CITY OF SCOTTSDALE

DESERT GREENBELT
PIMA ROAD THREE BASINS PROJECT

Design Sediment Report

The Desert Greenbelt
SCOTTSDALE, ARIZONA

STANTEC CONSULTING INC.
7776 Pointe Parkway West, Suite 290
Phoenix, Arizona 85044
(602) 438-2200

SCI Project No: 28900082

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1.0 Introduction

This report provides design information and background material relative to sedimentation and sediment transport considerations for the Desert Greenbelt, Pima Road Three Basins (PR3B) Project. Sediment delivery to the PR3B system is a function of hydrologic conditions (rainfall intensities, durations, etc.) and watershed conditions (drainage patterns, land use, vegetation cover, land slope, soils, geology, etc). Flood water conveyance systems that will be constructed as part of the PR3B system (conduits and channels) will be constructed of essentially, nonerodible material (concrete, cement stabilized alluvium, etc.) and those features will not constitute a source of sediment to the PR3B drainage system. The detention basins in the system will be essentially unlined except where erosion protection is warranted. For example, spillways into the basins will be constructed of concrete, cement stabilized alluvium or other erosion resistive material, and the banks of the Pima Freeway East- and West-Basins that are subject to erosive velocities are to be lined with shotcrete. Therefore, virtually the entire sediment and sediment transport related design and maintenance issues are a function of the sediment yield from the watershed.

This report provides the watershed sediment yield estimates and background information that is the basis for the sediment design of the PR3B system. That information is provided in Appendices A and B which is summarized in this report.

The watershed boundary and key features of the PR3B system are shown in Plate 1. Sediment transport through the PR3B system is a function of hydraulic characteristics and the operation of the detention basins. The basins are quite large in relation to the volumes of the inflow hydrographs and the basins will function as sediment traps for all coarse sands and gravels and much of the silt. Only fine particle size sediment fractions (some silt and clay) will be routed through the basins due to the low settling velocities of those particle sizes. Therefore, the conveyance systems (conduits and possibly open channels) downstream of the basins will receive essentially "clear water" discharges from the basins.

Sediment dead storage requirements for each of the basins are presented. A discussion of sediment transport factors that are considered in the design of the PR3B system are included in this report.

Scour and toe-down calculations for the bed and bank lining of the Pima Freeway East- and West-Basins are presented in separate design memos.

2.0 PR3B Watershed Sediment Yield

Sediment yield to the PR3B system is based on previous work by George V. Sabol Consulting Engineers, Inc. (GVSCE) as part of that firm's review of the Desert Greenbelt Project, Pima Road Channel. The Concept Review report (GVSCE, November 1996) provides watershed sediment yield results (Appendix A) and supporting documentation (Appendix B).

The sediment yield estimate by GVSCE (Appendix A) was prepared for a previous project configuration having a Union Hills Basin, a Miller Road Basin, and collector channels along the north side of the Pima Freeway that drained to each of those two basins. In the present PR3B configuration of the project, the Union Hills and Miller Road Basins are replaced by the Pima Freeway East- and West-Basin, and the collector channels are eliminated. That change means that the sediment yield for the Union Hills Basin needs to be adjusted slightly for the Pima Freeway East-Basin. Also, at the time that the sediment yield estimate was prepared (Appendix A), there was no sediment yield estimate made for the Miller Road Basin. However, the sediment yield information in Appendix A provides reliable estimates of sediment yield for the Pima Freeway East- and West-Basins.

The key data for estimating sediment yield to the basins are contained in Tables 1 and 2 of Appendix A. Table 1 (Appendix A) provides ranges of the mean annual sediment yields for the Happy Valley, Deer Valley, and Union Hills Basins. Similarly, Table 2 (Appendix A) provides ranges of 100-year flood sediment yields for those same basins.

A design criteria for the basins is that sediment dead storage is equal to five times the mean annual sediment yield plus the sediment yield from the 100-year flood. The calculation of sediment dead storage volume for the Happy Valley, Deer Valley and Union Hills Basins is provided in Table 3 (Appendix A), and accordingly, the dead storage for the Happy Valley Basin is 11.3 acre-feet and for the Deer Valley Basin is 13.2 acre-feet. The drainage area for the Union Hills Basin is 4.95 square miles (see Table 3, Appendix A) and the direct drainage area for the Pima Freeway East-Basin (11.05 square miles less the 2.90 square miles draining to the Happy Valley Basin and the 3.24 square miles draining to the Deer Valley Basin) is 4.91 square miles. Therefore, the sediment yield for the Union Hills Basin can be used for the dead storage estimate of the Pima Freeway East-Basin which is 8.4 acre-feet.

The GVSCE (November 1996) report does not provide a sediment yield estimate for the 0.93 square mile area that drains to the Pima Freeway West-Basin. However, the sediment yield characteristics and land use for the Pima Freeway East- and West-Basins are similar and the dead storage requirement for the Pima Freeway East-Basin is used to estimate the dead storage requirement for the West-Basin. That estimate is based on a ratio of the drainage areas, as follows:

$$\frac{0.93 \text{ square miles}}{4.91 \text{ square miles}} \times 8.4 \text{ acre-feet} = 1.6 \text{ acre-feet}$$

A summary of the sediment dead storage volumes that are provided in each of the four PR3B detention basins is provided in Table 1.

TABLE 1

Dead storage requirements for the PR3B detention basins

Basin	Total Contributing Drainage Area	Dead Storage Volume	Total Basin Volume	Ratio of Dead Storage to Total Volume	Design Storm Inflow Volume	Ratio of Basin Volume to Inflow Volume
	Sq. Mi.	Ac-Ft.	Ac-Ft	%	Ac-Ft	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Happy Valley	2.90	11.3	208	5.4	257	81
Deer Valley	6.14	13.2	183	7.2	480	38
Pima Freeway East-Basin	11.05	8.4	135	6.2	1,130	12
Pima Freeway West-Basin	0.93	1.5	37	4.1	91	41

3.0 Basin Sedimentation

Table 1 lists several key design data for the basins. Important facts to be noted from Table 1 are the following:

- The volume allocated for dead storage (Column 3) is a small percentage (Column 5) of the total basin capacity (Column 4). Therefore, sediment inflow and deposition will not adversely impact the performance of the basins in regard to routing of the inflow design flood through each basin. Only active storage volume (total volume minus dead storage) is used in basin routing for design purposes.

- The Happy Valley Basin is at the upper end of the main system. Outflow from the Happy Valley Basin drains to the Deer Valley Basin that in turn drains to the Pima Freeway East-Basin. Each basin will trap intervening sediment inflow and release essentially "clear water" to the next downstream basin. Therefore, sediment inflow is controlled near its point of origin to the drainage system and that sediment is not routed through the system. The volume of inflow to each subsequent downstream basin obviously increases (Column 6), but the equivalent concentration of sediment inflow to each downstream basin decreases due to the dilution effect of the release of "clear water" from the upstream basins. Therefore, although the ratio of basin volume to inflow volume decreases (Happy Valley to Deer Valley to Pima Freeway East-Basin) (Column 7), each downstream basin will function with a lower concentration of sediment inflow.

- The Pima Freeway West-Basin and the Happy Valley Basin do not have upstream sediment control from any PR3B project features. Those basins receive the full contribution of sediment inflow without reduction by upstream basins. Those basins have the highest ratio of basin volume to inflow volume (81 percent and 41 percent, respectively, see Table 1, Column 7). Those high ratios indicate the effectiveness of those basins to receive and trap incoming sediment.

The maintenance requirement of the basins will require that the basins be cleaned of accumulated sediment, on the average, once every five years, or after every major sediment producing runoff event. Therefore, the basins will always have dead storage capacity available at the start of storm runoff for the deposition and accumulation of sediment from the 100-year storm. (Note: All hydrologic routing of inflow design floods assume that the dead storage volume is depleted at the start of the storm. This is a hydrologically conservative assumption.)

Sediment inflow to the Happy Valley and Deer Valley Basins is at two locations in each basin. The main inlet is at the north end of each basin, and an additional inlet is at the east end of each basin where inflow enters from collector channels. For both of those basins, the outlet is generally located in the southwest quadrant of the basin. Therefore, sediment inflow will have to pass through a significantly long travel distance from the inflow point to the outlet, thus allowing sediment deposition to occur. Those basins are relatively deep and the sediment deposition will not adversely impact the function of the basins.

Sediment inflow to the Pima Freeway East-Basin is from two sources; from the outlet of the Pima Road Conduits, and from the rundown spillways along the north bank of the basin. Sediment discharge from the Pima Road Conduits will be relatively small because the majority of that discharge comes from routed outflows from the Happy Valley and Deer Valley Basins. Therefore, that component of discharge is essentially "clear water." The only significant quantity of sediment delivered to the East-Basin via the Pima Road Conduits is that which enters at lateral inflow junctions below the Deer Valley Basin. The East-Basin will function as a desilting basin once the sediment laden water enters the basin. The flow velocity in the basin will be lower than the velocity in the Pima Road Conduits and that basin flow velocity will be a function of the stage of the impounded water in the basin. Basin flow velocities will generally be in a range from 5 fps during initial inflows to less than 2 fps at maximum stage in the basin. The basin will function to sequentially trap finer sediment throughout the length of the approximately 3,500-foot long basin. Coarse sand will settle out some distance after entering the basin, followed by sand, fine sand, and at some distance downstream in the basin, some silt will settle out. Most of the clay and much of the fine silt will be transported through the basin because of the low settling velocities of those particles. Overall, the incoming sediment load will be distributed through much of the length of the basin.

Sediment that is delivered to the East-Basin via the rundown spillways is distributed over the length of the 3,500-foot long basin (see Plate 2). Each spillway will deliver a portion of the total sediment yield in relative proportion to the basin inflow at that spillway. Therefore, sediment deposition near each spillway will not cause an impediment to the operation and reservoir storage routing through the East-Basin.

Sediment inflow to the West-Basin is only via the rundown spillways. Therefore, sediment inflow is distributed over the length of that 5,000-foot long basin (see Plate 3). As with the East-Basin, sediment deposition near each spillway will not cause impediment to the operation and reservoir storage routing in the West-Basin.

4.0 Sediment Transport in Conduits

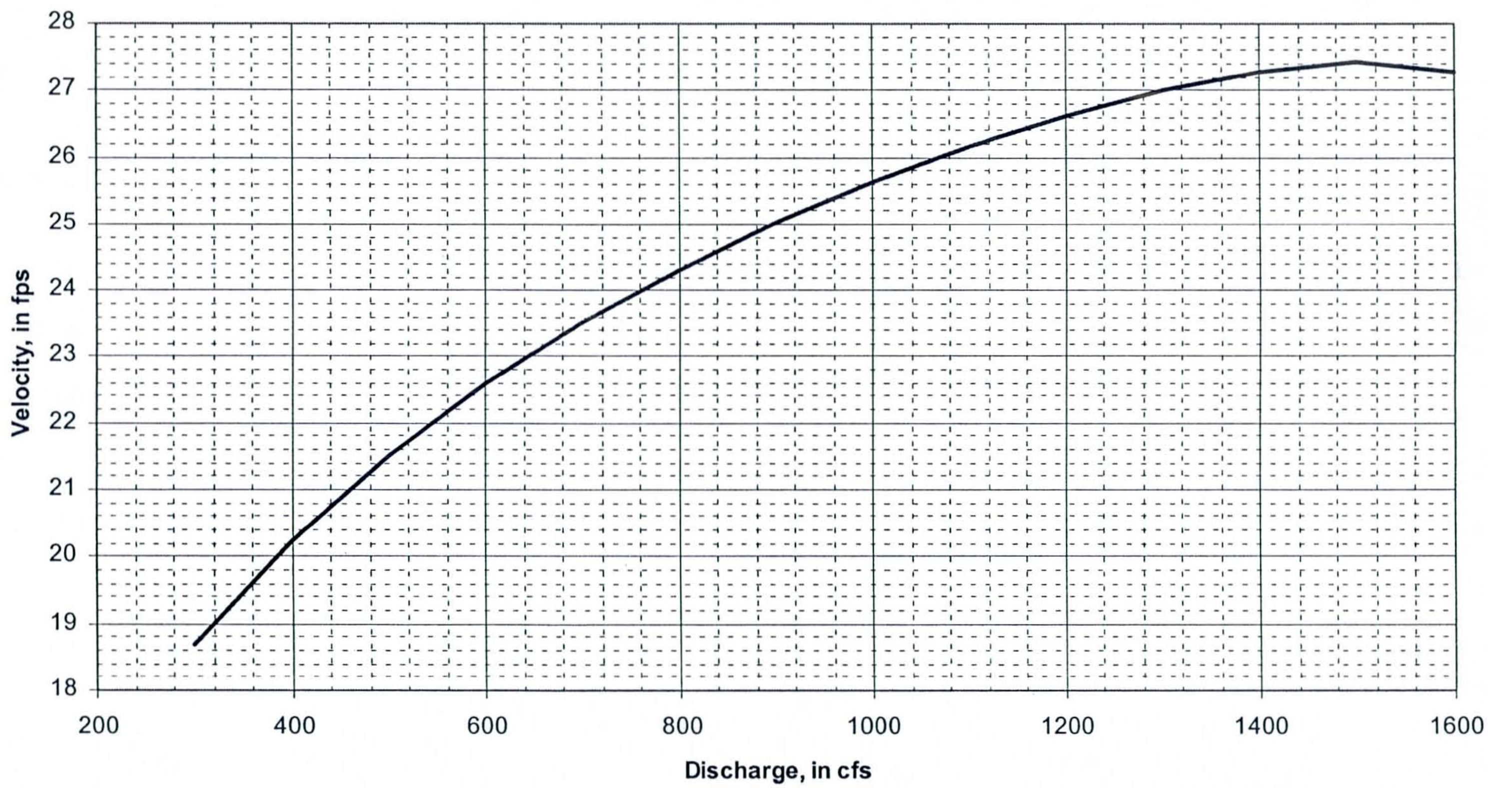
For the Phase 1 portion of the PR3B project, the conveyances are large diameter conduits. Those conveyances are the Pima Road Conduits and the Hayden Road Conduits. The quantity of sediment in those conduits is largely controlled by the upstream basins that effectively function as sediment traps, as previously described. Only fine sediments will be released from the basins to the conduits and those sediments will be transported in suspension throughout the length of the conduits.

