SIMPLIFIED METHOD OF ESTIMATING FLOOD PEAKS

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SIMONS, li & ASSOCIATES, INC.

SIMPLIFIED METHOD

OF

ESTIMATING FLOOD PEAKS

Prepared for

City of Tucson
Department of Transportation
Engineering Division

by

Simons, Li & Associates, Inc.
P.O. Box 2712
Tucson, AZ 85702

March, 1982

SIMONS, LI & ASSOCIATES, INC.

120 W. BROADWAY
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POST OFFICE BOX 2712
TUCSON, ARIZONA 85702

TELEPHONE (602) 884-9594

March 1, 1982

MAR 1982
RECEIVED
OFFICE OF
CITY ENGINEER
TUCSON, ARIZ.

Dr. Brian M. Reich, P.E.
Assistant City Engineer
Flood Plain Management
City of Tucson Engineering
P.O. Box 27210
Tucson, AZ 58726

RE: Simplified Method for
Estimating Flood Peaks

Dear Brian:

The firm of Simons, Li & Associates, Inc., has completed its contract with the City of Tucson for the preparation of a Simplified Method for Estimating Flood Peaks. As per your request, enclosed please find twelve (12) copies of the Manual. Also included are three (3) copies of the Manual and Project Report, one copy of which includes all back-up data and calculations for your office files.

This completes our Scope of Work for this project. If you have any questions, or need additional information, please contact me at your convenience.

Very truly yours,

Michael E. Zeller

Michael E. Zeller, P.E.
Manager

MEZ/sv
Enclosures

FORT COLLINS OFFICE: POST OFFICE BOX 1816, FORT COLLINS, COLORADO 80522 (303) 223-4100
DENVER OFFICE: 1780 E. BELLAIRE, SUITE 506, DENVER, COLORADO 80222 (303) 692-0369

This method can be applied, within the incorporated limits of the City of Tucson, to designs whose watersheds are smaller than two square miles. The procedure is a simplification of, and is compatible with, Pima County Flood Control District's "Hydrology Manual for Engineering Design and Flood Plain Management Within Pima County, Arizona," which will continue to be used for City work on larger watersheds.

Steps required in estimating the 100-year flood peak (Q_p^{100}) are given below and correspond to the numbers on the blank Hydrologic Data Sheet attached.

1. Enter the project name and location.

2. Describe the point where the flood is being estimated.

3. Enter the watershed area, in acres.

4. Enter the length, in feet (L_c), of the hydraulically longest collector within the study watershed. This extends upstream of the defined channel to include overland flow.

5. Enter the length of the main channel downstream of the watershed center (L_{ca}) in feet. If, for an unusually shaped watershed, the center is difficult to estimate, then L_{ca} may be approximated as $L_c/2$.

6. Enter the lengths of three segments of the longest collector and their corresponding changes in elevation onto lines a,b, and c. Channel slopes within each segment should be approximately constant.

7. Further space is provided for computing I, in a checkable form.

8. The mean slope (S_c) is calculated.

9. Enter the watershed type(s) (e.g., suburban, commercial, etc.) reflecting future land use. If two different land uses predominate within the study watershed, note the proportion of each (e.g., Industrial 25%, Rural 75%).

10. Enter the future basin factor(s) (n_b), chosen from Table I.

11. Enter future imperviousness (in %).

12. Choose the weighted runoff coefficient (C_w) from Table II. Where watershed parts are listed, weight their C's according to the ratios recorded on Line 9 before finding the average C_w.

13. Calculate the Z-factor.

14. The future time of concentration (T_c) in minutes is found, to the nearest minute, by entering Table III with the Z-factor. One should never use a time of concentration less than five (5) minutes, nor greater than sixty (60) minutes.

15. The 100-year rainfall intensity, as approved by the City Engineer on October 31, 1977, can now be determined from the equation:

$$i = \frac{12}{(1+0.05T_c)} .$$

16. The future 100-year flood peak for the design point is calculated by the "rational" formula, $Q_p^{100} = C_w iA$. If the study watershed is already developed to its ultimate, the word "future" should be lined out wherever it appears on the Hydrologic Data Sheet.

17. For determination of flood peaks which will recur more frequently than Q_p^{100}, simply multiply by the appropriate factor from Table IV.

Table I

Basin Factor (n_b) For Varying Degrees of Land Use
Within the Incorporated Limits of the City of Tucson

Natural	Rural		Suburban		*Mod. Urban		*Hvy. Urban		*Comm/Ind.	
N.C.	N.C.	I.C.	N.C.	I.C.	I.C.	L.C.	I.C.	L.C.	I.C.	L.C.
.035	.034	.027	.032	.026	.022	.018	.022	.018	.022	.018

Where N.C. = natural channels predominate within watershed boundaries;
I.C. = improved channels predominate within watershed boundaries;
and L.C. = totally lined channels predominate within watershed boundaries.

*Use n_b = .030 for these land uses when flow is principally in streets rather than in improved channels (I.C.'s). Interpolate between the values shown in Table I and n_b = .030 for combination street flows/improved channel flows in accordance with their watershed ratios.

Table II

100-Year Weighted Runoff Coefficient (C_w) for Varying Degrees of Land Use Within the Incorporated Limits of the City of Tucson (Percent in Parenthesis Represents Amount of Impervious Cover)

Natural	Rural	Suburban	Mod. Urban	Hvy. Urban	Comm/Ind.
(0%)	(10%)	(20%)	(40%)	(70%)	(90%)
0.60	0.65	0.70	0.75	0.85	0.95

Table III

Z-Factor Versus Time of Concentration (T_c)

Z	T_c	Z	T_c	Z	T_c	Z	T_c
4.57	5	14.55	19	22.34	33	28.97	47
5.40	6	15.15	20	22.84	34	29.43	48
6.20	7	15.74	21	23.37	35	29.86	49
6.99	8	16.34	22	23.83	36	30.29	50
7.76	9	16.94	23	24.33	37	30.72	51
8.52	10	17.50	24	24.83	38	31.16	52
9.25	11	18.06	25	25.29	39	31.59	53
9.94	12	18.63	26	25.79	40	31.98	54
10.64	13	19.19	27	26.25	41	32.42	55
11.34	14	19.72	28	26.71	42	32.85	56
12.00	15	20.25	29	27.18	43	33.24	57
12.66	16	20.78	30	27.64	44	33.64	58
13.29	17	21.31	31	28.07	45	34.07	59
13.92	18	21.84	32	28.54	46	34.47	60

Table IV

Factors for Determining Peaks of More Frequent Flood Recurrence Intervals as a Ratio of the 100-Year Flood Event

WATERSHED TYPE	RECURRENCE INTERVAL 2-Yr.	10-Yr.	25-Yr.	50-Yr.
Natural	0.05	0.30	0.50	0.70
Rural	0.10	0.35	0.55	0.75
Suburban	0.15	0.40	0.60	0.80
Moderately Urban	0.20	0.45	0.65	0.85
Highly Urban	0.25	0.50	0.70	0.85

EXAMPLE:

Problem

A 100-acre watershed outlets at the southwest corner of X-Street and J-Avenue. The watershed is moderately urbanized, and contains improved channels with lined sides and natural (earthen) bottoms. What is the 100-year flood peak for this watershed?

Solution:

City of Tucson
Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: No-Name Wash, X-Street & J-Avenue
2. Drainage Concentration Point: At SW Corner of Intersection
3. *Watershed Area (A) at Drainage Concentration Point: 100 acres.
4. Length of Hydraulically Longest Watercourse (L_c): 4500 ft.
5. Length from center of Watershed Area (L_{ca}), along L_c: 2250 ft.
6. Change in Length Factors - ft. / Change in Elevation Factors - ft.
   a. ΔL_1: 1300 $(\Delta L_1)^3$ 2,197,000,000 ΔH_1: 9 $\Delta L_1^3/\Delta H_1$ 244,111,111
   b. ΔL_2: 1900 $(\Delta L_2)^3$ 6,859,000,000 ΔH_2: 15 $\Delta L_2^3/\Delta H_2$ 457,266,667
   c. ΔL_3: 1300 $(\Delta L_3)^3$ 2,197,000,000 ΔH_3: 8 $\Delta L_3^3/\Delta H_3$ 274,625,000
7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{3}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{3}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{3}}$ = 15,624 + 21,384 + 16,572 = 53,580
8. Mean Slope $(S_c) = (L_c/I)^2 =$ (0.084)^2 = 0.0071 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	N/A ( )	
10. Basin Factor (n_b):	0.022	N/A	n_{bw} = 0.022
11. Imperviousness (%):	40%	N/A	I_w = 40%
12. Runoff Coefficient (C_w):	0.75	N/A	C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 10.02 (future)
14. **Time of Concentration (T_c), determined from Table III: 12 minutes (future)
15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 7.50 inches/hour
16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 × 7.50 × 100 = 563 cfs (future)
17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	113	253	366	479

* A may not exceed 1,280 acres (2 square miles) in size.
** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: J.D. Company: XYZ & Asso. Date: Jan. 1982

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: _____

2. Drainage Concentration Point: _____

3. *Watershed Area (A) at Drainage Concentration Point: _____ acres.

4. Length of Hydraulically Longest Watercourse (L_c): _____ ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: _____ ft.

6. Change in Length Factors - ft. | Change in Elevation Factors - ft.

a. ΔL_1: _____ $(\Delta L_1)^3$ _____ ΔH_1: _____ $\Delta L_1^3/\Delta H_1$ _____

b. ΔL_2: _____ $(\Delta L_2)^3$ _____ ΔH_2: _____ $\Delta L_2^3/\Delta H_2$ _____

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = _____ + _____ + _____ = _____

8. Mean Slope (S_c) = $(L_c/I)^2$ = (_____)^2 = _____ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average (future)
9. Watershed Type(s) (% of Total Area):	_____ (_____)	_____ (_____)	
10. Basin Factor (n_b):	_____	_____	n_{bw} = _____
11. Imperviousness (%):	_____	_____	I_w = _____
12. Runoff Coefficient (C_w):	_____	_____	C_w = _____

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = _____ (future)

14. **Time of Concentration (T_c), determined from Table III: _____ minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = _____ inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = _____ x _____ x _____ = _____ cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	_____	_____	_____	_____
Q (cubic feet/second):	_____	_____	_____	_____

---

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: _____ Company: _____ Date: _____

PROJECT REPORT

I. INTRODUCTION

The following pages briefly describe and/or document the different sources utilized by Simons, Li & Associates, Inc., (SLA) in the preparation of an hydrologic procedures manual entitled "Simplified Method of Estimating Flood Peaks." Results from providing this new method are headed "CITY OF TUCSON" in Table A This "simplified method" is based upon the Pima County Flood Control District's manual entitled "Hydrology Manual for Engineering Design and Flood Plain Management within Pima County, Arizona."

II. DEVELOPMENT OF THE MANUAL

The 17 procedural steps utilized in the development of the simplified method contained within the manual were developed as follows:

1. Steps 1 through 9 of the procedural approach are taken directly from the Pima County Hydrology Manual and are utilized in the same manner as within that document.

2. Step 10 is a reduced version of the Basin Factors taken from the Pima County Hydrology Manual. This reduced table is based upon the typical watershed conditions which would normally be encountered within the present or near-future limits of the City of Tucson.

3. Step 11 is self-explanatory.

4. Step 12 utilizes a table of weighted runoff coefficients which have been developed especially for the conditions which are believed to exist within the present or near-future limits of the City of Tucson. These are based upon the rainfall-duration-intensity curve developed by Brian M. Reich (1977) for the City of Tucson.

5. The "Z" factor was developed based upon the physical parameters of the watershed utilized in solving for the watershed's time of concentration (T_c). Such parameters include length, slope, and the basin factor.

6. Table 3, developed for use in Step 14 in order to solve for the time of concentration of the watershed, is used in conjunction with the "Z" factor to avoid an iterative solution of T_c as is done presently in Pima County's Hydrology Manual. The table was developed by equating the rainfall distribution in the Tucson and Pima County area to known times of concentration and graphically preparing a T_c versus intensity curve from which values could be plotted that were subsequently called "Z" factors.

7. The equation for the solution of rainfall intensity indicated in Step 15 was obtained through the development of a regression equation utilizing information in NOAA Atlas, Volume 8 (1973), Rainfall Statistical Data Summary for the State of Arizona, prepared by the National Weather Service.

8. Step 16 is self-explanatory, and is merely the standard application of a "rational" formula.

9. Table 4, utilized in Step 17, was developed primarily from the ratios stated in Pima County's Hydrology Manual. These ratios have been developed over time from observed and empirical ratio determinations for lesser magnitude floods when compared to the predicted or observed 100-year flood peaks for the particular watersheds under observation. These ratios are felt to be particularly applicable for the areas which are presently or soon to be within the limits of the City of Tucson, i.e., typically highly urbanized in nature.

III. MANUAL APPLICATION

The simplified method developed and prepared in manual form for the City of Tucson was applied to a spectrum of 20 typical watershed locations within and around the City of Tucson. In addition, comparisons were made for predictions of the 2-year, 25-year, and 100-year flood peaks against other standard procedures for estimating flood peaks which have been utilized in the past within

the City of Tucson by various agencies such as Pima County, the City of Tucson, the Arizona Department of Transportation (ADOT), the United States Geological Survey (USGS), etc. The comparison methods that were utilized are:

1. Pima County Flood Control District Hydrology Manual;
2. Quick Curve signed by Brian M. Reich and Michael E. Zeller on March 10, 1980;
3. The ADOT Manual;
4. The Walnut Gulch Q_{100} Curve signed by Brian M. Reich in April, 1979;
5. The latest published USGS Regional-Regression Curve developed by Jim Eychaner and Byron Aldridge; and
6. The Santa Barbara Urban Runoff Model.

The results of these comparisons for the various flood frequencies, as previously noted, are as indicated within Table A on the following page.

Also, four methods were used for comparison purposes in establishing times of concentration, rise times, and lag times for the 20 watershed locations versus the time of concentration that was developed through utilization of the simplified flood peak procedure. The four procedures utilized in this comparison were:

1. ADOT Manual's procedure;
2. The SCS, TR-55, procedure;
3. The Schaake Procedure, found in A.S.C.E. (1967); and
4. The rise time procedure of A.S.C.E. 10-minute Urban Hydrographs as found in A.S.C.E. (1977).

Results of the comparison of these procedures can be found within the attached Table B, following Table A.

TABLE A

*COMPARISON OF VARIOUS HYDROLOGIC PROCEDURES FOR THE ESTIMATION OF The 2-, 25-, and 100-YEAR FLOW EVENTS WITHIN THE VICINITY OF TUCSON, ARIZONA

NAME OF WASH	DRAINAGE AREA (Acres)	QUICK CURVE 2	QUICK CURVE 25	QUICK CURVE 100	W. GULCH CURVE 2	W. GULCH CURVE 25	W. GULCH CURVE 100	U.S.G.S. Reg.Eqs. 2	U.S.G.S. Reg.Eqs. 25	U.S.G.S. Reg.Eqs. 100	ADOT (Rational) 2	ADOT (Rational) 25	ADOT (Rational) 100	CITY OF TUCSON 2	CITY OF TUCSON 25	CITY OF TUCSON 100	S.B.U.H. 2	S.B.U.H. 25	S.B.U.H. 100	P.C.F.C.D. 2	P.C.F.C.D. 25	P.C.F.C.D. 100
Alamo	520	342	1196	1709	328	1149	1642	321	1125	1607	250	983	1456	480	1559	2399	435	1621	2261	252	1531	2438
Alvernon	284	213	746	1066	180	629	899	211	739	1055	159	616	932	256	831	1278	236	879	1226			
Anklam	1350	688	2409	4130	732	2562	4392	241	1324	2407	297	2106	3119	398	2186	3975						
Arcadia	787	466	1632	2332	476	1665	2379	422	1478	2111	283	1102	1637	545	1773	2727	513	1916	2690			
Cemetery	650	405	1416	2023	403	1410	2014	373	1305	1864	260	1047	1560	459	1492	2296				210	1409	2306
Cholla	273	207	723	1240	172	603	1034	200	701	1002	139	622	956	198	818	1377						
Columbus	176	144	505	722	106	370	529	149	521	744	99	394	577	154	502	772	141	526	734			
Este	1178	625	2186	3750	660	2310	3960	221	1218	2214	283	1343	2062	584	2225	3647						
Fr. Village	762	456	1595	2734	463	1620	2777	168	925	1681	152	1052	1600	384	1536	2560						
High School	576	369	1293	1847	361	1264	1805	344	1205	1721	207	933	1452	381	1379	2217	367	1535	2165	157	1318	2230
M.G. Vista	104	139	463	695	84	281	422	99	348	497	67	269	400	113	369	567	101	381	526			
Midway	656	407	1426	2037	406	1421	2030	375	1313	1875	289	1148	1680	492	1599	2460						
Navajo	697	426	1492	2132	428	1499	2142	390	1366	1951	279	1122	1673	534	1736	2671						
Pumping	544	177	885	1769	171	857	1713	135	740	1346	54	653	1012	70	700	1400						
Railroad	1216	639	2237	3196	676	2367	3382	555	1944	2777	389	1532	2335	706	2295	3530				306	2170	3555
Robb	1330	681	2384	3406	724	2533	3619	587	2053	2933	372	1397	2128	798	2594	3990						
Rolling Hills	31	31	109	188	11	37	63	15	82	149	17	113	174	30	120	200	34	150	210			
Rosehill	1045	574	2008	2868	601	2104	3005	506	1770	2528	251	951	1505	578	1880	2892	551	2113	2973			
W.Gulch #4	563	182	908	1816	177	884	1768	138	758	1378	68	788	1250	84	845	1689						
W. Speedway	294	219	767	1315	186	652	1118	88	484	880	129	900	1379	139	764	1389				122	1144	1772

*All Flow Estimates Measured in cfs.

TABLE B

Comparison of Estimates of
Times of Concentration (T_c's), Rise Times (T_r's), and Lag Times (T_L's)
Using Various Hydrologic Procedures

WASH	A	B	C	D	E	F
Alamo	48	38	12	22	19	36
Alvernon	39	30	11	22	20	38
Anklam	52	66	17	34	33	83
Arcadia	74	58	13	26	32	61
Cemetery	59	50	13	26	31	59
Cholla	28	17	11	22	13	28
Columbus	38	30	10	22	21	40
Este	76	82	15	29	35	73
Fr. Village	59	75	14	29	30	64
High School	47	39	13	27	25	51
M.G. Vista	30	22	10	20	13	25
Midway	54	45	12	25	28	53
Navajo	60	49	13	25	27	51
Pumping	58	107	32	64	36	119
Railroad	80	65	14	28	42	80
Robb	100	80	15	27	40	76
Rolling Hills	10	12	8	17	6	13
Rosehill	117	94	15	29	45	86
W. Gulch #4	45	79	29	55	28	93
West Speedway	16	20	13	26	13	33

WHERE, in time units of minutes:

Procedure A = ADOT T_c

Procedure B = SCS, TR-55, T_L

Procedure C = Schaake T_L, in A.S.C.E. (November, 1967)

Procedure D = A.S.C.E. 10-minute Unit Hydrograph T_r for Urban Areas (1977)

Procedure E = T_c from Manual (Simplified Method) for 100-year Flood

Procedure F = T_c from Manual (Simplified Method) for 2-year Flood

IV. BACK-UP MATERIAL

Tables A and B preceding were developed by application of each of the aforementioned procedures to 20 selected watershed locations in or within the vicinity of the City of Tucson. Development of the tables entailed considerable calculation time; and, rather than try to describe each of the individual applications of the procedural methods, attached to and made a part of this report are copies of all the calculation data sheets, where applicable indicating the procedure utilized and subsequent results obtained. To highlight, the following paragraphs will briefly describe particular instances where certain decisions were made in order to arrive at results which were consistent with regard to past methods and procedures for estimating flood peaks within the limits of the City of Tucson.

The Pima County Flood Control District Manual, the Quick Curve Method signed by Brian M. Reich and Michael E. Zeller, the Walnut Gulch Q_{100} Curve developed by Brian M. Reich in April of 1979, and the latest published USGS Regression Curve are straight forward in nature and need no other explanation other than to state that the curves that were utilized in developing the peak flow rate methods are attached and made a part of this report, including all calculation sheets developed for establishing estimated flood flows through utilization of the Pima County Flood Control District's procedure.

The Flood Control District's Manual, being the original basis upon which the simplified method was based, was expected to give results almost identical to the procedure. As such it was felt that an application of only five (5) typical watershed locations would establish this consistency, and therefore only five rather than 20 locations were utilized in the estimating of flood peaks through this procedure.

The ADOT Manual procedure is merely an application of the Rational Formula utilizing a time of concentration equation developed by P.Z. Kirpich from data gathered by Ramser. The equation utilized is as follows:

$$T_c = \frac{1}{7700} \left(\frac{L}{\sqrt{S}} \right)^{0.77}, \text{ in hours.}$$

This same equation was later utilized for developing the time of concentration for the 20 typical watersheds, as indicated in Table B.

The most interesting procedure for comparison with the simplified method was that of the Santa Barbara Urban Hydrograph Model. It was found through calibration of the method that routing times for use in the Santa Barbara Urban Hydrograph must be approximately 50% of the 100-year flood times of concentration obtained through utilization of the simplified method. In all cases, this 50% routing time was based upon a 100-year flood time of concentration. Using this routing time as a base, lesser magnitude floods were developed by adjusting the initial and final abstraction rates such that a constant phi index was used which was based on Soil Conservation Service Curve-Number (CN) procedures. Final results were: for a 100-year flood, the phi index is 1.1 inches/hour; for the 25-year flood, the phi index is 1.3 inches/hour; and, finally, for the 2-year flood, the phi index is 1.5 inches/hour. Again, in all cases the hydrologic routing time to be used in the Santa Barbara Urban Hydrograph procedure was based upon 50% of the 100-year flood time of concentration developed in conjunction with the simplified method for estimating flood peaks.

Table B was developed by employing the four methods, as previously noted, for estimating times of concentration, lag times, and rise times. The equations for these procedures are as follows:

1. ADOT:

$$T_c = \frac{1}{7700} \left(\frac{L}{\sqrt{S}} \right)^{0.77}, \text{ in hours.}$$

2. SCS, TR-55:

$$T_L = \frac{L^{0.8} (S+1)^{0.7}}{1900Y^{0.5}}, \text{ in hours.}$$

3. Schaake, in A.S.C.E. (1967):

$$T_L = 1.05\ L^{0.24}\ I^{-0.26}\ S^{-0.16}, \text{ in minutes.}$$

4. The rise time of A.S.C.E. 10-minute Urban Hydrographs, in A.S.C.E. (1977):

$$T_r = 3.1\ L^{0.23}\ S^{-0.25}\ I^{-0.18}\ \phi^{1.57}, \text{ in minutes.}$$

WHERE, for

1. L = length of the watershed in feet;

   S = length of the watershed in feet/feet.

2. L = length of the watershed in feet;

   $S = \frac{1000}{CN-10}$ (CN = SCS Curve No.);

   Y = slope, in percent

   (Modifications of this formula due to urbanization effects are described in the attached back-up material.)

3. L = length of the watershed in feet;

   I = impervious area, percent;

   S = slope of the watershed in percent.

4. L = length of the watershed in feet;

   S = slope of the watershed in feet/feet;

   I = impervious area, in percent;

   ϕ = a rise-time index dependent upon the physical characteristics of the watershed.

These equations and their parameters are more completely described in the back-up material which is provided in the appropriate sub-sections of this report.

The most interesting component of the four (4) above described equations is the lag time of Schaake (item 3) which is related somewhat to the necessity for utilizing 50% of the time of concentration in the simplified method as a routing time to be used in the Santa Barbara Urban Hydrograph procedure. It was found that Schaake's procedure seemed to produce lag times which were very consistent with this estimated time of routing quantity as described previously. Schaake describes his lag time as the time from the center of rainfall to the midpoint of the flood hydrograph. It is felt that a formula of this type probably more accurately reflects a routing interval that should be used when utilizing the Santa Barbara Urban Hydrograph procedure for desert conditions such as prevail within the Tucson community where "flashy" flood peaks are so dependent upon and caused by short, intense fainfall bursts that are common during the summer thunderstorms which occur over the Tucson Valley.

The following pages are the working materials and back-up data which support Tables A and B, as previously described. Additionally, at the end of this report an addendum is included which contains both user instructions and an optional program listing for use with an HP-41 computer. These are provided for the designer's use, if so desired.

BACK-UP DATA AND CALCULATIONS

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Alamo Wash

2. Drainage Concentration Point: Golf Links Road

3. *Watershed Area (A) at Drainage Concentration Point: 520 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 7500 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 3400 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 3200 $(\Delta L_1)^3$ 3.2768×10^{10} ΔH_1: 20 $\Delta L_1^3/\Delta H_1$ 1,638,400,000

b. ΔL_2: 4300 $(\Delta L_2)^3$ 7.9507×10^{10} ΔH_2: 40 $\Delta L_2^3/\Delta H_2$ 1,987,675,000

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 40,477 + 44,583 + _____ = 85,060

8. Mean Slope (S_c) = $(L_c/I)^2$ = (0.0882)^2 = 0.0078 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type (s) (% of Total Area):	Mod. Urban (100%)	_____ (_____)	
10. Basin Factor (n_b):	0.025 (Some St. flw.)		n_{bw} = 0.025
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 14.47 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 19 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 6.15 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 6.15 x 520 = 2399 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	480	1080	1559	2039

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller Company: SLA Date: _____

PCFCD METHOD

HYDROLOGIC DATA SHEET

Project Name and Location: Alamo Wash

Drainage Concentration Point: @ Golf Links Road

Watershed Area (A): 520 acres/~~square miles.~~

Length of Watercourse (L_c): 7500 ft. Length to Center of Gravity (L_{ca}): 3400 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3200	20
4300	40

Main Slope (S_c): 0.0078 ft./ft. Watershed Type(s): Moderately Urban ~~(future)~~

Basin Factor (n_b): 0.025 ~~(future)~~ Flood Frequency: 2 25 100 yrs.

P_4 (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): 1.0 2.3 3.0 in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): 80% B 20% D Cover Type(s): Urban lawns

Cover Density (pervious areas): Poor Impervious Cover: 40% ~~(future)~~

CN(s): 83, 91, 99 (pervious & impervious areas) CN*(s): (77.16, 86.11, 87.72); (86.88, 92.6, 93.63); 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s), (C): (.05, .47, .60); (.22, .68, .77) (pervious areas) .89, .95, .96 (impervious areas)

Runoff Supply Rate (q): .41, .69, .76 i in./hr. (function of i)

Time of Concentration (T_c): 50, 41, 39 $i^{-.4}$ ~~hrs.~~/mins. (function of i)

Iterative Solution of T_c: 47, 23, 19 ~~hrs.~~/mins.

Rainfall Intensity (i) at T_c: 1.18, 4.23, 6.12 in./hr.

Runoff Supply Rate (q) at T_c: .48, 2.92, 4.65 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 252, 1531, 2438 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Golf Links Road
Project No. _____ Station _____
Name of Stream Alamo Wash

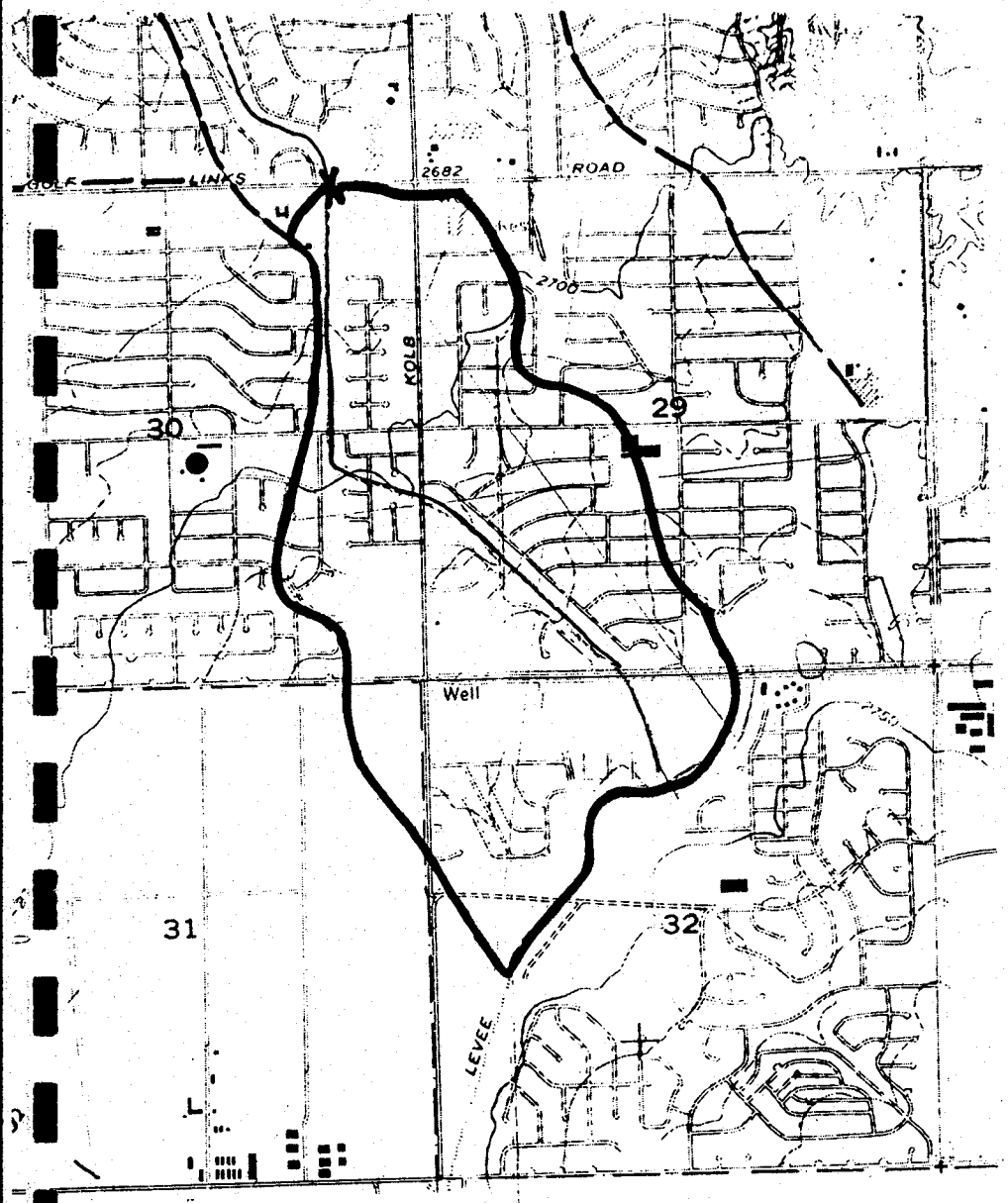
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	520	acres
	A_3		acres
Drainage Length		7500	feet
Elevation			
Top of Drainage Area		2740	feet
At Structure		2680	feet
Drainage Area Slope		0.80	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	48	minutes
Rainfall Intensity	i	1.2 2.7 3.5	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		250, 983, 1456	cfs

Computed by M. E. Zeller (SLA) Date _____



Alamo Wash

FIGURE 1

ALAMO WASH

1" = 2000'

@ Golf Links

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Alvernon Wash

2. Drainage Concentration Point: Speedway Blvd.

3. *Watershed Area (A) at Drainage Concentration Point: 284 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 5800 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 2850 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 660 $(\Delta L_1)^3$ 287,496,000 ΔH_1: 10 $\Delta L_1^3/\Delta H_1$ 28,749,600

b. ΔL_2: 2900 $(\Delta L_2)^3$ 2.4389×10^{10} ΔH_2: 22 $\Delta L_2^3/\Delta H_2$ 1,108,590,909

c. ΔL_3: 2240 $(\Delta L_3)^3$ 1.1239×10^{10} ΔH_3: 17 $\Delta L_3^3/\Delta H_3$ 661,142,588

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 5362 + 33,296 + 25,713 = 64,371

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.0901)^2$ = 0.0081 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	( )	
10. Basin Factor (n_b):	0.030 (St. Flow)		n_{bw} = 0.030
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 15.01 ~~(Future)~~

14. **Time of Concentration (T_c), determined from Table III: 20 minutes ~~(Future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 6.00 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 6.00 x 284 = 1278 cfs ~~(Future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	256	575	831	1086

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Speedway Blvd.
Project No. _____ Station _____
Name of Stream Alvernon Wash

DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	284	acres
	A_3		acres
Drainage Length		5800	feet
Elevation			
Top of Drainage Area		2533	feet
At Structure		2484	feet
Drainage Area Slope		0.84	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

