LATERAL MIGRATION

TANQUE VERDE CREEK
CRAYCROFT ROAD TO SABINO ROAD
BANK PROTECTION AND
RIPARIAN PRESERVE PROJECT

LATERAL MIGRATION ANALYSIS

Prepared for:

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I. INTRODUCTION

This report presents the results of a lateral migration analysis conducted for four proposed bank-protection alternatives located a study reach of the Tanque Verde Creek which lies between Craycroft Road and Sabino Canyon Road in Pima County, Arizona. This particular reach of Tanque Verde Creek contains approximately 9,500 linear feet of existing bank protection located along four isolated channel segments which lie between the Craycroft Road bridge and the Sabino Canyon Road bridge. Approximately 12,500 linear feet of channel banks are currently unprotected within the study reach. Figure 1, Location Map, shows the study reach and the existing bank protection within the study reach.

Three bank-protection alternatives have been defined to include varying lengths of bank protection within the study reach—all in conjunction with the creation of a Riparian Preserve along a portion of the north bank of the Tanque Verde Creek. All of the proposed bank protection would be located along the alignment of the existing channel banks. The three bank-protection alternatives, along with a "no-action" alternative, have been defined as follows:

Alternative 1: No action.

Alternative 2: Bank protection in the existing gaps along the south bank (5,900 linear feet);

Bank protection upstream of the Craycroft bridge on the north bank (1,600 linear feet); and

Riparian Preserve along the north bank.

Alternative 3: Bank protection along the south bank adjacent, to the golf course (4,200 linear feet);

Bank protection upstream of the Craycroft bridge on the north bank (1,600 linear feet); and

Riparian Preserve along the north bank.

Alternative 4: Bank protection in the existing gaps along the south bank (5,900 linear feet);

Bank protection upstream of the Craycroft bridge on the north bank (1,600 linear feet);

Riparian Preserve along the north bank, and

Bank protection (low flow) along the Riparian Preserve (5,000 linear feet).