The Hayden Road Conduits receive water only from the Pima Freeway East- and West-Basins. Those conduits will receive virtually no sediment influx other than suspended fine sand, silt and clay. Sediment transport is not a consideration for those conduits.

The Pima Road Conduits receive water from the Deer Valley Basin which is essentially "clear water" in regard to sediment transport. As previously described for the Pima Road Conduits, there are three significant lateral inflow points; at the Sierra Pinta Collector Channel, at Downing Olson, and at Union Hills Drive. Some sediment inflow to the conduits will occur at those laterals. Flow velocity in the conduits is a function of discharge, slope of conduit section, and other hydraulic conditions. In the 108-inch and 120-inch conduits at full discharge, the velocity ranges from about 17 fps to about 21 fps. At those velocities, sediment will undoubtedly be effectively transported throughout the length of the conduits without deposition or flow blockage. At lower discharges there will be some reduction in velocity, however, in circular sections the flow velocity remains high over a broad range of discharges. For example, Figure 1 provides a graph of velocity for uniform flow in a 108-inch diameter, 2 percent slope conduit. Notice that the range of velocity is from about 18 fps at 300 cfs to about 26 fps at 1,150 cfs (maximum discharge in a 108-inch section of the Pima Road Conduits). Therefore, even under less than design discharges, the conduits will have high velocity flows that will not result in sediment deposition.

Figure 1

Uniform depth flow velocity (double-barrel 108-inch diameter, 2% slope) as a function of discharge in each barrel



5.0 Summary of PR3B Design Factors Regarding Sediment

Sediment transport and related design issues for the PR3B system considers the following factors:

1. Discharge to conduits is generally regulated by upstream desilting basins. Little sediment yield enters conduits directly.

2. The surface of the contributing watershed is primarily composed of sand, silt and clay. There is little gravel in the watershed that would contribute significant quantities of coarse bedload material to the system.

3. Downstream sediment loads are diminished appreciably due to the high trap efficiency of the basins.

4. The basins release essentially "clear water" and that clear water increases the transport capacity in the conduits for any sediment that is introduced from the few lateral inflows.

5. The conduits themselves are not a source of sediment transport material.

6. The conduits have relatively steep slopes and high velocity flows. Incoming sediment will be effectively transported through the system. Sediment induced erosion of conduits and other structural elements will be negligible.

7. The Happy Valley and Deer Valley Basins are configured such that the two inflow spillways are located an adequate distance from the basin outlets to allow sufficient detention time for effective deposition of sand within the basins.

8. The Pima Freeway East- and West-Basins are relatively long, narrow basins. The East-Basin is about 3,500 feet long with the discharge outlet from the Pima Road Conduits located at the far east end and the basin outlet located at the far west end. The West-Basin is about 5,000 feet long with sediment inflow distributed throughout its length. Sediment inflow will be deposited throughout the length of each basin, contingent upon rates of basin filling, flow velocity through the basins, sediment load and size distribution of sediment.

APPENDIX A

FROM <u>CONCEPT REVIEW</u> GVSCE (NOVEMBER 1996)

SEDIMENT YIELD

An estimate of the sediment yield from the watershed to the Pima Road Channel is needed in regard to allocating dead storage in the detention basins, in estimating the sediment removal maintenance requirements and cost, and for hydraulic considerations in regard to channel design. Sediment yield was estimated by PACE for Concept A and those results are provided in the September 1995 report. Mr. Robert L. Ward, PE estimated the sediment yield in regard to basin 53R for the City of Scottsdale. Mr. Ward's work was used and evaluated in regard to independent estimation of the sediment yield, but is not subject to review for the intent of this project. Greiner did not provide sediment yield study results.

Mr. Winn Hjalmarson of the GVSCE team, provided independent estimation of the sediment yield (Appendix H). Several methods of estimating sediment yield are used by Hjalmarson and he also provides an evaluation of PACE's results and those by Ward. Although GVSCE indicates some questions over PACE's sediment yield procedures, the results by Hjalmarson, PACE and Ward are in general agreement considering the assumptions that are required and the uncertainty inherent in such estimates.

The results by Hjalmarson for the mean annual sediment yield to the Pima Road Channel are presented in Table 1. The results for the 100-year flood are shown in Table 2. The results for other flood frequencies can be obtained from Hjalmarson's report. The estimate of the dead storage requirement for the three basins of Concept A and for the one basin of Concept 1 are shown in Table 3. The criteria proposed for dead storage is a volume equal to five times the mean annual load plus the 100-year flood load. This provides ample opportunity for basin maintenance on a regular basis and after major flood events. This is the sediment dead storage criteria that is used by both Albuquerque and Clark County.

In regard to the sediment yield values of Table 2, the maximum likely sediment yields equate to average concentrations of 40,000 to more than 50,000 mg/l. The maximum concentrations would be considerably higher. As a point of reference, previous studies by Dr. Sabol for Reata Pass Wash indicated sediment concentrations of 80,000 mg/l at the apex of the fan during 100-year flood events. That result supports the sediment yield reported by Hjalmarson. Such high sediment loads have consequence in regard to the hydraulics of the Pima Road Channel.

The sediment yields that are reported are for current watershed conditions. There is question as to what impacts future land development will have on sediment yield. Considering the extend of land that will remain natural under the City of Scottsdale Environmentally Sensitive Lands ordinance, the mass grading under land development, the subsequent landscaping of yards with decomposed granite with no grass lawns and sparse vegetation, and the likely use of unlined drainage channels in urbanizing areas, it should be expected that future sediment yield will not be diminished.

TABLE 1

Mean annual sediment yield to the Pima Road Channel

Concentration Point	Mean Annual Sediment Yield, in acre-feet: Minimum [a]	Average [b]	Maximum [c]
(1)	(2)	(3)	(4)
30N	.025	.039	.061
31.1	.026	.035	.070
34.1	.051	.133	.564
Happy Valley Basin	.102	.207	.695
36.1	.005	.019	.035
36R	.076	.126	.456
36R2	.008	.030	.093
51.1A	.036	.064	.120
Deer Valley Basin	.125	.239	.704
52A	.005	.011	.006
52B2C	.061	.086	.225
53A2	.018	.030	.008
DB3	----	.090	.110
Union Hills Basin	.084	.237	.331
Total	.311	.681	1.730

a - RUSLE (likely), Hjalmarson, Table 7
b - Flaxman (1974), Hjalmarson, Table 3
c - Flaxman (1972), Hjalmarson, Table 5

TABLE 2

100-year flood sediment yield to the Pima Road Channel

Concentration Point (1)	Sediment Yield, in acre-feet: Minimum Likely [a] (2)	Average [b] (3)	Maximum Likely [c] (4)
30N	.308	.571	1.468
31.1	.266	.494	1.269
34.1	1.052	1.953	5.019
Happy Valley Basin	1.626	3.018	7.756
36.1	.122	.226	.580
36R	1.138	2.111	5.424
36R2	.208	.386	.993
51.1A	.557	1.033	2.653
Deer Valley Basin	2.025	3.756	9.650
52A	.066	.122	.312
52B2	.773	1.434	3.685
53A2	.236	.438	1.125
DB3	----	1.300	1.600
Union Hills Basin	1.075	3.294	6.722
Total	4.726	10.068	24.128

a - RUSLE (likely), Hjalmarson, Table 8

b - Flaxman (1974), Hjalmarson, Table 4

c - Flaxman (1972), Hjalmarson, Table 6

TABLE 3

Estimate of dead storage requirement for detention basins for the Pima Road Channel

Basin	Sediment Yield, in ac-ft		Dead Storage Volume [a]	Mean Annual Sediment Haul	Drainage Area	Mean Annual Sediment Yield
	Mean Annual	100-yr	ac-ft	cu. yards	sq. miles	ac-ft/sq. mi.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Concept A						
Happy Valley	0.70	7.76	11.3	1,130	2.38	0.29
Deer Valley	0.70	9.65	13.2	1,130	3.90	0.18
Union Hills	0.33	6.72	8.4	530	4.95	0.07
				2,790	11.23	
Concept 1						
Union Hills	1.73	24.13	32.8	2,790	11.23	0.15

[a] - Dead Storage Volume = 5 x Mean Annual + 100-yr

APPENDIX B

SEDIMENT YIELD REPORT BY H.H. HJALMARSON, PE

CITY OF SCOTTSDALE
DESERT GREENBELT PROJECT

Pima Road Channel

Review of sediment yield

by
Hjalmar W. Hjalmarson, PE

for

George V. Sabol
Consulting Engineers, Inc.

Aug. 8, 1996

Pima Road Channel

Review of sediment yield
by
Winn Hjalmarson, PE
Aug. 8, 1996

Registered Professional Engineer (Civil)
Certificate No. 3997
HJALMAR W. HJALMARSON
Date Signed 8-8-96
ARIZONA, U.S.A.

INTRODUCTION

The original intent of this review was to examine sediment yield estimates by Greiner and PACE but Greiner did not furnish us with such an analysis. Ward's work was furnished to us by the City of Scottsdale and is used for comparison purposes only. This review and comparison of sediment yield for storms estimated by the PACE and Ward models uses published regional relations of average or typical peak discharge, annual runoff and mean annual sediment yield. Also, published average soil and vegetation parameters such as the total annual dry weight production of plants and soil particle size were used for the analyses of sediment yield. The corresponding estimated sediment yield for storms at the Pima Road sites that is used for this review is for average hydrologic and watershed conditions in the area. Judicious use of this review analysis for purposes other than review, such as design, is suggested because of the large variability associated with estimates of sediment yield.

The HEC1 input of the Ward and PACE models was first examined. Several apparent mismatches between model parameters and physical features were observed (See appendix of this review). Model parameters were discussed with Bob Ward on July 30, 1996 and the Ward model generally seems reasonable. There are apparently serious problems with the factors used by PACE (really the Greiner HEC1 model). This is especially true with the channel characteristics on the R/K records. Thus, further review of the HEC1 model by PACE was not performed. Rather, an independent estimate of runoff and sediment yield was made using U.S. Geological Survey and NRCS data and information. PACE's estimate of sediment yield also is briefly reviewed in the appendix. The sediment yield computations by PACE also were reviewed as described in the appendix and at the end of this review. This analysis brings forward potentially useful U.S. Geological Survey information for peak discharge, runoff and sediment yield estimation in central Arizona.

Most of this review is of sediment yield from basins draining directly into the Pima Road channel. Estimates of sediment yield directly into Basin 53R from the area to the west of Pima Road and to the north are also made because of possible use for design.

PEAK DISCHARGE, RUNOFF AND SEDIMENT YIELD

Runoff and sediment yield for the sub-areas was computed and estimated independent of the methods used by PACE (includes Greiner) and Ward. Regional flood frequency, peak discharge-runoff volume and runoff volume frequency relations for storms based on USGS data and published reports was the basis of this review technique. Such a review is not influenced by model limitations and assumptions made by model users when attempting to match model parameters with the physical features of the basins. The Flaxman methods of estimating sediment yield and the RUSLE method of estimating soil loss are used.

Site conditions

The sediment balance along the slopes to the east of the proposed Pima Road channel appears to be fairly steady and may have turned slightly negative during the early part of this century. Some channel trenching with incision into the piedmont surface is evident a few miles to the northwest where channel sedimentation on the lower piedmont appears to have been replaced by erosion in the geological recent past. Channel headcutting also is evident along Cave Creek and adjacent tributary channels located to the west and northwest of the Pima Road sites. In general, any channel trenching in the area is restricted by the erosion resistant calcium carbonate of developed soil on fan terraces. For example, along Pima Road and in much of the subareas the landforms are fan terraces where runoff is slow and the hazard of water erosion is slight (Camp, 1986). However, a good plant and ground cover should be maintained if erosion and sediment yield are to be controlled.