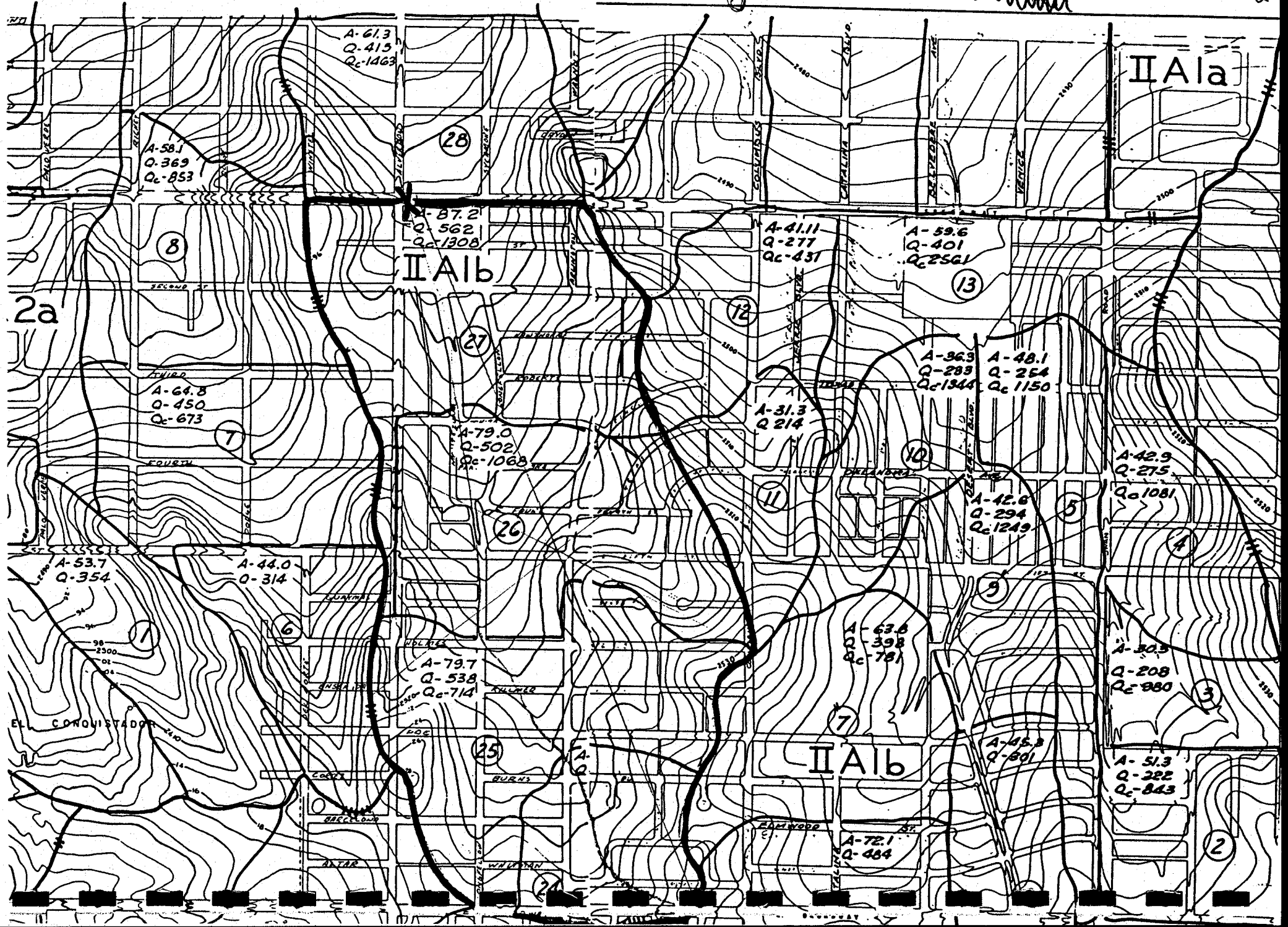
DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	39	minutes
Rainfall Intensity	i	1.4 3.1 4.1	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		159 616 932	cfs

Computed by M.E. Zeller (SLA) Date _____

Alvernon Wash @ Speedway

1" = 880' CI = 2'



City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Anklam Wash

2. Drainage Concentration Point: Anklam Road

3. *Watershed Area (A) at Drainage Concentration Point: 1350 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 13,700 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 7550 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 7000 $(\Delta L_1)^3$ 3.43×10^{11} ΔH_1: 100 $\Delta L_1^3/\Delta H_1$ 3,430,000,000

b. ΔL_2: 4400 $(\Delta L_2)^3$ 8.5184×10^{10} ΔH_2: 100 $\Delta L_2^3/\Delta H_2$ 851,840,000

c. ΔL_3: 2300 $(\Delta L_3)^3$ 1.2167×10^{10} ΔH_3: 100 $\Delta L_3^3/\Delta H_3$ 121,670,000

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 58,566 + 29,186 + 11,030 = 98,782

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.1387)^2$ = 0.0192 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average (future)
9. Watershed Type(s) (% of Total Area):	Rural (100%)	( )	
10. Basin Factor (n_b):	0.034		n_{bw} = 0.034
11. Imperviousness (%):	10%		I_w = 10%
12. Runoff Coefficient (C_w):	0.65		C_w = 0.65

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 22.12 (future)

14. **Time of Concentration (T_c), determined from Table III: 33 minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.53 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.65 x 4.53 x 1350 = 3975 cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.10	0.35	0.55	0.75
Q (cubic feet/second):	398	1391	2186	2981

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location Anklam Road
Project No. _____ Station _____
Name of Stream Anklam Wash

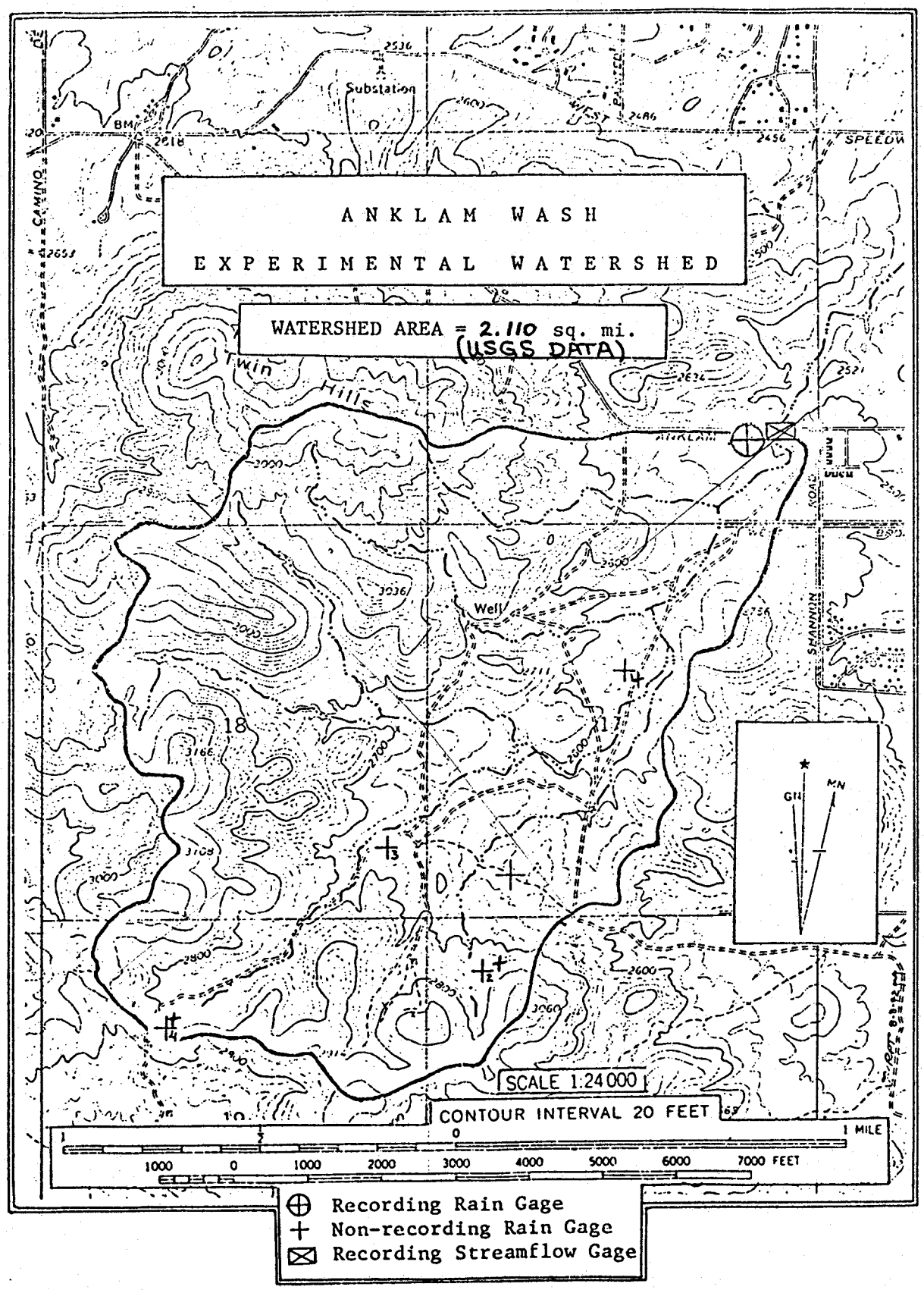
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	1350	acres
	A_3		acres
Drainage Length		13700	feet
Elevation			
Top of Drainage Area		2800	feet
At Structure		2500	feet
Drainage Area Slope		2.19	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	52	minutes
Rainfall Intensity	i	1.1 2.6 3.3	inches/hour
Runoff Coefficient	C_1	0.2 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		297 2106 3119	cfs

Computed by M.E. Zeller (SLA) Date _____



URBAN HYDROLOGY STUDIES, TUCSON

UNIVERSITY OF ARIZONA

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Arcadia Wash

2. Drainage Concentration Point: Craycroft Road

3. *Watershed Area (A) at Drainage Concentration Point: 787 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 13,600 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 6,600 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 6000 $(\Delta L_1)^3$ 2.16×10^{11} ΔH_1: 50 $\Delta L_1^3/\Delta H_1$ 4.32×10^9

b. ΔL_2: 7600 $(\Delta L_2)^3$ 4.3898×10^{11} ΔH_2: 70 $\Delta L_2^3/\Delta H_2$ 6,271,085,714

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 65,727 + 79,190 + _____ = 144,917

8. Mean Slope (S_c) = $(L_c/I)^2$ = (0.0938)^2 = 0.0088 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	( )	
10. Basin Factor (n_b):	0.027 (Some I.C.)		n_{bw} = 0.027
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 21.72 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 32 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.62 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 4.62 x 787 = 2727 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	545	1227	1773	2318

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller Company: SLA Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Craycroft Road
Project No. _____ Station _____
Name of Stream Arcadia Wash

DESIGN DATA

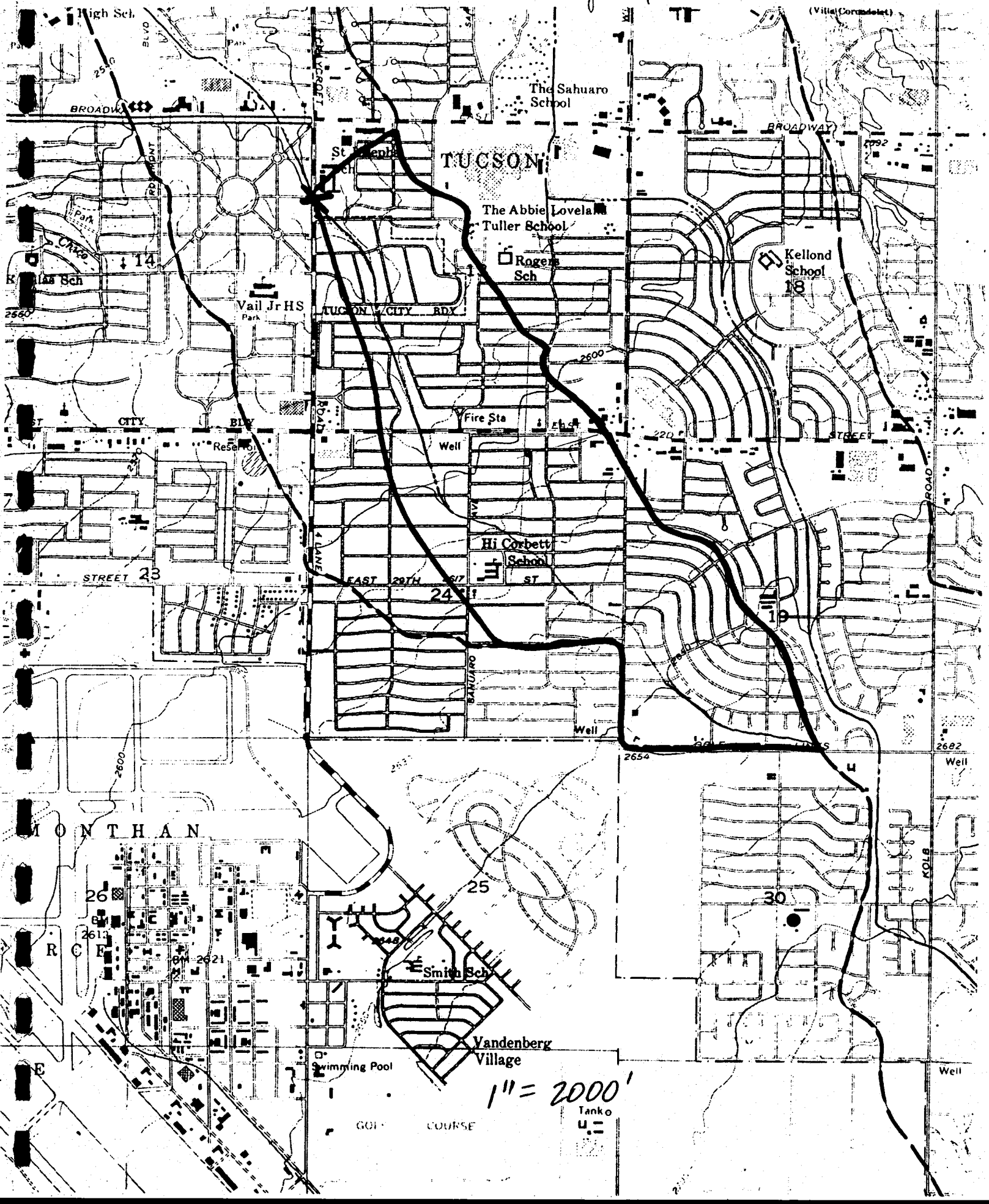
Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	787	acres
	A_3		acres
Drainage Length		13,600	feet
Elevation			
Top of Drainage Area		2670	feet
At Structure		2550	feet
Drainage Area Slope		0.88	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	74	minutes
Rainfall Intensity	i	0.9 2.0 2.6	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		283 1102 1637	cfs

Computed by M.E. Zeller (SLA) Date _____

Arcadia Wash @ Craycroft



City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Cemetery Wash

2. Drainage Concentration Point: Oracle Road

3. *Watershed Area (A) at Drainage Concentration Point: 650 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 10,560 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 5070 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 4400 $(\Delta L_1)^3$ 8.5184×10^{10} ΔH_1: 22 $\Delta L_1^3/\Delta H_1$ 3,872,000,000

b. ΔL_2: 6160 $(\Delta L_2)^3$ 2.3374×10^{11} ΔH_2: 76 $\Delta L_2^3/\Delta H_2$ 3,075,590,737

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 62,225 + 55,458 + _____ = 117,683

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.0897)^2$ = 0.0081 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	_____ ( )	
10. Basin Factor (n_b):	0.030 (St. Flow)	_____	n_{bw} = 0.030
11. Imperviousness (%):	40%	_____	I_w = 40%
12. Runoff Coefficient (C_w):	0.75	_____	C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 21.36 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 31 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.71 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 4.71 x 650 = 2296 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	459	1033	1492	1952

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date: _____

PCFCD METHOD

HYDROLOGIC DATA SHEET

Project Name and Location: Cemetery Wash

ainage Concentration Point: @ Oracle Road

tershed Area (A): 650 acres/~~square miles.~~

Length of Watercourse (L_c): 10,560 ft. Length to Center of Gravity (L_{ca}): 5070 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
4400	22
6160	76

an Slope (S_c): 0.0081 ft./ft. Watershed Type(s): Moderately Urban ~~(future)~~

Basin Factor (n_b): .030 (st. flow) ~~(future)~~ Flood Frequency: 2 25 100 yrs.

P_{24} (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

(1 hour): 1.0 2.3 3.0 in. Areal Value: _____ in.

(2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

il Group(s): 80% B, 20% D Cover Type(s): Urban Lawns

Cover Density (pervious areas): Poor Impervious Cover: 40% ~~(future)~~

(s): 83, 91, 99 (pervious & impervious areas) CN*(s): (77.16, 86.11, 87.72; 86.88, 92.60, 93.63;) 99
(curve number) (adjusted curve number)

off to Rainfall Ratio(s), (C): (.05, .47, .60) (.22, .68, .77) (pervious areas) .89, .95, .96 (impervious areas)

Runoff Supply Rate (q): .41, .69, .76 i in./hr. (function of i)

e of Concentration (T_c): 74, 60, 57 $i^{-.4}$ ~~hrs.~~/mins. (function of i)

rative Solution of T_c: 82, 38, 31 ~~hrs.~~/mins.

Rainfall Intensity (i) at T_c: 0.77, 3.12, 4.63 in./hr.

off Supply Rate (q) at T_c: 0.32, 2.15, 3.52 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 210, 1409, 2306 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Oracle Road
Project No. _____ Station _____
Name of Stream Cemetery Wash

DESIGN DATA

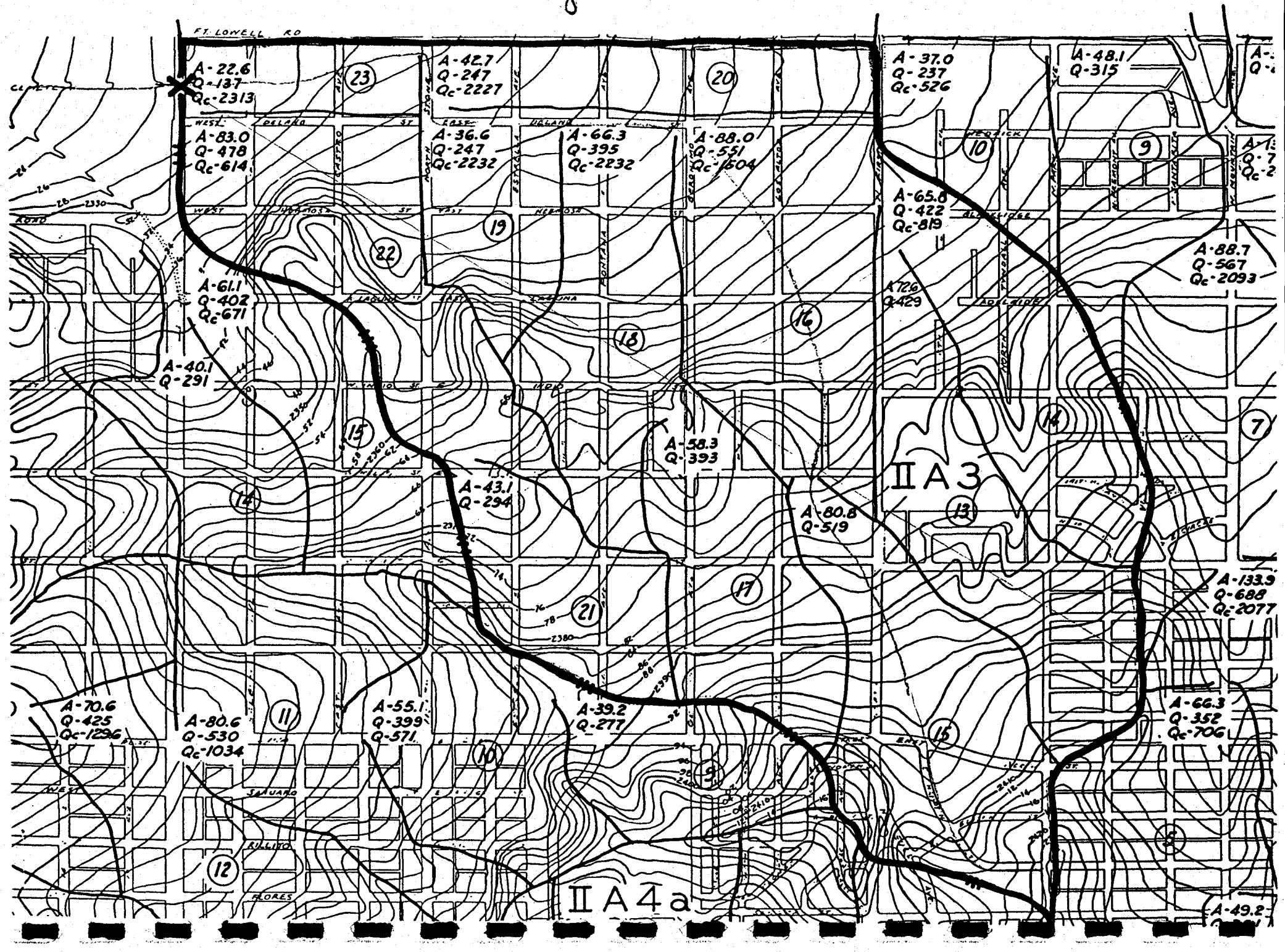
Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	650	acres
	A_3		acres
Drainage Length		10,560	feet
Elevation			
Top of Drainage Area		2424	feet
At Structure		2326	feet
Drainage Area Slope		0.93	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	59	minutes
Rainfall Intensity	i	1.0 2.3 3.0	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		260 1047 1560	cfs

Computed by M.E. Zeller (SLA) Date _____

Cemetary Wash @ Oracle 1" = 880' CI = 2'



City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Cholla Wash

2. Drainage Concentration Point: Greasewood Road

3. *Watershed Area (A) at Drainage Concentration Point: 273 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 7600 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 3600 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 5100 $(\Delta L_1)^3$ 1.3265×10^{11} ΔH_1: 100 $\Delta L_1^3/\Delta H_1$ 1.3265×10^9

b. ΔL_2: 2500 $(\Delta L_2)^3$ 1.5625×10^{10} ΔH_2: 160 $\Delta L_2^3/\Delta H_2$ 97,656,250

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 36,421 + 9882 + _____ = 46,303

8. Mean Slope (S_c) = $(L_c/I)^2$ = (0.1641)^2 = 0.0269 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average (future)
9. Watershed Type(s) (% of Total Area):	Mod. Urban (44%)	Rural (56%)	
10. Basin Factor (n_b):	0.022	0.034	n_{bw} = 0.028
11. Imperviousness (%):	40%	10%	I_w = 23.2%
12. Runoff Coefficient (C_w):	0.75	0.65	C_w = 0.694

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 10.40 (future)

14. **Time of Concentration (T_c), determined from Table III: 13 minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 7.27 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.694 x 7.27 x 273 = 1377 cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.144	0.394	0.594	0.794
Q (cubic feet/second):	198	543	818	1093

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller Company: SLA Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Greasewood Road
Project No. _____ Station _____
Name of Stream Cholla Wash

DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	273	acres
	A_3		acres
Drainage Length		7600	feet
Elevation			
Top of Drainage Area		2740	feet
At Structure		2480	feet
Drainage Area Slope		3.42	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	28	minutes
Rainfall Intensity	i	1.7 3.8 5.0	inches/hour
Runoff Coefficient	C_1	0.3 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		139 622 956	cfs

Computed by M.E. Zeller (SLA) Date _____

Cholla Wash at Greasewood
Substation
BM
2618
SPEEDWAY
Archery Range
PIPELINE
Well
WEST
Twin Hills
ANKLAM
ROAD
Trailer Park
BROADWAY
SHANNON
GREASEWOOD
STREET
220
TRAIL
JEEP
Radio Towers
SAN JUAN
36TH
Water Tank
JOHNSON
1 in = 2000'

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Columbus Wash

2. Drainage Concentration Point: Grant Road

3. *Watershed Area (A) at Drainage Concentration Point: 176 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 5720 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 3500 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 440 $(\Delta L_1)^3$ 85,184,000 ΔH_1: 8 $\Delta L_1^3/\Delta H_1$ 10,648,000

b. ΔL_2: 5280 $(\Delta L_2)^3$ 1.4720×10^{11} ΔH_2: 42 $\Delta L_2^3/\Delta H_2$ 3,504,713,143

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 3263 + 59,201 + _____ = 62,464

8. Mean Slope $(S_c) = (L_c/I)^2 = (0.0916)^2 = 0.0084$ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	( )	
10. Basin Factor (n_b):	0.030 (St. Flow)		n_{bw} = 0.030
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 15.68 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 21 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 5.85 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 5.85 x 176 = 772 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	154	347	502	656

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Grant Road
Project No. _____ Station _____
Name of Stream Columbus Wash

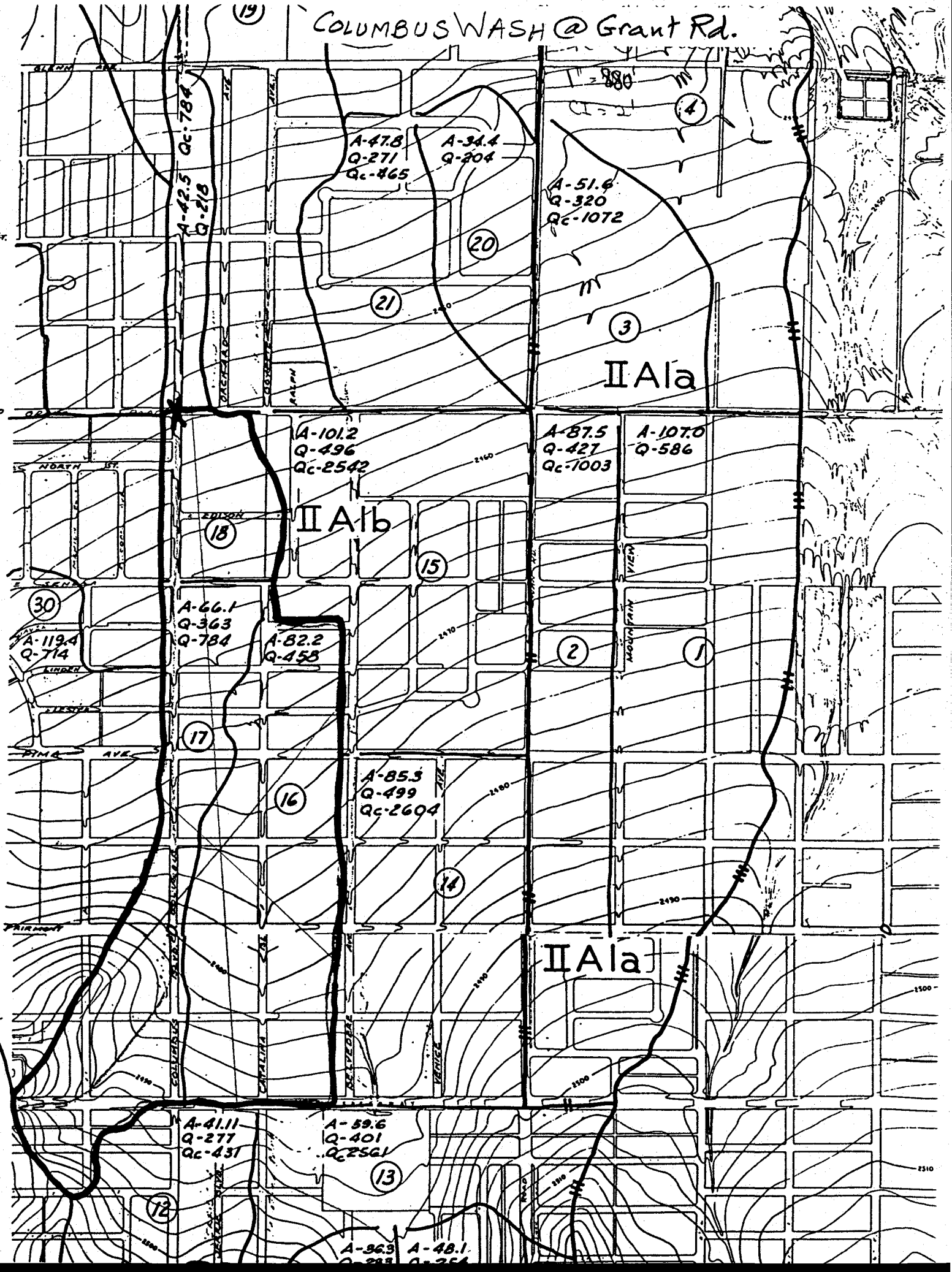
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	176	acres
	A_3		acres
Drainage Length		5720	feet
Elevation			
Top of Drainage Area		2452	feet
At Structure		2502	feet
Drainage Area Slope		0.87	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	38	minutes
Rainfall Intensity	i	1.4 3.2 4.1	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		99 394 577	cfs

Computed by M.E. Zeller (SLA) Date _____


COLUMBUS WASH @ Grant Rd.
1" = 880'
GLENN AVE.
NORTH ST.
EDISON
SENECA
LINDEN
PIMA AVE.
FAIRMONT
MOUNTAIN VIEW
COLUMBUS
CAMELIA
DESERT
VENICE
A-42.5
Q-218
Qc-784
A-47.8
Q-271
Qc-465
A-34.4
Q-204
A-51.6
Q-320
Qc-1072
II A1a
A-101.2
Q-496
Qc-2542
A-87.5
Q-427
Qc-1003
A-107.0
Q-586
II A1b
A-66.1
Q-363
Q-784
A-82.2
Q-458
A-119.4
Q-714
A-85.3
Q-499
Qc-2604
II A1a
A-41.11
Q-277
Qc-431
A-59.6
Q-401
Qc-2561
A-36.3
A-48.1

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Este Wash

2. Drainage Concentration Point: Bonanza Ave.

3. *Watershed Area (A) at Drainage Concentration Point: 1178 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 20,400 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 9600 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 4200 $(\Delta L_1)^3$ 7.4088×10^{10} ΔH_1: 100 $\Delta L_1^3/\Delta H_1$ 7.4088×10^8

b. ΔL_2: 8000 $(\Delta L_2)^3$ 5.12×10^{11} ΔH_2: 140 $\Delta L_2^3/\Delta H_2$ 3,657,142,857

c. ΔL_3: 8200 $(\Delta L_3)^3$ 5.5137×10^{11} ΔH_3: 130 $\Delta L_3^3/\Delta H_3$ 4,241,292,308

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 27,219 + 60,474 + 65,125 = 152,818

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.1335)^2$ = 0.0178 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average (future)
9. Watershed Type(s) (% of Total Area):	Mod. Urban (19.5%)	Suburban (80.5%)	
10. Basin Factor (n_b):	0.022	0.032	n_{bw} = 0.030
11. Imperviousness (%):	40%	20%	I_w = 23.9%
12. Runoff Coefficient (C_w):	0.75	0.70	C_w = 0.710

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 23.52 (future)

14. **Time of Concentration (T_c), determined from Table III: 35 minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.36 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.71 x 4.36 x 1178 = 3647 cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.16	0.41	0.61	0.81
Q (cubic feet/second):	584	1495	2225	2954

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Bonanza Ave.
Project No. _____ Station _____
Name of Stream Este Wash

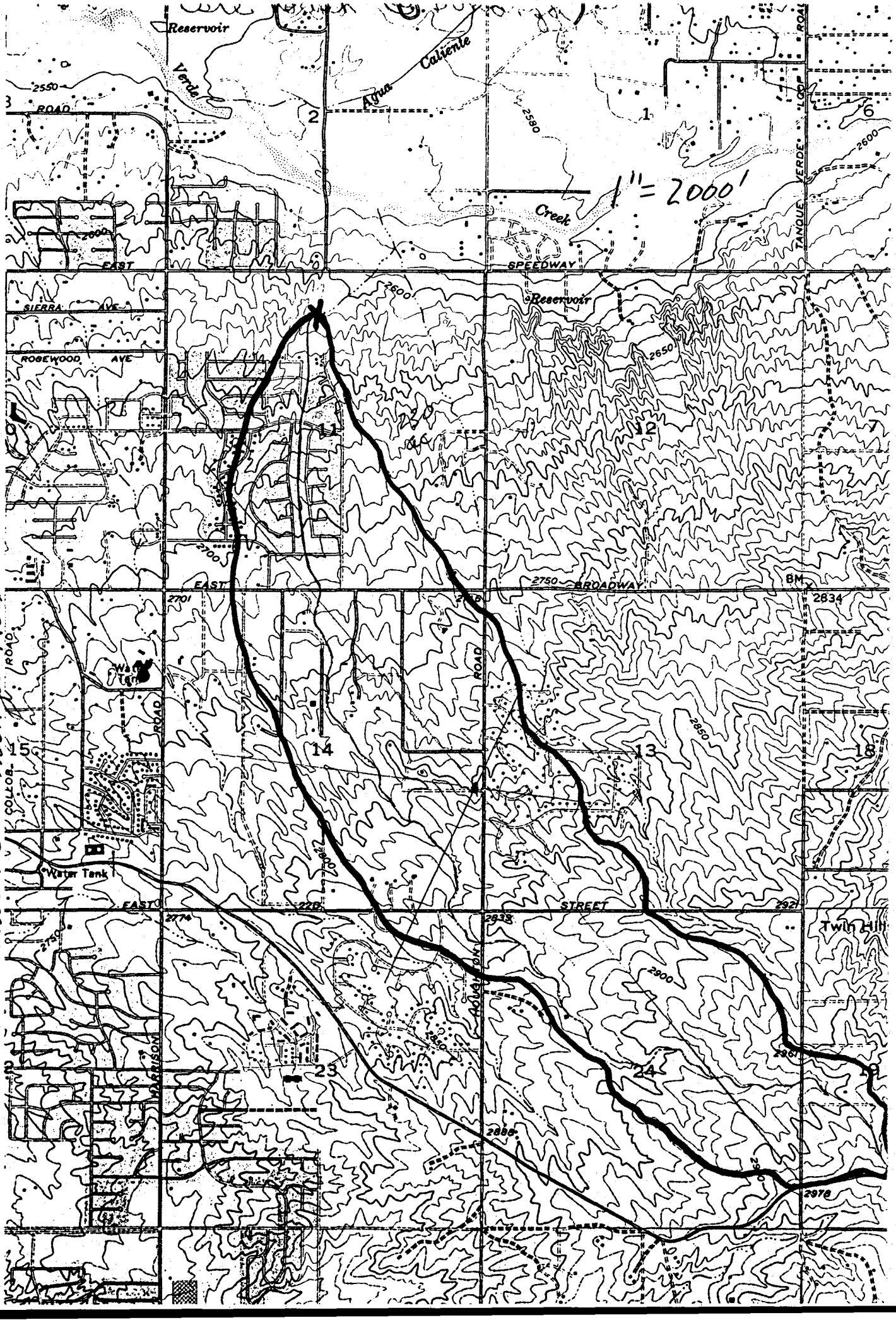
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	1178	acres
	A_3		acres
Drainage Length		20,400	feet
Elevation			
Top of Drainage Area		2980	feet
At Structure		2610	feet
Drainage Area Slope		1.81	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	76	minutes
Rainfall Intensity	i	0.8 1.9 2.5	inches/hour
Runoff Coefficient	C_1	0.3 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		283 1343 2062	cfs

Computed by M.E. Zeller (SLA) Date _____


Reservoir
Verde
Agua Caliente
Creek
1" = 2000'
EAST
SPEEDWAY
SIERRA AVE
ROSEWOOD AVE
Reservoir
EAST
BROADWAY
BM
2834
Water Tank
EAST
STREET
Twin Hill
TANQUE VERDE LOOP ROAD
COLLOB. ROAD
HARRISON ROAD
HOUGHTON ROAD
Este Wash @ Bonanza Ave

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Friendly Village Wash

2. Drainage Concentration Point: Just above Rillito River

3. *Watershed Area (A) at Drainage Concentration Point: 762 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 17,000 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 8,700 ft.