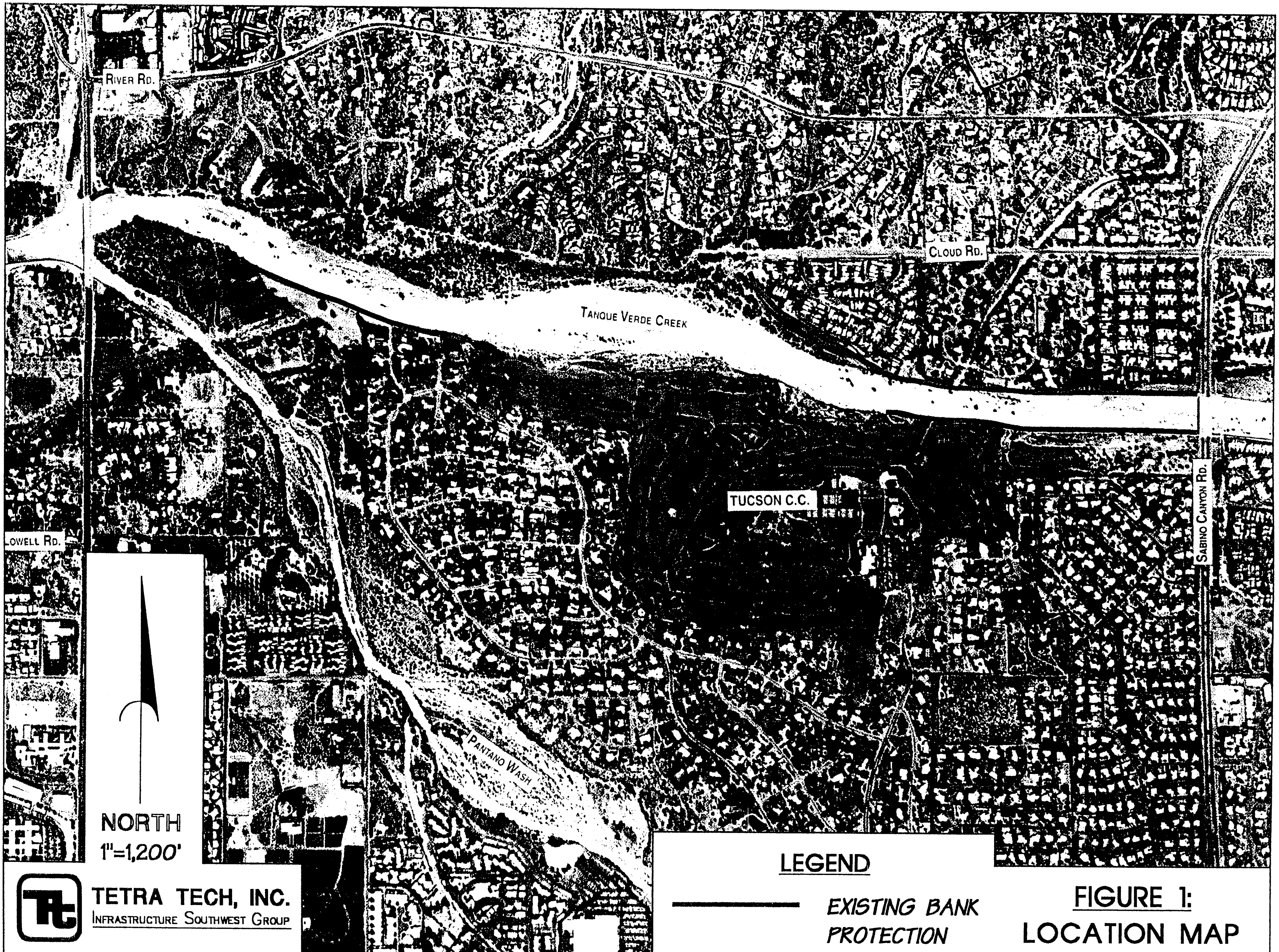

FIGURE 1:
LOCATION MAP

II. PREVIOUS STUDIES

In 1996 the Pima County Flood Control District (District) asked the U.S. Army Corp of Engineers to evaluate flooding and erosion hazards along the study reach of the Tanque Verde Creek. (Pima County, 1996). The District outlined the existing flooding and erosion hazards, and prepared preliminary cost estimates for their proposed solution. The District's 1996 proposal has been included as Alternative 2 in this report.

Subsequently, a hydraulic and geomorphic analysis was completed for the study reach of the Tanque Verde Creek (SLA, 1998) which addressed four major areas of concern. The four areas of concern were (1) the potential for bank erosion, lateral migration, and channel migration along the project reach; (2) the relative stability of the Craycroft Road and Sabino Road bridges; (3) the flooding potential along the study reach during the 100-year event; and (4) the potential threat, if any, that the project might pose on the recently completed Rillito Creek bank stabilization project. For the purpose of the analysis presented within this report, the results of the 1998 SLA analysis regarding the first area of concern—bank erosion, lateral migration, and channel migration—will be examined in further detail and expanded upon in order to assess the impacts that bank stabilization might create along the proposed Riparian Preserve which is to be located along a portion of the north bank of the study reach.

III. QUALITATIVE GEOMORPHIC ANALYSIS

A. Historical Geomorphic Analysis

The 1998 SLA analysis incorporated a fluvial geomorphologic assessment which included an evaluation of aerial photographs of the study reach for the years 1936, 1953, 1960, 1967, 1971, 1979, 1983, 1993, and 1996. Using these historical aerial photographs and USGS flow records, movements of channel banks along the study reach were documented and correlated to flow events over the 60-year time period of the aerial photographs. In addition, changes in land uses and vegetation location and volume were also documented and correlated to the movements of the channel banks. The 1998 analysis presented summaries of the movements of channel banks, land-use changes, and vegetation changes which occurred during the intervening time periods between each successive aerial photograph.

The results of the 1998 fluvial geomorphologic analysis revealed that 650 feet was the maximum lateral movement of the channel banks which occurred during the 60-year time period of 1936 to 1996. A review of historic flow records indicates that a flow event of 12,200 cfs in December of 1965 was responsible for the majority of this severe bank erosion. While the peak flow rate for this event was much less than the adopted 100-year discharge of 34,000 cfs, the extensive bank erosion which occurred during the 1965 event was considered to be primarily due to the prolonged duration of flow (Pearthree and Baker, 1987). Another primary factor was that the flow was directed toward the outside of a appreciable meander bend which existed at the time.