Little channel trenching is evident in the subareas to the east of Pima Road and below the Reata Pass channel that diverts floodflow to the south at the apex of the Reata Pass Alluvial Fan. Near stationarity of average annual soil loss appears likely. Stationarity is important if useful estimates of sediment yield are made using soil loss methods such as RUSLE and sediment yield equations of Flaxman. There also is no evidence of runoff or peak discharge trends for small streams in the area (Thomas, Hjalmarson, and Waltemeyer, 1994). Accordingly, this review of computed sediment yield from the hillslopes of the sub-areas does not include sediment derived from significant gullying and channel bed and bank cutting.

The rather dense desert vegetation consists of scattered Palo Verde trees, brush and grass. Along Pima Road the characteristic vegetation is Triangle Bursage, Big Galleta, Bush Muhly, Creosote bushes with numerous grasses and forbs. A close examination of the soil surface typically will reveal cryptogamic crusts in sunny areas and grasses in the more shady areas under tree and brush canopies. Desert vegetation is very important for soil stabilization and control of sediment yield (Ken Renard, oral communication, July 1996). General soil and desert shrub land conditions are described in the NRCS soil survey report by Camp (1986).

Deposited sediment along the channels is from water flows and not debris flows based on a field examination of several channels. However, large amounts of bed sediment can be remobilized into debris type slugs for at least short distances during flash flows.

Limitations

Equations of mean annual soil loss like RUSLE do not account for climate changes that produce unidirectional space-time changes in channel processes such as gullies. For example, in the San Pedro River Basin of southern Arizona, where there has been geological recent headcutting of the river and it's tributaries, the sediment yield from gullies and channel enlargement in more than 30 times the sediment yield from rill and inter-rill processes estimated by RUSLE (Figure 3 of Toy and Osterkamp, 1995). Renard (1981) found sediment yield increases of nearly 4 times that for overland flow estimated by USLE as a result of channel and bank erosion at two small watersheds in San Pedro Basin of southeastern Arizona. The widespread recent headcutting of the San Pedro River channel and the many of the tributary channels is obvious from field reconnaissance of the drainage area south of Interstate Highway 10. Obvious headcutting also is displayed in photographs of New Mexico basins but the gully erosion was only 7 percent of the total erosion (Leopold, Emmett and Myrick, 1966). Recent head cutting, perhaps post 1890, also is apparent in the Cave Creek and Indian Bend Wash basins especially near the main channel of Cave Creek. Channel incision also is apparent in other nearby places such as Lost Dog Wash at the southern end of the McDowell Mountains. Thus, for watersheds larger than a few acres that have channels, mean annual soil loss may or may not be a large part of the sediment yield. The proportion of sediment yielded from the soil and from channel and bank cutting is difficult to estimate.

The above San Pedro Basin examples serve as a reminder that large amounts of sediment can be derived from the channels of small desert watersheds. There are large deposits of sediment on the hillslopes above the proposed Pima Road channel that potentially could be mobilized especially during construction of homes when soils are disturbed. Large amounts of sediment can be derived from rill development , gullying and channel and bank cutting where concentrated runoff from urban development crosses unprotected soil.

This review/evaluation is for the natural watersheds and assumes surface disturbances from urban development on runoff and sediment yield are small. A prominent and vexing feature of the area is the steep slopes of the piedmont on the west facing slopes of the McDowell Mountains and along the Pima Road channel alignment. Another important feature that influences this review is the often invisible cryptogamic crust that binds the soil surface particles together with strands of "glue". A fundamental approach to land development in this area should address (1) the effect of supercritical flow velocities on channel erosion and (2) the effect of surface disturbances of the desert soils on accelerated soil loss by wind and water erosion.

The steep piedmont slopes pose difficult hydrologic and hydraulic modeling challenges. The rough hillslopes convey runoff at tranquil velocities while confined floodflow travels at rapid velocities. There may be chutes and pools in the steeper channels as flow changes back and forth from upper and lower regime. Photographs of sheetflow during the June 22, 1972 flood show a mix of cross currents and possibly both upper and lower regime flow. The roughness coefficient for these shallow flow conditions is high. Translatory waves are possible during major floods where channel width-depth ratios are large and slopes exceed about 3 percent.

Available sediment yield data

Sediment yield data for two nearby sites were available for this review. These sites are Black Hills Tank to the north of the McDowell Mountains and Cave Creek Dam to the west. Other sediment yield data for a few arid basins in Arizona and California are also used (Table 1). The wide range of unit yield is partly the result of soil differences where, for example, the relatively small yield of 0.08 ac-ft/mi^2 from the 30 mi^2 basin above Saddleback Dam which is old-developed soil covered with desert pavement. The differences of unit yield are also related to climate differences where, for example, the sites in San Diego County, CA with yields of only 0.07 and 0.13 ac-ft/mi^2 have an annual precipitation of only 3 inches. Some sites with a large sediment yield such as Davis Tank, AZ have channel bed and bank erosion. Lastly, other sites with relatively high yield such as Black Hills Tank, AZ may have experienced a large flood during a short period of data collection.

Table 1. Measured sediment yield at southwestern desert basins in Arizona and California.

Site	Area (mi^2)	Sediment Yield Ac-ft	Sediment Yield Ac-ft/mi^2	Reference
Camp Marston, CA	1.59	.*	0.14	1
Cave Ck, AZ	121	.*	.31	1
San Diego Co., CA	.*	.*	.13	1
San Diego Co., CA	.*	.*	.07	1
Spookhill, AZ	16.4	.*	.15	1
Saddleback Dam, AZ	30	.*	.08	1
Davis Tank, AZ	.21	.18	.96	2
Kennedy tank, AZ	.97	.26	.27	2
Juniper Tank, AZ	2.00	.58	.29	2
Alhambra Tank, AZ	6.61	.20	.03	2
Black Hills Tank, AZ	1.14	.78	.68	2
Black Hills Tank, AZ	1.56	.9	.58	3
Mesquite Tank, AZ	9.0	.30	.03	2
Tank 76, AZ	1.17	.25	.21	2

References: (1) Letter on file at City of Scottsdale, (2) Peterson, 1962, and (3) Langbien, Hains and Culler, 1951.

Runoff and sediment yield data were collected at the Black Hills Tank, near Cave Creek, Arizona, from 1945 to 1948 (Langbien, Hains and Culler, 1951 and Peterson, 1962). The precise location of the site is uncertain but it was near the northern end of the McDowell Mountains on a granite pediment at an elevation of about 2,600 ft. Vegetation was mountain-brush type consisting mainly of snakeweed, yucca, creosote bush, cactus, small palo-verde trees and with mesquite along the channels. According to Langbien, Hains and Culler (1951) the approximately 2-1/2 mile long drainage basin was 1.56 mi^2 and headed at 3,200 ft. Elevation. The basin was drained by a network of 0.5 to 2 feet deep channels at a slope of about 2 percent. The granitic rock was capped with a thin veneer of coarse residual soil. Average annual sediment was 0.9 acre-feet based on capacity surveys at the beginning and end of the data collection. A field examination of the 1948 flood reportedly showed coarse sediment with uprooted mesquite trees deposited in a fan at the entrance to the tank. There was no spill during the period.

According to Peterson (1962) the drainage basin was only 1.14 mi^2 and the average annual sediment yield was 0.78 acre-feet. This results in an average annual yield of 0.68 ac-ft or 17 percent greater than the yield reported by Langbien, Hains and Culler (1951) apparently for the same site. This difference in reported sediment yield is not significant. However, the reported large flood in 1948 probably is significant because unusually large amounts of sediment were deposited in the tank. The reported average annual sediment yield for the four year period probably is too high because of the 1948 flood.

Peak discharge

A convenient method of estimating the magnitude and frequency of flood peaks on ungaged watersheds in the arid southwestern United States is the USGS regional method developed by Thomas, Hjalmarson and Waltemeyer (1994). This method is used by many state agencies in the western United States and is recommended for flood plain management levels 1 and 2 of the recent Arizona State Standards Work Group (See Arizona State Standard 2-96). The 2-year to 100-year peak discharges were computed using this method for the 11 subareas (Table 2-A and Figure 1).

The storm of June 22, 1972 produced record amounts of runoff at nearby sites. Very heavy rains in amounts up to 4 inches in 2 hours were recorded. The heaviest rain probably was to the southwest of the subareas in the Phoenix Mountains and also along the southern end of McDowell Mountains. The peak discharge for Indian Bend Wash that drained 139 $mi.^2$ was 21,000 ft^3/sec and is the highest peak since at least 1922. Unit peak discharges at miscellaneous sites determined by the USGS were from 528 to 956 $ft^3/s/mi^2$ at the southern end of the McDowell Mountains and from 1,920 to 3,400 $ft^3/s/mi^2$ along the north side of the Phoenix Mountains (nearby recorded rainfall was 3.24 in.) a few miles west of the subareas (Figure 1). There was a considerable amount of runoff crossing Pima Road in the many small channels.

NOTE

The tables in this review contain data from Minitab (a registered trademark) statistical software package that have too many significant figures. The precision of computed amounts generally is about 2 and possibly 3 significant figures. Apologies are made for any inconvenience.

Table 2. Peak discharge, runoff, volume frequency and mean annual discharge for storms at Pima Road sites.

A. Peak discharge, in ft^3/s.

Site*	Area	Q2	Q5	Q10	Q25	Q50	Q100
30N	0.660	31.647	130.764	256.88	518.49	761.66	1145.86
31.1	.515	27.075	112.142	222.14	451.52	637.26	947.52
31.2	.465	25.390	106.055	210.98	429.93	596.90	883.01
34.1	.740	34.009	144.763	284.27	571.19	857.77	1298.24
36.1	.227	16.173	65.666	133.29	277.56	332.06	467.99
36R	2.15	66.519	297.932	568.35	1105.36	1891.84	2951.61
36R2	.300	19.273	81.134	163.86	338.01	431.96	622.22
51.1A	1.221	46.605	209.695	407.65	805.58	1303.98	2011.76
52A	.146	12.268	50.790	1 04.80	220.82	238.37	323.76
52B2	1.586	54.931	260.626	505.36	989.06	1661.15	2584.20
53A2	.566	28.732	132.846	265.59	535.90	782.03	1173.30
Total	8.58	158.857	794.652	1467.28	2730.38	5059.66	7910.82

B. Runoff, in ac-ft.

Site*	v2	v5	v10	v25	v50	v100
30N	0.13695	7.6153	17.231	40.286	64.141	105.11
31.1	0.11340	6.3242	14.454	34.081	51.699	83.52
31.2	0.10492	5.9114	13.581	32.121	47.766	76.70
34.1	0.14940	8.6120	19.477	45.289	74.053	122.24
36.1	0.06081	3.3108	7.793	18.922	23.503	35.59
36.R	0.33628	20.6143	45.017	100.631	192.733	330.04
36R2	0.07518	4.2758	10.004	24.013	32.305	50.23
51.1A	0.21870	13.4808	30.119	68.640	122.890	207.60
52A	0.04354	2.4267	5.827	14.350	15.741	22.79
52B2	0.26679	17.5352	39.056	87.971	164.687	281.03
53A2	0.1218	7.7622	17.940	41.928	66.220	108.16
Total	0.9636	67.5155	141.737	300.361	633.306	1087.27

C. Mean annual runoff, in ac-ft.

Site *	.4v2	.2v5	.08v10	.04v25	.015v50	.015v100	sum
30N	0.0548	1.5231	1.3785	1.6115	0.96211	1.5766	7.1065
31.1	0.0453	1.2648	1.1563	1.3632	0.77548	1.2528	5.8581
31.2	0.0419	1.1823	1.0865	1.2848	0.71649	1.1505	5.4625
34.1	0.0597	1.7224	1.5581	1.8116	1.11080	1.8335	8.0962
36.1	0.0243	0.6622	0.6235	0.7569	0.35254	0.5339	2.9532
36.R	0.1345	4.1229	3.6013	4.0252	2.89099	4.9505	19.7255
36R2	0.0300	0.8552	0.8003	0.9605	0.48457	0.7534	3.8841
51.1A	0.0875	2.6962	2.4095	2.7456	1.84335	3.1140	12.8961
52A	0.0174	0.4853	0.4662	0.5740	0.23611	0.3419	2.1210
52B2	0.1067	3.5070	3.1245	3.5189	2.47030	4.2154	16.9428
53A2	0.0487	1.5524	1.4352	1.6771	0.99330	1.6224	7.3292
Total	0.3854	13.5031	11.3390	12.0144	9.49959	16.3091	63.0506

*Corresponds to HEC1 concentration point along Pima Road channel (typical).