6. Change in Length Factors - ft. Change in Elevation Factors - ft.

a. ΔL_1: 7500 $(\Delta L_1)^3$ 4.2188×10^{11} ΔH_1: 210 $\Delta L_1^3/\Delta H_1$ 2,008,928,571

b. ΔL_2: 9500 $(\Delta L_2)^3$ 8.5738×10^{11} ΔH_2: 200 $\Delta L_2^3/\Delta H_2$ 4,286,875,000

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 44,821 + 65,474 + _____ = 110,295

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.1541)^2$ = 0.0238 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type (s) (% of Total Area):	Suburban (100%)	_____ ( )	
10. Basin Factor (n_b):	0.032	_____	n_{bw} = 0.032
11. Imperviousness (%):	20%	_____	I_w = 20%
12. Runoff Coefficient (C_w):	0.70	_____	C_w = 0.70

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 20.65 (future)

14. **Time of Concentration (T_c), determined from Table III: 30 minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.80 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.70 x 4.80 x 762 = 2560 cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.15	0.40	0.60	0.80
Q (cubic feet/second):	384	1024	1536	2048

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller Company: SLA Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location Just above Rillito River
Project No. _____ Station _____
Name of Stream Friendly Village Wash

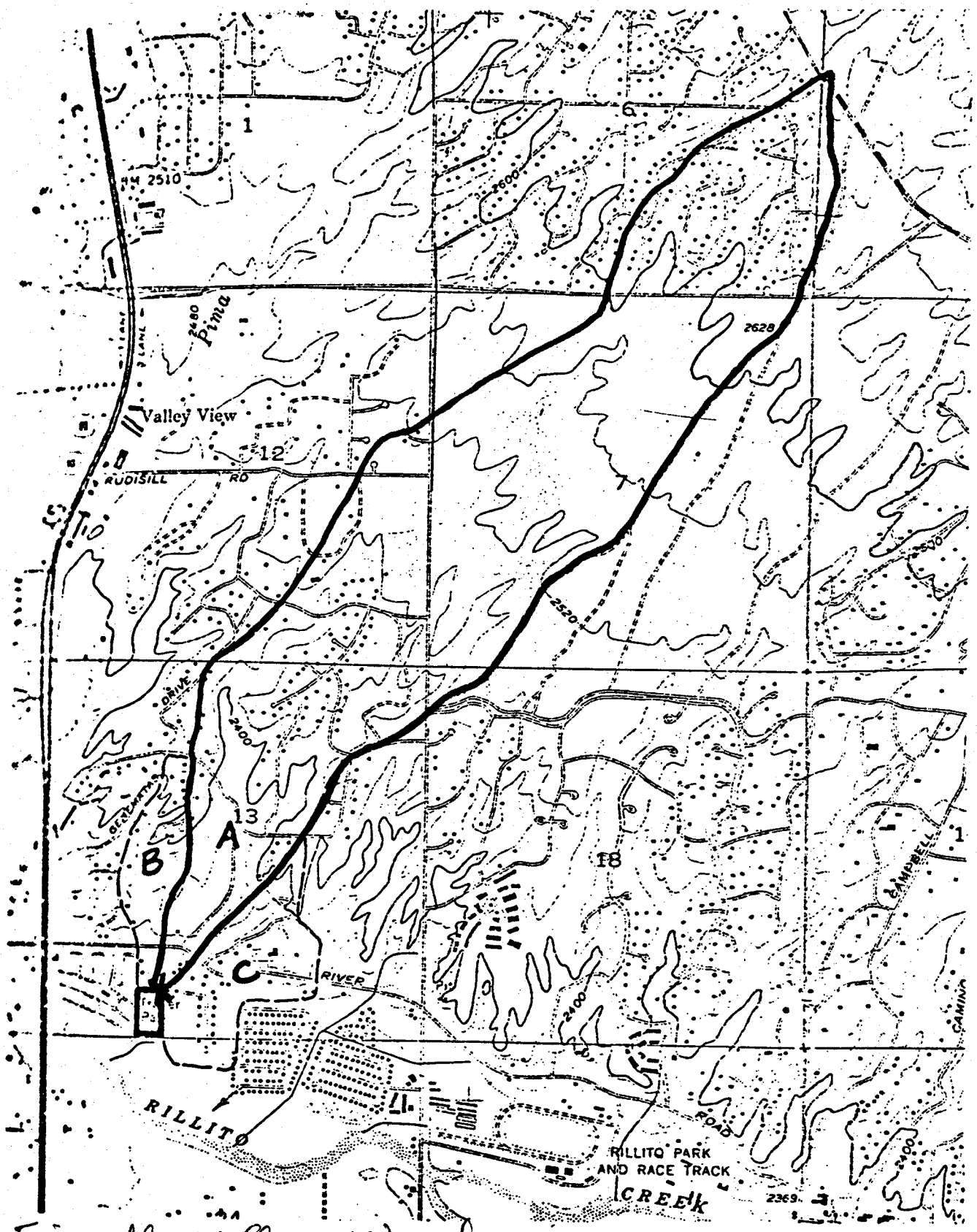
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	762	acres
	A_3		acres
Drainage Length		17,000	feet
Elevation			
Top of Drainage Area		2730	feet
At Structure		2320	feet
Drainage Area Slope		2.41	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	59	minutes
Rainfall Intensity	i	1.0 2.3 3.0	inches/hour
Runoff Coefficient	C_1	0.2 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		152 1052 1600	cfs

Computed by M.E. Zeller (SLA) Date _____



Friendly Village Wash
1" = 2000'

LOCATION PLAN

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: High School Wash

2. Drainage Concentration Point: @ Cherry Ave. (Gage Site)

3. *Watershed Area (A) at Drainage Concentration Point: 576 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 8100 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 4200 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 3900 $(\Delta L_1)^3$ 5.9319×10^{10} ΔH_1: 50 $\Delta L_1^3/\Delta H_1$ 1,186,380,000

b. ΔL_2: 2200 $(\Delta L_2)^3$ 1.0648×10^{10} ΔH_2: 20 $\Delta L_2^3/\Delta H_2$ 532,400,000

c. ΔL_3: 2000 $(\Delta L_3)^3$ 8×10^9 ΔH_3: 10 $\Delta L_3^3/\Delta H_3$ 800,000,000

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 34,444 + 23,074 + 28,284 = 85,802

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.0944)^2$ = 0.0089 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Med. Urban (100%)	( )	
10. Basin Factor (n_b):	0.030 (St. Flow, min. I.C.)		n_{bw} = 0.030
11. Imperviousness (%):	28.8%		I_w = 28.8%
12. Runoff Coefficient (C_w):	0.722		C_w = 0.722

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 18.23 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 25 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 5.33 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.722 x 5.33 x 576 = 2217 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.172	0.422	0.622	0.822
Q (cubic feet/second):	381	936	1379	1822

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

(Greenberg 10/82)

PCFCD METHOD

HYDROLOGIC DATA SHEET

Project Name and Location: High School Wash

rainage Concentration Point: @ Cherry Ave. (Gage Site)

atershed Area (A): 576 (646) acres/~~square miles~~

Length of Watercourse (L_c): 8100 (8080) ft. Length to Center of Gravity (L_{ca}): 4200 (4743) ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3900	50
2200	20
2000	10

an Slope (S_c): 0.0089 (.0097) ft./ft. Watershed Type(s): Moderately Urban (do) ~~(future)~~

Basin Factor (n_b): .030 (St. flow) minor I.C. (do) ~~(future)~~ Flood Frequency: 2 25 100 yrs.

P_4 (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): 1.0 2.3 3.0 in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

il Group(s): 80% B, 20% D Cover Type(s): Urban Lawns

Cover Density (pervious areas): Poor Impervious Cover: 28.8% (42) ~~(future)~~

(s): 83, 91, 99 (curve number) (pervious & impervious areas) CN*(s): (77,16,86,11,87,12); (82,89,92,60,93,63) 99 (adjusted curve number)

unoff to Rainfall Ratio(s), (C): (.05, .47, .60) (.22, .68, .77) (pervious areas) .89, .95, .96 (impervious areas)

Runoff Supply Rate (q): .32, .64, .73 i in./hr. (function of i)

me of Concentration (T_c): 68, 52, 49 $i^{-.4}$ ~~hrs.~~/mins. (function of i)

erative Solution of T_c: 72, 31, 25 ~~hrs.~~/mins.

Rainfall Intensity (i) at T_c: .855, 3.55, 5.26 in./hr.

unoff Supply Rate (q) at T_c: .27, 2.27, 3.84 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 157, 1318, 2230 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Cherry Ave. (Gage Site)
Project No. _____ Station _____
Name of Stream High School Wash

DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	576	acres
	A_3		acres
Drainage Length			feet
Elevation			
Top of Drainage Area		2500	feet
At Structure		2420	feet
Drainage Area Slope		0.99	%
Precipitation			
P = 6-hour			inches
P = 24-hour			inches

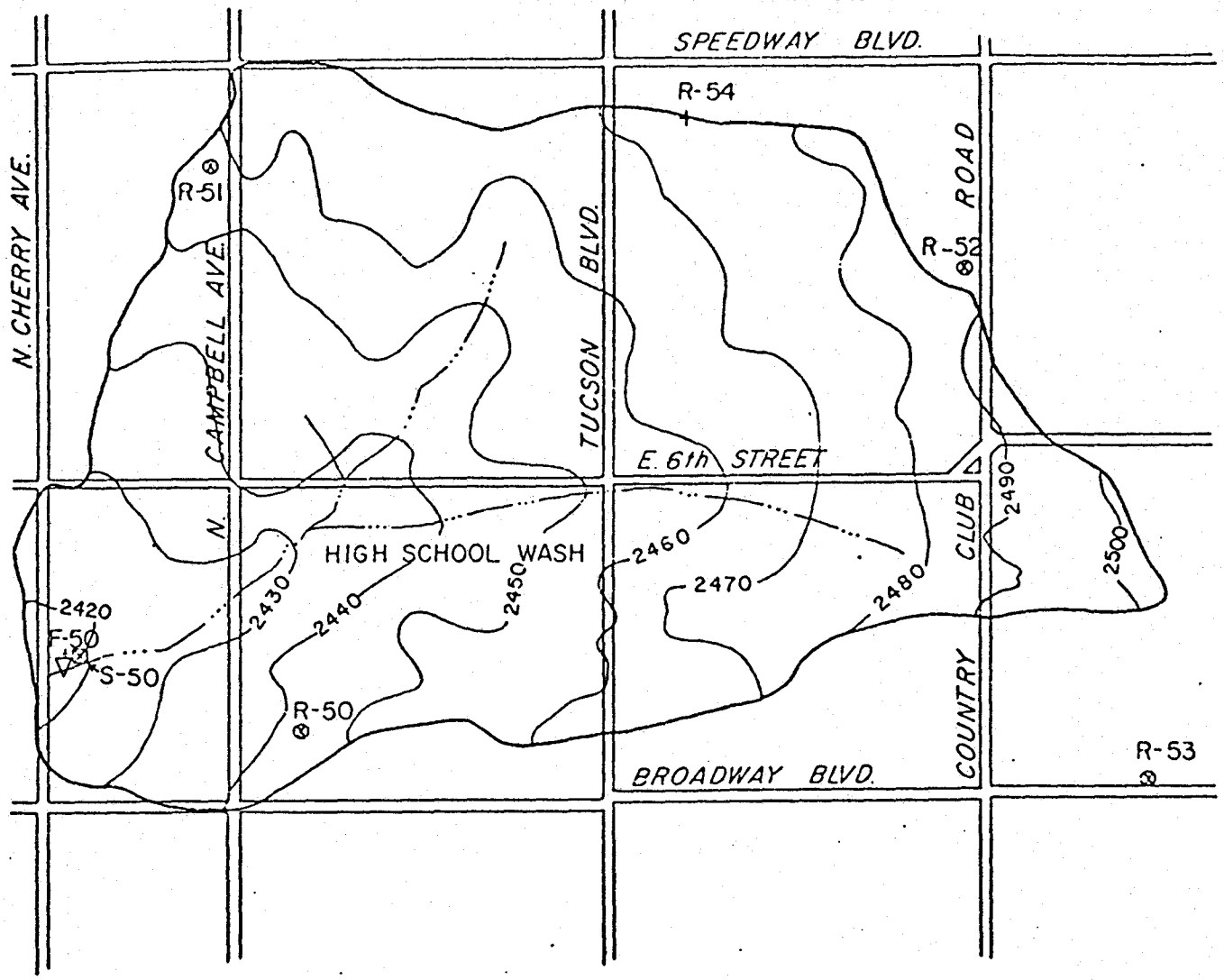
DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	47	minutes
Rainfall Intensity	i	1.2 2.7 3.6	inches/hour
Runoff Coefficient	C_1	0.3 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		207 933 1452	cfs

Computed by M. E. Zeller (SLA) Date _____

NOTE: ENTIRE WATERSHED LIES WITHIN CITY OF TUCSON IN FULLY DEVELOPED RESIDENTIAL AREA.

WATERSHED AREA = 0.9 SQ. MI.



WATER RESOURCES RESEARCH CENTER AND
CIVIL ENGINEERING DEPARTMENT
HIGH SCHOOL WASH EXPERIMENTAL WATERSHED
UNIVERSITY OF ARIZONA
1971

EXPLANATION

MAIN WATERSHED BOUNDARY
RECORDING RAIN GAGE ⊗
NON-RECORDING RAIN GAGE +
AUTOMATIC WATER SAMPLER ⊠
FLUME ▽

SCALE
0 1/4 1/2
MILES

N

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Mañana Grande Vista Wash

2. Drainage Concentration Point: 29th Street

3. *Watershed Area (A) at Drainage Concentration Point: 104 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 4800 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 1900 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 2200 $(\Delta L_1)^3$ 1.0648×10^{10} ΔH_1: 25 $\Delta L_1^3/\Delta H_1$ 425,920,000

b. ΔL_2: 2600 $(\Delta L_2)^3$ 1.7576×10^{10} ΔH_2: 30 $\Delta L_2^3/\Delta H_2$ 585,866,667

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 20,638 + 24,205 + _____ = 44,843

8. Mean Slope (S_c) = $(L_c/I)^2$ = (0.1070)^2 = 0.0115 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	_____ (_____)	
10. Basin Factor (n_b):	0.030 (street flow)	_____	n_{bw} = 0.030
11. Imperviousness (%):	40%	_____	I_w = 40%
12. Runoff Coefficient (C_w):	0.75	_____	C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 10.92 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 13 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 7.27 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 7.27 x 104 = 567 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	113	255	369	482

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ 29th Street
Project No. _____ Station _____
Name of Stream Mañana Grande Vista Wash

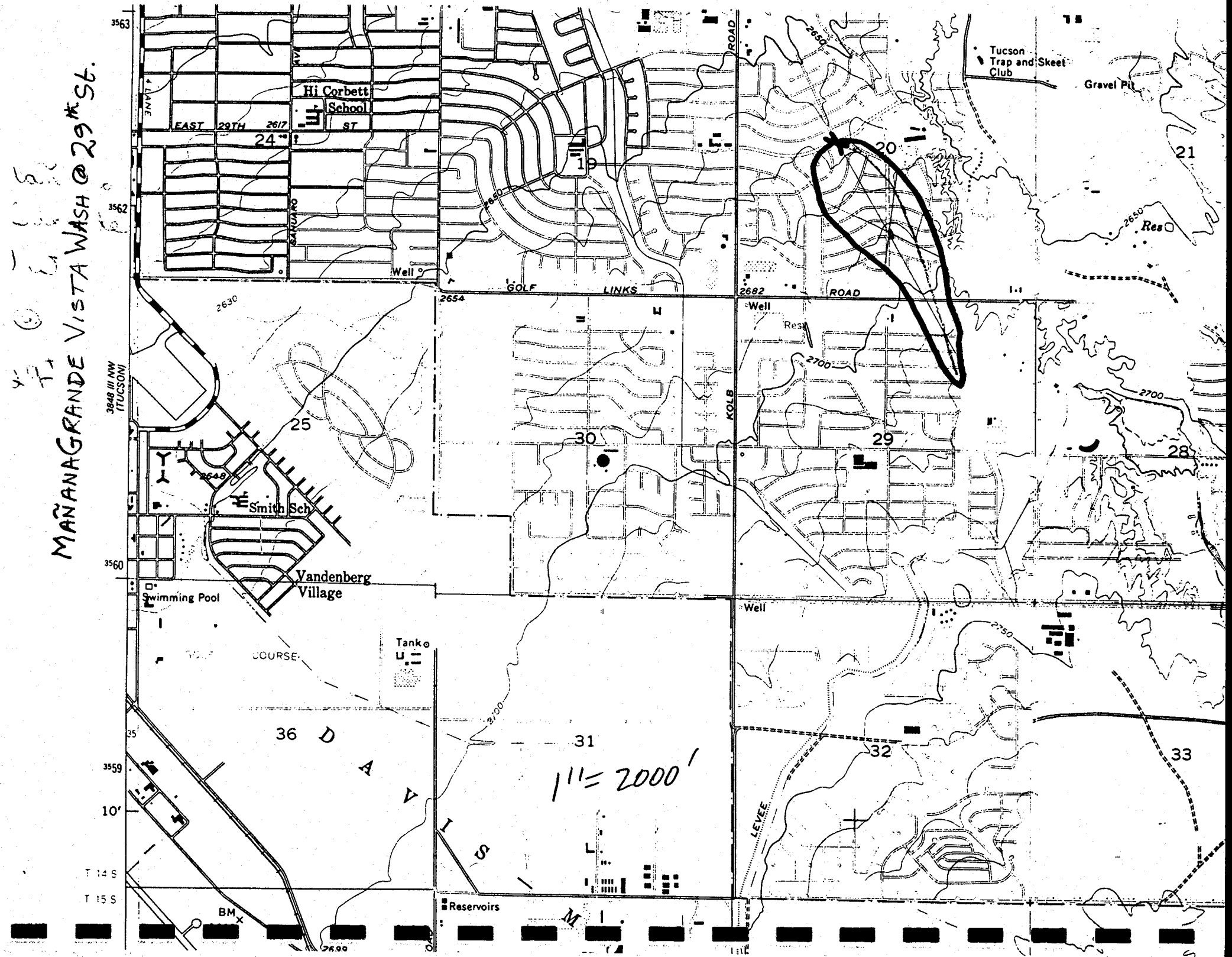
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	104	acres
	A_3		acres
Drainage Length		4800	feet
Elevation			
Top of Drainage Area		2720	feet
At Structure		2665	feet
Drainage Area Slope		1.15	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	30	minutes
Rainfall Intensity	i	1.6 3.7 4.8	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		67 269 400	cfs

Computed by M.E. Zeller (SLA) Date _____


MAÑANA GRANDE VISTA WASH @ 29th St.
Hi Corbett School
EAST 29TH ST
SANUARO
GOLF LINKS ROAD
KOLB ROAD
Tucson Trap and Skeet Club
Gravel Pit
Res
Well
Smith Sch
Vandenberg Village
Swimming Pool
COURSE
Tank
Reservoirs
LEVEE
BM
3848 III NW (TUCSON)
T 14 S
T 15 S
1" = 2000'

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Midway Wash

2. Drainage Concentration Point: Speedway Blvd.

3. *Watershed Area (A) at Drainage Concentration Point: 656 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 9060 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 4400 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 2900 $(\Delta L_1)^3$ 2.4389×10^{10} ΔH_1: 38 $\Delta L_1^3/\Delta H_1$ 641,815,790

b. ΔL_2: 800 $(\Delta L_2)^3$ 512,000,000 ΔH_2: 2 $\Delta L_2^3/\Delta H_2$ 256,000,000

c. ΔL_3: 5360 $(\Delta L_3)^3$ 1.5399×10^{11} ΔH_3: 40 $\Delta L_3^3/\Delta H_3$ 3,849,766,400

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 25,334 + 16,000 + 62,046 = 103,380

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.0876)^2$ = 0.0077 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	( )	
10. Basin Factor (n_b):	0.030 (St. Flow)		n_{bw} = 0.030
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 19.96 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 28 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 5.00 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 5.00 x 656 = 2460 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	492	1107	1599	2091

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M. E. Zeller

Company: SLA

Date:

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Speedway Blvd.
Project No. _____ Station _____
Name of Stream Midway Wash

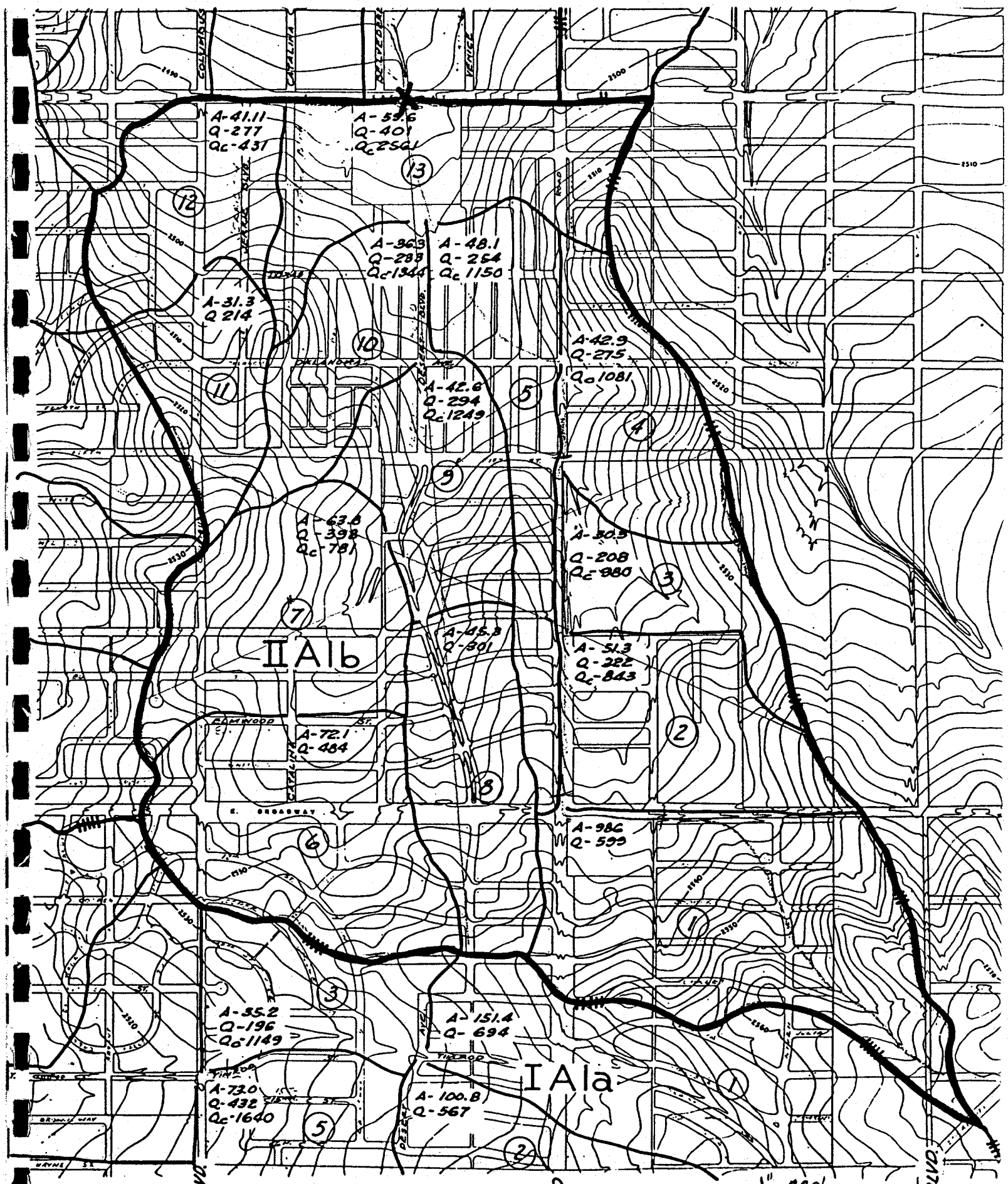
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	656	acres
	A_3		acres
Drainage Length		9060	feet
Elevation			
Top of Drainage Area		2568	feet
At Structure		2488	feet
Drainage Area Slope		0.88	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	54	minutes
Rainfall Intensity	i	1.1 2.5 3.2	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		289 1148 1680	cfs

Computed by M.E. Zeller (SLA) Date _____



Midway Business Park @ Speedway

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Navajo Wash

2. Drainage Concentration Point: Mountain Ave @ Hedrick Drive

3. *Watershed Area (A) at Drainage Concentration Point: 697 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 10,740 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 5370 ft.

