydraulic and sediment transport analyses conducted for the reach between I-10 and Thomas Road, the following conclusions are made regarding channelization and expected channel maintenance problems.

1. Levees are necessary to contain the 100-year flood. Suggested measures include a channel with an 1,100-foot bottom width between Thomas Road and McDowell Road, expanding to 1,410 feet at I-10. The channel shape should be trapezoidal, with 1:1 side slopes if protected with soil cement and 3:1 side slopes if protected with riprap. The proposed channel grade in this reach is approximately .002 and the dynamic equilibrium slope for this reach is 0.0012.

2. Bank protection is required to stabilize the channel due to the large velocities that occur during floods. Toe-down depths eight feet below the equilibrium bed profile are necessary to prevent undermining of the levees due to (1) the formation of a low-flow thalweg, (2) the formation of bed forms on the channel bottom, and (3) impingement scour of meandering low-flow thalwegs. The toe down around the west bend of the Agua Fria from 1,200 feet upstream of I-10 to 2,000 feet downstream of I-10 should be extended fifteen feet below the equilibrium bed profile because of the increased velocity and scour potential around the outside of the bend.

3. Several structural measures are required in the channel, including two four-foot drop structures located 2,200 feet upstream of the proposed McDowell Road bridge and 200 feet downstream of Thomas Road, gabion protection of transmission towers located within channel banks, riprap blanket protection of I-10 bridge piers, and integration of the I-10 collector channel drainage into the Agua Fria.

4. Three Salt River Project transmission towers and five Tucson Electric Power Company transmission towers are located within the channel banks between Thomas Road and I-10. The local scour potential for the 100-year flood is such that all towers require reinforcement.

5. Two pipelines cross the Agua Fria at Thomas Road. The city of Avondale has a 16-inch water line and the Southern Pacific Pipeline, Inc. has a six-inch high pressure gas line. Approximately 600 feet of the water line near the west bank will have to be lowered. It is recommended that ten feet of soil cover be maintained on top of the pipe. The depth of the gas line will have to be field verified before recommendations regarding its depth of burial can be made.

6. No instream gravel mining is recommended between Camelback and Buckeye Roads. Between Camelback and the ISRB flood plain, gravel pits should be limited to 25 feet in depth and 500 feet from channelization, dikes, and levees if periodic maintenance is done to prevent lateral migration of the channel. It may be possible to increase the depth of pits between Camelback and ISRB if certain management practices of gravel pits are followed such as continuous backfilling of gravel pits, protection of where water spills into the gravel pits, or diking around pits. Between ISRB and Thomas Road, gravel mine operators on the east and west overbank

and the Maricopa County Attorney's office agreed to leave a 50-foot buffer zone between the back toe of the levee and gravel pits. It is recommended that a berm be placed between the back toe of levees and gravel pits to reduce the headcut potential if floods spill over the levees. Between Thomas and Buckeye Roads it is recommended that a 200-foot buffer zone be provided between pits and levees and that a 500-foot buffer zone be provided near bridge crossings.

7. Periodic inspection of levees once every two months and after flood flows is necessary to assess if repairs are needed. The inspector should report if any excessive vegetation is present, if rodent burrows are a problem, and if vandalism or flood damage has occurred and necessitates repair. The inspections should be documented and kept in files for future reference.