Runoff

Flood volume is generally related to the peak discharge of storms. Data from gaging stations in Arizona have been plotted by the U. S. Geological Survey and although data are widely scattered, there is a definite trend between flood volume and peak discharge. Relations for three groups of gaging stations have been defined. The gaging stations are in northern Arizona, southern Arizona (Aldridge and Condes, 1970) and in southeastern Arizona (Burkham, 1976). A forth relation for a single USGS stream gage 09512200 south of Phoenix was developed by Hjalmarson and Kemna (1991). The relations shown in Figure 2 are of the form

$$V = CQ_p^a \qquad (1)$$

where V = volume of runoff, in acre-feet,
C = coefficient,
Q_p = corresponding peak discharge, in ft³/sec, and
a = exponent.

The coefficient and exponent for the three regional relations are:

Region	C	a
Northern Arizona	0.008	1.5
Southern Arizona	0.026	1.18
Southeastern Arizona	0.03	1.14

Because none of the regional relations is specifically for the Pima Road subareas and because of the wide scatter of data about the relations, the volume of storm runoff corresponding to the 2-year to 100-year peak discharges in the 11 subareas was computed using the following mean relation

$$V = 0.021\ Q_p^{1.209}, \qquad (2)$$

It is important to note the average relation of the three relations closely agrees with the southern and southeastern Arizona relations. The gaged peak discharge and runoff for the October 6, 1993 storm at the FCDMC gage on Indian Bend Wash at Indian Bend Road (Figure 2) plot to the left of the mean relation. This gage is located to the south of the Pima Road subareas in the City of Scottsdale below much of the area of storm rainfall on October 6, 1993 (Waters, 1993). The annual peak discharge-runoff volume data at the U.S. Geological Survey gaging station at the same site where the drainage area is 142 mi^2 also plot to the left of the mean relation. Larger runoff volumes are expected downstream along the main drainage because of flood peak attenuation resulting from sheetflow (Figure 2). The storm runoff volumes are given in Table 2-B.

The flow duration curve (Figure 3) was developed and integrated to compute the mean annual runoff as follows:

$$Q_{mean} = \int Q\,dP \qquad (3)$$

where P is the probability of the flood volume = $1/t$
where t = recurrence interval, in years.

Using storm volumes for the 2-, 5-, 10, 25-, 50-, and 100-year floods the mean annual runoff is:

$$Qmean = 0.015Q_{100} + 0.0155Q_{50} + 0.04Q_{25} + 0.08Q_{10} + 0.2Q_5 + 0.4Q_2 \qquad (4)$$

And the results are given in Table 2-C. The corresponding mean annual runoff for the 11 subareas plots to the right of the regional relation of mean annual runoff to size of basin for central Arizona by Moosburner (Burkham, 1976) shown in Figure 4. However, the annual runoff for the subareas more closely agrees with the very general relation for a map of the U.S. by Langbein(1952). Close agreement between the estimated mean annual runoff from storms is not expected because of the variable nature of runoff as discussed by Burkham(1976). The flow duration curve (runoff frequency curve) was next used to estimate the sediment yield for storms.

Sediment Yield

Sediment yield from sheetflow, the wash load typically from watershed hillslopes, is estimated for storms and for the average year. The technique used is (1) an estimate of mean annual sediment yield is made using a bulk parameter model such as RUSLE (1995) and (2) the mean annual yield is apportioned to the storms by differentiating the flow-duration relation. This wash load component of total sediment load is assumed directly proportional to the amount of storm runoff. Because this component is related to soil particle movement initiated by raindrop impact and the subsequent transport by sheetflow to rills and channels, this assumption is considered reasonable. Obviously this assumption does not pertain to the general climate-sediment yield relation where yield is low for both arid and humid climes. For storms, sediment yield from watershed hillslopes is assumed directly proportional to the amount of runoff.

Flaxman

Estimated total average annual sediment yield for the sites is 0.573 ac-ft using the modified Flaxman method (1974) (Table 3). A sediment yield of 1.64 ac-ft / year was estimated using Flaxman's (1972) (Table 5) original equation. Results for both of Flaxman's methods are presented for comparison with the results being reviewed. The factors are:

CLIM	=	ratio of average annual precipitation (in) to average annual temperature (°F),
SLOPE	=	average watershed slope (%),
COARSE	=	soil particles greater than 1.0 mm (%),
Q2	=	50% chance peak discharge (csm). Determined from the USGS regional equation (Thomas, Hjalmarson and Waltemeyer, 1994).

The soil aggregation index was zero based on the large amount of coarse sediment at the soil surface at all sites. The results of the revised Flaxman equation are in Table 3.

Table 3. Estimated mean annual sediment yield at Pima Road sites.

			FLAXMAN (1974)				
SITE	**AREA**	**CLIM**	**SLOPE**	**COARSE**	**Q2**	**SEDIMENT YIELD**	
	mi^2				**csm**	**$Ac\text{-}ft/mi^2$**	**Ac-ft**
30N	0.6600	0.17	5.38	50	32	0.058	0.039
31.1	0.5150	0.17	8.04	60	27	0.067	0.035
31.2	0.4650	0.17	8.27	35	25	0.109	0.051
34.1	0.7400	0.17	9.41	35	34	0.111	0.082
36.1	0.2270	0.17	3.46	30	16	0.082	0.019
36R	2.1500	0.17	4.46	35	67	0.059	0.126
36R2	0.3000	0.16	3.41	25	19	0.100	0.030
51.1A	1.2212	0.16	2.99	40	47	0.053	0.064
52A	0.1463	0.16	3.00	45	12	0.077	0.011
52B2	1.5859	0.16	3.13	37	55	0.055	0.086
53A2	0.5660	0.16	2.54	45	29	0.052	0.030
Sum	8.58	-	-	-	-	-	0.573
Mean	-	-	-	-	-	0.0667*	-
ALL	8.58	0.16	3.77	39*	159	0.041	0.355
*Area weighted value.							
Black Hills Tank, AZ	1.56**	0.171	2.3	30	20	0.20	.31
**Peterson(1962).							

The corresponding sediment yield of each subarea for storms was computed by using the sediment yield frequency relation like that for storm runoff (Figure 3). The area under the relation is equal to the average annual sediment from Flaxman's method. The corresponding yield for each storm was then computed using Equation 4. The estimated sediment yield for the subareas to the east of Pima Road is based of Flaxman's annual yield of 0.573 ac-ft where sediment yield is assumed proportional to the runoff for storms (Table 4).

Table 4. Sediment yield volume frequency for storms at Pima Road sites.

Site	SY2	SY5	SY10	SY25	SY50	SY100
			FLAXMAN (1974)			
			(IN AC-FT)			
30N	0.0007444	0.041395	0.093662	0.218985	0.34865	0.57133
31.1	0.0006707	0.037401	0.085481	0.201555	0.30574	0.49395
31.2	0.0009771	0.055046	0.126460	0.299104	0.44479	0.71419
34.1	0.0015148	0.087313	0.197465	0.459167	0.75079	1.23930
36.1	0.0003855	0.020989	0.049407	0.119961	0.14900	0.22563
36R	0.0021512	0.131870	0.287971	0.643733	1.23291	2.11124
36R2	0.0005785	0.032902	0.076981	0.184780	0.24858	0.38649
51.1A	0.0010879	0.067056	0.149815	0.341428	0.61127	1.03265
52A	0.0002322	0.012942	0.031076	0.076532	0.08395	0.12157
52B2	0.0013617	0.089497	0.199336	0.448995	0.84054	1.43432
52A2	0.0004932	0.031421	0.072621	0.169724	0.26806	0.43782
Total	0.010197	0.60783	1.3703	3.1640	5.2843	8.7685

The results of the original Flaxman (1972) equation are given in Table 5.

Table 5. Estimated mean annual sediment yield at Pima Road sites.

SITE	AREA mi^2	CLIM	SLOPE	COARSE	SEDIMENT YIELD $Ac\text{-}ft/mi^2$	Ac-ft
			FLAXMAN (1972)			
30N	0.6600	0.17	5.38	50	0.092	0.061
31.1	0.5150	0.17	8.04	60	0.136	0.070
31.2	0.4650	0.17	8.27	35	0.429	0.200
34.1	0.7400	0.17	9.41	35	0.493	0.364
36.1	0.2270	0.17	3.46	30	0.154	0.035
36R	2.1500	0.17	4.46	35	0.212	0.456
36R2	0.3000	0.16	3.41	25	0.309	0.093
51.1A	1.2212	0.16	2.99	40	0.098	0.120
52A	0.1463	0.16	3.00	45	0.041	0.006
52B2	1.5859	0.16	3.13	37	0.142	0.225
53A2	0.5660	0.16	2.54	45	0.014	0.008
Sum	8.58	-	-	-	-	1.637
ALL	8.58	0.16	3.77	39*	0.129	1.110**
Black Hills	1.56***	0.171	2.3	30	.15	.23

*Area weighted value. **For natural basin not altered by Pima Road channel. ***From Peterson(1962).

The small computed mean annual sediment yields for sites 52A and 53A2 are the result of the lesser basin slope and the coarser surface material. Estimated storm sediment yield for the subareas based of Flaxman's annual yield of 1.637 ac-ft follow:

Table 6. Sediment yield volume frequency for storms at Pima Road sites.

			FLAXMAN (1972)			
Site	SY2	SY5	SY10	SY25	SY50	SY100
			(IN AC-FT)			
30N	0.0019125	0.106343	0.240618	0.56257	0.89569	1.46774
31.1	0.0017229	0.096083	0.219602	0.51779	0.78546	1.26896
31.2	0.0025101	0.141414	0.324877	0.76840	1.14267	1.83475
34.1	0.0038914	0.224307	0.507287	1.17960	1.92879	3.18376
36.1	0.0009904	0.053921	0.126927	0.30818	0.38278	0.57964
36R	0.0055265	0.338773	0.739797	1.65375	3.16734	5.42377
36R2	0.0014862	0.084525	0.197764	0.47470	0.63860	0.99290
51.1A	0.0027947	0.172266	0.384875	0.87713	1.57036	2.65288
52A	0.0005965	0.033247	0.079834	0.19661	0.21566	0.31230
52B2	0.0034982	0.229919	0.512095	1.15347	2.15935	3.68476
52A2	0.0012671	0.080721	0.186563	0.43602	0.68864	1.12476
Total	0.0262	1.56	3.52	8.13	13.6	22.5

RUSLE

The revised universal soil loss equation (RUSLE) was used to estimate mean annual soil loss and to make rough estimates of sediment yield of the subareas. The equation is:

$$A = RKLSCP$$

where A = average annual soil loss from sheet and rill erosion caused by overland flow,
R = factor for climatic erosivity,
K = factor for soil erodibility measured under standard condition,
L = factor for slope length,
S = factor for slope steepness,
C = factor for cover (trees, grasses and cryptogamic crusts), and
P = factor for support practices.

These factors were determined mostly by field inspection and the use of secondary information such as aerial photographs, soil survey reports and maps, topographic maps, and the RUSLE user guide. Estimates of the percent canopy and ground cover, slope lengths, and slope steepness generally were made by field inspection and use of aerial photographs. An R factor of 30 was selected using the RUSLE user guide. Values of K and annual site production of vegetation, used for factor C, were determined from the NRCS soil survey by Camp (1986). Typical values are R = 30, K = 0.1 to 0.2, LS = 0.4 to 1.3, C = 0.035 to 0.058 and P = 1. A sediment porosity of 0.4 was used to convert the computed soil loss from tons to ac-ft. The results of the computations are the "likely" values in Table 7.

Field estimates of percent of ground cover and the percent of canopy cover consisted mostly of pacing transects and logging the type and amount of vegetation condition. These estimates are crude mostly because only a few transects were made and because the cryptogamic crusts are difficult to see. Because of these conditions, worst case or minimum cover conditions also were used in the estimate of C values. The cover factor, C, is very sensitive to the percent of ground cover and the percent of canopy cover. This resulted in the rather large C = 0.182 for all subareas with the "maximum" soil loss (Table 7). The maximum soil loss may represent post fire conditions and is considered the upper limit for soil loss from the soil surface and rills.

Table 7. Estimated mean annual soil loss of subareas using RUSLE.

Site	Basin	Annual Soil Loss			
	Area	Likely		Maximum	
	mi^2	T/ac	ac-ft	T/ac	ac-ft
30N	0.660	0.13	0.02521	0.40	0.07758
31.1	0.515	0.17	0.02573	0.55	0.08323
31.2	0.465	0.13	0.01776	0.57	0.07788
34.1	0.740	0.15	0.03262	0.71	0.15439
36.1	0.227	0.07	0.00467	0.37	0.02468
36R	2.150	0.12	0.07582	0.63	0.39802
36R2	0.300	0.09	0.00793	0.29	0.02556
51.1A	1.221	0.10	0.03588	0.39	0.13995
52A	0.146	0.11	0.00473	0.41	0.01763
52B2	1.586	0.13	0.06059	0.52	0.24233
52A2	0.566	0.11	0.01829	0.36	0.05987
Sum	8.58	--	0.309	--	1.30

Estimated sediment yield for storms at the subareas using RUSLE's average annual soil loss of 0.309 ac-ft (likely) and 1.301 ac-ft (maximum) are in Table 8-A and 8-B, respectively. Obviously, these estimated yields do not include sediment derived from channel bed and bank erosion and gullying.