6. Change in Length Factors - ft. Change in Elevation Factors - ft.

a. ΔL_1: 6600 $(\Delta L_1)^3$ 2.875×10^{11} ΔH_1: 45 $\Delta L_1^3/\Delta H_1$ 6,388,800,000

b. ΔL_2: 4140 $(\Delta L_2)^3$ 7.0958×10^{10} ΔH_2: 56 $\Delta L_2^3/\Delta H_2$ 1,267,106,143

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 79,930 + 35,596 + _____ = 115,526

8. Mean Slope (S_c) = $(L_c/I)^2$ = (0.0930)^2 = 0.0086 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	( )	
10. Basin Factor (n_b):	0.027 (Part I.C.)		n_{bw} = 0.027
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 19.20 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 27 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 5.11 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 5.11 x 697 = 2671 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	534	1202	1736	2270

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller Company: SLA Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location Mountain Ave. @ Hedrick Drive
Project No. _____ Station _____
Name of Stream Navajo Wash

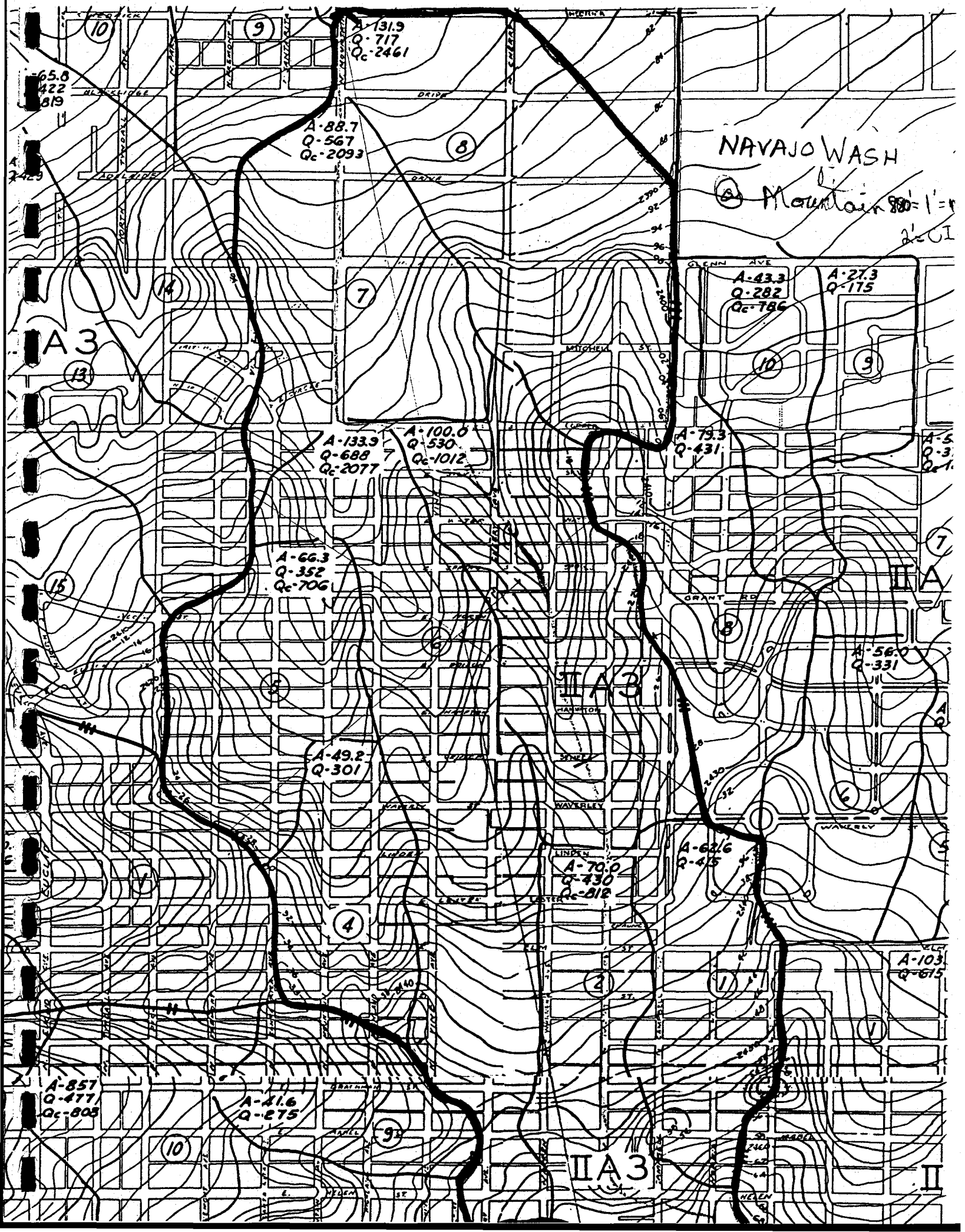
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	697	acres
	A_3		acres
Drainage Length		10,740	feet
Elevation			
Top of Drainage Area		2472	feet
At Structure		2371	feet
Drainage Area Slope		0.94	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	60	minutes
Rainfall Intensity	i	1.0 2.3 3.0	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		279 1122 1673	cfs

Computed by M. E. Zeller (SLA) Date _____


NAVAJO WASH
A-131.9
Q-717
Qc-2461
A-88.7
Q-567
Qc-2093
A-43.3
Q-282
Qc-786
A-27.3
Q-175
A-133.9
Q-688
Qc-2077
A-100.0
Q-530
Qc-1012
A-79.3
Q-431
A-66.3
Q-352
Qc-706
A-56.0
Q-331
A-49.2
Q-301
A-62.6
Q-415
A-70.0
Q-430
Qc-812
A-103
Q-615
A-85.7
Q-477
Qc-808
A-41.6
Q-275
A3
IIA
IIA3
IIA3
II
GLENN AVE
MITCHELL ST
GRANT RD
WAVERLEY
LINDEN
ELM ST
HELEN ST
MARIL

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Pumping Wash

2. Drainage Concentration Point: Rita Road

3. *Watershed Area (A) at Drainage Concentration Point: 544 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 11,600 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 4800 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 7000 $(\Delta L_1)^3$ 3.43×10^{11} ΔH_1: 100 $\Delta L_1^3/\Delta H_1$ 3.43×10^9

b. ΔL_2: 4600 $(\Delta L_2)^3$ 9.7336×10^{10} ΔH_2: 40 $\Delta L_2^3/\Delta H_2$ 2,433,400,000

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 58,566 + 49,330 + _____ = 107,896

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.1075)^2$ = 0.0116 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type (s) (% of Total Area):	Natural (100%)	_____ ( )	
10. Basin Factor (n_b):	0.035		n_{bw} = 0.035
11. Imperviousness (%):	0%		I_w = 0%
12. Runoff Coefficient (C_w):	0.60		C_w = 0.60

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 23.88 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 36 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.29 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.60 x 4.29 x 544 = 1400 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.05	0.30	0.50	0.70
Q (cubic feet/second):	70	420	700	980

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Rita Road
Project No. _____ Station _____
Name of Stream Pumping Wash

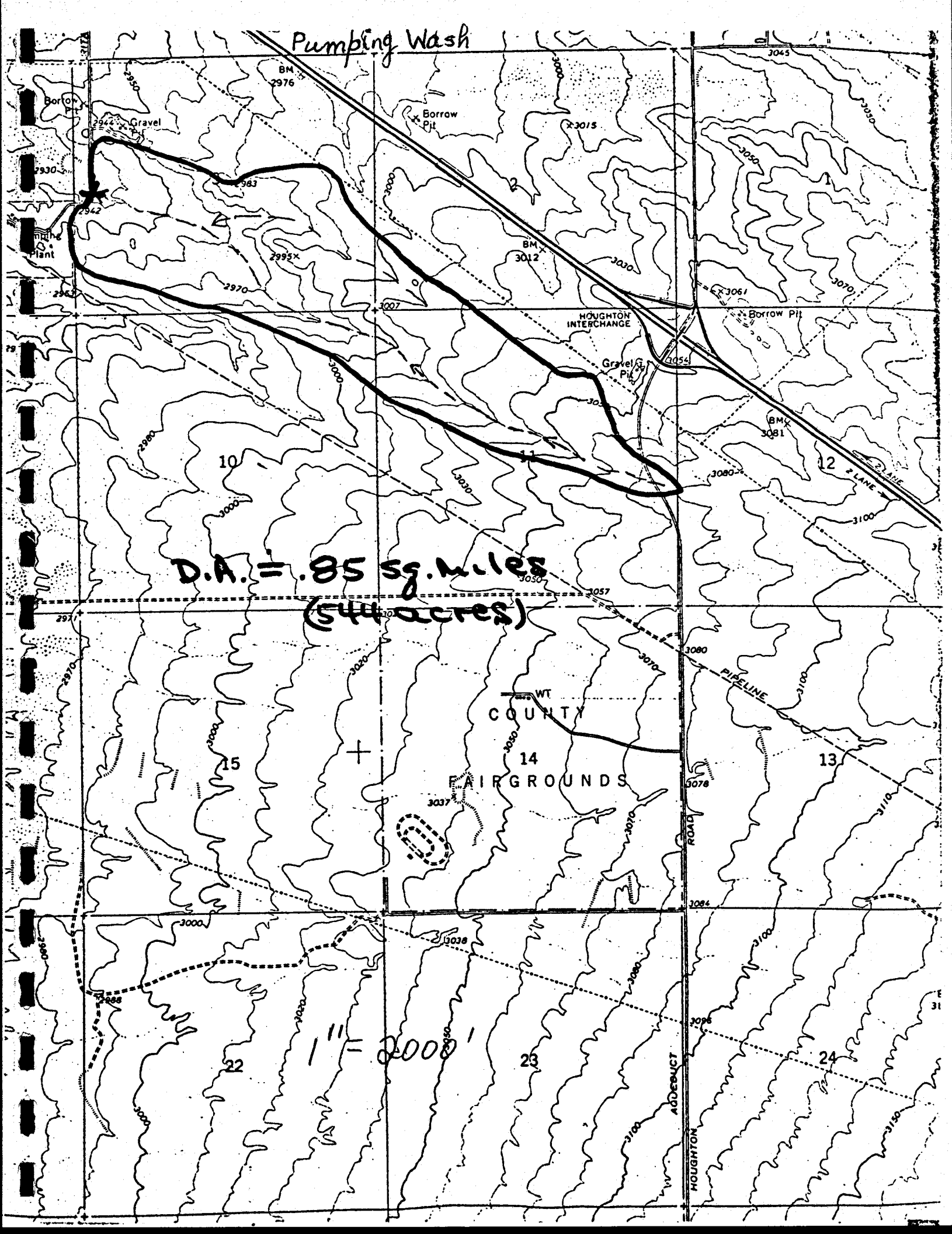
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	544	acres
	A_3		acres
Drainage Length		11,600	feet
Elevation			
Top of Drainage Area		3076	feet
At Structure		2936	feet
Drainage Area Slope		1.21	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	58	minutes
Rainfall Intensity	i	1.0 2.4 3.1	inches/hour
Runoff Coefficient	C_1	0.1 0.5 0.6	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		54 653 1012	cfs

Computed by M.E. Zeller (SLA) Date _____


Pumping Wash
D.A. = .85 sq. miles
(544 acres)
1" = 2000'
Borrow Pit
Gravel Pit
Mining Plant
BM 2976
BM 3012
BM 3081
HOUGHTON INTERCHANGE
Borrow Pit
Gravel Pit
2 LANE
PIPELINE
COUNTY
FAIRGROUNDS
WT
ROAD
AQUEDUCT
HOUGHTON
10
11
12
13
14
15
22
23
24

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Railroad Wash

2. Drainage Concentration Point: Just above Cherry Ave.

3. *Watershed Area (A) at Drainage Concentration Point: 1216 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 14,500 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 7100 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 6900 $(\Delta L_1)^3$ 3.2851×10^{11} ΔH_1: 60 $\Delta L_1^3/\Delta H_1$ 5,475,150,000

b. ΔL_2: 3300 $(\Delta L_2)^3$ 3.5937×10^{10} ΔH_2: 20 $\Delta L_2^3/\Delta H_2$ 1,796,850,000

c. ΔL_3: 4300 $(\Delta L_3)^3$ 7.9507×10^{10} ΔH_3: 34 $\Delta L_3^3/\Delta H_3$ 2,338,441,176

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 73,994 + 42,389 + 48,357 = 164,740

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.0880)^2$ = 0.0077 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Natural (43%)	Hvy. Urban (57%)	
10. Basin Factor (n_b):	0.035	0.022	n_{bw} = 0.030
11. Imperviousness (%):	0%	70%	I_w = 40%
12. Runoff Coefficient (C_w):	0.60	0.85	C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 26.53 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 42 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 3.87 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 3.87 x 1216 = 3530 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	706	1589	2295	3000

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

PCFCD METHOD

HYDROLOGIC DATA SHEET

Project Name and Location: Railroad Wash

Drainage Concentration Point: Just above Cherry Avenue

Watershed Area (A): 1216 acres/~~square miles.~~

Length of Watercourse (L_c): 14,500 ft. Length to Center of Gravity (L_{ca}): 7100 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
6900	60
3300	20
4300	34

Main Slope (S_c): 0.0077 ft./ft. Watershed Type(s): Natural & Hvy. Urban ~~(future)~~

Basin Factor ($\bar{n}_b$): 0.030 ~~(future)~~ Flood Frequency: 2 25 100 yrs.

P_1 (24 hour): _____ in. Areal Value: _____ in.

P_2 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): 1.0 2.3 3.0 in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): 80% B, 20% D Cover Type(s): Urban Lawns

Cover Density (pervious areas): Poor Impervious Cover: 40% ~~(future)~~

CN(s): 83, 91, 99 (pervious & impervious areas) CN*(s) (77,16 86,11 87,72; 88,88 92,60 93,63;) 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s), (C): (.05, 47, 60)(.22, 68, 77) pervious areas), 89, 95, 96 (impervious areas)

Runoff Supply Rate (q): .41, .69, .76 i in./hr. (function of i)

Time of Concentration (T_c): 91, 74, 71 $i^{-.4}$ ~~hrs.~~/mins. (function of i)

Iterative Solution of T_c: 112, 51, 42 ~~hrs.~~/mins.

Rainfall Intensity (i) at T_c: .598, 2.57, 3.82 in./hr.

Runoff Supply Rate (q) at T_c: .25, 1.77, 2.90 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 306, 2170, 3555 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location Just above Cherry Ave.
Project No. _____ Station _____
Name of Stream Railroad Wash

DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	1216	acres
	A_3		acres
Drainage Length		14,500	feet
Elevation			
Top of Drainage Area		2540	feet
At Structure		2426	feet
Drainage Area Slope		0.79	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

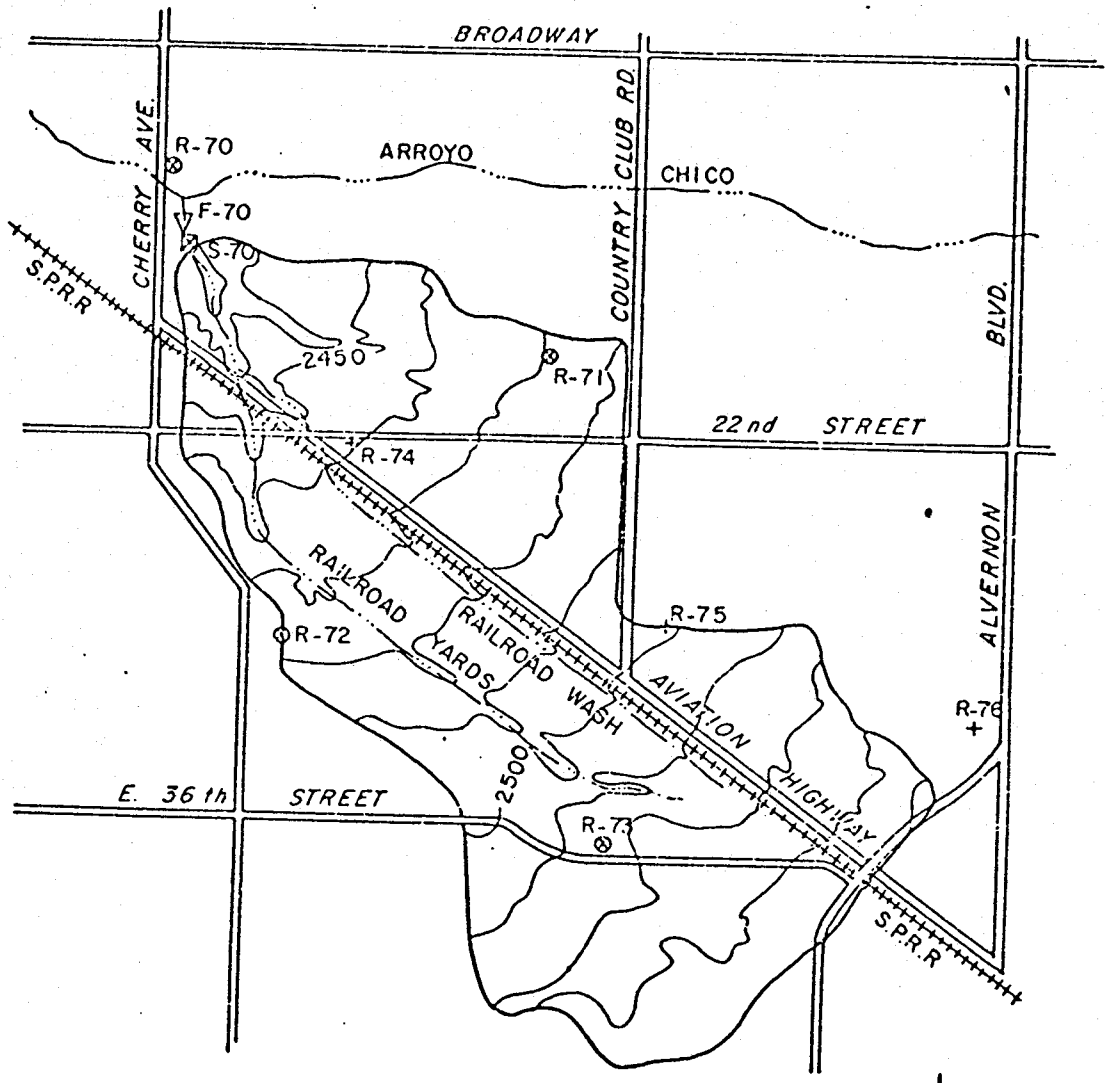
DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	80	minutes
Rainfall Intensity	i	0.8 1.8 2.4	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		389 1532 2335	cfs

Computed by M.E. Zeller (SLA) Date _____

NOTE: WATERSHED CONTAINS INDUSTRIAL, COMMERCIAL, AND RESIDENTIAL AREAS

WATERSHED AREA = 1.9 SQ. MI.



WATER RESOURCES RESEARCH CENTER AND
CIVIL ENGINEERING DEPARTMENT
RAILROAD WASH EXPERIMENTAL WATERSHED

UNIVERSITY OF ARIZONA
1971

EXPLANATION

MAIN WATERSHED BOUNDARY
RECORDING RAIN GAGE ⊗
NON-RECORDING RAIN GAGE +
AUTOMATIC WATER SAMPLER ⊠
FLUME ▽

SCALE
0 1/2 1
MILES

N

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Robb Wash

2. Drainage Concentration Point: Speedway Blvd.

3. *Watershed Area (A) at Drainage Concentration Point: 1330 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 23,800 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 12,100 ft.

6. Change in Length Factors - ft. Change in Elevation Factors - ft.

a. ΔL_1: 12,800 $(\Delta L_1)^3$ 2.0972×10^{12} ΔH_1: 110 $\Delta L_1^3/\Delta H_1$ 1.9065×10^{10}

b. ΔL_2: 11,000 $(\Delta L_2)^3$ 1.3310×10^{12} ΔH_2: 180 $\Delta L_2^3/\Delta H_2$ 7,394,444,444

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 138,076 + 85,991 + _____ = 224,067

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.1062)^2$ = 0.0113 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	_____ (_____)	(future)
10. Basin Factor (n_b):	0.025 (Some N.C.)	_____	n_{bw} = 0.025
11. Imperviousness (%):	40%	_____	I_w = 40%
12. Runoff Coefficient (C_w):	0.75	_____	C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 25.82 (future)

14. **Time of Concentration (T_c), determined from Table III: 40 minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 4.00 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 4.00 x 1330 = 3990 cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	798	1796	2594	3392

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Speedway Blvd.
Project No. _____ Station _____
Name of Stream Robb Wash

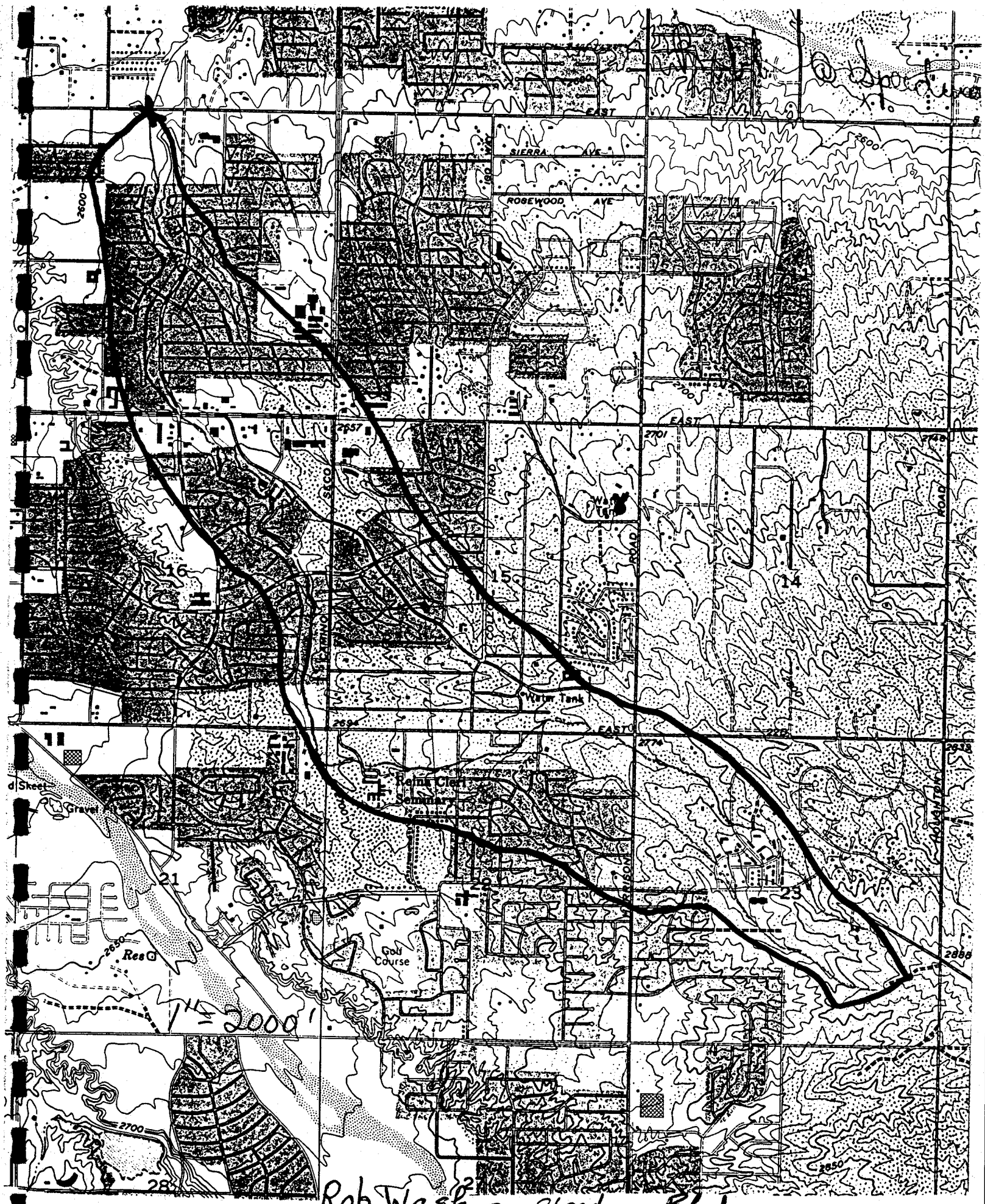
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	1330	acres
	A_3		acres
Drainage Length		23,800	feet
Elevation			
Top of Drainage Area		2870	feet
At Structure		2580	feet
Drainage Area Slope		1.22	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	100	minutes
Rainfall Intensity	i	0.7 1.5 2.0	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		372 1397 2128	cfs

Computed by M.E. Zeller (SLA) Date _____



Rob Wash @ Speedway Blvd.

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Rolling Hills Wash

2. Drainage Concentration Point: Harrison Road

3. *Watershed Area (A) at Drainage Concentration Point: 31 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 1800 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 900 ft.

6. Change in Length Factors - ft. Change in Elevation Factors - ft.

a. ΔL_1: 900 $(\Delta L_1)^3$ 729,000,000 ΔH_1: 15 $\Delta L_1^3/\Delta H_1$ 48,600,000

b. ΔL_2: 900 $(\Delta L_2)^3$ 729,000,000 ΔH_2: 35 $\Delta L_2^3/\Delta H_2$ 20,828,571

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 6971 + 4564 + _____ = 11,535

8. Mean Slope (S_c) = $(L_c/I)^2$ = (0.1560)^2 = 0.0244 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Suburban (100%)	_____ (_____)	
10. Basin Factor (n_b):	0.032	_____	n_{bw} = 0.032
11. Imperviousness (%):	20%	_____	I_w = 20%
12. Runoff Coefficient (C_w):	0.70	_____	C_w = 0.70

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 5.28 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 6 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 9.23 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.70 x 9.23 x 31 = 200 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.15	0.40	0.60	0.80
Q (cubic feet/second):	30	80	120	160

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller Company: SLA Date: _____

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Harrison Road
Project No. _____ Station _____
Name of Stream Rolling Hills Wash

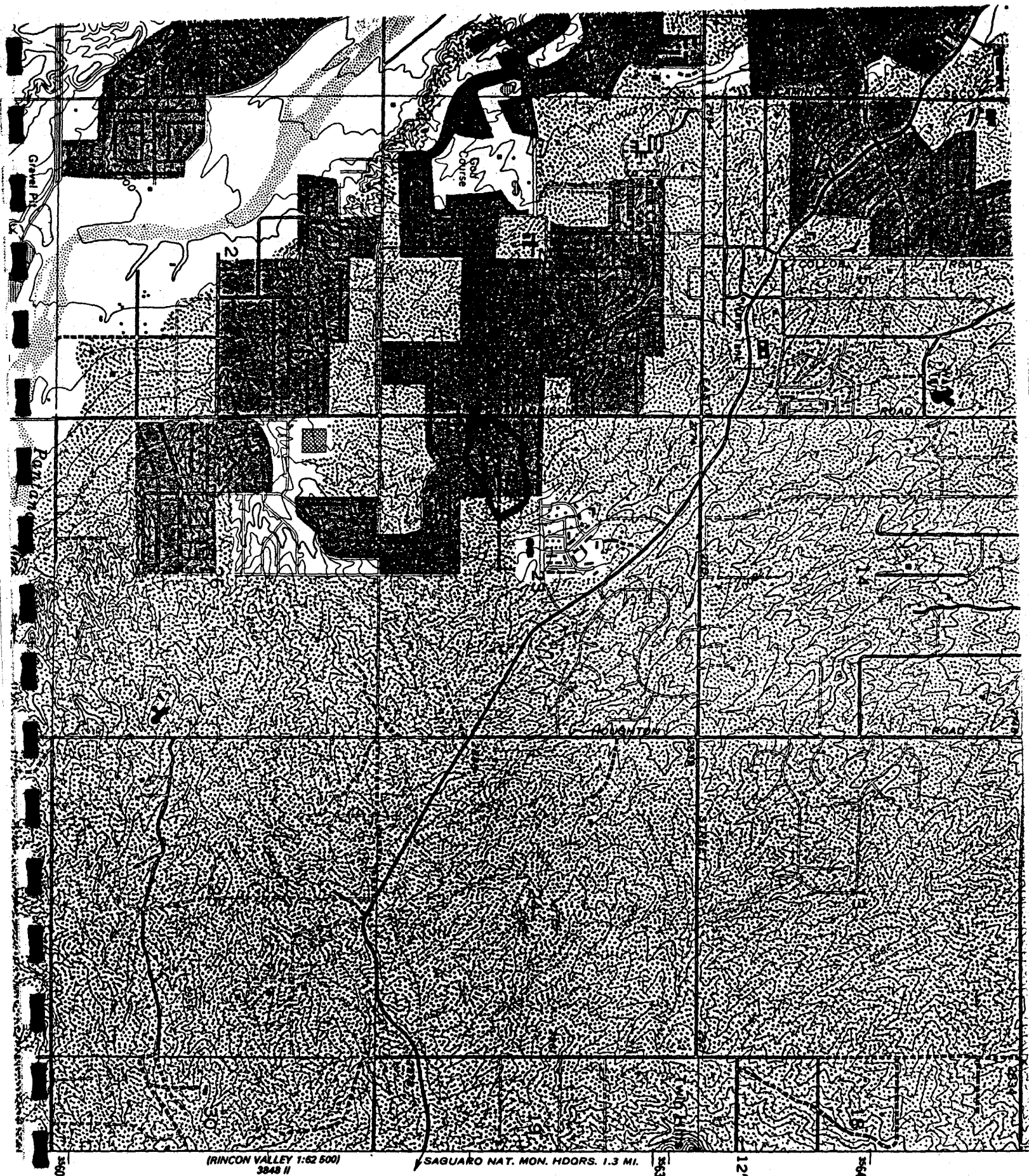
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	31	acres
	A_3		acres
Drainage Length		1800	feet
Elevation			
Top of Drainage Area		2825	feet
At Structure		2775	feet
Drainage Area Slope		2.78	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	10	minutes
Rainfall Intensity	i	2.7 6.1 8.0	inches/hour
Runoff Coefficient	C_1	0.2 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		17 113 174	cfs

Computed by M.E. Zeller (SLA) Date _____



Rolling Hills @ Harrison 1" = 2000'

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Rosehill Wash

2. Drainage Concentration Point: Grant Road

3. *Watershed Area (A) at Drainage Concentration Point: 1045 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 25,400 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 13,000 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 8200 $(\Delta L_1)^3$ 5.5137×10^{11} ΔH_1: 85 $\Delta L_1^3/\Delta H_1$ 6,486,682,353

b. ΔL_2: 9200 $(\Delta L_2)^3$ 7.7869×10^{11} ΔH_2: 80 $\Delta L_2^3/\Delta H_2$ 9,733,600,000

c. ΔL_3: 8000 $(\Delta L_3)^3$ 5.120×10^{11} ΔH_3: 68 $\Delta L_3^3/\Delta H_3$ 7,529,411,765

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 80,540 + 98,659 + 86,772 = 265,971

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.0955)^2$ = 0.0091 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Mod. Urban (100%)	( )	
10. Basin Factor (n_b):	0.024 (Some St. flow)		n_{bw} = 0.024
11. Imperviousness (%):	40%		I_w = 40%
12. Runoff Coefficient (C_w):	0.75		C_w = 0.75

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 28.16 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 45 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 3.69 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.75 x 3.69 x 1045 = 2892 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.20	0.45	0.65	0.85
Q (cubic feet/second):	578	1301	1880	2458

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Grant Road
Project No. _____ Station _____
Name of Stream Rosehill Wash

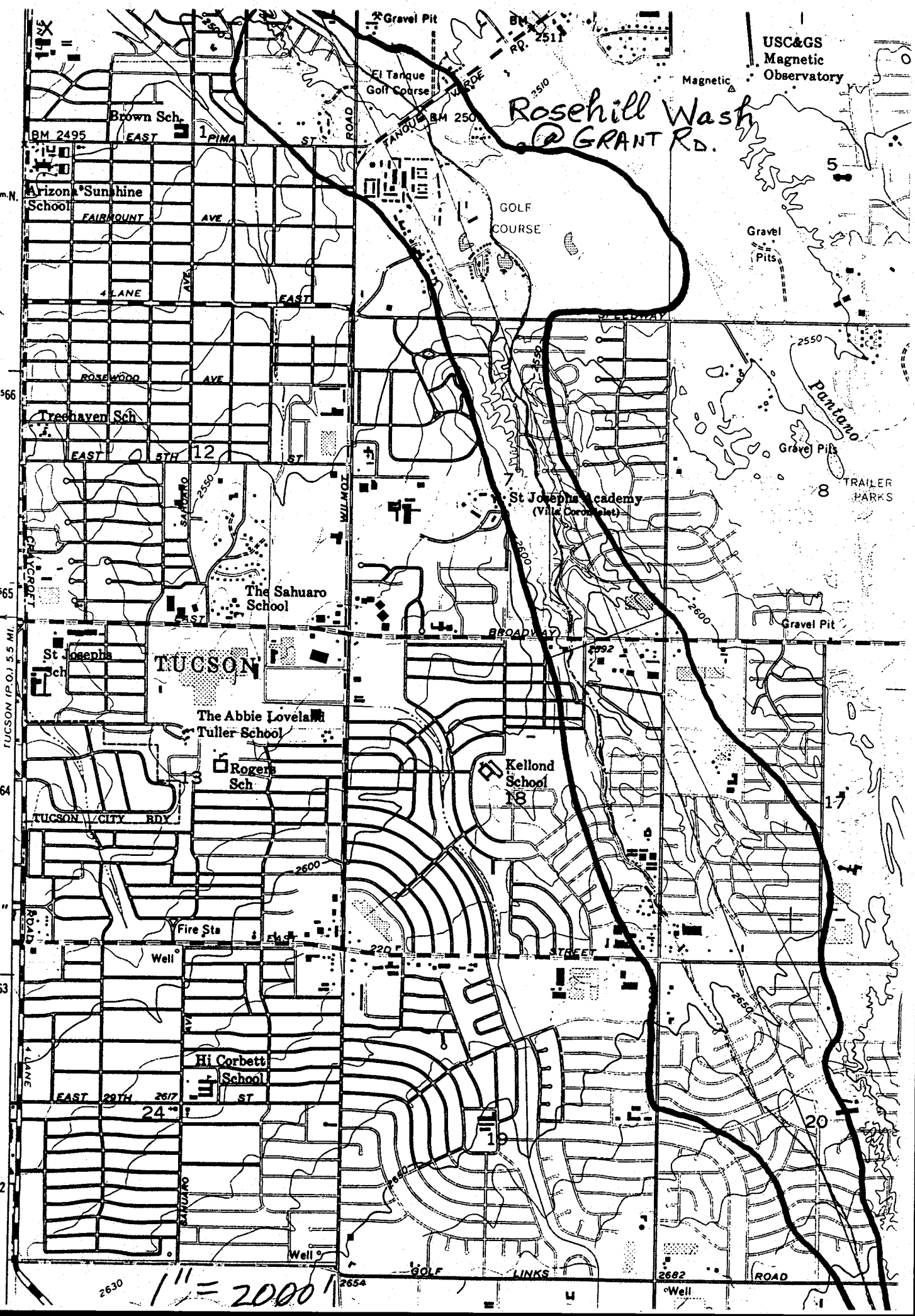
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	1045	acres
	A_3		acres
Drainage Length		25,400	feet
Elevation			
Top of Drainage Area		2717	feet
At Structure		2484	feet
Drainage Area Slope		0.92	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	117	minutes
Rainfall Intensity	i	0.6 1.3 1.8	inches/hour
Runoff Coefficient	C_1	0.4 0.7 0.8	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		251 951 1505	cfs

Computed by M.E. Zeller (SLA) Date _____


Rosehill Wash @ GRANT RD.
Gravel Pit
BM 2511
USC&GS Magnetic Observatory
Magnetic
El Tanque Golf Course
BM 2510
BM 2495
Brown Sch.
EAST
PIMA
ST
ROAD
3567000m.N.
Arizona Sunshine School
FAIRMOUNT
AVE
GOLF COURSE
Gravel Pits
4 LANE
EAST
BROADWAY
ROSEWOOD
AVE
3566
Treehaven Sch
EAST
5TH
ST
12
2550
Pantano
Gravel Pits
TRAILER PARKS
St Josephs Academy
(Ville Corondelet)
WILMOT
SAHUARO
CRAYCROFT
3565
The Sahuaro School
EAST
ST
BROADWAY
Gravel Pit
St Josepha Sch
TUCSON
TUCSON (P.O.) 5.5 MI.
The Abbie Loveland Tuller School
Rogers Sch
13
Kellond School
18
17
3564
TUCSON CITY BDY
2600
12'30"
ROAD
Fire Sta
EAST
220
STREET
Well
3563
2650
Hi Corbett School
EAST 29TH
2617
ST
24
19
20
3562
Well
GOLF LINKS
2682
ROAD
2630
2654
Well
1" = 2000'

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: Walnut Gulch (63.004) [Tombstone]