B. Localized Bank Protection along Regional Watercourses

Each of the proposed alternatives would result in varying levels of bank protection along the study reach. The alternatives range from Alternative 1, with no new bank protection, to Alternative 4, with complete bank protection. Alternatives 1, 2, and 3 would all result in localized, or "piecemeal," areas of bank protection within the study reach, with unprotected channel banks located between, and adjacent to, protected channel banks.

The occurrence of increased bank erosion adjacent to localized bank protection has been well documented for regional watercourses within the Tucson basin such as the Tanque Verde Creek, the Rillito Creek, and the Santa Cruz River. During the October, 1983, flow events on these regional watercourses, a systematic pattern of erosion at meander bends was documented that appeared to be *directed or otherwise facilitated by existing localized bank protection* [emphasis added] (Pearthree and Baker, 1987). Localized bank protection, such as is proposed with Alternatives 1, 2, and 3, clearly will concentrate potential bank erosion and focus it upon those unprotected banks which remain within the study reach.

IV. ENGINEERING GEOMORPHIC ANALYSIS

A. Sediment Transport Continuity and Equilibrium Slopes

In order to determine the effect of any proposed channel improvements on channel stability, a quantitative engineering-geomorphic analysis can be conducted to determine both existing and with-project characteristics (ADWR, 1985). That is, an analysis of sediment transport rates and equilibrium slopes can be used to determine the effect of a proposed alternative on the stability of both the channel bed and banks of an alluvial watercourse.

Hydraulic models for both existing and with-project conditions were completed as part of the 1998 SLA analysis. Using hydraulic parameters (i.e., depth, velocity, width) obtained from these hydraulic models for both existing and with-project conditions, sediment transport rates can be calculated and compared to one another in order to identify any changes in sediment transport continuity within the study reach. Such a comparison showed little predicted change, however, since the proposed bank protection for each alternative will generally be located along the existing alignment of channel banks, and therefore existing flow hydraulics and corresponding sediment transport rates will remain essentially unchanged. Consequently, comparison of existing versus with-project sediment transport rates does not predict the occurrence of any substantive change in sediment transport continuity within the study reach.

Any instability in the sediment transport continuity of the study reach can also be identified through an analysis of equilibrium slopes—a procedure which can be used to determine long-term trends toward aggradation or degradation of the streambed. In the 1998 SLA analysis, equilibrium slopes were calculated for the study reach (SLA, 1982) and were compared to existing slopes. Differences in the two slopes were small, between 0.0002 ft./ft. and 0.0003 ft./ft. (i.e., 1.1 ft./mile to 1.6 ft./mile), with a slight trend towards aggradation indicated. Consequently, instability in the sediment transport continuity of the study reach due to either streambed aggradation or degradation is not predicted to occur for either existing or with-project conditions.

B. Shear Stress Analysis at Bendways

The occurrence of lateral migration and bank erosion is not exclusively a function of system sediment imbalances or long-term equilibrium slopes. Localized bank movement along the outside of meander bends will also occur. The extent of this localized bank-erosion process can be predicted by calculating the change in shear stress which occurs on the outside of meander bends during the progression of a flood hydrograph (SLA, 1997). Increased shear stress on the outside of a meander bend is created by the curvature effect induced in the flow as it passes through the bend. Physical model studies have shown that "bend shear stresses" can be more than four times as great as the shear stresses which occur along a straight channel segment.

Single-event bank erosion distance along the outside of an existing meander bend can be predicted by (1) utilizing representative cross sections along the study reach for both a straight approach channel and a meander bend; by (2) adjusting channel hydraulics to represent the outer portion of flow within the representative cross sections; by (3) computing corresponding sediment transport rates; by (4) considering the geometry of existing meander bends along the study reach; by (5) accounting for the increased shear stress on the outside of the meander bend; and by (6) considering the sediment composition of the eroding bank. Two existing meander bends located along the north bank of the study reach were evaluated for single-event bank erosion using this approach. Results, provided in the appendix to this report, indicate that for current conditions within the study reach, the maximum northward lateral movement of the north bank of the Tanque Verde Creek is predicted to be in the range of 200 feet to 300 feet during the occurrence of a 100-year flow event.