Table 8. Sediment yield from RUSLE for likely and maximum yield conditions.

A. RUSLE Likely C.

Site	SY2	SY5	SY10	SY25	SY50	SY100
30N	0.0004013	0.0223118	0.050484	0.118033	0.187923	0.30795
31.1	0.0003615	0.0201591	0.046074	0.108638	0.164797	0.26624
31.2	0.0005266	0.0296699	0.068162	0.161217	0.239742	0.38495
34.1	0.0008165	0.0470617	0.106434	0.247491	0.404678	0.66798
36.1	0.0002078	0.0113131	0.026630	0.064659	0.080311	0.12161
36R	0.0011595	0.0710778	0.155216	0.346972	0.664537	1.13796
36R2	0.0003118	0.0177342	0.041493	0.099597	0.133985	0.20832
51.1A	0.0005864	0.0361429	0.080750	0.184030	0.329476	0.55660
52A	0.0001252	0.0069756	0.016750	0.041251	0.045247	0.06552
52B2	0.0007340	0.0482391	0.107442	0.242008	0.453051	0.77310
52A2	0.0002659	0.0169361	0.039143	0.091481	0.144484	0.23598
Sum	0.0054963	0.32762	0.73858	1.7054	2.8482	4.7262

B. RUSLE Maximum C.

Site	SY2	SY5	SY10	SY25	SY50	SY100
30N	0.0015204	0.084543	0.191291	0.44725	0.71207	1.16685
31.1	0.0013697	0.076386	0.174583	0.41165	0.62444	1.00882
31.2	0.0019955	0.112424	0.258277	0.61088	0.90842	1.45862
34.1	0.0030937	0.178324	0.403293	0.93778	1.53339	2.53109
36.1	0.0007874	0.042867	0.100907	0.24500	0.30431	0.46082
36R	0.0043935	0.269325	0.588139	1.31473	2.51804	4.31189
36R2	0.0011815	0.067198	0.157223	0.37739	0.50769	0.78936
51.1A	0.0022218	0.136951	0.305975	0.69732	1.24844	2.10904
52A	0.0004742	0.026432	0.063468	0.15630	0.17145	0.24828
52B2	0.0027811	0.182785	0.407116	0.91701	1.71668	2.92938
52A2	0.0010074	0.064173	0.148317	0.34664	0.54747	0.89418
Sum	0.020826	1.2414	2.7986	6.4619	10.792	17.908

MUSLE

The modified universal soil loss equation (MUSLE) was briefly examined because it was used by PACE. MUSLE tends to over-predict sediment yields for small floods and under-predict sediment yields for large floods. PACE's use of MUSLE is considered incorrect because the factor, C, for ground cover is much less than 0.45 for rangeland(Renard and Stone, 1982 and Jackson, Gebhardt, and Van Haveren, 1986). A maximum C = 0.182 was used for the Pima Road sites for this review and the range of likely C = 0.035 to 0.058 is in agreement with rangeland conditions in Arizona. Also, PACE said P=0 was used when they correctly used P = 1. It is unclear how the C=0.45 was calculated by PACE.

Application of MUSLE to the Pima Road sites for Q100 using the regional values for peak discharge and runoff volume(Table 2) gives the results shown in Table 9. The likely factors for basin conditions give a total sediment yield of 3,719 tons or only 1.71 ac-ft. This value seems low. The maximum conditions(at C=.182) give a total sediment yield of 15,673 tons or 7.2 ac-ft. This amount of sediment yield closely agrees with the revised Flaxman yield. The sediment yield by PACE(Table 6 of PACE) is about 3 times the maximum total yield in Table 9-B.

It is interesting that the ratio of the estimated 100-year and 2-year sediment yield by PACE for the Happy Valley Road detention basin is 6.1 to 1 and the corresponding ratio for Flaxman(Table 4) is 860 to 1. This finding supports information published several years ago that the MUSLE method gives too little yield for large floods and too much yield for small floods. Use of MUSLE is not recommended for this project unless PACE can substantiate the use of C=0.45 and other probable deficiencies discussed above.

AREA WEST OF PIMA ROAD

Average annual and storm sediment yield was also estimated for the 2.655 mi^2 area to the west of Pima Road that drains directly into basin 53R. These estimates may be useful for design of basin 53R. No basins within the 2.655 mi^2 area are assumed and all of the runoff goes directly into basin 53R. The two Flaxman methods are used with the following results:

Flaxman method	Mean annual sediment yield (ac-ft)	Storm yield (ac-ft) 2yr	5yr	10yr	25yr	50yr	100yr
1972	0.11	0.005	0.11	0.27	0.62	0.98	1.6
1974	0.09	0.004	0.09	0.22	0.51	0.80	1.3

According to the Flaxman methods the affect of the percent of coarse rock particles on the soil surface has a significant effect on the computed amount of yield. Ken Renard(oral

Table 9. Sediment yield for 100-year flood using MUSLE method.
A. Using RUSLE likely conditions.

Site	Area mi^2	KLSC	Q100 ft^3/s	V100 ac-ft	Sy tons
30N	0.6600	0.004292	1145.86	105.11	285.502
31.1	0.5150	0.005600	947.52	83.52	294.450
31.2	0.4650	0.004410	883.01	76.70	212.510
34.1	0.7400	0.004978	1298.24	122.24	386.447
36.1	0.2270	0.002295	467.99	35.59	50.418
36R	2.1500	0.004060	2951.61	330.04	870.716
36R2	0.3000	0.003024	622.22	50.23	94.502
51.1A	1.2212	0.003240	2011.76	207.60	432.436
52A	0.1463	0.003800	323.76	22.79	52.920
52B2	1.5859	0.004320	2584.20	281.03	785.972
52A2	0.5660	0.003696	1173.30	108.16	253.160
Total	8.5800	*	*	*	3719

B. Using RUSLE maximum conditions.

Site	AREA mi^2	KSLC	Q100 ft^3/s	V100 ac-ft	Sy tons
30N	0.6600	0.013468	1145.86	105.11	895.88
31.1	0.5150	0.018200	947.52	83.52	956.96
31.2	0.4650	0.019110	883.01	76.70	920.88
34.1	0.7400	0.023842	1298.24	122.24	1850.88
36.1	0.2270	0.012285	467.99	35.59	269.88
36R	2.1500	0.021112	2951.61	330.04	4527.73
36R2	0.3000	0.009828	622.22	50.23	307.13
51.1A	1.2212	0.013104	2011.76	207.60	1748.96
52A	0.1463	0.013832	323.76	22.79	192.63
52B2	1.5859	0.017472	2584.20	281.03	3178.82
52A2	0.5660	0.012012	1173.30	108.16	822.77
Total	8.5800	*	*	*	15673

communication, July 1996) also stressed the importance of large sand and gravel particles on the soil surface. Renard stressed the importance of rock particles >1/4 inch that are not disturbed by raindrop impact. The entire 2.655 mi^2 area is Momoli soil (Camp, 1986) that has about 35 to 50% of surface particles > 1mm and about 25% of the particles > 1/4 inch. Thus, the Flaxman methods estimate small amounts of sediment yield for this area.

DISCUSSION

The review of sediment yield is independent of the methods used by PACE and Ward and attempted to determine the best method of estimating sediment yield along Pima Road. The review also attempts to shed light on the assumptions and limitations associated with estimates of sediment yield in this area. This review method may be useful for other studies and projects in central and southern Arizona. Several items related to the potential use of this review/analysis of sediment yield along Pima Road are discussed below.

D1.--The revised universal soil loss equation (RUSLE) is considered by some soil scientists and engineers to be the latest-reliable method. This method should produce reliable results where there is no headcutting and little, if any, sediment is yielded from channel bed and bank cutting. Thus, any estimates of sediment yield (by PACE, Ward, or other engineers) are expected to be about equal to or probably greater than the RUSLE soil loss (Figure 5).

D2.--The revised Flaxman (1974) method should produce rough but reliable estimates of sediment yield for typical watershed-channel conditions in the western U.S. The estimates by PACE using the sediment transport rate equation(STR) for the 100-year flood at the detention basins are in good agreement with the revised Flaxman method. PACE, however, did not use the revised Flaxman method and PACE made several fatal errors in their use of Flaxman's original method (See appendix).

D3.--The estimate by Ward at detention basin 53R is considerably more than the estimate using revised Flaxman but it is in good agreement with both Flaxman(1972) and the maximum soil loss that could be estimated using RUSLE. The estimates by PACE using the modified universal soil loss equation (MUSLE) for the 100-year flood at the Happy Valley Road and Deer Valley Road detention basins are also in good agreement with the original Flaxman method.

D4.--Photographs of channels following the June 22, 1972 flooding in the area clearly show channel bed and bank cutting and therefore, sediment yields from larger basins with developed channel networks is expected to be larger than yields estimated using RUSLE. There is little headcutting or channel bed and bank cutting above Pima Road and therefore, this component of sediment yield is not expected to be significantly more than the RUSLE yield for average annual conditions (Table 7). However, during major storms like that of June 22, 1972, the storm sediment yield might be larger than the amount estimated using RUSLE-likely (Table 8-A).

D5.--The comparison of the sediment yield frequency for storms from Flaxman's methods and Ward's unbulked bed-material yield suggests a significant channel degradation potential (Figure 6). Clearly, the transport capacity by Ward is much greater than the total sediment supply.

D6.--Sediment yield is related to basin and climate parameters and large differences in time and space are the rule (See Table 1). The computed annual sediment yield of this review and the measured annual yields shown in Table 1 have a similar and large scatter(Figure 7). Estimates of sediment yield in the semi-arid southwestern U.S. typically are imprecise and subject to intrinsic factors such as basin ground cover and extrinsic factors such as the prolonged absence of major storm precipitation that leads to accumulation of basin sediment. Thus, for engineering design, both upper and lower limits and an average relation of yield for storms seems a reasonable approach.

D7.--The basis of factors used for estimating equations such as MUSLE should be given. For example, the cover management factor, C,.can be incorrectly used to give a wide variety of results. Use of the RUSLE software potentially can narrow the range of factor values selected and reduce errors. The factors used for this review were selected with a limited amount of field data. Some of the factors used by PACE, however, appear to be selected without consideration of physical characteristics of the basins and published data.

CONCLUSIONS AND RECOMMENDATIONS

1. The Flaxman(1972)(Tables 5 and 6), PACE-MUSLE and Ward's(Option 1, Table 7.1 of Ward) methods produce similar results and are in general agreement. It is a coincidence the the PACE-MUSLE method produced similar results because the C factor is unreasonable for rangeland and the basis of the value of C was not given. These methods may over estimate the total amount of natural sediment yield (Figure 5) and the estimated mean annual and storm sediment yield appears to represent the upper limit for channel and detention basin design.

2. RUSLE (using the likely basin factors) (Table 7 and Table 8-A) appears to define the lower limit of sediment yield for channel design.

3. The revised Flaxman(1974) method and PACE-STR are in general agreement and appear to define average or expected sediment yield conditions.

4. For detention basin design the Flaxman(1974) method appears to provide reasonable estimates for sizing of dead storage. Dead storage sizing probably should include capacity for the 100-year storm and also for lesser storms because back to back storms may occur before sediment can be mechanically removed from dead storage. Also, the sediment yields for this review are associated with the 100-year peak discharge and may be less than yields associated with storms that produce lesser peak discharge but greater volumes of storm runoff.

5. The RUSLE-likely method should be used when considering minimum likely sediment yield for purposes such as unlined channel scour like that proposed by PACE. The

estimated storm sediment yield from this method is a reasonable lower limit for unlined channel scour evaluation.

6. The Flaxman (1974) method provides a useful sediment yield for both channel and detention basin design but the extreme conditions as discussed above should be considered. The great variability of sediment yield as depicted in Figure 7 and Table 1 and in Table III-7 of PACE needs to be appropriately considered for design purposes.

7. The sediment samples taken at 1 to 2 ft. depth by Greiner and used by PACE do not represent sediment actively leaving the subarea basins and leaving particular types of soil. Sediment samples should represent the sediment leaving areas of different types of soil. For example, the Anthony and Tres Hermanos soils are much finer grained than other soils in the area.

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APPENDIX

Specific review comments of the PACE methods and comparison of Ward's analysis is summarized.

HEC1 Models

The PACE and Ward models were briefly examined by assuming each model is of the existing network of desert washes. Most of the following comments are related to apparent inconsistencies between the modeling options selected from the several options available as defined in the HEC1 manual(1990) and the physical features and floodflow characteristics of the area.