2. Drainage Concentration Point: At Gage Outlet (#4)

3. *Watershed Area (A) at Drainage Concentration Point: 563 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 11,400 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 5500 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 3100 $(\Delta L_1)^3$ 2.9791×10^{10} ΔH_1: 100 $\Delta L_1^3/\Delta H_1$ 2.9791×10^8

b. ΔL_2: 5200 $(\Delta L_2)^3$ 1.4061×10^{11} ΔH_2: 100 $\Delta L_2^3/\Delta H_2$ 1.4061×10^9

c. ΔL_3: 3100 $(\Delta L_3)^3$ 2.9791×10^{10} ΔH_3: 50 $\Delta L_3^3/\Delta H_3$ 595,820,000

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 17,260 + 37,498 + 24,409 = 79,167

8. Mean Slope (S_c) = $(L_c/I)^2$ = $(0.1440)^2$ = 0.0207 ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Natural (100%)	( )	
10. Basin Factor (n_b):	0.035		n_{bw} = 0.035
11. Imperviousness (%):	0%		I_w = 0%
12. Runoff Coefficient (C_w):	0.60		C_w = 0.60

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 19.63 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 28 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 5.00 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.60 x 5.00 x 563 = 1689 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.05	0.30	0.50	0.70
Q (cubic feet/second):	84	507	845	1182

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M.E. Zeller

Company: SLA

Date:

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location At Gage Outlet (#4)
Project No. _____ Station _____
Name of Stream Walnut Gulch (63.004) [Tombstone]

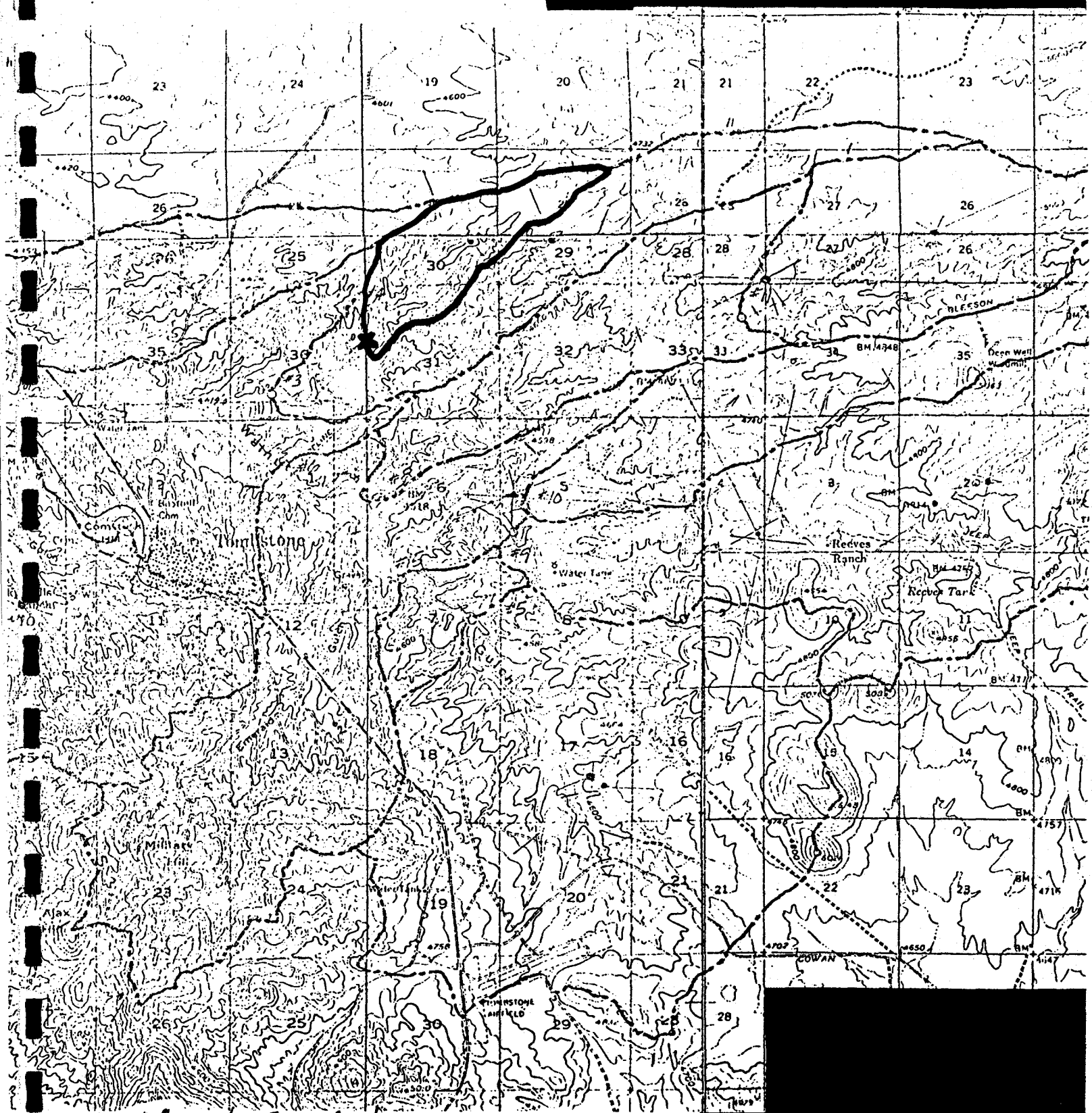
DESIGN DATA

Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	563	acres
	A_3		acres
Drainage Length		11,400	feet
Elevation			
Top of Drainage Area		4720	feet
At Structure		4470	feet
Drainage Area Slope		2.19	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	45	minutes
Rainfall Intensity	i	1.2 2.8 3.7	inches/hour
Runoff Coefficient	C_1	0.1 0.5 0.6	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		68 788 1250	cfs

Computed by M.E. Zeller (SLA) Date _____



Walnut Gulch 63-004

1" = 5208'

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: West Speedway Wash

2. Drainage Concentration Point: @ Gage Site (near Power Substation)

3. *Watershed Area (A) at Drainage Concentration Point: 294 acres.

4. Length of Hydraulically Longest Watercourse (L_c): 7000 ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: 3500 ft.

6. Change in Length Factors - ft. / Change in Elevation Factors - ft.

a. ΔL_1: 5000 $(\Delta L_1)^3$ 1.25×10^{11} ΔH_1: 120 $\Delta L_1^3/\Delta H_1$ 1,041,666,667

b. ΔL_2: 2000 $(\Delta L_2)^3$ 8.0×10^9 ΔH_2: 660 $\Delta L_2^3/\Delta H_2$ 12,121,212

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = 32,275 + 3482 + _____ = 35,757

8. Mean Slope $(S_c) = (L_c/I)^2 = (0.1958)^2 = 0.0383$ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	Rural (100%)	_____ ( )	
10. Basin Factor (n_b):	0.034		n_{bw} = 0.034
11. Imperviousness (%):	10%		I_w = 10%
12. Runoff Coefficient (C_w):	0.65		C_w = 0.65

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = 10.89 ~~(future)~~

14. **Time of Concentration (T_c), determined from Table III: 13 minutes ~~(future)~~

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = 7.27 inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = 0.65 x 7.27 x 294 = 1389 cfs ~~(future)~~

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	0.10	0.35	0.55	0.75
Q (cubic feet/second):	139	486	764	1042

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: M. E. Zeller

Company: SLA

Date: _____

PCFCD METHOD

HYDROLOGIC DATA SHEET

Project Name and Location: West Speedway Wash

Drainage Concentration Point: @ Gage Site (near Power Substation)

Watershed Area (A): 294 acres/~~square miles.~~

Length of Watercourse (L_c): 7000 ft. Length to Center of Gravity (L_{ca}): 3500 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
5000	120
2000	660

Mean Slope (S_c): 0.0383 ft./ft. Watershed Type(s): Rural ~~(future)~~

Basin Factor (n_b): 0.034 ~~(future)~~ Flood Frequency: 2 25 100 yrs.

P_4 (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): 1.0 2.3 3.0 in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): 100% D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: 10% ~~(future)~~

CN(s): 91 & 99 (pervious & impervious areas) CN*(s): 86, 88, 92.60, 93, 63, 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s), (C): .22, .68, .77 (pervious areas), .89, .95, .96 (impervious areas)

Runoff Supply Rate (q): .29, .71, .79 i in./hr. (function of i)

Time of Concentration (T_c): 41, 28, 27 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 36, 14, 12 hrs./mins.

Rainfall Intensity (i) at T_c: 1.41, 5.44, 7.57 in./hr.

Runoff Supply Rate (q) at T_c: .41, 3.86, 5.98 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 122, 1144, 1772 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

ARIZONA HIGHWAY DEPARTMENT
BRIDGE DIVISION

HYDROLOGIC DESIGN DATA SHEET
RATIONAL METHOD

LOCATION DATA

Highway _____ County _____
Location @ Gage Site (Near Power Substation)
Project No. _____ Station _____
Name of Stream West Speedway Wash

DESIGN DATA

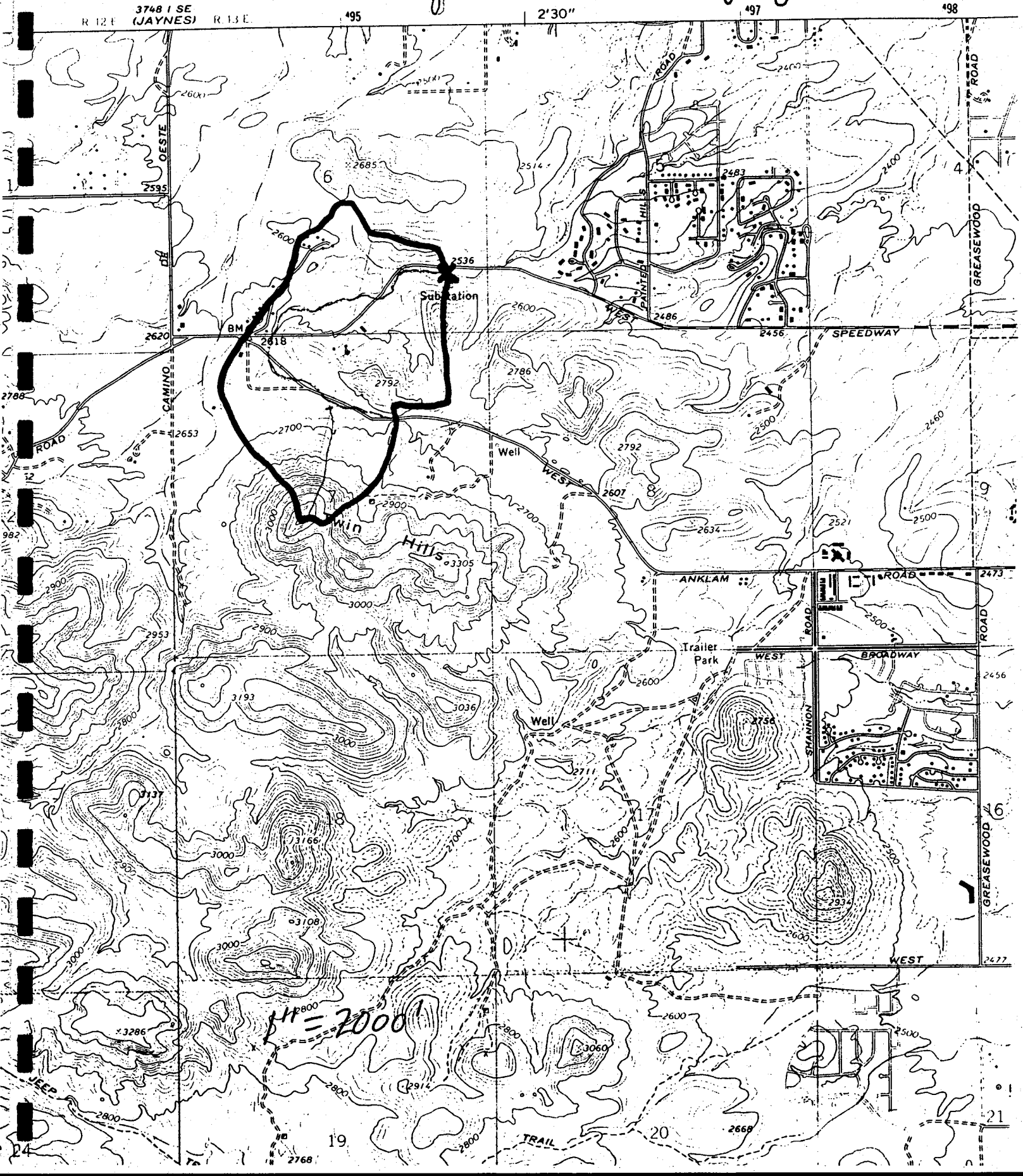
Design Frequency		2 25 100	years
Drainage Area	A_1		acres
	A_2	294	acres
	A_3		acres
Drainage Length		7000	feet
Elevation			
Top of Drainage Area		3300	feet
At Structure		2520	feet
Drainage Area Slope		11.14	%
Precipitation			
P = 6-hour		N/A	inches
P = 24-hour			inches

DESIGN COMPUTATIONS

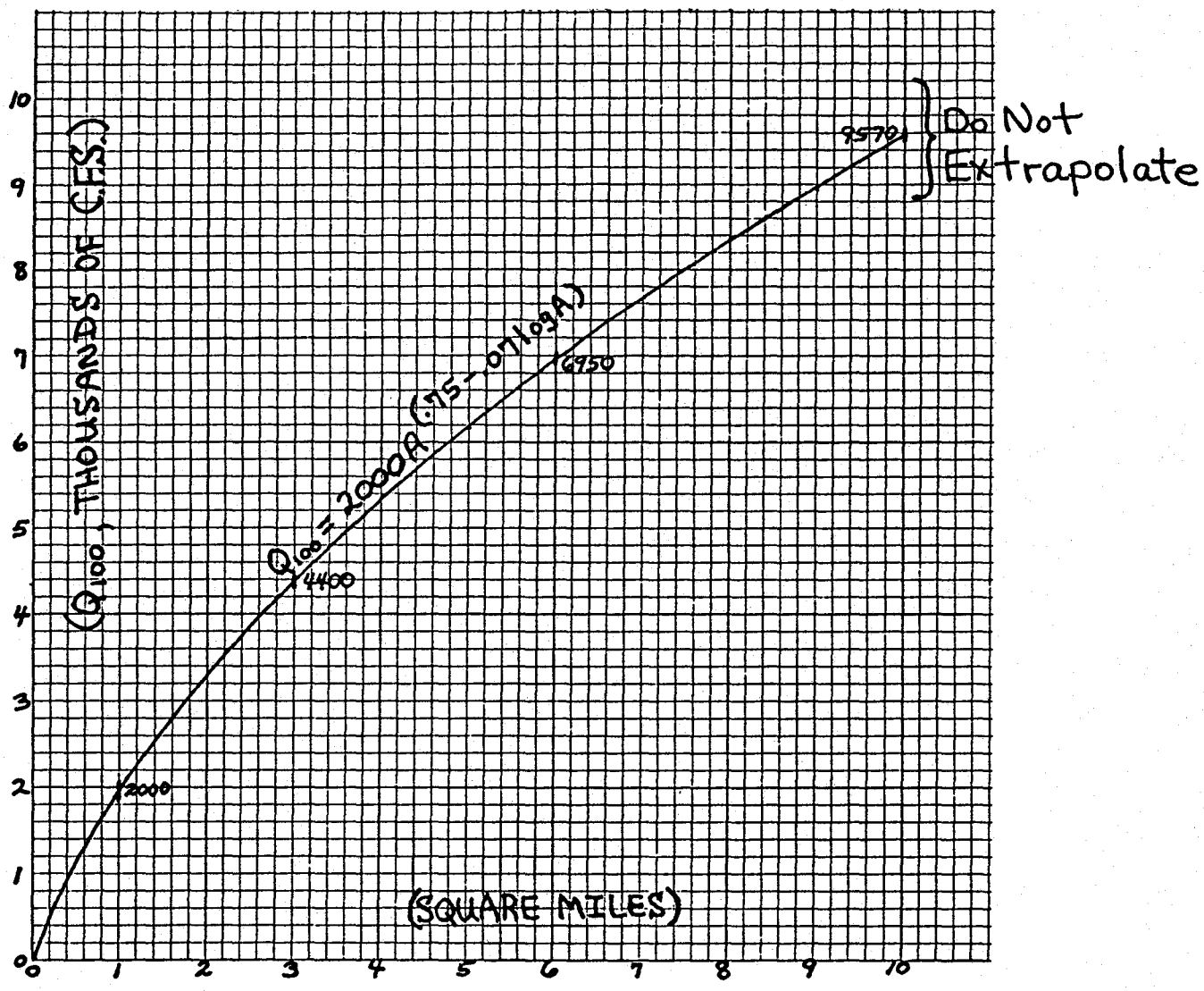
Precipitation P_1 = 1-hour		1.0 2.3 3.0	inches
Time of Concentration	Tc	16	minutes
Rainfall Intensity	i	2.2 5.1 6.7	inches/hour
Runoff Coefficient	C_1	0.2 0.6 0.7	
	C_2		
	C_3		
Weighted Runoff Coefficient	C		
Peak Discharge Qp = CiA =		129 900 1379	cfs

Computed by M.E. Zeller (SLA) Date _____

West Speedway Wash @ Gaging Station



QUICK METHOD FOR FLOOD ESTIMATION ON
CITY OF TUCSON (URBAN VALLEY) WATERSHEDS:
(CURVE GIVES ESTIMATE OF Q_{100}, WITH ONE PERCENT (1%)
CHANCE OF BEING EXCEEDED EACH YEAR.)



FOR OTHER RETURN PERIODS:

$Q_{50} = 0.85\ Q_{100}$

$Q_{25} = 0.70\ Q_{100}$

$Q_{10} = 0.50\ Q_{100}$

$Q_2 = 0.20\ Q_{100}$

Registered Professional Engineer (Civil) CERTIFICATE NO. 12831 MICHAEL E. SELLER Date Signed 3/10/80 ARIZONA, U.S.A.

Registered Professional Engineer (Civil) CERTIFICATE NO. 10713 BRIAN M. REICH Date Signed 3/10/80 ARIZONA, U.S.A.

SOURCE: PIMA COUNTY DEPARTMENT OF TRANSPORTATION & FLOOD CONTROL DISTRICT

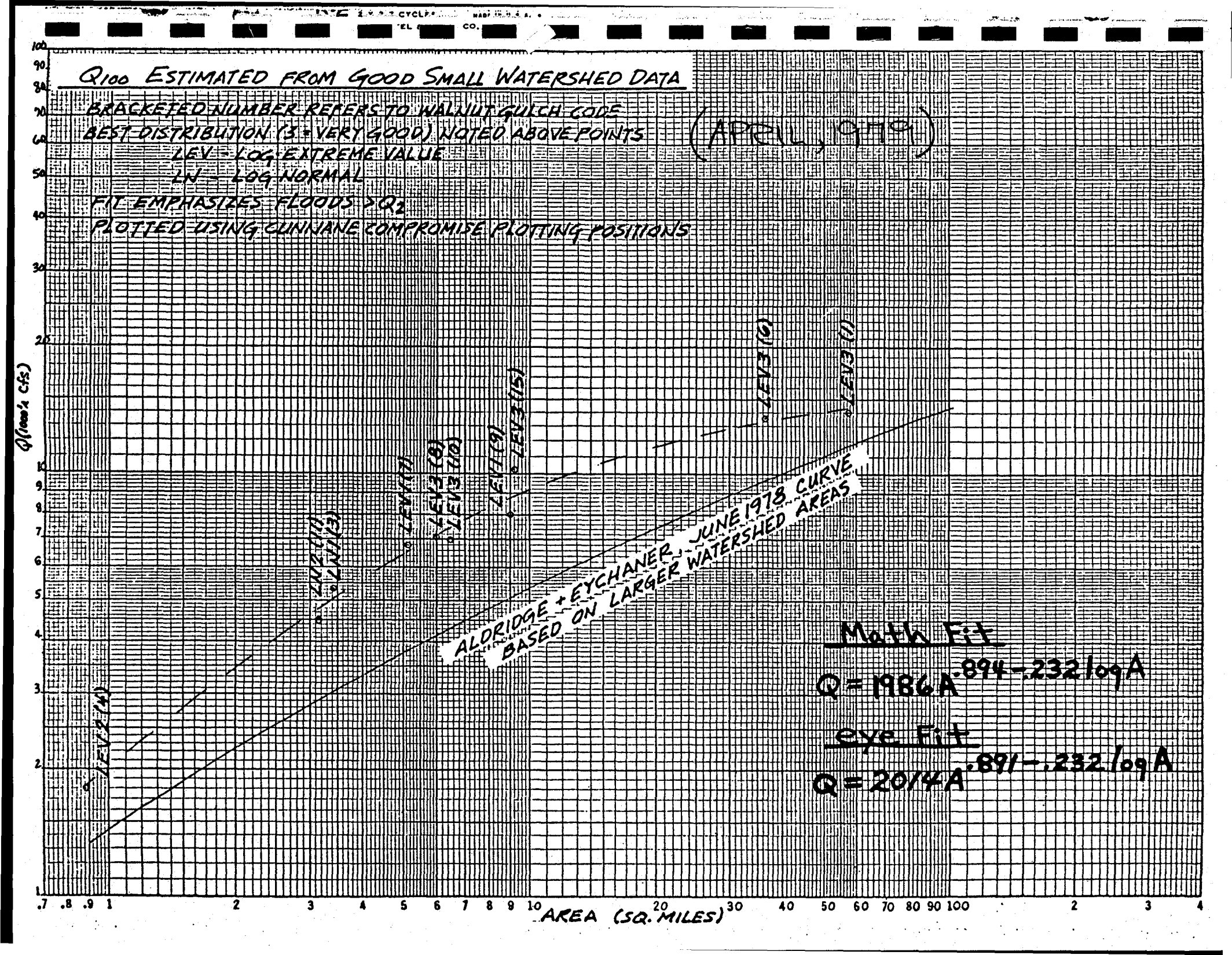
Regional Flood Frequency Equations

USGS	PCFCD (W.G.)
$Q_{100} = 1500 A^{.659 - .079 \log A}$ (square miles)	$Q_{100} = 2000 A^{.75 - .07 \log A}$ (square miles)
$Q_{100} = 5.06 A^{1.102 - .079 \log A}$ (acres)	$Q_{100} = 4.42 A^{1.143 - .070 \log A}$ (acres)

$$\left.\begin{aligned} Q_{50} &= .7\, Q_{100} \\ Q_{25} &= .5\, Q_{100} \\ Q_{10} &= .3\, Q_{100} \\ Q_{2} &= .1\, Q_{100} \end{aligned}\right\} \text{For PCFCD } Q_{100}$$

For Urban Areas: (Multiply PCFCD Q_{100} by following coefficients)

years	Suburban Valley ≤ 2 houses/Ac.	Urban Valley ≥ 2 houses/ac	Sub. Fthills ≤ 2h/ac.	Urban Fthills ≥ 2 h/ac
100	0.8	1.0	1.2	1.5
25	0.5	0.7	0.7	1.0
10	0.3	0.5	0.5	0.8
2	0.1	0.2	0.2	0.3
	slopes ≤ 1% avg. channel		slopes ≥ 1% avg. channel	


Q100 ESTIMATED FROM GOOD SMALL WATERSHED DATA
BRACKETED NUMBER REFERS TO WALNUT GULCH CODE
BEST DISTRIBUTION (3 = VERY GOOD) NOTED ABOVE POINTS
LEV - LOG EXTREME VALUE
LN - LOG NORMAL
FIT EMPHASIZES FLOODS > Q2
PLOTTED USING CUNNANE COMPROMISE PLOTTING POSITIONS
(APRIL, 1979)
LEV3 (6)
LEV3 (1)
LEV3 (15)
LN3 (9)
LEV3 (8)
LEV3 (10)
LEV3 (11)
LN2 (11)
LN1 (3)
LEV3 (4)
ALDRIDGE + EYCHANER, JUNE 1978 CURVE
BASED ON LARGER WATERSHED AREAS
Math Fit
Q = 1986A^.894 - .232 log A
eye Fit
Q = 2014A^.891 - .232 log A
Q (1000's CFS)
AREA (SQ. MILES)

Alpbridge
Run ~~100~~ S. Cruz & S. Pedro 61 w/s.
April 1979

$Q_{100} = 1500\ A^{(.659 - .079 \log A)}$ — SEE −34% +52% ave 43%

$Q_{50} = 1140\ A^{(.653 - .073 \log A)}$ — −31% +45% ave 38%

$Q_{10} = 502\ A^{(.634 - .053 \log A)}$ — −28% +38% ave 33%

$1500(10)^{(.659 - .079)}$ .580

$1500\ (3.809) = 5703$

$1140(10)^{(.653 - .073)}$ .580

$502(10)^{(.634 - .053)}$ .581

3.81066

1912.95 Q_{100} + SEE

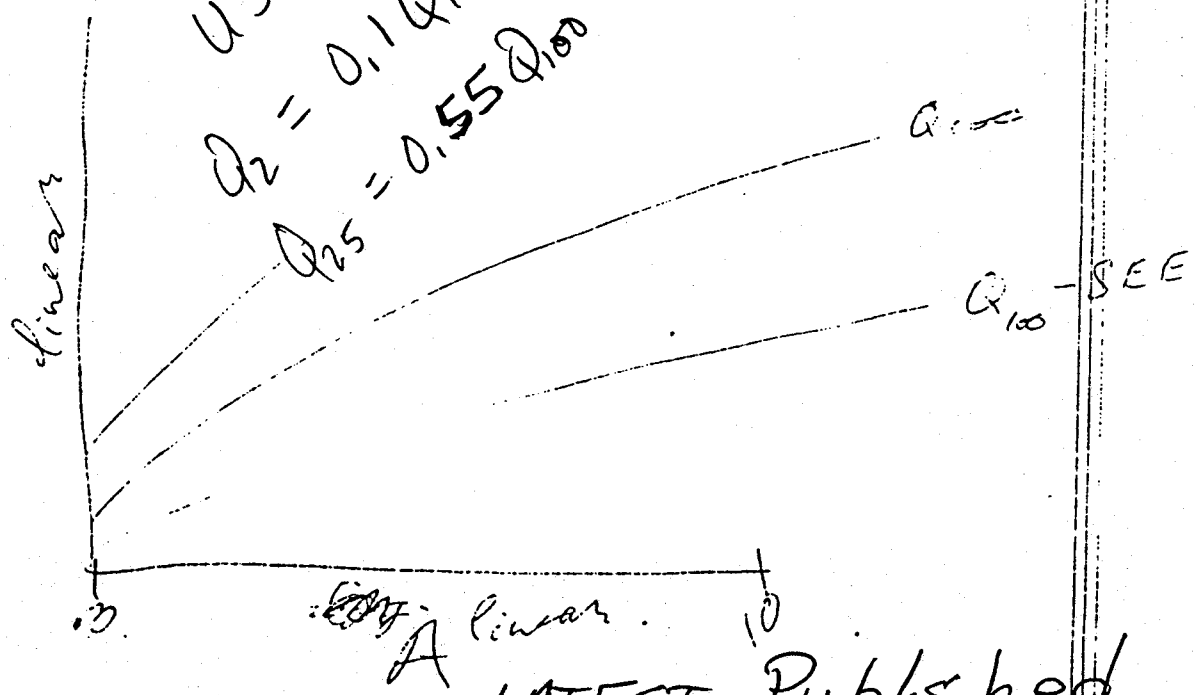
2 year = .08 Q_{100}

25 year = .56 Q_{100}

Use

$Q_2 = 0.1 Q_{100}$

$Q_{25} = 0.55 Q_{100}$



FROM: USGS LATEST Published

With/USGS latest Published

Tucson Arroyo, which drains a completely urbanized basin, has been gaged since 1940. During that time the drainage area contributing to the gage has been reduced from 27.0 mi^2, to 8.2 mi^2 by a series of flood-detention and diversion projects. However, since 3 of the 5 largest floods occurred from the minimum drainage area, some undefinable historic adjustment would be necessary to analyze the period of fixed area alone. Using the entire record of variable drainage area should produce an upper limit frequency curve above that possible from the present reduced basin. Therefore all the data were plotted and the subjective curve drawn through them was used for Tucson Arroyo.

☆ Five other urban washes (Alamo, Arcadia, Rose Hill, Robb and Rodeo) were estimated from the average departure of 8 urban gages from the regional regression equations. The gage records range from 0.9 to 8.2 mi^2 and from 7 to 38 years. Results of this graphical analysis show the 10-year urban flood 1.62 times the regional equation, the 50-year 1.32 times, and the 100-year 1.23 times. These adjustments correspond closely to those which would result from using a 2-year flood ratio of 3.0 in the theoretical urban adjustment scheme described by Sauer for Oklahoma. This agrees favorably with the 2-year flood ratio of 2.4 on Tucson Arroyo.

A consulting engineer estimated 50- and 100 year floods on West Branch Santa Cruz River in a 1975 report to the City of Tucson. He used SCS methods and concluded that about 11,000 cfs would reach the Santa Cruz River by two routes from the West Branch. In reviewing his report, SCS pointed out several problems in the analysis. In addition, the consultant used hydrologic soil group D for the entire basin, but the SCS "General Soil Map of Pima County" shows about two-thirds of the contributing drainage area to be group B. Therefore, his results may be grossly in error.

For Big Wash (Escalante Hills), a tributary to the West Branch, the consultant properly used group D soil and arrived at Q100=2,940 cfs. We believe Big Wash is sufficiently similar to Silvercroft Wash to use the same ratio to the regional equations. This analysis gives a result very close to the consultant's.

The West Branch is a complex basin, partially influenced by the Tucson Mountains and partially similar to the general regional trend of the valley floor. Therefore, we estimate West Branch in proportion between the Tucson Mountain basins and the general regional equations.

USGS Correspondence to PCFCD on 3/29/78

☆ This converts to (after interpolation):

$$\left.\begin{aligned} Q_{25} &= 0.7\,Q_{100} \\ Q_{2} &= 0.2\,Q_{100} \end{aligned}\right\}$$ urban areas (where Q_{100} = urban peak)

SCS, TR-55, METHOD

of conditions ranging from steep to flat and from heavily forested to smooth. The equation for watershed lag is:

$$L = \frac{\ell^{0.8}(S + 1)^{0.7}}{1{,}900\ Y^{0.5}} \qquad \text{(Eq. 3-2)}$$

where

L = lag in hours

ℓ = hydraulic length of watershed in feet

$S = \frac{1{,}000}{CN'} - 10$ (where CN' is the retardance factor and is equivalent to the runoff curve number)

Y = average watershed land slope in percent.

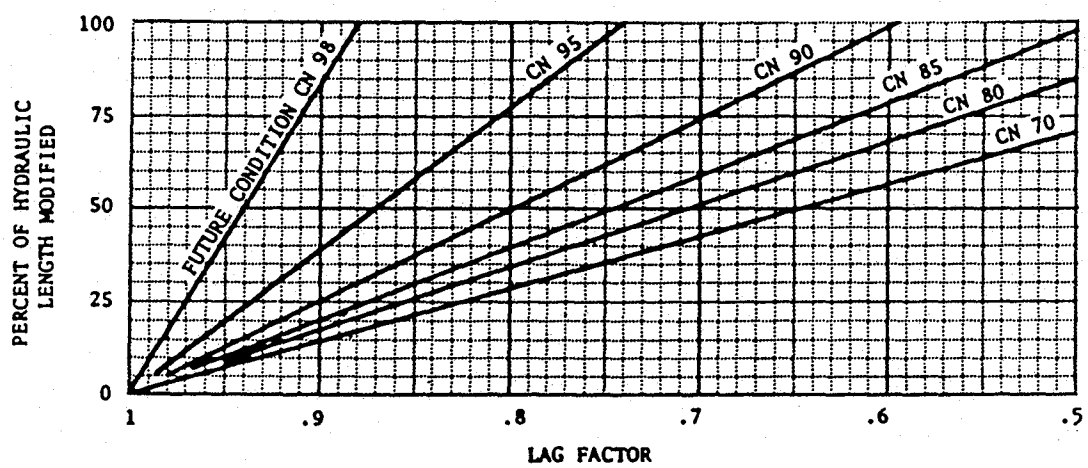


Figure 3-4.--Factors for adjusting lag from equation 3-2 or figure 3-3 when the main channel has been hydraulically improved.