An earlier fluvial geomorphologic assessment (SLA, 1998) of the study reach of the Tanque Verde Creek recommended 650 feet as a reasonable prediction of long-term lateral migration potential. On an average-annual basis, this represents only a few feet of migration per year. However, the amount of lateral migration predicted to occur during a major single event, such as a 100-year flood, accounts for a significant portion of the total lateral migration that is anticipated to occur within the study reach over the long term. Consequently, the ability to passively monitor erosion impacts along the proposed Riparian Preserve—and then take appropriate mitigation measures, as necessary, to preserve the integrity of the Preserve—can be severely compromised since the passage of a major single event can cause several hundred feet of lateral bank movement to occur along the study reach of the Tanque Verde Creek in a matter of only a few hours time.

V. RESULTS

All of the proposed alternatives incorporate installation of varying levels of bank protection for the unprotected channel banks along the study reach. The alternatives range from Alternative 1, with no new bank protection, to Alternative 4, with complete bank protection. Alternatives 1, 2, and 3 would all result in localized, or "piecemeal," areas of bank protection within the study reach, with unprotected channel banks located between, and adjacent to, the protected channel banks. As a result, the potential for erosion along the unprotected segments of channel banks is expected to be high for Alternatives 1, 2, and 3, due to the "piecemeal" nature of the existing and proposed bank protection.

The occurrence of increased bank erosion for unprotected banks located adjacent to localized protected banks has been well documented for regional watercourses within the Tucson basin. Erosion at meander bends has either been caused, or exacerbated by, existing localized bank protection. Localized bank protection, such as is proposed with Alternatives 1, 2, and 3, will clearly concentrate potential bank erosion along those segments of unprotected banks located within the study reach.

Existing fluvial-geomorphic and engineering-geomorphic analyses of the study reach of the Tanque Verde Creek were evaluated for the purpose of determining the effects, if any, of the proposed bank-protection alternatives on lateral migration. Using existing and with-project hydraulic parameters, it was determined that sediment transport rates, and thus overall sediment transport continuity, will not be altered by any of the proposed alternatives. Similarly, a comparison of existing and equilibrium slopes in the study reach indicates that the channel bed profile is approaching long-term equilibrium conditions. These two quantitative methodologies indicate that no substantive change in sediment continuity results from the proposed alternatives.

Using a quantitative methodology which considers the hydraulics and shear stress of flow on the outside of a meander bend, single-event bank erosion estimates were determined along the study reach to range between 200 feet to 300 feet for the two meander bends located within the study reach. Although these estimates are less than historical single-event bank movements that have been recorded, the estimate is considered to be reliable for the geomorphology of the Tanque Verde Creek as it exists today along the study reach (i.e., the existing channel alignment is straighter than in the past, and the ability of the channel to meander has been reduced significantly due to the presence of two bridges and 9,500 linear feet of existing bank protection).

Because the amount of lateral migration predicted to occur during a major single event, such as a 100-year flood, accounts for a significant portion of the total lateral migration that is anticipated to occur within the study reach over the long term, the ability to passively monitor erosion impacts along the proposed Riparian Preserve—and then take appropriate mitigation measures, as necessary, to preserve the integrity of the Preserve—can be severely compromised since the passage of a major single event can cause several hundred feet of lateral bank movement to occur along the study reach of the Tanque Verde Creek in a matter of only a few hours time.

Results of the historical geomorphic analysis indicate that 650 feet represents the maximum long-term lateral movement of the channel banks during the 60-year period of record analyzed (1936 to 1996). As noted in the 1998 SLA analysis of the study reach, this maximum observed lateral migration distance correlates closely to a building setback distance of 652 feet which was calculated using local City of Tucson standards (City of Tucson, 1989). Therefore, while lateral bank movements of this magnitude are less likely today, due to the limiting effect of recent bridge construction and bank protection within the study reach, 650 feet is still considered to be a conservative estimate of worst-case channel movement within the study reach over the long term.

In order to quantify the erosion hazards that are associated with each alternative, unprotected sections of channel bank were tabulated and potential areas of bank erosion were calculated. The results, shown in Table 1 and Figure 2, indicate the relative erosion hazards for each alternative. With the exception of Alternative 4, all of the alternatives are predicted to result in a high risk of erosion along the proposed Riparian Preserve.