Ward.--The input generally appears reasonable except for modeling of a few channels and some of the landslopes. No major problems were found but some of the factors are unclear. It is unclear why the diversion option to model distributary flow was not used. This option coupled with the RK/RD option seems to allow reasonable physically based modeling of floodflow of many piedmont slopes. Clearly, the use of a wide-flat-shallow flow channel to model a network of small rather parallel distributary channels is an oversimplification of the system of drainage channels. For example, the several small channels used for sub-area 31A generally match the physiography but the single 50 ft. wide channel with 130:1 bank slopes that was used to model sub-area 36L1 may be a mismatch. Sub-areas 31A and 36L1 are adjacent and appear very similar and the use of several small channels seems a better match of physical factors. It is unclear why these sub-areas were modeled differently but the model seems to produce reasonable results.

Modeling of sub-area 51 is another example of a possible mismatch of the model and physiography. The northwest part of this sub-area is composed of Pleistocene sediments with a tributary channel network. The remainder of the area is mostly Holocene sediments with distributary networks of channels. There are many individual and rather parallel distributary channels each with floodplains and with ridges between the channels. Typical side slopes of the small channels are about 4 to 1 or less. The channel banks are lined with brush and scattered desert trees. The channels are coarse sand and the floodplains are covered with grasses and brush. The resistance to shallow flows on the floodplains is great with Manning roughness coefficients of at least 0.1 for shallow depths. The larger distributary channels are trapezoidal and about 10 ft. wide with perhaps 4:1 perhaps sideslopes. Much of the floodflow on this surface will be shallow and not unlike overland flow (See Table 3.5 of HEC1 manual). Thus, it is unclear why a single channel 1500 ft wide with n=.045 is used for the model unless sheetflow is being modeled. If sheetflow is being modeled then an n=0.045 probably is too small. Also, it is unclear why the basin slope is considerably less than the channel slope (the slope on the UK record =.0213 and on the RK record=.0329). Seems like there is (1) a component of general land slope that is about the same as the slope of the many channels, (2) a component of transverse slope that results from the incised channels and (3) the combined slope component that is for the land surface runoff component given on the UK record. In other words, (3) = (2) ÷ (1).

Perhaps the selected model parameters produce the desired result but the available RK/RD option and possibly the diversion option might produce a more physically based model.

The channel parameters for subarea 34R such as the large length (6800), low roughness coefficient (0.045) and large effective width (50 with 100:1 sloping banks) appear unreasonable. The comment about instability on the land surface is informative but there may also be a problem with the channel. For the channel conditions on the RK record the resulting Froude numbers are greater than 1 and increase from 1.14 at 0.2 ft. depth to 1.49 at 1 ft. depth. Such a condition of high velocity seems unreasonable for the model.

The above comments may be overly critical because the results of Ward's model compare reasonable well with this review analysis. Ward may have been adjusting model parameters to match field observations of sheetflow and channel flow.

PACE-Griener. -- The RK records appear to not represent the physical system of channels and hillslopes. Several problems appear typical of the input to HEC1. For example, the channel lengths of the collector and main channel are longer than basin along the thalwag. The effective channel shape of a wide-flat channel with nearly flat side slopes does not match the several small channels that are incised a foot or so below the lower part of the landform. The combination of the roughness coefficient, slope and shape yields super critical velocities once a rain drop falls on the channel bed. There are several examples of a mismatch between RK factors and physical features.

Sediment yield

PACE.--The Flaxman method for estimating sediment yield was used for this review and therefore, the PACE computation was examined (See item 2 of PACE's sedimentation computations). Flaxman's 1972 method was used by PACE but the coefficient for the X_3 factor should be -0.01644 and not -0.01944. Also, the mean annual temperature of 85 and mean annual precipitation of 7 should be changed to about 70°F and 12 in, respectively. Also the effective slope of 2% is too small and the percent soil >1mm of about 60 percent is too large for the basins. Rather, the percent soil used appears to be from the cores along Pima Rd where the samples were taken to depths of 2 ft. Samples of the near surface soil such as those in Camp(1986) should be used for the Flaxman method. Particle size at depth has little meaning for sediment yield in this area. Flaxman's revised 1974 method may be better than his 1972 method.

WARD.--The practice of computing the bed-material load using equilibrium channel scour methods appears reasonable but the use of a factor to estimate wash load as a proportion of bed load is questionable especially where wash load is several times larger than the bed load. Perhaps such a practice is necessary for engineering design but where does the factor of 3 (Ward, Table 7.1) for the Pima Road sites come from? There are no known samples of sediment taken during flooding in the area and therefore the factor of 3 appears to be a guess. The effect of this guess on detention basin sizing can be significant.

Samples of sediment

Some confusion surrounds the collection and use of the sediment along the Pima Road channel right-of-way. The precise location of the 15 samples collected by ATL for Greiner is uncertain. These samples were collected at about 1-2 ft. depth apparently along the right-of-way as depicted on orthophoto maps at 1 inch = 800 ft scale. Most of these samples apparently are of the Momoli soil that is "fan terrace" material and is well developed. For comparison, Ward's three samples were taken from the beds of washes somewhere in the general area.

Samples at 1 to 2 ft. depth of the Momoli soil, which is along most of the Pima Road channel alignment but not in the basins, have little value for estimates of both sediment yield and for computations of sediment transport rate. In regard to sediment yield, the Momoli soil is not representative of basin soils to the east. Also, the soil is coarser at depth (Camp, 1986, p.281) and thus the samples are not representative of surface conditions for estimates of sediment yield and soil loss. In regard to bed material transport, the transported sediment is from the upslope basins and not from developed Momoli soil that is at least thousands of years old.

PACE's use of the particle size for these samples is confusing. PACE apparently assumed the samples were representative of basin soil (the upper 2 inches) for the Flaxman method (Method 2 of PACE's sedimentation calculations). According to Camp (1986) the soil particles typically are smaller than used by PACE. Clearly, samples of soil along Pima Road are not representative of basin soil and any samples should be of the upper 2 inches of the representative basin soil. PACE apparently ignored published information on soils of the basins (Camp, 1986).

Ward is clearly on the right track with sediment samples in the beds of active stream channels. For channel design, samples of the bed material of the larger channels and of stream channels draining areas of a particular soil seems reasonable. For example, subarea 34R drains a large area of Anthony soil that is very young. The D_{50} particle size for this soil is only about 0.15mm or about a log cycle less than the average D_{50} of the samples used by both PACE and Ward. The adjacent Tres Hermanos soil also is much finer than the average values used by Ward and Pace. Clearly, samples of the soil in the channels that represent sediment conveyed from the basins to the proposed Pima Road channel are important. The 15 Greiner samples apparently do not accomplish this need. Ward's limited number of samples of channel bed material also seem insufficient for computations of bed material transport.

Also, based on the diverse particle sizes of the difference soils such as the Anthony, Tres Hermanos, Pinalino, Monoli and Nickel, it is doubtful that a mean particle distribution should be used for channel design. For example, sediment crossing Pima Road between

Happy Valley Road and Pinnacle Peak Road probably is much finer than sediment in the channels to the north.