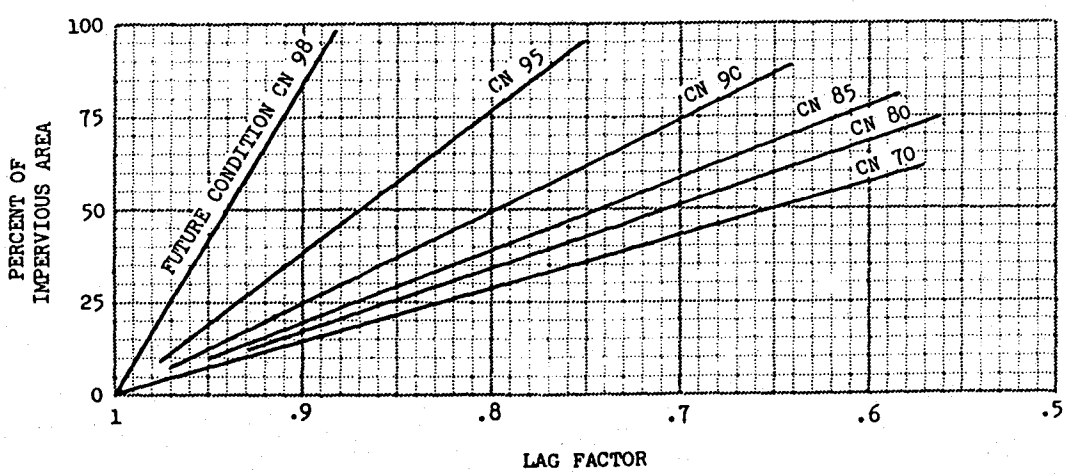


Figure 3-5.--Factors for adjusting lag from equation 3-2 or figure 3-3 when impervious areas occur in the watershed.

SCS, TR-55, METHOD

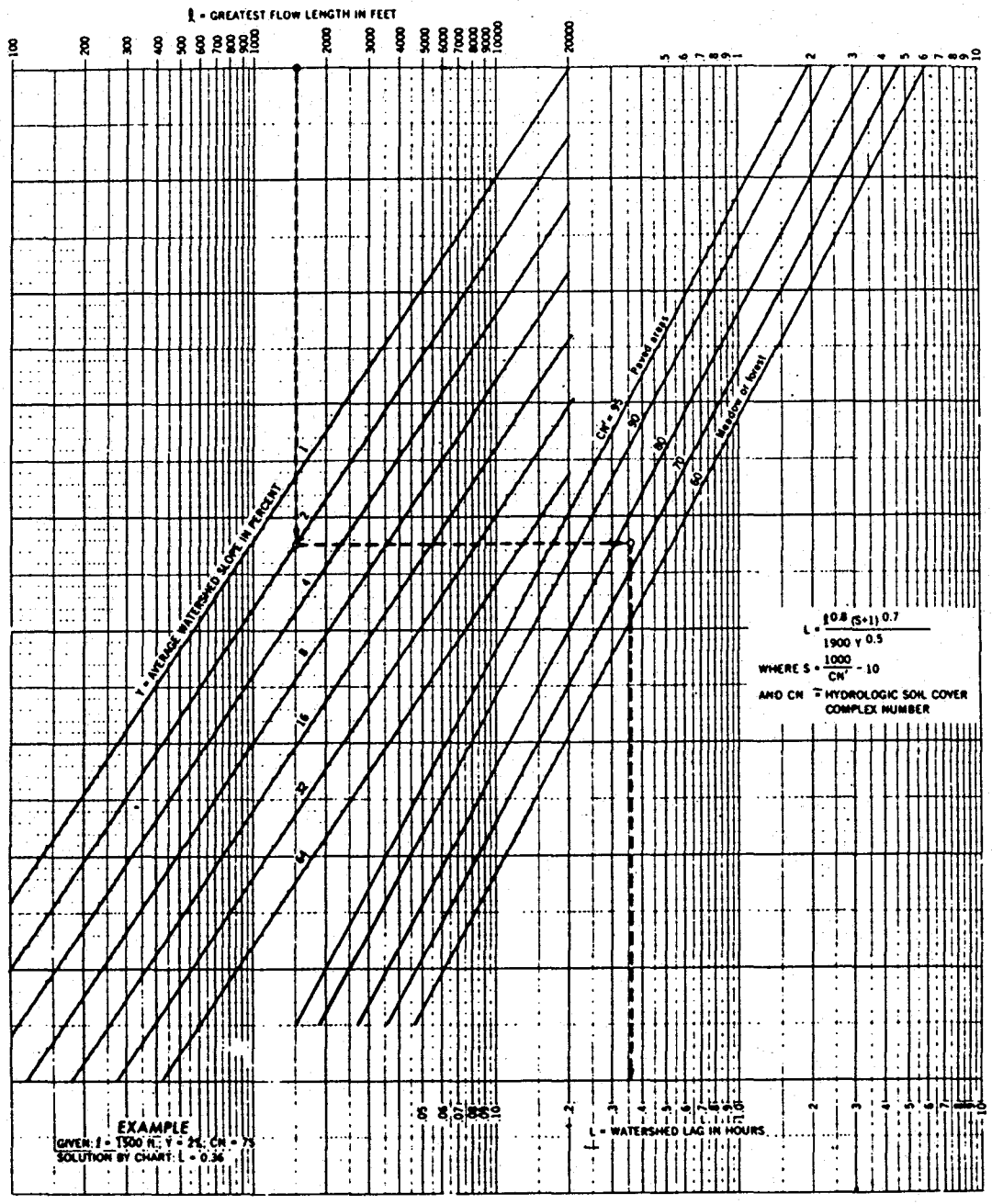
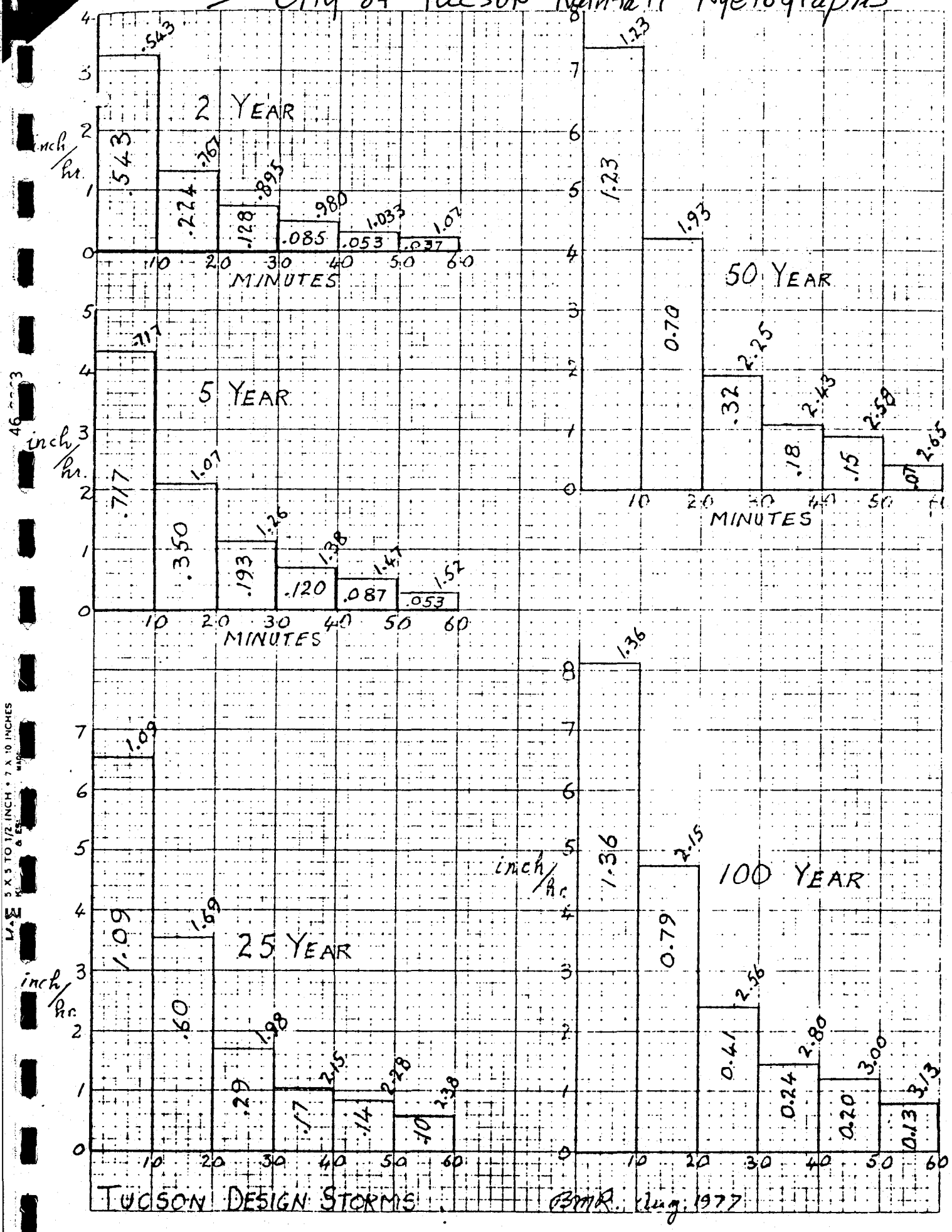
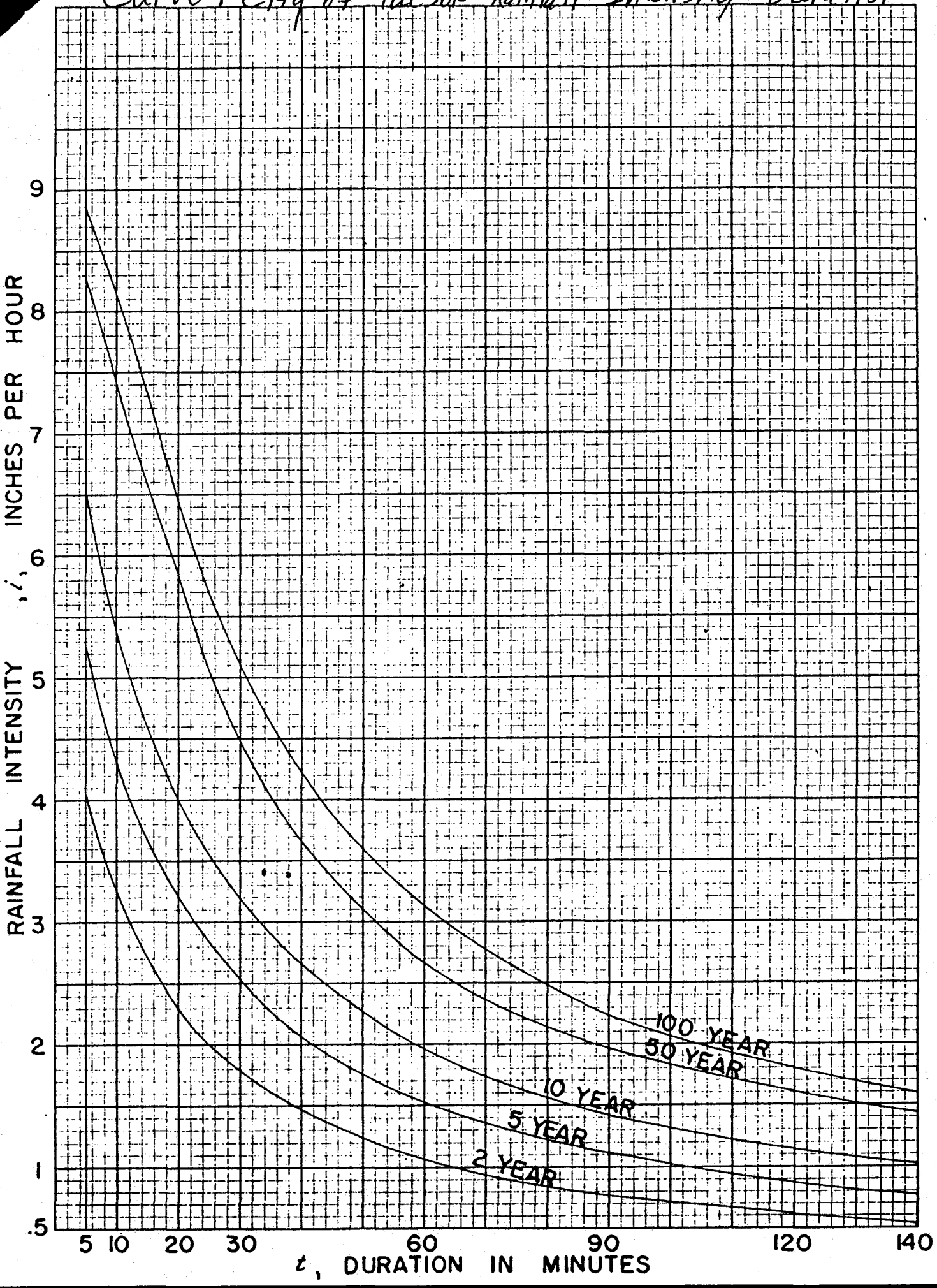


Figure 3-3.--Curve number method for estimating lag (L) for homogeneous watersheds under natural conditions up to 2,000 acres.

City of Tucson Rainfall Hyetographs



Curve i City of Tucson Rainfall-Intensity-Duration



ASCE (1977)

TABLE 3.1

TEN-MINUTE UNIT HYDROGRAPH EQUATIONS

Equations	Total Explained Variation of the Logarithms
$T_R = 3.1\ L^{.23}\ S^{-.25}\ I^{-.18}\ \Phi^{1.57}$	0.802
$Q = 31.62 \times 10^3\ A^{.96}\ T_R^{-1.07}$	0.936
$T_B = 125.89 \times 10^3\ A\ Q^{-.95}$	0.844
$W_{50} = 16.22 \times 10^3\ A^{.93}\ Q^{-.92}$	0.943
$W_{75} = 3.24 \times 10^3\ A^{.79}\ Q^{-.78}$	0.834

L is the total distance (in feet) along the main channel from the point being considered to the upstream watershed boundary.

S is the main channel slope (in feet per foot) as defined by H/0.8L where L is the main channel length as described above and H is the difference in elevation between two points, A and B. A is a point on the channel bottom at a distance of 0.2L downstream from the upstream watershed boundary. B is a point on the channel bottom at the design location.

I is the impervious area within a particular watershed (in percent).

Φ is the dimensionless watershed conveyance factor as described previously in the text.

A is the drainage area (in square miles).

T_R is the time of rise of the unit hydrograph (in minutes).

Q is the peak flow of the unit hydrograph (in cfs).

T_B is the time base of the unit hydrograph (in minutes).

W_{50} is the width of the hydrograph at 50% of the Q (in minutes).

W_{75} is the width of the unit hydrograph at 75% of Q (in minutes).

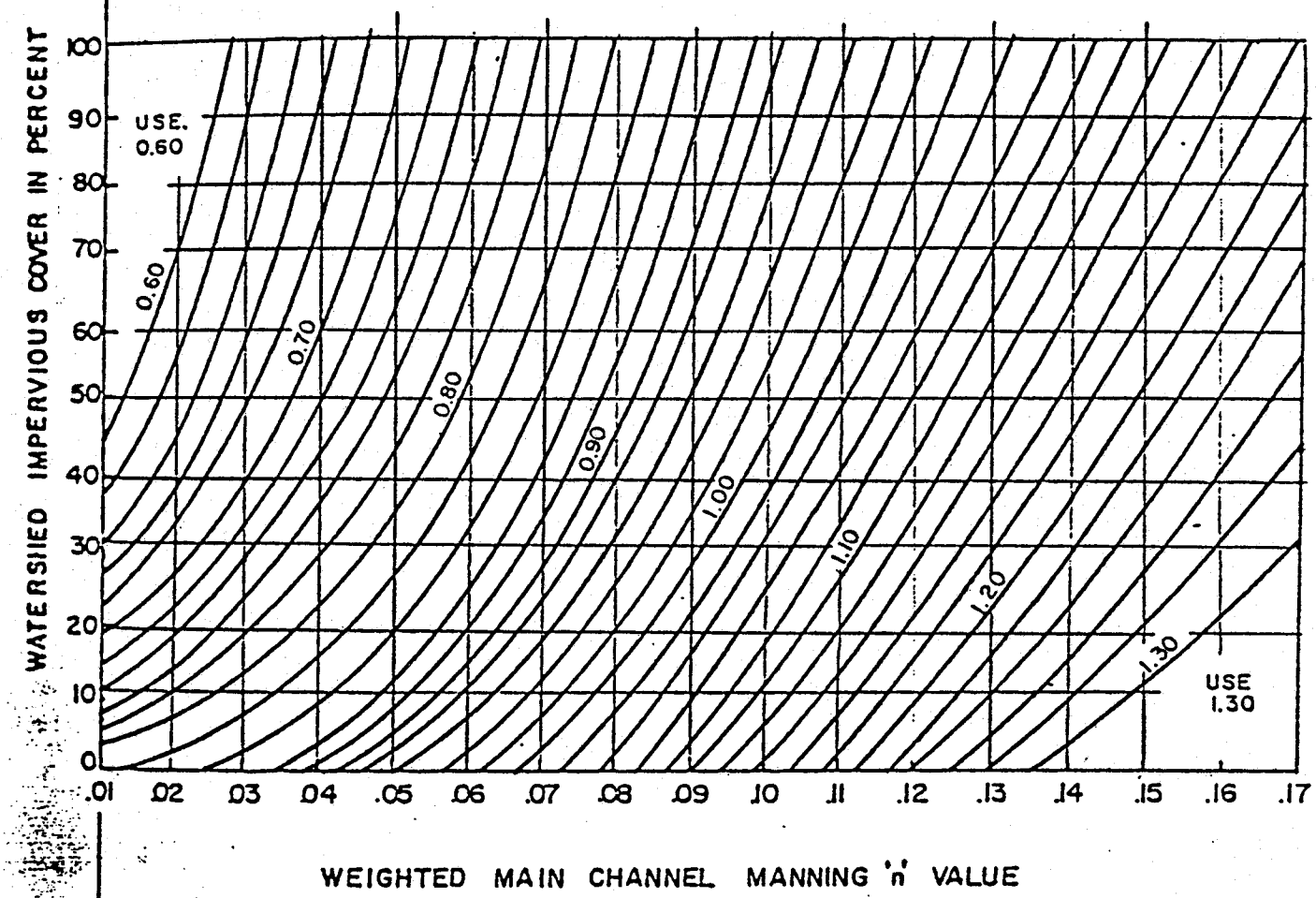


FIGURE 2.1 WATERSHED CONVEYANCE FACTOR, Φ, AS A FUNCTION OF PERCENT WATERSHED IMPERVIOUS COVER, I, AND WEIGHTED MAIN CHANNEL MANNING 'n' VALUE. (AUSTIN, DRAINAGE MANUAL, 1977)

ASCE 10-MINUTE UNIT Hydrographs (1977)

SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Alamo Wash

STORM TYPE:

100-year

SOIL TYPE "B"
AREA= 520.00 acres
40% Impervious
40% Directly Connected
Time of Conc.= 10 min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5 min.

100 year

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

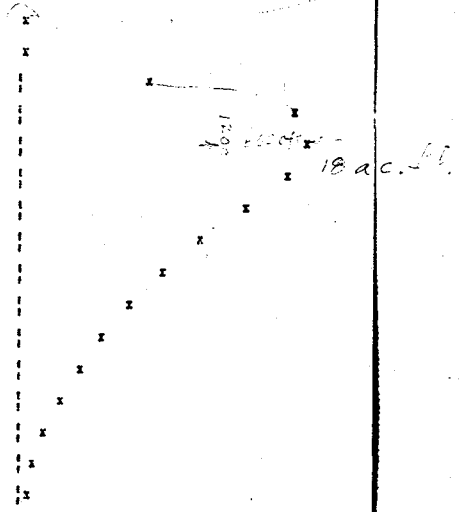
TUCSON
RAINFALL HYETOGRAPH
DESIGN STORM
Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.##
 10.###
 15.#################
 20.############
 25.##########
 30.########
 35.#####
 40.#####
 45.####
 50.###
 55.###
 60.###
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	25.30
15.00	995.31
20.00	2122.29
25.00	2261.15
30.00	2078.09
35.00	1741.57
40.00	1389.69
45.00	1104.57
50.00	859.15
55.00	638.60
60.00	470.78
65.00	325.46
70.00	193.51
75.00	115.06
80.00	68.42
85.00	40.68

Q Peak= 2,261.15 (cfs)
Time to Peak= 25. min
Vol.= 4,328,884.97 cf
Vol.= 2.29 in.

```
    Y (UNITS= E 3.) →
 0.00                2.26
 0.00
|-----------------------|
```



SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Alamo Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 520.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 10. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

25 YEAR

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.▮▮
 10.▮▮
 15.▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮
 20.▮▮▮▮▮▮▮▮▮▮▮▮
 25.▮▮▮▮▮▮▮▮▮▮
 30.▮▮▮▮▮▮▮▮
 35.▮▮▮▮▮
 40.▮▮▮▮▮
 45.▮▮▮▮
 50.▮▮▮
 55.▮▮▮
 60.▮▮▮
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	5.06
15.00	710.07
20.00	1535.28
25.00	1621.20
30.00	1469.90
35.00	1202.86
40.00	930.24
45.00	717.55
50.00	541.75
55.00	403.07
60.00	310.50
65.00	220.04
70.00	130.83
75.00	77.79
80.00	46.25

Q Peak= 1,621.20 (cfs)
Time to Peak= 25. min
Vol.= 2,976,719.81 cf
Vol.= 1.58 in.

Y (UNITS= E 3.) →

```
 0.00                    1.62
 0.00
|----------------------|
x
x
|          x ———————
|                    x
|                     x
|                   x
|                 x
|               x
|             x
|           x
|         x
|       x
|     x
|   x
|  x
|x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Alamo Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 520.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 10. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

2 year

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

TUCSON
RAINFALL HYETOGRAPH

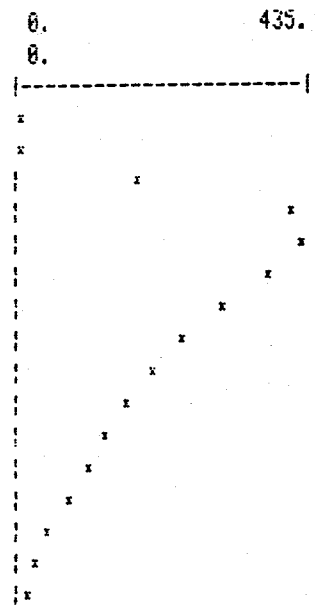
Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIII
 25.IIIIIIIIII
 30.IIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	183.41
20.00	412.62
25.00	435.07
30.00	378.85
35.00	311.27
40.00	250.86
45.00	204.81
50.00	167.31
55.00	134.90
60.00	110.57
65.00	88.92
70.00	48.12
75.00	28.61
80.00	17.01
85.00	10.11

Q Peak= 435.07 (cfs)
Time to Peak= 25. min
Vol.= 832,333.59 cf
Vol.= 0.44 in.

Y (UNITS= 1.) →



SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Alvernon Wash

STORM TYPE:

100-year

SOIL TYPE "B"
AREA= 284.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 10. min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  5.▮▮
 10.▮▮▮
 15.▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮
 20.▮▮▮▮▮▮▮▮▮▮▮▮
 25.▮▮▮▮▮▮▮▮▮▮
 30.▮▮▮▮▮▮▮▮
 35.▮▮▮▮▮
 40.▮▮▮▮▮
 45.▮▮▮▮
 50.▮▮▮
 55.▮▮▮
 60.▮▮▮
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
```

T (min.)	Q (cfs)
5.00	0.00
10.00	13.63
15.00	536.42
20.00	1146.59
25.00	1226.42
30.00	1131.18
35.00	951.35
40.00	761.66
45.00	606.95
50.00	473.22
55.00	352.78
60.00	260.74
65.00	180.98
70.00	108.59
75.00	65.15
80.00	39.09
85.00	23.46

Q Peak= 1,226.42 (cfs)
Time to Peak= 25. min
Vol.= 2,363,457.93 cf
Vol.= 2.29 in.

```
    Y (UNITS= E 3.) →
 0.00                1.23
 0.00
|----------------------|
x
x
|        x
|                 x
|                  x
|                 x
|             x
|          x
|       x
|     x
|    x
|   x
|  x
|x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Alvernon Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 284.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 10. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.▌▌
 10.▌▌
 15.▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌
 20.▌▌▌▌▌▌▌▌▌▌▌▌
 25.▌▌▌▌▌▌▌▌▌▌
 30.▌▌▌▌▌▌▌▌
 35.▌▌▌▌▌
 40.▌▌▌▌▌
 45.▌▌▌▌
 50.▌▌▌
 55.▌▌▌
 60.▌▌▌
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	2.73
15.00	382.65
20.00	829.40
25.00	879.33
30.00	800.24
35.00	657.36
40.00	510.29
45.00	394.78
50.00	298.89
55.00	222.96
60.00	171.94
65.00	122.25
70.00	73.35
75.00	44.01
80.00	26.41
85.00	15.84

Q Peak= 879.33 (cfs)
Time to Peak= 25. min
Vol.= 1,629,732.68 cf
Vol.= 1.58 in.

Y (UNITS= 1.) →

```
 0.                    879.
 0.
|----------------------|
x
x
|        x
|                   x
|                    x
|                  x
|             x
|          x
|        x
|      x
|     x
|   x
| x
|x
|x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Alvernon Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 284.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 10. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

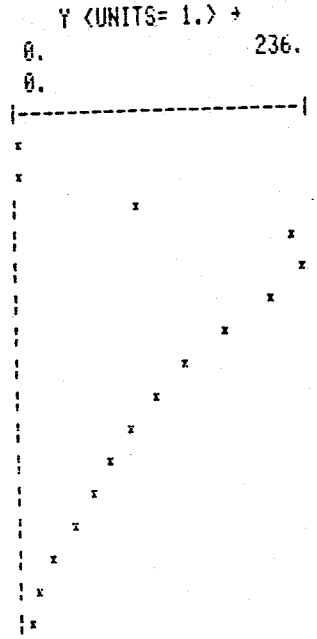
Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIII
 25.IIIIIIIIII
 30.IIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	98.83
20.00	222.88
25.00	235.97
30.00	206.33
35.00	170.15
40.00	137.53
45.00	112.51
50.00	92.04
55.00	74.31
60.00	60.94
65.00	44.75
70.00	26.85
75.00	16.11
80.00	9.67
85.00	5.80

Q Peak= 235.97 (cfs)
Time to Peak= 25. min
Vol.= 454,403.20 cf
Vol.= 0.44 in.

Y (UNITS= 1.) →



SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Arcadia Wash

STORM TYPE:

100 - year

SOIL TYPE "B"
AREA= 787.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 16. min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

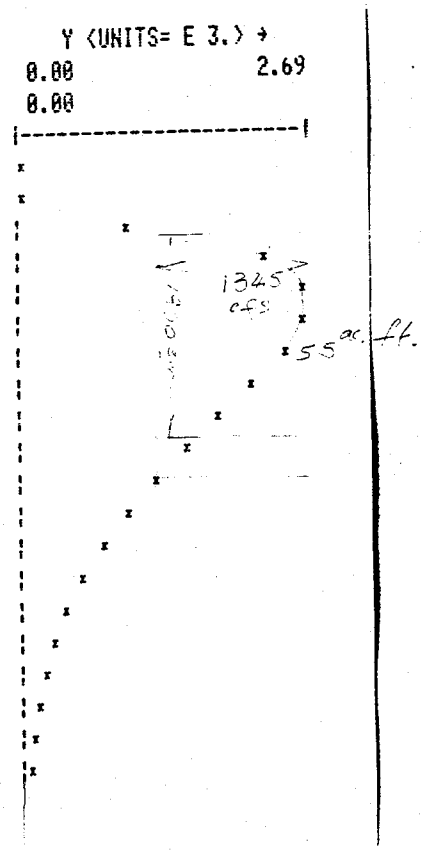
RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
++++++++++++++++++++++++
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIIII
 25.IIIIIIIIII
 30.IIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
++++++++++++++++++++++++
```

T (min.)	Q (cfs)
5.00	0.00
10.00	25.52
15.00	1007.69
20.00	2279.57
25.00	2671.68
30.00	2689.81
35.00	2473.32
40.00	2162.20
45.00	1858.59
50.00	1560.46
55.00	1267.61
60.00	1016.90
65.00	788.01
70.00	575.03
75.00	419.62
80.00	306.21
85.00	223.45
90.00	163.06
95.00	118.99
100.00	86.83
105.00	63.36

Q Peak= 2,689.81 (cfs)
Time to Peak= 30. min
Vol.= 6,527,367.47 cf
Vol.= 2.28 in.



SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Arcadia Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 787.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 16. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
++++++++++++++++++++++++
  5.##
 10.##
 15.##################
 20.############
 25.##########
 30.########
 35.#####
 40.#####
 45.####
 50.###
 55.###
 60.###
++++++++++++++++++++++++
```

T (min.)	Q (cfs)
5.00	0.00
10.00	5.10
15.00	717.13
20.00	1646.38
25.00	1916.09
30.00	1908.72
35.00	1724.66
40.00	1475.50
45.00	1242.62
50.00	1022.91
55.00	828.13
60.00	675.78
65.00	528.87
70.00	385.93
75.00	281.63
80.00	205.51
85.00	149.97
90.00	109.44
95.00	79.86
100.00	58.28
105.00	42.53

Q Peak= 1,916.09 (cfs)
Time to Peak= 25. min
Vol.= 4,501,507.93 cf
Vol.= 1.58 in.

Y (UNITS= E 3.) →

```
0.00                1.92
0.00
|----------------------|
x
x
|        x
|                x
|                   x
|                   x
|               x
|            x
|         x
|      x
|     x
|    x
|   x
|  x
|  x
|  x
|  x
|  x
```

SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Arcadia Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 787.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 16. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIII
 25.IIIIIIIIII
 30.IIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	185.05
20.00	441.33
25.00	513.48
30.00	495.94
35.00	448.69
40.00	393.78
45.00	343.51
50.00	296.61
55.00	252.18
60.00	214.65
65.00	171.95
70.00	125.48
75.00	91.57
80.00	66.82
85.00	48.76
90.00	35.58
95.00	25.96
100.00	18.95
105.00	13.83

Q Peak= 513.48 (cfs)
Time to Peak= 25. min
Vol.= 1,255,241.06 cf
Vol.= 0.44 in.

Y (UNITS= 1.) →

```
 0.                    513.
 0.
|----------------------|
x
x
|       x
|                x
|                   x
|                   x
|                x
|             x
|           x
|         x
|       x
|     x
|    x
|   x
|  x
|  x
|  x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Columbus Wash

STORM TYPE:

100-year

SOIL TYPE "B"
AREA= 176.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 11. min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

RAINFALL HYETOGRAPH

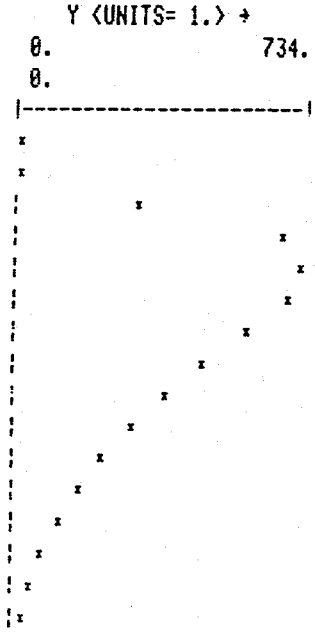
Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.▮▮
 10.▮▮▮
 15.▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮
 20.▮▮▮▮▮▮▮▮▮▮▮▮
 25.▮▮▮▮▮▮▮▮▮▮
 30.▮▮▮▮▮▮▮▮
 35.▮▮▮▮▮
 40.▮▮▮▮▮
 45.▮▮▮▮
 50.▮▮▮
 55.▮▮▮
 60.▮▮▮
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	7.92
15.00	311.85
20.00	674.07
25.00	734.13
30.00	688.51
35.00	588.72
40.00	478.83
45.00	386.39
50.00	304.85
55.00	230.53
60.00	172.59
65.00	122.13
70.00	76.33
75.00	47.71
80.00	29.82
85.00	18.64

Q Peak= 734.13 (cfs)
Time to Peak= 25. min
Vol.= 1,461,901.69 cf
Vol.= 2.29 in.

Y (UNITS= 1.) →



SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Columbus Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 176.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 11. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
 5.II
10.II
15.IIIIIIIIIIIIIIIIIIII
20.IIIIIIIIIIIII
25.IIIIIIIIIII
30.IIIIIIII
35.IIIII
40.IIIII
45.IIII
50.III
55.III
60.III
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	1.58
15.00	222.35
20.00	487.45
25.00	526.42
30.00	487.41
35.00	407.59
40.00	322.06
45.00	252.77
50.00	194.02
55.00	146.60
60.00	113.80
65.00	82.22
70.00	51.38
75.00	32.12
80.00	20.07
85.00	12.55

Q Peak= 526.42 (cfs)
Time to Peak= 25. min
Vol.= 1,008,121.05 cf
Vol.= 1.58 in.

Y (UNITS= 1.) →

```
0.                    526.
0.
|----------------------|
x
x
|        x
|                 x
|                  x
|                 x
|            x
|         x
|       x
|      x
|     x
|    x
|   x
|  x
|  x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Columbus Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 176.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 11. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

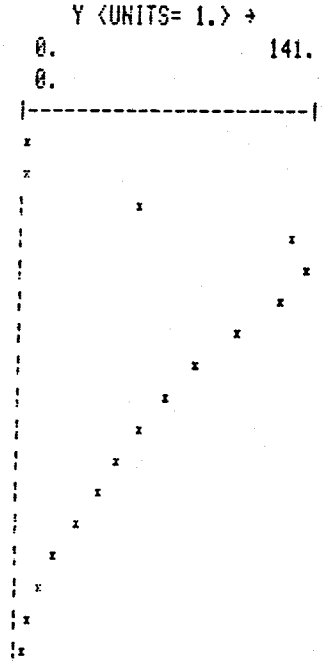
Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIII
 25.IIIIIIIIII
 30.IIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	57.42
20.00	130.93
25.00	141.23
30.00	125.89
35.00	105.61
40.00	86.60
45.00	71.55
50.00	58.97
55.00	47.95
60.00	39.47
65.00	29.42
70.00	18.39
75.00	11.49
80.00	7.18
85.00	4.49
90.00	2.81

Q Peak= 141.23 (cfs)
Time to Peak= 25. min
Vol.= 281,816.30 cf
Vol.= 0.44 in.