TABLE 1: EROSION HAZARDS FOR PROPOSED ALTERNATIVES

Alternative	Proposed Bank Protection (linear feet)	Unprotected Banks (linear feet)	Acreage at Risk (acres)	Structures at Risk
1	0	12,500	187	21 homes, the north and south approaches to the Craycroft bridge, a golf course, and the Riparian Preserve
2	7,500	5,000	75	15 homes, along with the Riparian Preserve
3	5,800	6,700	100	15 homes, the Riparian Preserve, and the south approach to the Craycroft bridge
4	12,500	0	0	None

VI. RECOMMENDATION

Based upon the lateral migration assessment conducted under this study effort, it is recommended that Alternative 4—bank protection in the existing gaps along the south bank (5,900 linear feet); bank protection upstream of the Craycroft bridge on the north bank (1,600 linear feet); Riparian Preserve along the north bank, and Bank protection (low flow) along the Riparian Preserve (5,000 linear feet), be adopted as the preferred alternative for the project.

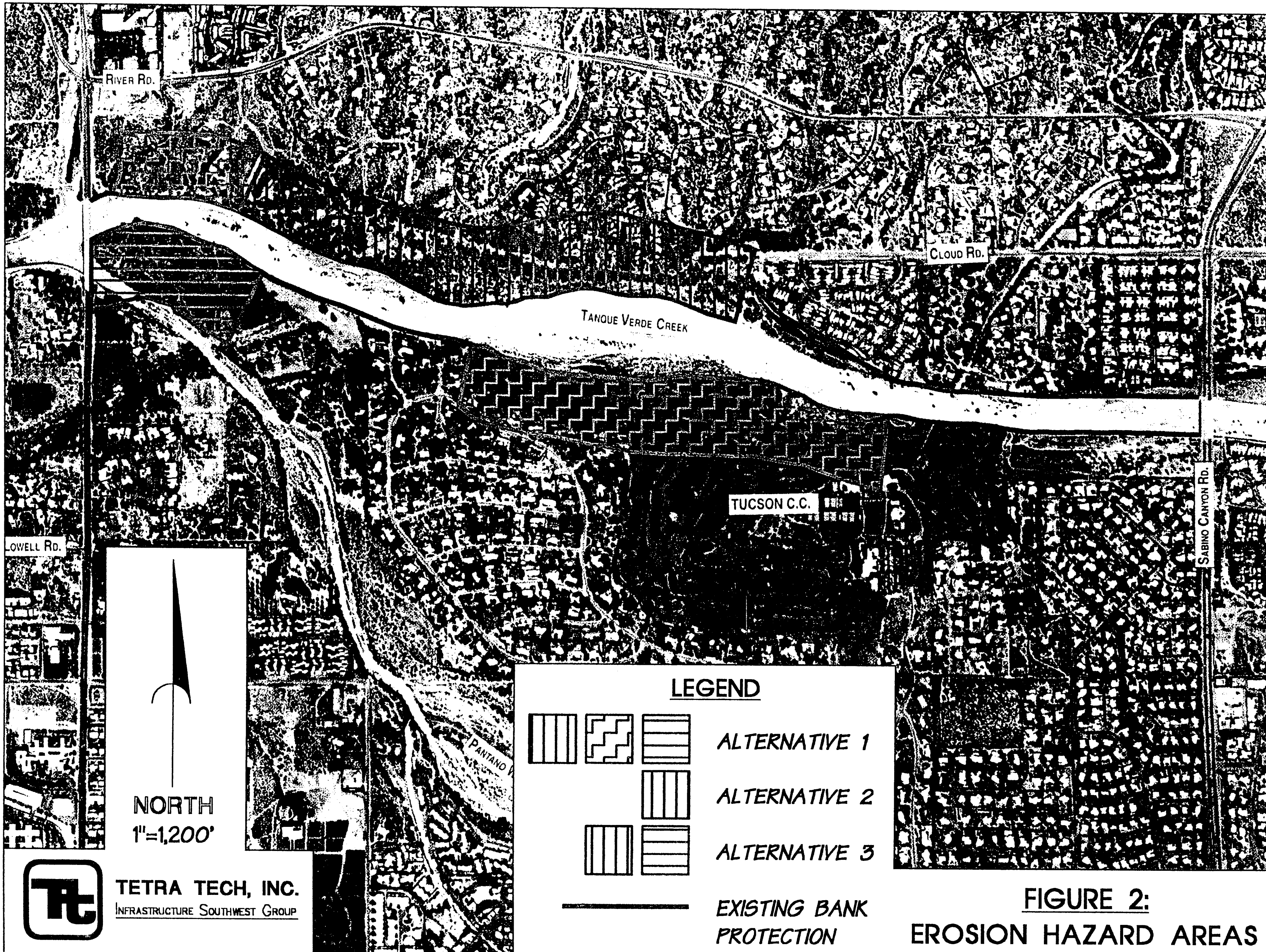

FIGURE 2:
EROSION HAZARD AREAS

VII. REFERENCES

1. *Sediment Transport Analysis of Rillito River and Tributaries for the Tucson Urban Study*; a report by Simons, Li & Associates, Inc., Fort Collins, Colorado & Tucson, Arizona; April 9, 1982.

2. *An Approach to Estimating Single-Event and Long-Term Lateral Migration Distances Along Alluvial Channels;* a paper by Michael Zeller, Simons, Li & Associates, Inc., Tucson, Arizona; November, 1997.

3. *Tanque Verde Creek, Craycroft Road to Sabino Road, Bank Protection and Riparian Preserve Project Limited Reevaluation Report (LRR), Feasibility Level Engineering Analysis*; a report by Simons, Li & Associates, Inc., Tucson, Arizona; May 4, 1998.

4. *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona*; by Simons, Li & Associates, Inc., Tucson, Arizona; December, 1989.

5. *Design Manual for Engineering Analysis of Fluvial Systems*; Arizona Department of Water Resources; 1985.

6. *Rillito River and Associated Streams, Bank Stabilization and Riparian Area Preserve, Tanque Verde Creek, Craycroft Road to Sabino Canyon Road*; Pima County Department of Transportation and Flood Control District, Flood Control Engineering Division; December, 1996.