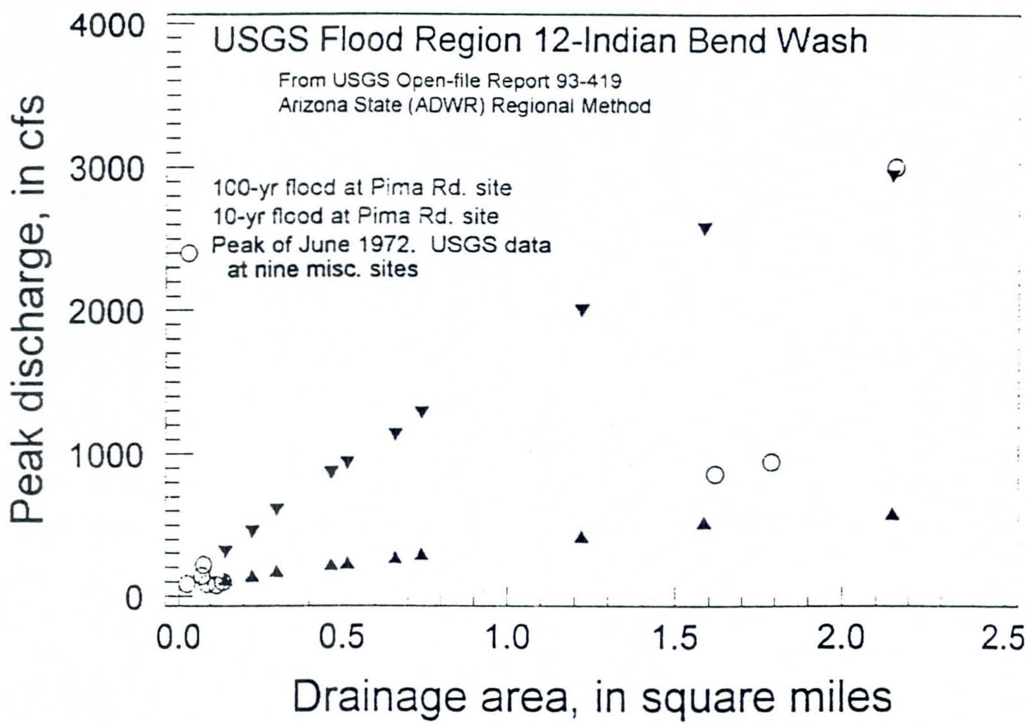


Figure 1. Paek discharges for Pima Road sub-areas & misc. sites

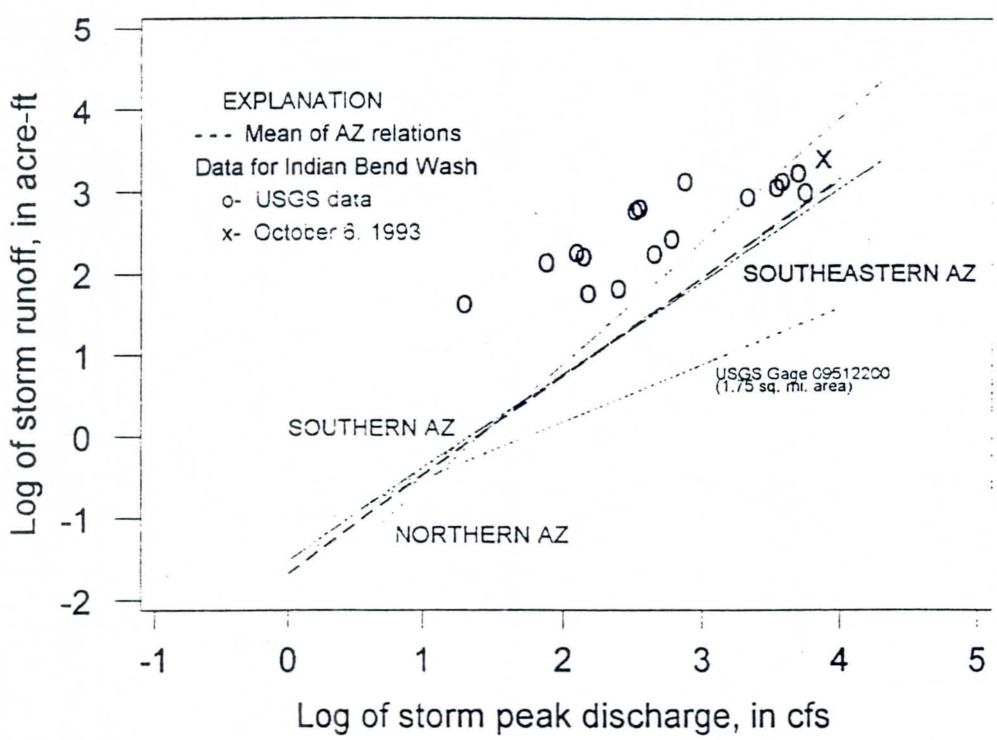


Figure 2. Peak discharge and runoff volume for storms in Arizona

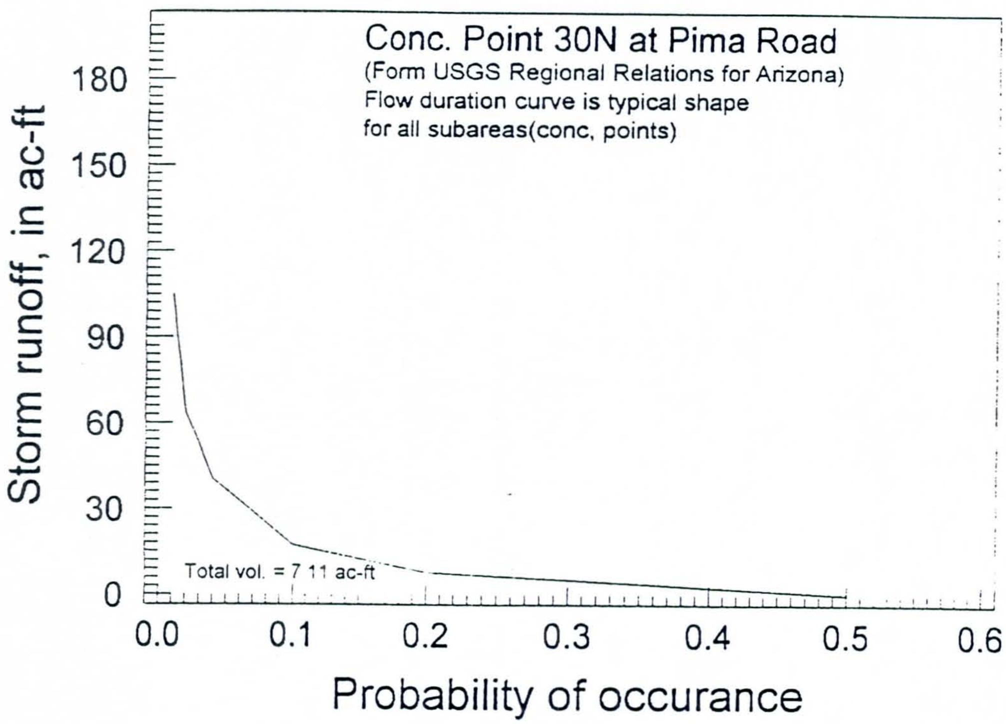


FIGURE 3. Storm runoff frequency curve for Pima Road subareas

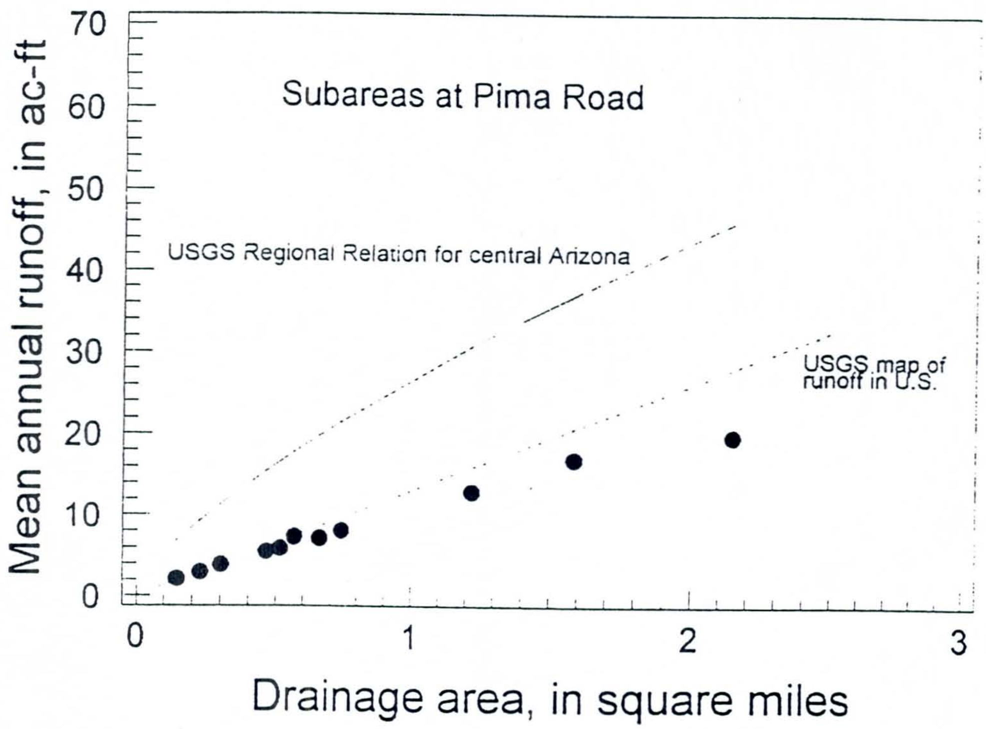


Figure 4. Relation of mean annual runoff to basin area

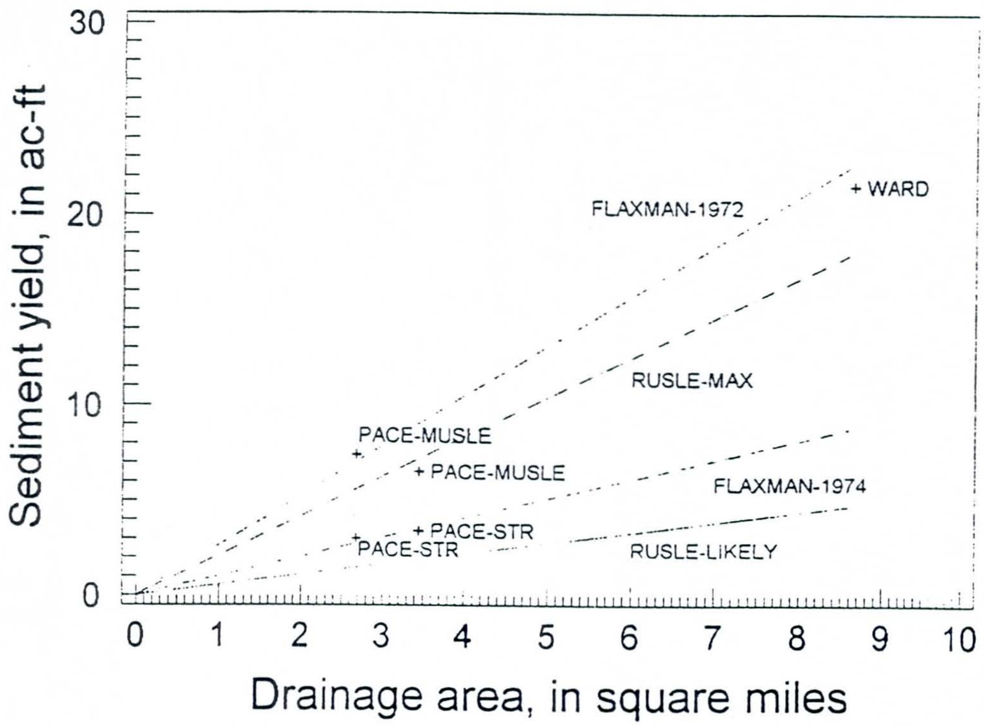


Figure 5. Sediment yield for 100-Year storm along Pima Road

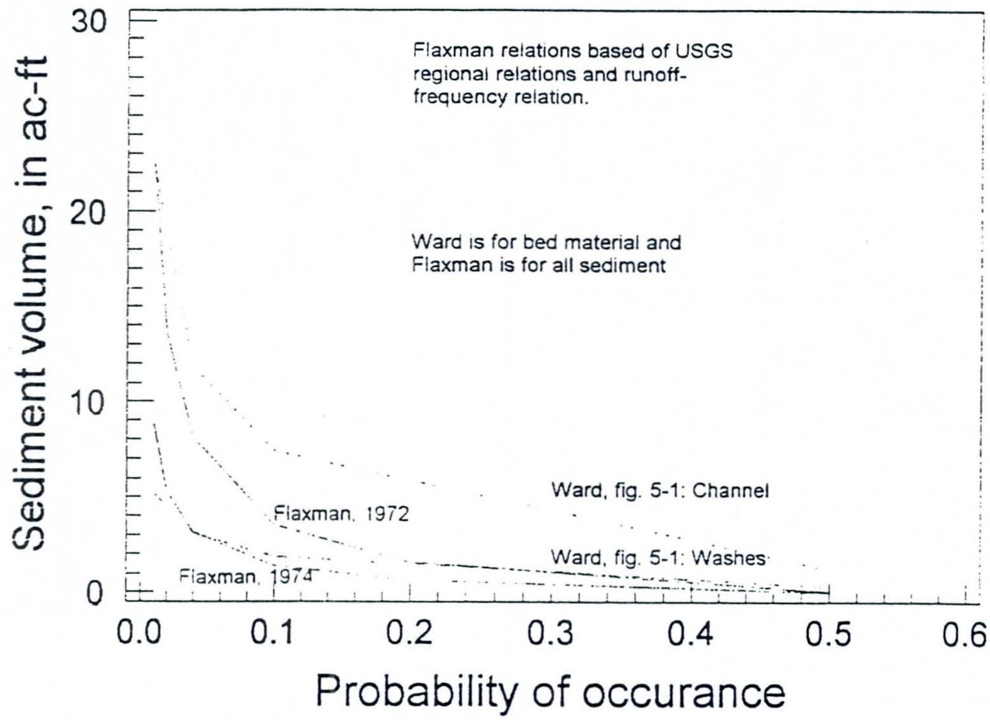


Figure 6. Sediment frequency curves for Pima Road

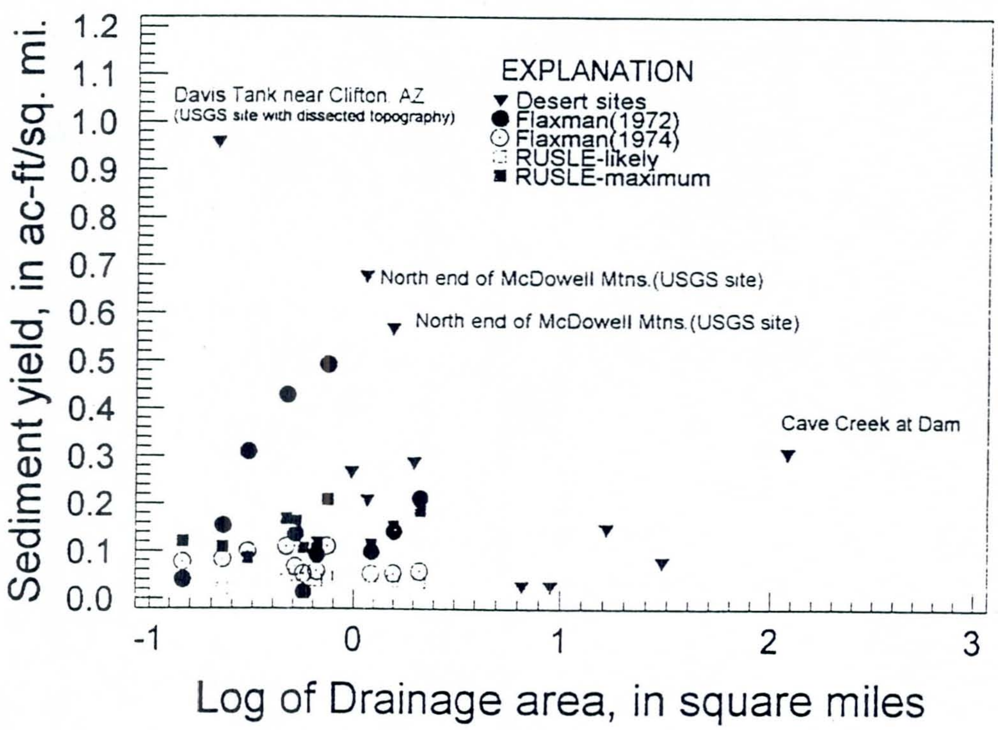
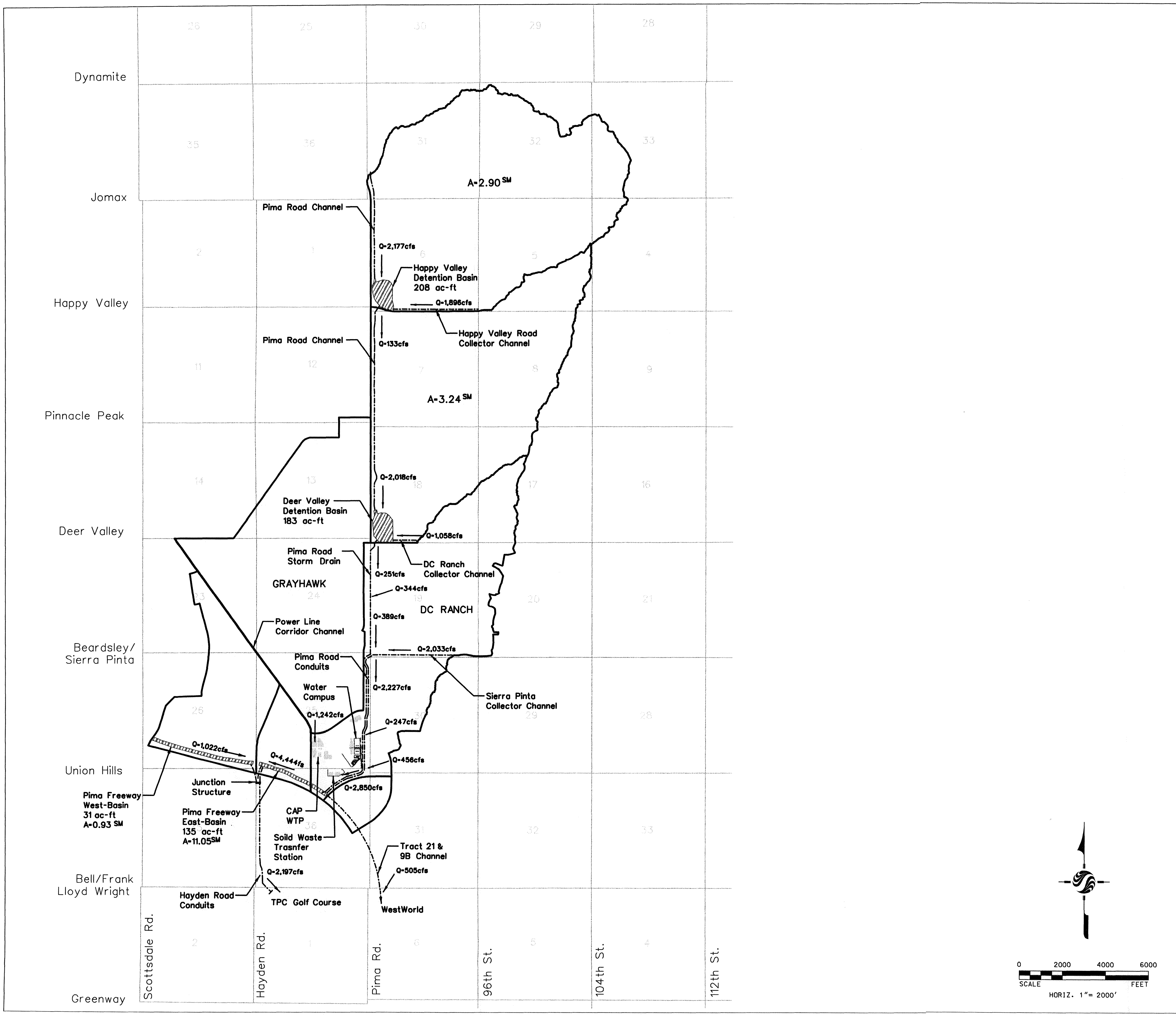