Y (UNITS= 1.) →



SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

High School Wash

STORM TYPE:

100-year

SOIL TYPE "B"
AREA= 576.00 acres
29.% Impervious
29.% Directly Connected
Time of Conc.= 13. min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.##
 10.###
 15.##################
 20.############
 25.##########
 30.########
 35.#####
 40.#####
 45.####
 50.###
 55.###
 60.###
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	16.34
15.00	866.84
20.00	1925.07
25.00	2164.90
30.00	2089.86
35.00	1836.44
40.00	1530.42
45.00	1256.57
50.00	1004.41
55.00	768.19
60.00	576.52
65.00	417.94
70.00	281.65
75.00	189.81
80.00	127.92
85.00	86.20
90.00	58.09

Q Peak= 2,164.90 (cfs)
Time to Peak= 25. min
Vol.= 4,559,148.60 cf
Vol.= 2.18 in.

```
    Y (UNITS= E 3.) →
 0.00              2.16
 0.00
|---------------------|
x
x
|        x
|                 x
|                   x
|                   x
|                x
|             x
|          x
|       x
|     x
|    x
|   x
|  x
|x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

High School Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 576.00 acres
29.% Impervious
29.% Directly Connected
Time of Conc.= 13. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.▮▮
 10.▮▮
 15.▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮
 20.▮▮▮▮▮▮▮▮▮▮▮▮
 25.▮▮▮▮▮▮▮▮▮▮
 30.▮▮▮▮▮▮▮▮
 35.▮▮▮▮▮
 40.▮▮▮▮▮
 45.▮▮▮▮
 50.▮▮▮
 55.▮▮▮
 60.▮▮▮
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	3.27
15.00	617.50
20.00	1381.01
25.00	1534.91
30.00	1458.32
35.00	1248.93
40.00	1006.39
45.00	797.87
50.00	615.66
55.00	467.19
60.00	360.60
65.00	265.89
70.00	179.19
75.00	120.76
80.00	81.38
85.00	54.84
90.00	36.96

Q Peak= 1,534.91 (cfs)
Time to Peak= 25. min
Vol.= 3,069,203.02 cf
Vol.= 1.47 in.

Y (UNITS= E 3.) →

```
 0.00                1.53
 0.00
!----------------------!
x
x
!        x
!                 x
!                  x
!                  x
!              x
!           x
!        x
!      x
!     x
!    x
!   x
!  x
!x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

High School Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 576.00 acres
29.% Impervious
29.% Directly Connected
Time of Conc.= 13. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

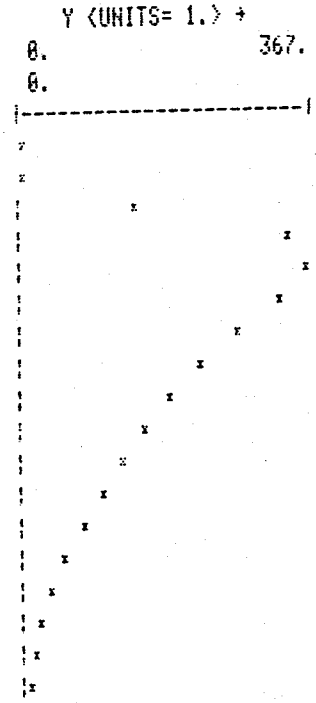
Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.XX
 10.XXX
 15.XXXXXXXXXXXXXXXXXXXX
 20.XXXXXXXXXXXX
 25.XXXXXXXXXX
 30.XXXXXXXX
 35.XXXXX
 40.XXXXX
 45.XXXX
 50.XXX
 55.XXX
 60.XXX
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	147.91
20.00	339.16
25.00	366.62
30.00	326.24
35.00	275.41
40.00	228.09
45.00	189.66
50.00	157.23
55.00	128.84
60.00	106.43
65.00	81.53
70.00	54.95
75.00	37.03
80.00	24.95
85.00	16.82
90.00	11.33
95.00	7.64

Q Peak= 366.62 (cfs)
Time to Peak= 25. min
Vol.= 749,951.49 cf
Vol.= 0.36 in.

Y (UNITS= 1.) →



SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Mañana Grande Vista Wash

STORM TYPE:

100-year

SOIL TYPE "B"
AREA= 104.00 acres
40% Impervious
40% Directly Connected
Time of Conc.= 7 min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5 min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIIII
 25.IIIIIIIIIII
 30.IIIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	6.69
15.00	262.18
20.00	526.21
25.00	508.40
30.00	429.93
35.00	333.32
40.00	248.36
45.00	188.85
50.00	141.17
55.00	99.30
60.00	70.17
65.00	44.62
70.00	20.71
75.00	9.62

Q Peak= 526.21 (cfs)
Time to Peak= 20. min
Vol.= 866,856.30 cf
Vol.= 2.30 in.

Y (UNITS= 1.) →

```
 0.                    526.
 0.
|----------------------|
x
x
!            x
!                     x
!                     x
!                  x
!               x
!            x
!         x
!      x
!    x
!   x
! x
!x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:
Mañana Grande Vista Wash

STORM TYPE:
25-year

SOIL TYPE "B"
AREA= 104.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 7. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.▌▌
 10.▌▌
 15.▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌▌
 20.▌▌▌▌▌▌▌▌▌▌▌▌
 25.▌▌▌▌▌▌▌▌▌▌
 30.▌▌▌▌▌▌▌▌
 35.▌▌▌▌▌
 40.▌▌▌▌▌
 45.▌▌▌▌
 50.▌▌▌
 55.▌▌▌
 60.▌▌▌
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	1.34
15.00	187.49
20.00	381.22
25.00	364.19
30.00	302.80
35.00	227.50
40.00	162.45
45.00	118.88
50.00	85.62
55.00	61.14
60.00	47.11
65.00	31.23
70.00	14.50
75.00	6.73

Q Peak= 381.22 (cfs)
Time to Peak= 20. min
Vol.= 597,663.99 cf
Vol.= 1.58 in.

```
    Y (UNITS= 1.) →
 0.                    381.
 0.
|----------------------|
x
x
|          x
|                   x
|                  x
|               x
|            x
|         x
|       x
|     x
|   x
|  x
| x
|x
```

SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:
Mañana Grande Vista Wash

STORM TYPE:
2-year

SOIL TYPE "B"
AREA= 104.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 7. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
++++++++++++++++++++++++
  5.II
 10.III
 15.IIIIIIIIIIIIIIIIIIII
 20.IIIIIIIIIIII
 25.IIIIIIIIII
 30.IIIIIIII
 35.IIIII
 40.IIIII
 45.IIII
 50.III
 55.III
 60.III
++++++++++++++++++++++++
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	47.62
20.00	101.38
25.00	97.28
30.00	77.28
35.00	58.94
40.00	45.00
45.00	35.76
50.00	28.76
55.00	22.82
60.00	18.69
65.00	12.80
70.00	6.06
75.00	2.87

Q Peak= 101.38 (cfs)
Time to Peak= 20. min
Vol.= 166,581.65 cf
Vol.= 0.44 in.

Y (UNITS= 1.) →

```
 0.                    101.
 0.
|----------------------|
x
x
|          x
|                    x
|                    x
|               x
|            x
|         x
|       x
|      x
|     x
|   x
|  x
```

SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:
Rolling Hills Wash

STORM TYPE:
100-year

SOIL TYPE "B"
AREA= 31.00 acres
20.% Impervious
20.% Directly Connected
Time of Conc.= 3. min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.##
 10.###
 15.##################
 20.############
 25.##########
 30.########
 35.#####
 40.#####
 45.####
 50.###
 55.###
 60.###
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	1.69
15.00	126.41
20.00	209.89
25.00	146.46
30.00	105.19
35.00	71.00
40.00	47.60
45.00	35.33
50.00	24.07
55.00	13.12
60.00	7.28
65.00	3.71

Q Peak= 209.89 (cfs)
Time to Peak= 20. min
Vol.= 237,522.44 cf
Vol.= 2.11 in.

Y (UNITS= 1.) →

```
 0.                    210.
 0.
|----------------------|
x
x
|            x
|                  x
|               x
|          x
|       x
|    x
|   x
|  x
| x
|x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Rolling Hills Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 31.00 acres
20.% Impervious
20.% Directly Connected
Time of Conc.= 3. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
  5.▮▮
 10.▮▮
 15.▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮
 20.▮▮▮▮▮▮▮▮▮▮▮▮
 25.▮▮▮▮▮▮▮▮▮▮
 30.▮▮▮▮▮▮▮▮
 35.▮▮▮▮▮
 40.▮▮▮▮▮
 45.▮▮▮▮
 50.▮▮▮
 55.▮▮▮
 60.▮▮▮
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.34
15.00	90.55
20.00	149.70
25.00	100.97
30.00	69.49
35.00	42.95
40.00	25.32
45.00	16.96
50.00	10.22
55.00	6.34
60.00	5.31
65.00	2.85

Q Peak= 149.70 (cfs)
Time to Peak= 20. min
Vol.= 156,303.30 cf
Vol.= 1.39 in.

```
    Y (UNITS= 1.) →
 0.                  150.
 0.
|----------------------|
x
x
¦              x
¦                   x
¦             x
¦          x
¦      x
¦   x
¦  x
¦ x
¦x
¦x
```

SANTA BARBARA URBAN HYDROGRAPH

LOCATION:

Rolling Hills Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 31.00 acres
20.% Impervious
20.% Directly Connected
Time of Conc.= 3. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
++++++++++++++++++++++++
  5.##
 10.###
 15.#####################
 20.############
 25.##########
 30.########
 35.#####
 40.#####
 45.####
 50.###
 55.###
 60.###
++++++++++++++++++++++++
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	20.29
20.00	33.97
25.00	20.00
30.00	10.27
35.00	6.68
40.00	5.00
45.00	4.17
50.00	3.42
55.00	2.68
60.00	2.27
65.00	1.22
70.00	0.11

Q Peak= 33.97 (cfs)
Time to Peak= 20. min
Vol.= 33,030.27 cf
Vol.= 0.29 in.

```
    Y (UNITS= 1.) →
 0.0                34.0
 0.0
|----------------------|
x
x
|            x
|                    x
|            x
|      x
|    x
|   x
|  x
| x
| x
|x
```

SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Rosehill Wash

STORM TYPE:

100-year

SOIL TYPE "B"
AREA= 1,045.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 23. min.
fo= 1.10 (in./hr.)
fc= 1.10 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.06
10.00	0.09
15.00	0.81
20.00	0.51
25.00	0.39
30.00	0.30
35.00	0.21
40.00	0.18
45.00	0.15
50.00	0.12
55.00	0.09
60.00	0.09
65.00	0.00

Total Precip.= 3.00 in.

RAINFALL HYETOGRAPH

Pk. 5.min int.= 0.81 in
Y units= 0.04 in. →

```
min.
++++++++++++++++++++++++
 5.##
10.###
15.#####################
20.#############
25.##########
30.########
35.#####
40.#####
45.####
50.###
55.###
60.###
++++++++++++++++++++++++
```

T (min.)	Q (cfs)
5.00	0.00
10.00	24.75
15.00	978.93
20.00	2283.09
25.00	2810.11
30.00	2973.23
35.00	2881.41
40.00	2659.21
45.00	2406.62
50.00	2129.63
55.00	1834.29
60.00	1561.36
65.00	1297.75
70.00	1041.61
75.00	836.03
80.00	671.03
85.00	538.59
90.00	432.29
95.00	346.97
100.00	278.49
105.00	223.52
110.00	179.41
115.00	144.00
120.00	115.58
125.00	92.77
130.00	74.46

Q Peak= 2,973.23 (cfs)
Time to Peak= 30. min
Vol.= 8,644,527.32 cf
Vol.= 2.28 in.

Y (UNITS= E 3.) →

```
 0.00                2.97
 0.00
|----------------------|
x
x
!       x
!                x
!                     x
!                      x
!                      x
!                    x
!                  x
!                x
!              x
!            x
!          x
!        x
!      x
!    x
!   x
!  x
! x
!x
!x
!x
```

SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Rosehill Wash

STORM TYPE:

25-year

SOIL TYPE "B"
AREA= 1,045.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 23. min.
fo= 1.30 (in./hr.)
fc= 1.30 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.05
10.00	0.06
15.00	0.62
20.00	0.39
25.00	0.30
30.00	0.23
35.00	0.16
40.00	0.14
45.00	0.12
50.00	0.09
55.00	0.07
60.00	0.07
65.00	0.00

Total Precip.= 2.30 in.

RAINFALL HYETOGRAPH

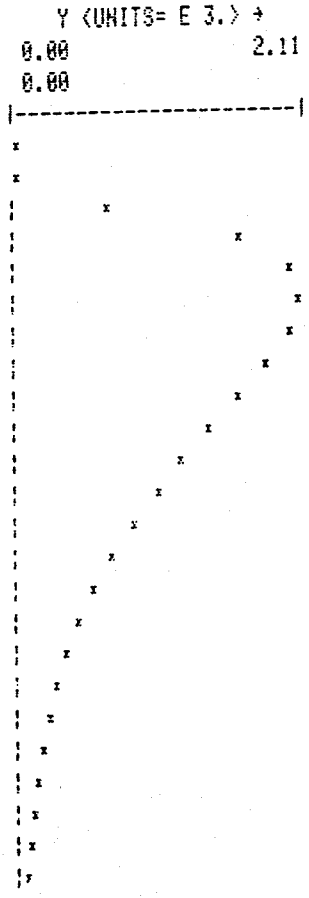
Pk. 5.min int.= 0.62 in
Y units= 0.03 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
  5.▒▒
 10.▒▒
 15.▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
 20.▒▒▒▒▒▒▒▒▒▒▒▒
 25.▒▒▒▒▒▒▒▒▒▒
 30.▒▒▒▒▒▒▒▒
 35.▒▒▒▒▒
 40.▒▒▒▒▒
 45.▒▒▒▒
 50.▒▒▒
 55.▒▒▒
 60.▒▒▒
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	4.95
15.00	695.74
20.00	1647.42
25.00	2015.27
30.00	2112.52
35.00	2017.33
40.00	1823.54
45.00	1629.32
50.00	1420.36
55.00	1219.23
60.00	1047.89
65.00	875.72
70.00	702.88
75.00	564.15
80.00	452.81
85.00	363.44
90.00	291.71
95.00	234.13
100.00	187.92
105.00	150.83
110.00	121.06
115.00	97.17
120.00	77.99
125.00	62.60

Q Peak= 2,112.52 (cfs)
Time to Peak= 30. min
Vol.= 5,946,592.58 cf
Vol.= 1.57 in.

Y (UNITS= E 3.) →



SANTA
BARBARA
URBAN
HYDROGRAPH

LOCATION:

Rosehill Wash

STORM TYPE:

2-year

SOIL TYPE "B"
AREA= 1,045.00 acres
40.% Impervious
40.% Directly Connected
Time of Conc.= 23. min.
fo= 1.50 (in./hr.)
fc= 1.50 (in./hr.)
F= 0.00 (in.)
Time Int.= 5. min.

T (min.)	P (in.)
5.00	0.02
10.00	0.03
15.00	0.27
20.00	0.17
25.00	0.13
30.00	0.10
35.00	0.07
40.00	0.06
45.00	0.05
50.00	0.04
55.00	0.03
60.00	0.03
65.00	0.00

Total Precip.= 1.00 in.

RAINFALL HYETOGRAPH

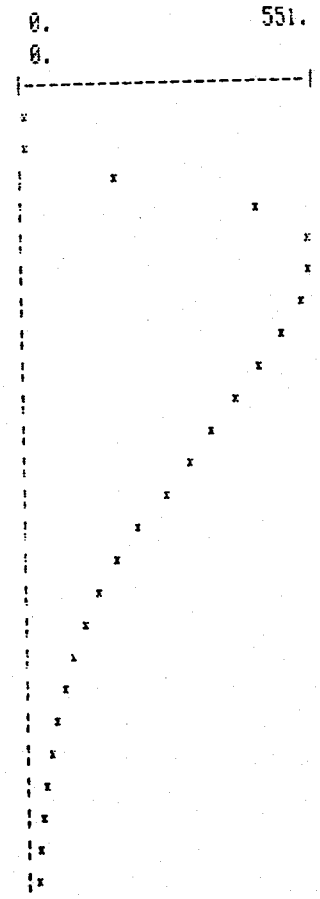
Pk. 5.min int.= 0.27 in
Y units= 0.01 in. →

```
min.
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
 5.##
10.###
15.#####################
20.############
25.##########
30.########
35.#####
40.#####
45.####
50.###
55.###
60.###
♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦
```

T (min.)	Q (cfs)
5.00	0.00
10.00	0.00
15.00	179.44
20.00	441.02
25.00	539.60
30.00	550.67
35.00	526.13
40.00	486.64
45.00	445.04
50.00	401.75
55.00	357.11
60.00	316.33
65.00	268.75
70.00	215.70
75.00	173.13
80.00	138.96
85.00	111.53
90.00	89.52
95.00	71.85
100.00	57.67
105.00	46.29
110.00	37.15
115.00	29.82
120.00	23.93
125.00	19.21
130.00	15.42

Q Peak= 550.67 (cfs)
Time to Peak= 30. min
Vol.= 1,662,802.99 cf
Vol.= 0.44 in.

Y (UNITS= 1.) →



C = runoff ratio = $\frac{Q_1}{P_1}$ (Q_1 = 1-hr runoff)

P_1 = 1-hr rainfall

$$S = 10P_1\left[C + 0.5 - \sqrt{C(C+1.25)}\right]$$

S = total abstraction

$$CN = \frac{1000}{S+10}$$

t	P_f	P_{100}	P_{25}	P_2
5	.27	0.81	0.62	0.27
10	.17	0.51	0.39	0.17
15	.13	0.39	0.30	0.13
20	.10	0.30	0.23	0.10
25	.07	0.21	0.16	0.07
30	.06	0.18	0.14	0.06
35	.05	0.15	0.12	0.05
40	.04	0.12	0.09	0.04
45	.03	0.09	0.07	0.03
50	.03	0.09	0.07	0.03
55	.03	0.09	0.06	0.03
60	.02	0.06	0.05	0.02
65	.00	0.00	0.00	0.00

SANTA BARBARA ~~UNIT~~ URBAN HYDROGRAPH MODEL

"This model computes a runoff hydrograph from an urban area directly from sucessive rainfall increments without going through any intermediate process"*

Some program algorithims were derived from Bernard Golding's HP-97 program (enclosed). Equations and calculations are nearly identical.

Package includes 3 programs, the S.B.U.H. Model (program "SB"), a data loading program (program "LD"), and a hyetograph plotting program (program "PH").

Program requires a HP-41C with at least 3 memory modules or a quad module or a HP-41CV. A printer and card reader are also necessary.

Printer should be set to MANUAL mode for execution.

Programs contain synthetic functions and characters.

USER mode is <u>not</u> required for execution of any of the programs.

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"Santa Barbara Unit Hydrograph Method", Hewlett Packard Users Club, Program Description for HP67, #02946 D, 15p.,

* Bernard L. Golding, 1979

Stubacher, J.M. "The Santa Barbara Urban Hydrograph Method". Proc. National Symposium on Hydrology and Sediment Control, ORES Publication, College of Engineering, University of Kentucky, November 1975.

Golding, B.L., "HNV-Santa Barbara Urban Hydrograph Method — Automatic". Hewlett Packard Users Club. HP-97, # 19065 9030, 2p., 1979.

do. — ProSWMM Users Group Mtg. 1979

USER'S GUIDE FOR THE SANTA BARBARA UNIT HYDROGRAPH PACKAGE

Inputting Rainfall Data: (Program "LD")

Load Program "LD" into calculator. Size must be set to at least 19 + N, where N = number of rainfall intervals of storm.

Execute program (XEQ ALPHA "LD" ALPHA).

Program prompts "T. INT.? (MIN)". Input time (minutes) of rainfall intervals and key R/S.

Program prompts "T='x' P= ?" where 'x' = corresponding time of rainfall interval. Input rainfall amount and key R/S.

Continue until all rainfall data has been entered. To continue execution of program, at the prompt, merely key R/S without entering any data.

Program prompts "RDY 01 of 'y'", where 'y' = total number of mag. card tracks (2 tracks / card) required to store data. Insert cards until prompts are satisfied. This step can be bypassed by keying R/S twice if user does not want to store data on cards and only wants to use the data for a single run of the S.B.U.H. Model, or user does not desire a plot of the runoff hydrograph (i.e. Flag 02 has been manually set by user) in which case the rainfall data will remain stored in calculator after execution of the model. (The use of Flag 02 will be further explained later on).

Program prompts "CARD MO. = 'z'", where z = N + 19. This value should be recorded on the card by the user as it is required for future execution of the S.B.U.H. Model. Register z is the register following the last register containing a rainfall value. Register z contains a zero.

Rainfall data is now stored in registers 19 through z-1. Register 18 contains the time interval in hours (program has converted the 'minutes' input to hours). Register 17 contains the value of z. Registers 00 - 16 are used in the execution of program "SB".

Program "LD" may now be cleared if desired. (CLP ALPHA "LD" ALPHA).

The S.B.U.H. Model: (Program "SB")

The following flags can be manually set or cleared by the user for the following effects:

Flag 01: When clear, program will list rainfall data with corresponding time intervals, calculate and print total rainfall amount and if program "PH" exists in the calculator, will plot a rainfall hyetograph.

When set program will not list rainfall data, total rainfall amount, or plot a hyetograph. Execution time will be increased and less printer paper will be used.

Flag 02: When clear, program will store calculated runoff in registers previously occupied by rainfall data and plot a runoff hydrograph. A larger 'size' is required though as the time duration of the runoff event is greater then that of the rainfall event. A very approximate method of determining required size is:

$$S = \text{INT}: \sqrt{P_t}\ (27 + N)$$

where:

S = size requirement

P_t = total rainfall amount (inches)

N = number of rainfall intervals

INT = integer value of

In most cases this is an over estimate of the required size, but conditions can exist where method will give an under-estimate of the required size, in which case program will prompt NONEXISTANT.. Program can be reexecuted by keying in a larger size and then keying R/S. If possible set size greater then calculated S. To reexecute program "SB" after execution of the program with Flag 02 clear, rainfall data will have to be reloaded, either by mag. cards or program "LD",

When set, program will not store calculated runoff data and a hydrograph will not be plotted. A size of N + 19 is sufficient. Execution time will be reduced and less printer paper used. Program "SB" can be reexecuted without reinputing rainfall data.

Flag 03: When clear, program will print a header, including space for the user to mark location and storm type on print-out and list all input data. (The prompt and printing of "SOIL TYPE" is included so user can keep a record of the soil type at location of watershed and is not used in any program calculations).

When set, program will not print header or input data. Execution time will be increased and less printer paper used.

EXECUTING THE S.B.U.H. MODEL.

(1) Execute "SB" (XEQ ALPHA "SB" ALPHA). Program prompts "CARD NO. ?". Input card number (card number = N + 19) and key R/S. If rainfall data was previously loaded no input is required and execution will continue by keying R/S. Program examines data registers to determine if registers contain rainfall data and agree will card number. If registers do contain rainfall data go to (2). Program now prompts "LOAD RAIN Cd.". Load mag. cards containing rainfall data until prompts are satisfied.

(2) Program promts "AREA= ? (ACRES)". Input area of basin. Key R/S.

(3) Program prompts "I= ? (%)". Input percentage of basin that's impervious. See Gouldings description.

(4) Program prompts "It= ? (%)". Input percentage of impervious area that runs off directly into channel. Key R/S.

(5) Program prompts Tc= ? (MIN). Input time of concentration of basin in minutes. See Goldings description. Key R/S.

(6) Program prompts FO= ? (IN./HR.). Input initial soil infiltration rate. See Golding description. Key R/S.

(7) Program prompts Fc= ? (IN./HR.). Input final soil infiltration rate

See Golding description.

(8) Program prompts F= ? (IN). Input inches of available soil moisture. See Golding description. Key R/S.

(9) If Flag 01 is set go to (11). Program prompts SOIL TYPE?. Calculator is preset to ALPHA mode. Input soil type. See Golding description. Key R/S.

(10) Program lists rainfall data and prints total storm rainfall amount.

(11) Program calculates area under infiltration curve. See Goldings description. Execution time is proportional to the F value and may take as long as 2 minutes. If the F value is unreasonably large, program will appear to be in a continous loop and may eventually error out. Program uses a decay coefficient of .2. This may be changed by changing lines 193 and and 238 of program "SB" to the negative of the desired decay coefficient.

(12) Program prints calculated runoff with corresponding time. Program continues ~~when~~ until Q is less then 3% of Q peak.

(13) Program prints Q peak, Time to Peak, Volume of runoff in ft^3. and in inches over basin.

(14) If flag 02 is set program will terminate. If flag 02 is clear program plots runoff hydrograph.

(15) Program sounds a tone and prompts RDY 01 of 'x'. This allows the user to store the calculated runoff data on mag. cards if desired. Load mag. cards until prompts are satisfied. Execution terminates. If it is not desired to store runoff data on mag. cards, key R/s twice and execution will terminate.

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
	Listing of Program SB cont. (3/3)			
	Listing of Program PH			
	Listing of Program LD			

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
	Listing of Program SB (1/3)			

Program 5B

STEP	KEY ENTRY	KEY CODE	COMMENTS
01	*LBL "5B"		
02	SPEC 06		
03	CLE		
04	SPEC 11		
05	CLE		
06	FIL 17		
07	"CARD NO. ?"		
08	PROMPT		
09	STO 17		
10	ENTER↑		
11	ENTER↑		
12	RCL IND X		
13	X≠0?		
14	GTO 14		
15	X<>Y		
16	1		
17	-		
18	RCL IND X		
19	X≠0?		
20	GTO 11		
21	*LBL 14		
22	R↑		
23	E3		
24	/		
25	17		
26	+		
27	CF 21		
28	"LOAD RAIN Cd."		
29	AVIEW		
30	RDTA		
31	SF 21		
32	*LBL 11		
33	"A= ? (ACRES)"		
34	PROMPT		
35	STO 00		
36	"I= ? (%)"		
37	PROMPT		
38	E		
39	%		
40	STO 02		
41	"IT= ? (%)"		
42	PROMPT		
43	E		
44	%		
45	STO 01		
46	"Tc= ? (MIN)"		
47	PROMPT		
48	STO 04		
49	"F0"		
50	XEQ 10		
51	STO 03		
52	"Fc"		
53	XEQ 10		
54	STO 05		
55	-		
56	STO 12		
57	"F= ? (IN)"		
58	PROMPT		
59	STO 15		
60	FIX 2		
61	FS? 03		
62	GTO 14		
63	"SOIL TYPE ?"		
64	ASTO Y		
65	AON		
66	PROMPT		
67	ASTO X		
68	AOFF		
69	SF 12		
70	" SANTA"		
71	AVIEW		
72	" BARBARA"		
73	AVIEW		
74	" UNIT"		
75	AVIEW		
76	" HYDROGRAPH"		
77	AVIEW		
78	CF 12		
79	ADV		
80	"LOCATION:"		
81	AVIEW		
82	ADV		
83	ADV		
84	"STORM TYPE:"		
85	AVIEW		
86	ADV		
87	ADV		
88	ADV		
89	CLD		
90	CLA		
91	ARCL Y		
92	"⊢YPE "		
93	ACA		
94	ACX		
95	PRBUF		
96	"AREA= "		
97	ARCL 00		
98	"⊢ acres"		
99	PRA		
100	RCL 02		
101	E2		
102	*		
103	FIX 0		
104	CLA		
105	ARCL X		
106	"⊢% Impervious"		
107	PRA		
108	CLA		
109	RCL 01		
110	E2		
111	*		
112	ARCL X		

REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	"⊢% Directly Con"		
114	"⊢nected"		
115	PRA		
116	"Time of Conc.= "		
117	ARCL 04		
118	"⊢ min."		
119	PRA		
120	FIX 2		
121	RCL 03		
122	"fo"		
123	XEQ 13		
124	RCL 05		
125	"fc"		
126	XEQ 13		
127	"F= "		
128	ARCL 15		
129	"⊢ (in.)"		
130	PRA		
131	"Time Int.= "		
132	↑LBL 14		
133	RCL 18		
134	HMS		
135	E2		
136	*		
137	FIX 0		
138	STO 07		
139	ARCL X		
140	"⊢ min."		
141	FC? 03		
142	PRA		
143	RCL 04		
144	LASTX		
145	/		
146	HR		
147	STO 04		
148	FIX 2		
149	18		
150	STO 03		
151	FS? 01		
152	GTO 01		
153	"P (in."		
154	XEQ 12		
155	↑LBL 00		
156	E		
157	ST+ 03		
158	RCL 07		
159	ST+ 11		
160	RCL 11		
161	ACX		
162	7		
163	SKPCHR		
164	RCL IND 03		
165	ST+ 08		
166	ACX		
167	2		
168	SKPCHR		
169	ADV		
170	RCL 03		
171	RCL 17		
172	X>Y?		
173	GTO 00		
174	ADV		
175	"Total Precip.= "		
176	ARCL 08		
177	"⊢ in."		
178	PRA		
179	SF 25		
180	XEQ "PH"		
181	CF 25		
182	.		
183	STO 08		
184	STO 09		
185	CF 29		
186	FIX 2		
187	18		
188	STO 03		
189	↑LBL 01		
190	E-2		
191	ST+ 08		
192	RCL 08		
193	-2		
194	*		
195	E↑X		
196	RCL 12		
197	*		
198	STO 11		
199	E		
200	%		
201	ST+ 09		
202	RCL 09		
203	RCL 15		
204	X>Y?		
205	GTO 01		
206	RCL 11		
207	RCL 05		
208	+		
209	STO 15		
210	CLX		
211	STO 09		
212	"Q (cfs"		
213	XEQ 12		
214	CF 29		
215	↑LBL 02		
216	E		
217	ST+ 03		
218	RCL IND 03		
219	STO [		
220	ENTER↑		
221	RCL 14		
222	E-1		
223	X<=Y?		
224	GTO 03		

Cont.