7. *Channel Change Along the Rillito Creek System of Southeastern Arizona, 1941 through 1983*; Marie Slezak Pearthree and Victor R. Baker, Special Paper 6, Arizona Bureau of Geology and Mineral Technology Geological Survey Branch, 1987.

APPENDIX

CALCULATIONS FOR BANK EROSION IN BENDS DUE TO INCREASED SHEAR STRESS

TANQUE VERDE CREEK - CRAYCROFT ROAD TO SABINO ROAD
100-YEAR LATERAL MIGRATION ANALYSIS
WEST MEANDER NEAR CRAYCROFT ROAD

Hydraulics from HEC-2 Design Run (SLA, 98)
Unit Sediment Discharge from Tucson Urban Study (SLA, 82)

qs = (2.75x10^-6) * v^4.29 * y^-0.261

Total Sediment Discharge for Shear Stress Analysis (1/2 section)

Qs = qs * (width/2)

420	Supply channel width
400	Bend channel width
32	Angle of curvature
7	Average height of outer bank
0.7	Fraction of bed material found in bank
0.4	Porosity
5.5	Shape factor

Hydrograph		Supply Reach (XS-5)				Bend Reach (XS-3)					
Time Increment (hr)	Discharge (cfs)	Velocity (ft)	Depth (ft)	Sediment Discharge (cfs)	Sediment Volume (cf) (bulked)	Velocity (ft)	Depth (ft)	Adjusted Velocity (ft)	Adjusted Depth (ft)	Sediment Discharge (cfs)	Sediment Volume (cf) (bulked)
1.5	2200	1.98	3.83	0.0762	686	1.0	6.7	1.13	6.72	0.0056	51
1	8600	5.66	4.83	6.4957	38974	3.6	6.9	4.28	6.97	1.6931	10159
1	15700	7.77	5.98	23.9188	143513	6.2	7.2	7.33	7.54	16.7344	100407
1	26400	9.21	7.52	46.7232	280339	9.1	8.1	10.77	8.73	83.7157	502294
1	33800	9.62	8.51	54.5333	327200	10.3	8.8	12.23	9.67	140.7046	844227
1	27200	9.27	7.63	47.8614	287168	9.2	8.2	10.96	8.82	89.9955	539973
1	20200	8.59	6.64	35.7929	214757	7.6	7.6	8.97	8.00	39.1727	235036
1	17700	8.17	6.28	29.2898	175739	6.8	7.4	8.09	7.73	25.3857	152314
1	13800	7.33	5.69	18.8696	113218	5.5	7.1	6.57	7.36	10.5269	63161
1	10200	6.25	5.1	9.7994	58797	4.2	6.9	5.02	7.08	3.3343	20006
1	7600	5.24	4.66	4.7101	28261	3.2	6.8	3.80	6.91	1.0239	6143
1	5700	4.33	4.34	2.1169	12701	2.4	6.8	2.89	6.83	0.3154	1892
1	4200	3.45	4.09	0.8112	4867	1.8	6.7	2.14	6.77	0.0872	523
1	3300	2.83	3.96	0.3497	2098	1.4	6.7	1.69	6.75	0.0316	189
1	2500	2.22	3.86	0.1243	746	1.1	6.7	1.28	6.73	0.0098	59
2	1700	1.56	3.78	0.0275	330	0.7	6.7	0.87	6.71	0.0018	22
2.5	900	0.84	3.72	0.0019	29	0.4	6.7	0.46	6.70	0.0001	2
Total Sediment Volume (bulked cf)					*1689423*						*2476459*
Sediment Deficit (bulked cf)									*787036*		
Lateral Migration Potential (ft)									***209***		