Figure 7. Measured and estimated annual sediment yield



Stantech Consulting
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Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

LEGEND

- Section Lines
- Subbasin Boundary
- Non-Contributing Areas
- Q=1,058cfs Design Discharge

PLATE 1

ENGINEER

TRANSPORTATION DEPARTMENT
TRANSPORTATION PLANNING
3939 CIVIC CENTER BLVD.
SCOTTSDALE, ARIZONA 85251

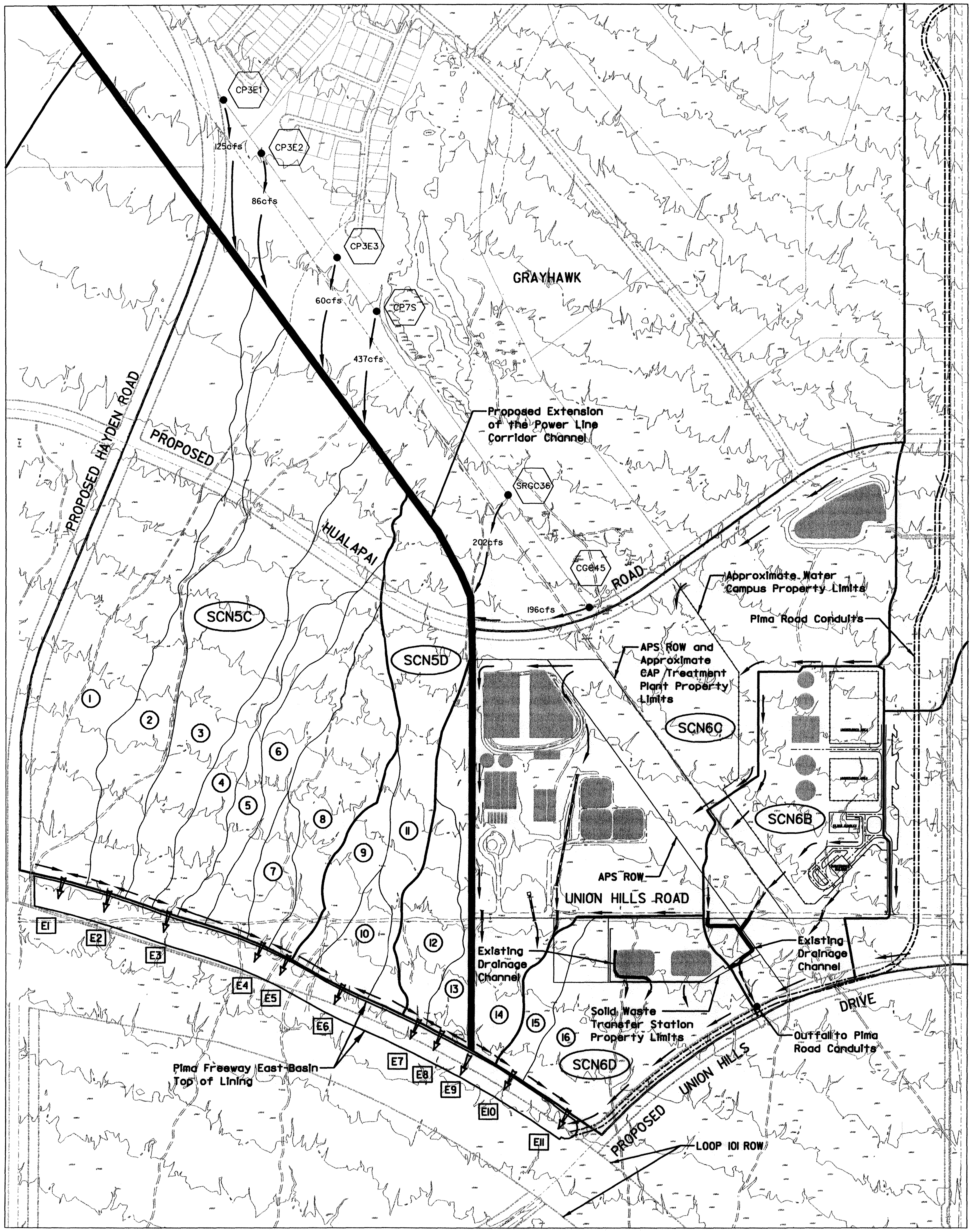
PROJECT TITLE Desert Greenbelt PIMA ROAD 3 BASIN PROJECT
PIMA ROAD THREE BASINS PROJECT
SYSTEM DIAGRAM

SCALE	DESIGNED BY	DATE	BID NO.	SHT.
HORIZ. 1"=2000'	M. GERLACH	10/13/98		
VERT. N/A	DRAWN BY R. CORBETT	AS-BUILT	PROJECT NO. 28900082	1 OF 1

Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

LEGEND

Symbol	Description
(heavy line)	HEC-I Modeling Subbasin Boundary
(light line)	Spillway Drainage Area Boundary
CP3E1	Grayhawk Drainage Concentration Point
SCN5D	HEC-I Modeling Subbasin Delineator
(5)	Spillway Drainage Area Delineator
S5	Spillway Identifier
(arrow)	Spillway Location



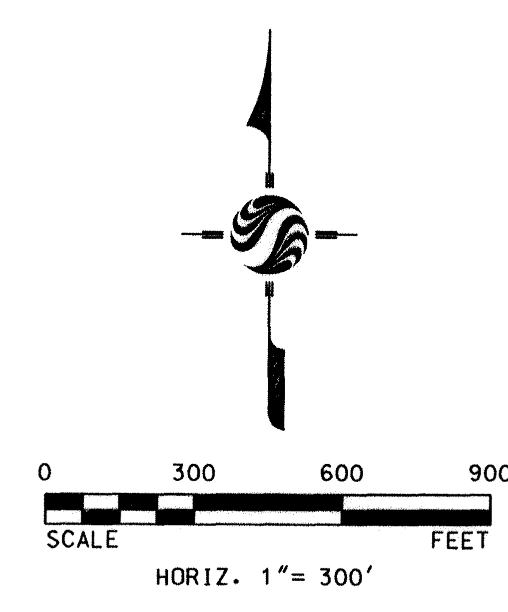
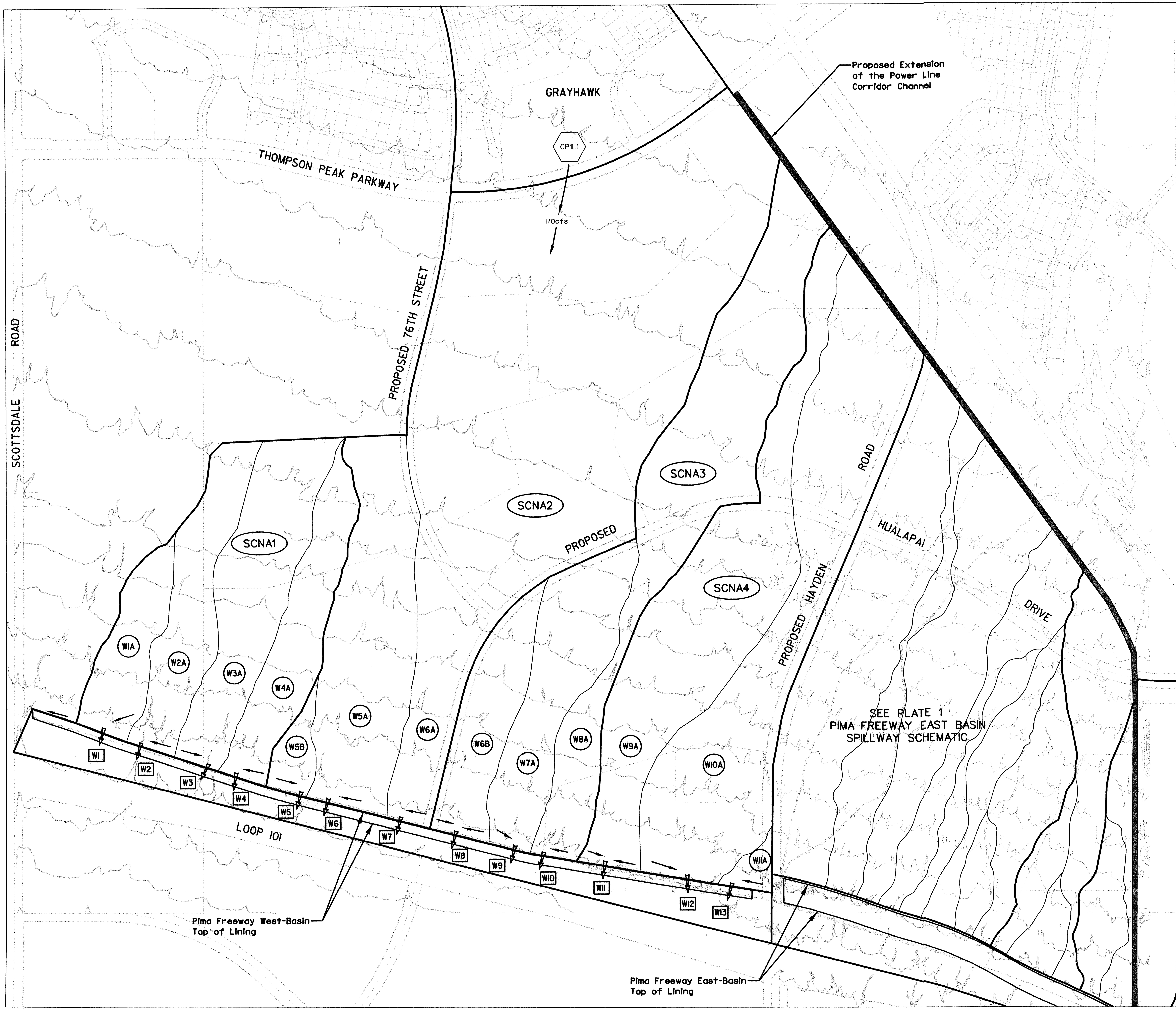


PLATE 2

ENGINEER	TRANSPORTATION DEPARTMENT TRANSPORTATION PLANNING 3939 CIVIC CENTER BLVD. SCOTTSDALE, ARIZONA 85251

PROJECT TITLE: Desert Greenbelt PIMA ROAD 3 BASIN PROJECT
PIMA FREEWAY EAST-BASIN
SPILLWAY SCHEMATIC

SCALE	DESIGNED BY	DATE	BID NO.	SHT.
HORIZ. 1"=300'	M.GERLACH	9/11/98		
VERT. N/A	DRAWN BY R.CORBETT	AS-BUILT	PROJECT NO. 28900082	1 OF 1



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LEGEND

- HEC-I Modeling Subbasin Boundary
- Spillway Drainage Area Boundary
- CP1L1 — Grayhawk Drainage Concentration Point
- SCNA2 — HEC-I Modeling Subbasin Delineator
- W6A — Spillway Drainage Area Delineator
- W7 — Spillway Identifier
- Spillway Location

PLATE 3

ENGINEER	TRANSPORTATION DEPARTMENT TRANSPORTATION PLANNING 3939 CIVIC CENTER BLVD. SCOTTSDALE, ARIZONA 85251

CITY OF SCOTTSDALE ARIZONA

PROJECT TITLE	Desert Greenbelt PIMA ROAD 3 BASIN PROJECT PIMA FREEWAY WEST-BASIN SPILLWAY SCHEMATIC			
SCALE HORIZ. 1"=300' VERT. N/A	DESIGNED BY R.SCRIVO DRAWN BY R.CORBETT	DATE 11/20/98 AS-BUILT	BID NO. PROJECT NO. 28900082	SHT. 1 OF 1