TANQUE VERDE CREEK - CRAYCROFT ROAD TO SABINO ROAD
100-YEAR LATERAL MIGRATION ANALYSIS
EAST MEANDER NEAR SABINO ROAD

Hydraulics from HEC-2 Design Run (SLA, 98)
Unit Sediment Discharge from Tucson Urban Study (SLA, 82)

qs = (2.75x10^-6) * v^4.29 * y^-0.261

Total Sediment Discharge for Shear Stress Analysis (1/2 section)

Qs = qs * (width/2)

360	Supply channel width
705	Bend channel width
35	Angle of curvature
7	Average height of outer bank
0.7	Fraction of bed material found in bank
0.4	Porosity
6.1	Shape factor

Hydrograph		Supply Reach (XS-15)				Bend Reach (XS-12)					
Time Increment (hr)	Discharge (cfs)	Velocity (ft)	Depth (ft)	Sediment Discharge (cfs)	Sediment Volume (cf) (bulked)	Velocity (ft)	Depth (ft)	Adjusted Velocity (ft)	Adjusted Depth (ft)	Sediment Discharge (cfs)	Sediment Volume (cf) (bulked)
1.5	2200	3.66	2.53	1.0156	9140	4.0	1.7	4.90	1.86	7.5432	67889
1	8600	7.06	4.3	14.8130	88878	6.3	3.4	7.67	3.75	42.9264	257558
1	15700	9.27	5.65	44.3703	266222	7.1	4.6	8.73	5.15	68.6535	411921
1	26400	11.6	7.22	108.9060	653436	8.3	6.0	10.21	6.75	125.4274	752564
1	33800	12.8	8.14	161.0138	966083	8.9	6.9	10.94	7.74	163.1262	978757
1	27200	11.74	7.32	114.2468	685481	8.4	6.1	10.29	6.87	129.4549	776729
1	20200	10.36	6.36	69.3101	415860	7.7	5.2	9.44	5.85	92.9302	557581
1	17700	9.78	5.98	55.0098	330059	7.4	4.9	9.06	5.47	79.2813	475688
1	13800	8.74	5.33	34.9956	209974	6.8	4.4	8.36	4.83	58.0495	348297
1	10200	7.62	4.65	20.1366	120820	6.2	3.8	7.55	4.20	38.9012	233407
1	7600	6.66	4.09	11.6856	70113	6.0	3.2	7.29	3.52	35.0940	210564
1	5700	5.82	3.62	6.7655	40593	5.4	2.8	6.56	3.04	23.1090	138654
1	4200	5.04	3.2	3.7687	22612	4.8	2.4	5.89	2.61	15.2435	91461
1	3300	4.51	2.9	2.4007	14404	4.6	2.0	5.65	2.26	13.1905	79143
1	2500	3.97	2.61	1.4278	8567	4.2	1.8	5.12	1.98	8.9696	53817
2	1700	3.33	2.26	0.6974	8369	3.8	1.5	4.61	1.64	5.9860	71832
2.5	900	2.47	1.83	0.2045	3068	2.9	1.2	3.55	1.28	2.0958	31437

Total Sediment Volume (bulked cf)	3913678	5537301
Sediment Deficit (bulked cf)		1623623
Lateral Migration Potential (ft)		285