LABELS					FLAGS
A	B	C	D	E	0
a	b	c	d	e	1
[illegible]	1	2	3	4	2
[illegible]	6	7	8	9	3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☐	FIX	☐
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n ____	

STEP	KEY ENTRY	KEY CODE	COMMENTS
225	RCL [		
226	ST+ 14		
227	X<>Y		
228	RCL 14		
229	X<=Y?		
230	GTO 06		
231	X<>Y		
232	-		
233	STO [		
234	♦LBL 03		
235	RCL 18		
236	ST+ 08		
237	RCL 08		
238	-2		
239	*		
240	E↑X		
241	RCL 12		
242	*		
243	RCL 05		
244	+		
245	STO 11		
246	RCL 15		
247	+		
248	2		
249	/		
250	RCL 18		
251	*		
252	E		
253	RCL 01		
254	-		
255	*		
256	E		
257	RCL 02		
258	-		
259	RCL [		
260	*		
261	X<>Y		
262	-		
263	X<0?		
264	GTO 04		
265	RCL [		
266	RCL 02		
267	*		
268	+		
269	GTO 05		
270	♦LBL 04		
271	RCL [		
272	RCL 02		
273	*		
274	♦LBL 05		
275	RCL 00		
276	*		
277	RCL 18		
278	/		
279	STO [		
280	RCL 06		
281	+		
282	RCL 10		
283	2		
284	*		
285	-		
286	RCL 04		
287	2		
288	*		
289	RCL 18		
290	+		
291	LASTX		
292	X<>Y		
293	/		
294	*		
295	RCL 10		
296	+		
297	STO 10		
298	ST+ 16		
299	RCL [		
300	STO 06		
301	RCL 11		
302	STO 15		
303	♦LBL 06		
304	RCL 18		
305	ST+ 09		
306	RCL 09		
307	FRC		
308	HMS		
309	RND		
310	E2		
311	*		
312	RCL 09		
313	INT		
314	60		
315	*		
316	+		
317	ACX		
318	RCL 10		
319	ENTER↑		
320	X<=0?		
321	E		
322	LOG		
323	INT		
324	7		
325	X<>Y		
326	-		
327	SKPCHR		
328	X<>Y		
329	ACX		
330	2		
331	SKPCHR		
332	ADV		
333	RCL 13		
334	RCL 10		
335	FC? 02		
336	STO IND 03		

REGISTERS

0	1	2	3	4	5	6	7	8	9

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
337	X<=Y?		
338	GTO 09		
339	STO 13		
340	RCL 09		
341	STO 07		
342	GTO 02		
343	♦LBL 09		
344	RCL 17		
345	RCL 03		
346	X<Y?		
347	GTO 02		
348	RCL 13		
349	3		
350	%		
351	RCL 10		
352	X<=Y?		
353	GTO 14		
354	E		
355	RCL 03		
356	+		
357	.		
358	STO IND Y		
359	GTO 02		
360	♦LBL 14		
361	CHS		
362	STO IND 03		
363	ADV		
364	SF 29		
365	"Q Peak= "		
366	ARCL 13		
367	"⊢ (cfs)"		
368	PRA		
369	FIX 0		
370	"Time to Peak= "		
371	RCL 07		
372	HMS		
373	FRC		
374	E2		
375	*		
376	RCL 07		
377	INT		
378	60		
379	*		
380	+		
381	ARCL X		
382	"⊢ min"		
383	PRA		
384	FIX 2		
385	RCL 18		
386	60		
387	X↑2		
388	*		
389	RCL 16		
390	*		
391	"Vol.= "		
392	ARCL X		
393	"⊢ cf"		
394	PRA		
395	RCL 00		
396	3630		
397	*		
398	/		
399	"Vol.= "		
400	ARCL X		
401	"⊢ in."		
402	PRA		
403	ADV		
404	FS? 02		
405	STOP		
406	CLX		
407	STO 00		
408	STO 04		
409	RCL 13		
410	STO 01		
411	168		
412	STO 02		
413	CLX		
414	19		
415	STO 11		
416	XROM "PRAXIS"		
417	♦LBL 08		
418	RCL IND 11		
419	X<0?		
420	GTO 14		
421	REGPLOT		
422	E		
423	ST+ 11		
424	GTO 08		
425	♦LBL 10		
426	"⊢=? (IN./HR.)"		
427	PROMPT		
428	RTN		
429	♦LBL 12		
430	ASTO X		
431	ADV		
432	"T (min.) "		
433	ARCL X		
434	"⊢) "		
435	ACA		
436	ADV		
437	RTN		
438	♦LBL 13		
439	"⊢= "		
440	ARCL X		
441	"⊢ (in./hr.)"		
442	PRA		
443	RTN		
444	♦LBL 14		
445	ADV		
446	ADV		
447	ADV		
448	ADV		

LABELS					FLAGS
A	B	C	D	E	0
a	b	c	d	e	1
0	1	2	3	4	2
5	6	7	8	9	3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☐	FIX	☐
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n_____	

Program LD

STEP	KEY ENTRY	KEY CODE	COMMENTS
449	RCL 11		
450	E		
451	-		
452	E3		
453	/		
454	10		
455	+		
456	BEEP		
457	WDTAX		
458	END		

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STEP	KEY ENTRY	KEY CODE	COMMENTS
01	♦LBL "LD"		
02	10		
03	STO 03		
04	"T. INT.? (MIN)"		
05	PROMPT		
06	STO 05		
07	STO 09		
08	E2		
09	/		
10	HR		
11	STO 18		
12	FIX 0		
13	♦LBL 00		
14	E		
15	ST+ 03		
16	"T="		
17	ARCL 09		
18	"⊢ P= ?"		
19	.		
20	PROMPT		
21	STO IND 03		
22	RCL 05		
23	ST+ 09		
24	RCL 03		
25	STO 17		
26	FS?C 22		
27	GTO 00		
28	RCL 17		
29	E3		
30	/		
31	17		
32	+		
33	WDTAX		
34	"CARD NO.= "		
35	ARCL 17		
36	PROMPT		
37	END		

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REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A B C D E I

Program

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
01	♦LBL "PH"		
02	SF 29		
03	0		
04	STO 03		
05	STO 08		
06	RCL 18		
07	HMS		
08	ENTER↑		
09	FRC		
10	E2		
11	*		
12	X<>Y		
13	INT		
14	60		
15	*		
16	+		
17	STO 11		
18	FIX 0		
19	19		
20	STO 09		
21	♦LBL 00		
22	RCL 03		
23	RCL IND 09		
24	X>Y?		
25	STO 03		
26	1		
27	ST+ 09		
28	RCL 09		
29	RCL 17		
30	X>Y?		
31	GTO 00		
32	RCL 03		
33	ENTER↑		
34	ENTER↑		
35	18		
36	/		
37	STO 03		
38	19		
39	STO 09		
40	ADV		
41	" RAINFALL HYET"		
42	"⊢OGRAPH"		
43	PRA		
44	ADV		
45	"Pk. "		
46	ARCL 11		
47	"⊢min int.= "		
48	FIX 2		
49	ARCL Z		
50	"⊢ in"		
51	PRA		
52	"Y units= "		
53	ARCL Y		
54	"⊢ in. →"		
55	PRA		
56	ADV		
57	FIX 0		
58	"min."		
59	PRA		
60	XEQ 14		
61	♦LBL 01		
62	RCL 09		
63	RCL 17		
64	X<=Y?		
65	GTO 14		
66	RCL 11		
67	ST+ 08		
68	RCL 08		
69	X=0?		
70	1		
71	LOG		
72	INT		
73	2		
74	X<>Y		
75	-		
76	SKPCHR		
77	RCL 08		
78	ACX		
79	"*"		
80	0		
81	♦LBL 02		
82	RCL 03		
83	+		
84	RCL IND 09		
85	X=0?		
86	CLA		
87	ACA		
88	X<>Y		
89	X<=Y?		
90	GTO 02		
91	PRBUF		
92	1		
93	ST+ 09		
94	GTO 01		
95	♦LBL 14		
96	"-------"		
97	ACA		
98	ACA		
99	ACA		
100	ACA		
101	ADV		
102	.END.		

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LABELS					FLAGS	SET STATUS
A	B	C	D	E	0	
	b	c	d	e	1	
	1	2	3	4	2	
5	6	7	8	9	3	

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☐	FIX	☐
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n_____	

User Instructions

1 Return to Reg 2

58.

INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
Print - Out Examples			

STEP	KEY ENTRY	KEY CODE	COMMENTS
001			

SANTA
BARBARA
~~UNIT~~
HYDROGRAPH

LOCATION:
Tucson, Az.

STORM TYPE:
1 hour, 100 yr.

SOIL TYPE "B"
AREA= 120.00 acres
40.% Impervious
35.% Directly Connected
Time of Conc.= 30. min.
fo= 8.00 (in./hr.)
fc= 0.50 (in./hr.)
F= 1.40 (in.)
Time Int.= 10. min.

T (min.)	P (in.)
10.00	1.36
20.00	0.79
30.00	0.41
40.00	0.24
50.00	0.20
60.00	0.13
70.00	0.00

Total Precip.= 3.13 in.

RAINFALL HYETOGRAPH

Pk. 10.min int.= 1.36 in
Y units= 0.08 in. →

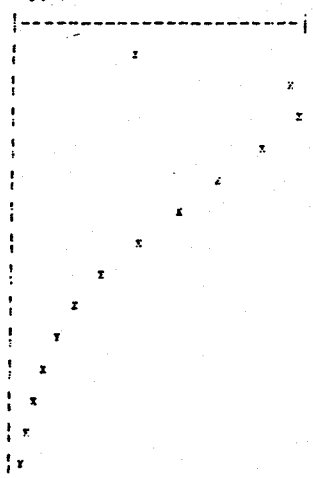
```
min.
-----------------------
 10.##################
 20.###########
 30.######
 40.####
 50.###
 60.##
-----------------------
```

STEP	KEY ENTRY	KEY CODE	COMMENTS

T (min.)	Q (cfs)
10.00	79.65
20.00	180.42
30.00	189.62
40.00	162.19
50.00	133.95
60.00	109.26
70.00	83.39
80.00	59.56
90.00	42.55
100.00	30.39
110.00	21.71
120.00	15.50
130.00	11.07
140.00	7.91
150.00	5.65

Q Peak= 189.62 (cfs)
Time to Peak= 30. min
Vol.= 679,690.95 cf
Vol.= 1.56 in.

Y (UNITS= 1.) →
0. 190.
0.



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110		

REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS

SANTA
BARBARA
UNIT
HYDROGRAPH

LOCATION:

STORM TYPE:

SOIL TYPE "C"
AREA= 850.00 acres
20.% Impervious
50.% Directly Connected
Time of Conc.= 45. min.
fo= 5.00 (in./hr.)
fc= 0.25 (in./hr.)
F= 2.00 (in.)
Time Int.= 10. min.

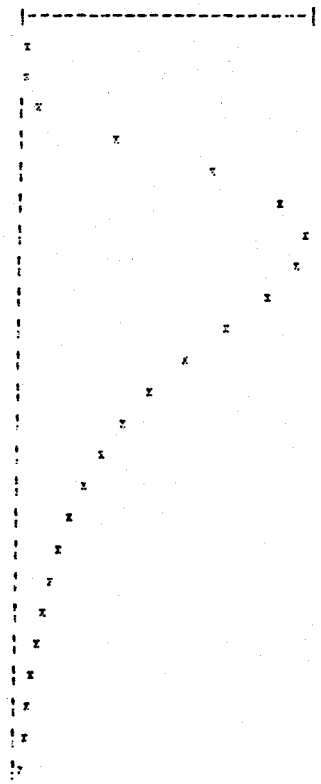
T (min.)	P (in.)
10.00	0.03
20.00	0.08
30.00	0.11
40.00	0.28
50.00	0.20
60.00	0.24
70.00	0.11
80.00	0.10
90.00	0.05
100.00	0.01
110.00	0.00

Total Precip.= 1.21 in.

T (~~min.~~ hr.)	Q (cfs)
0.17	0.00
0.17	1.02
0.17	29.11
0.17	169.70
0.17	336.92
0.17	456.65
0.17	511.07
0.17	486.47
0.17	438.53
0.17	364.25
0.17	292.42
0.17	233.94
0.17	187.15
0.17	149.72
0.17	119.78
0.17	95.82
0.17	76.66
0.17	61.33
0.17	49.06
0.17	39.25
0.17	31.40
0.17	25.12
0.17	20.10
0.17	16.08
0.17	12.86

Q Peak= 511.07 (cfs)
Time to Peak= 70. min
Vol.= 2,522,634.26 cf
Vol.= 0.82 in.

Y (UNITS= 1.) →
0. 511.
0.



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STEP	KEY ENTRY	KEY CODE	COMMENTS
220			

LABELS					FLAGS
A	B	C	D	E	0
a	b	c	d	e	1
0	1	2	3	4	2
5	6	7	8	9	3

SET STATUS

FLAGS	ON	OFF	TRIG	DISP
0	☐	☐	DEG ☐	FIX ☐
1	☐	☐	GRAD ☐	SCI ☐
2	☐	☐	RAD ☐	ENG ☐
3	☐	☐		n_____

02946D Program Descript

Program Title SANTA BARBARA URBAN HYDROGRAPH METHOD

Contributor's Name Bernard L. Golding
Address 8982 Islesworth Court
City Orlando State Florida Zip Code 32811

Program Description, Equations, Variables

GENERAL:

The Santa Barbara Urban Hydrograph Method (SBUH Method), developed by Mr. James M. Stubachaer, F. ASCE, of the Santa Barbara County (California) Flood Control and Water Conservation District (1), computes a hydrograph directly without going through any intermediate process, as does the unit hydrograph method.

The SBUH Method is in many respects similar to some of the time-area-concentration curve procedures for hydrograph computation in which an instantaneous hydrograph in a basin is developed and then routed through an element of linear storage to determine basin response. However, in the SBUH Method, the final design (outflow) hydrograph is obtained by routing the instantaneous hydrograph for each time period (obtained by multiplying the various incremental rainfall-excesses by the entire watershed area in acres) through an imaginary linear reservoir with a routing constant equivalent to the time of concentration of the drainage basin. Therefore, the difficult and time consuming process of preparing a time-area-concentration curve for the basin is eliminated.

A step-by-step description of the basic SBUH Method is given below:

1. Runoff depths for each time period are calculated using the following equations:

(1) Impervious Area Runoff - $R(0) = I\,P(t)$ (inches)

(2) Pervious Area Runoff - $R(1) = (1-I)[P(t)-f]$ (inches)

(3) Total Runoff Depth - $R(t) = R(0) + R(1)$ (inches)

where,

$P(t)$ = Rainfall depth during time increment Δt (inches)

f = Infiltration during time increment Δt (inches)

I = Impervious portion of drainage basin (decimal)

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Program Description

(CONTINUATION SHEET)

Δt = Incremental time period (hours, i.e., 0.25, 0.50, etc.)

2. The instantaneous hydrograph is then computed by multiplying the total run-off depth R(t) for each time period t by the drainage basin area A in acres and dividing by the time increment Δt in hours.

(4) $I(t) = R(t)\ A/\Delta t$ (cfs)

(Note that as in the Rational Method, we have ignored the conversion factor 1.008 which was originally included in equation (4) in Mr. Stubachaer's report.)

3. The final design (outflow) hydrograph Q(t) is then obtained by routing the instantaneous hydrograph I(t) through an imaginary reservoir with a time delay equal to the time of concentration (T_c) of the drainage basin. This flood routing may be done by use of the following equation which is subsequently derived:

(5) $Q(t) = Q(t-1) + \overline{K}\left[I(t-1) + I(t) - 2Q(t-1)\right]$ (cfs)

where,

$$\overline{K} = \frac{\Delta t}{2T_c + \Delta t}$$

and where T_c = Time of concentration of the basin (hours).

In the SBUH Method, the impervious portion I of the drainage basin is considered to be that directly (hydraulically) connected portion of the impervious area.

Also, in the SBUH Method, all of the rain which falls on this impervious portion of the basin is considered runoff except for the first 0.1 inch (depression storage) which is automatically subtracted from the rainfall in the program.

INFILTRATION:

In this program for the SBUH Method, infiltration is computed in accordance with the relationships illustrated on Figure 1 as first described by Holtan and developed and presented by Terstriep and Stall(2). In this methodology, it is assumed that an

Program Description

(CONTINUATION SHEET)

Initial (Maximum) Infiltration Rate fo in inches per hour is available in the soil mantle when rainfall starts which drops off exponentially with time as the voids in the soil become filled with water to some Final (Constant) Infiltration Rate fc - also in inches per hour. The total cross-hatched area below the Infiltration Curve and above the Final (Constant) Infiltration Rate line (=S) represents the total available water storage in the soil mantle. As shown on Figure 1, this Total Available Water Storage Capacity, S, in the soil in inches is divided into two parts 1) the water already stored in the soil when rainfall begins (F) which is the result of previous rainfalls, and 2) the actual Available Storage in the Soil (S-F). Of course, if a long dry period preceded the start of rainfall, the total area (actually a volume) under the Infiltration Curve (=S) would be available for water storage. In the computer program the infiltration f shown on Figure 1, is computed by the Horton equation.

$$f = fc + (fo-fc)e^{-kt}$$

where

f = infiltration rate at some time t after the start of rainfall, inches per hour

fo = initial infiltration rate, inches per hour

fc = final constant infiltration rate, inches per hour

k = a shape factor (=2)

e = base of natural logs

In using the SBUH Method, the Standard Infiltration Curves for each of the four general U. S. Soil Conservation Service Classifications (A, B, C and D) shown on Figure 2 as originally established by Terstriep and Stall as modified by Golding (3) can be used to compute infiltration. Standard Antecedent Moisture Conditions for these four types of soils, as also established by Terstriep and Stall and which are subsequently discussed, can be used to determine F.

02946D Program Description I

Program Title SANTA BARBARA URBAN HYDROGRAPH METHOD

Contributor's Name Bernard L. Golding
Address 8982 Islesworth Court
City Orlando State Florida Zip Code 32811

Program Description, Equations, Variables

The various factors used to compute the Standard Infiltration Curves shown on Figure 2 as established by Terstriep and Stall for each of the four SCS Standard Hydrologic Soil Groups are listed on Table 2.

The four antecedent moisture conditions listed in this Table - Bone Dry (Condition 1), Rather Dry (Condition 2), Rather Wet (Condition 3) and Saturated (Condition 4), are dependent on the total rainfall that occurred during the five days preceding the particular storm (Antecedent Moisture Condition) as shown in Table 3.

In this computer program, the infiltration f, at some particular value of F, is first computed for the particular Antecedent Moisture Condition by first summing up incremental volumes under the curve for increments of 0.01 hour, computing a second value of infiltration f_2 at incremental time Δt later and then averaging the two computed infiltration values. To compute rainfall-excess from the previous areas this average infiltration over the Δt time period is then applied to that rainfall-excess increment during which time element a total rainfall of 0.1 inch has fallen (depression storage).

Theoretically, the 0.1 initial depression storage should be subtracted from the rainfall and the infiltration curve applied only at that subsequent time after rainfall has started, at which the total volume of rainfall and the total volume of infiltration storage under the infiltration curve are equal. As this procedure program applies the infiltration curve immediately after rainfall begins and the 0.1 depression storage has been satisfied, a storm with small initial amounts of rainfall falling over an extended period of time will cause a premature reduction of the infiltration rate (a decay of the infiltration rate with time), which will result in higher runoff than would actually be the case. However, since the infiltration accumulated in the soil matter due to antecedent rainfall (=F) is very broadly defined and since

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Program Description I

Program Title SANTA BARBARA URBAN HYDROGRAPH METHOD

Contributor's Name Bernard L. Golding

Address 8982 Islesworth Court

City Orlando State Florida Zip Code 32811

Program Description, Equations, Variables

the pervious area contribution is generally small, this induced error is normally not significant.

REFERENCES:

(1) Stubachaer, J.M., "The Santa Barbara Urban Hydrograph Method", Proceedings, National Symposium on Hydrology and Sediment Control, ORES Publication, College of Engineering, University of Kentucky, November 1975.

(2) Terstriep, M.L. and Stall, J.B., "The Illinois Urban Drainage Area Simulator ILLUDAS", Illinois State Water Survey, Bulletin 58, State of Illinois Department of Registration and Education, 1974.

(3) Golding, B.L., Personal Communication with M. L. Terstriep, January 18, 1978.

NOTES:

(1) SHAPE (DECAY) FACTOR K IN HORTON'S EQUATION MAY BE CHANGED FROM 2 IN PROGRAM TO OTHER VALUES BY DELETING 2 FROM STEPS 11 AND 62 OF PROGRAM AND PLACING OTHER VALUES AT SAME LOCATION.

(2) DIRECTLY (HYDRAULICALLY) CONNECTED IMPERVIOUS AREAS ARE THOSE IMPERVIOUS AREAS WHERE RUNOFF THEREFROM DOES NOT FLOW OVER A PERVIOUS AREA BEFORE REACHING AN ELEMENT OF THE DRAINAGE SYSTEM (STREETS WITH CURBS, STORM DRAINS, ETC.).

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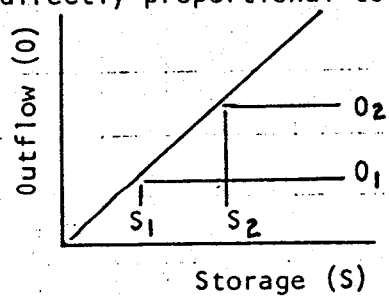
Program Description

(CONTINUATION SHEET)

DERIVATION OF ROUTING EQUATION:

1. Consider a linear reservoir with a definite storage S such that the storage is directly proportional to the outflow, $S \propto O$



$$\text{Time}^{(1)} = \frac{S_2 - S_1}{Q_2 - Q_1}$$

2. Slope of Storage Curve $T_c = \dfrac{\Delta S}{Q_2 - Q_1}$ = Flow travel Time(1) in Reach = Time Delay in Reservoir

$$\Delta S = T_c\,(Q_2 - Q_1)$$

where T_c = Time of concentration

3. Substituting in the General Storage Equation -

$$T_c\,(Q_2 - Q_1) = \Delta S = \frac{(I_1 + I_2)}{2}\,\Delta t - \frac{(Q_1 + Q_2)}{2}\,\Delta t$$

4. From which can be derived -

$$Q_2 = Q_1 + \bar{K}\,(I_1 + I_2 - 2Q_1)$$

$$\text{Where } \bar{K} = \frac{\Delta t}{2T_c + \Delta t}$$

(1) Flow Travel Time = K in Muskingum Method

Program Description I

Program Title: SANTA BARBARA URBAN HYDROGRAPH METHOD

Contributor's Name: Bernard L. Golding
Address: 8982 Islesworth Court
City: Orlando State: Florida Zip Code: 32811

Program Description, Equations, Variables: Table 2

Factors Used For Calculating The Standard Infiltration Curves For Grassed Areas

Item	Value			
Hydrologic soil group USDA designation	A	B	C	D
Final constant infiltration rate f_c in. per hour	1.0	0.50	0.25	0.10
Initial infiltration rate, f_o, inches per hour	10	8	5	3
Shape factor, k, or infiltration curve	2	2	2	2
Available storage capacity, S, in soil mantle, inches, for four antecedent conditions				
Bone dry, condition 1	4.3	3.4	2.3	1.3
Rather dry, condition 2	3.4	2.8	1.8	1.1
Rather wet, condition 3	1.9	1.4	1.0	0.6
Saturated, condition 4	0	0	0	0
Infiltration accumulated, F, in soil mantle, inches, at start of rainfall				
Bone dry, condition 1	0	0	0	0
Rather dry, condition 2	1.9	1.4	1.0	0.6
Rather wet, condition 3	3.4	2.8	1.8	1.1
Saturated, condition 4	4.3	3.4	2.3	1.3

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02946D Program Description I

Program Title: SANTA BARBARA URBAN HYDROGRAPH METHOD

Contributor's Name: Bernard L. Golding
Address: 8982 Islesworth Court
City: Orlando State: Florida Zip Code: 32811

Program Description, Equations, Variables: Table 3

Antecedent Moisture Conditions For Previous Areas (grass)

Description	Total rainfall during 5 days preceding storm (inches)
Bone dry	0
Rather dry	0 to 0.5
Rather wet	0.5 to 1
Saturated	over 1

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Program Description

(CONTINUATION SHEET)

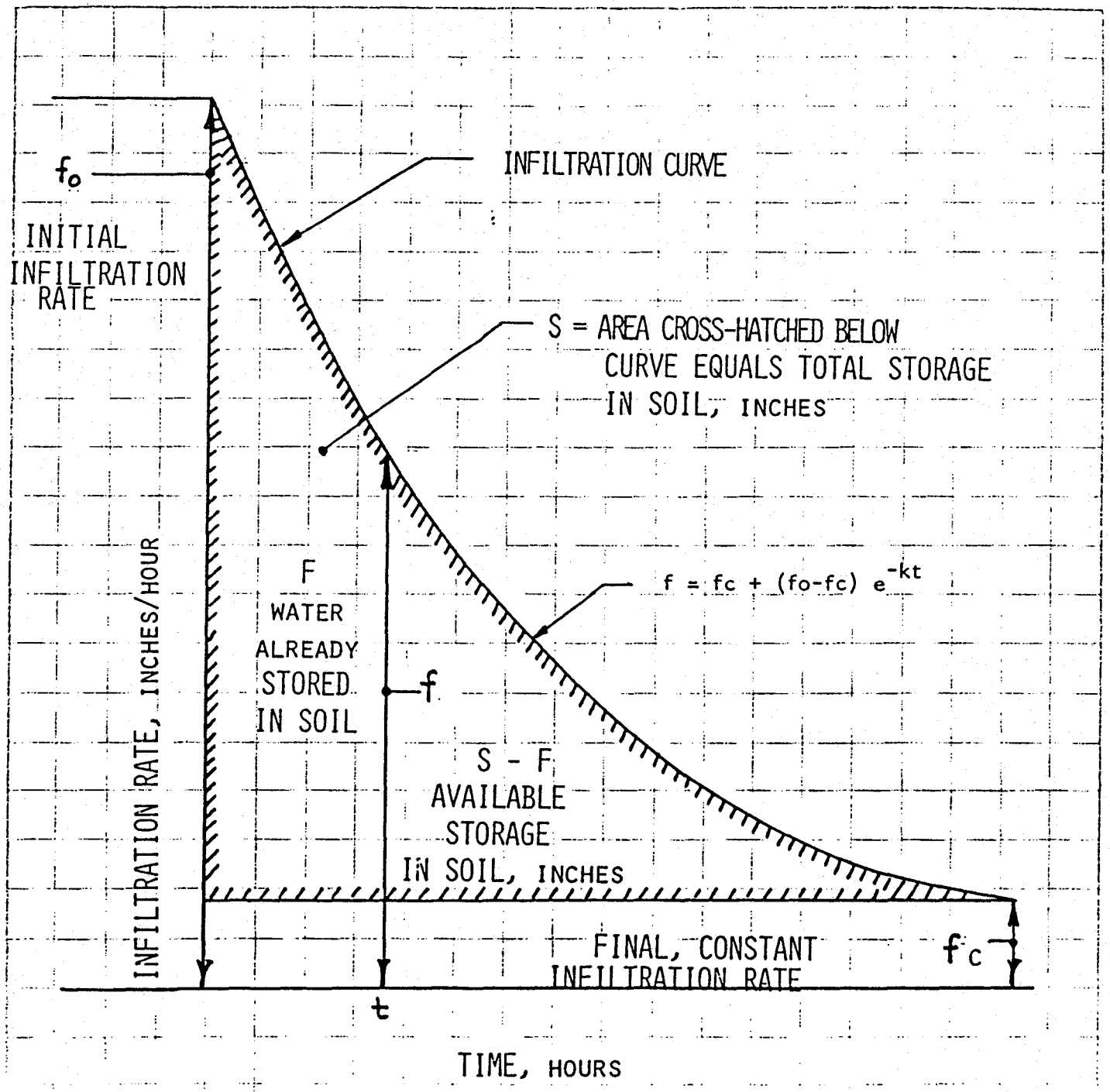

FIGURE 1 DIAGRAM OF INFILTRATION CURVE AND INFILTRATION RATES AS RELATED TO STORAGE IN SOIL

Program Description

(CONTINUATION SHEET)

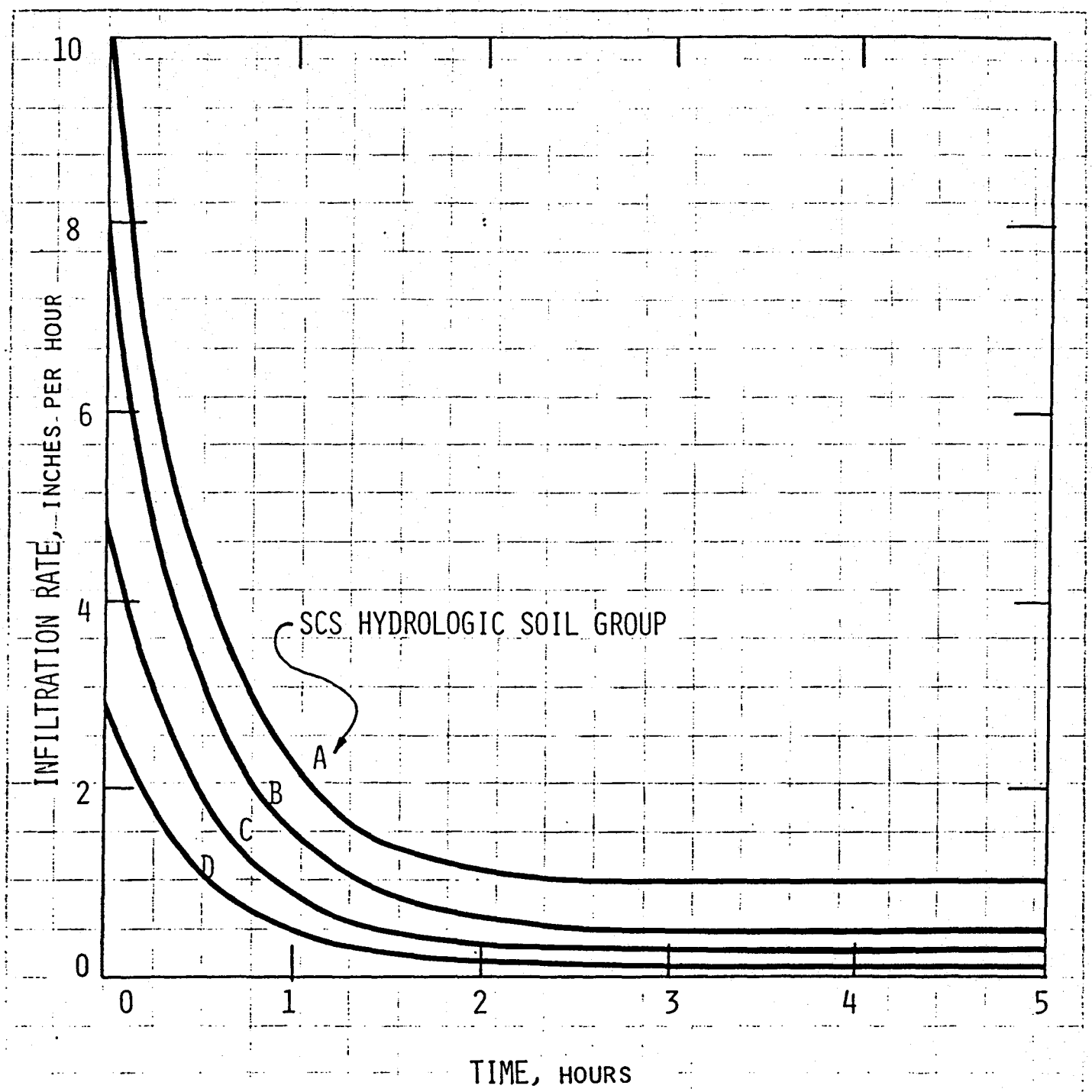

FIGURE 2 STANDARD INFILTRATION CURVES FOR GRASS FOR USE IN THE SBUH-METHOD

02946D Program Description II

PROBLEM: COMPUTE THE RUNOFF HYDROGRAPH FROM A 245 ACRE URBAN BASIN SUBJECT TO THE FOLLOWING 15 MINUTE RAINFALL INCREMENTS. THE TOTAL ACCUMULATED RAINFALL IN THE 5 DAYS PRECEDING THIS RAINFALL AMOUNTED TO 0.75 INCHES (RATHER WET - CONDITION 3).

Time Increment	Time (hrs)	Incremental Rainfall, P(t) (in)	Time Increment	Time (hrs)	Incremental Rainfall, P(t) (in)
0	0				
1	0.25	0.09	13	3.25	0.21
2	0.50	0.09	14	3.50	0.21
3	0.75	0.10	15	3.75	0.15
4	1.00	0.13	16	4.00	0.13
5	1.25	0.14	17	4.25	0.13
6	1.50	0.14	18	4.50	0.11
7	1.75	0.24	19	4.75	0.11
8	2.00	0.26	20	5.00	0.11
9	2.25	0.93	21	5.25	0.11
10	2.50	0.99	22	5.50	0.10
11	2.75	0.26	23	5.75	0.10
12	3.00	0.26	24	6.00	0.10

THE SOIL IN THE BASIN IS TYPE A (INITIAL INFILTRATION RATE fo = 10 in/hr, FINAL INFILTRATION RATE fc=1.0 in/hr, ACCUMULATED INFILTRATION F=3.4 in); THE TIME OF CONCENTRATION OF THE BASIN IS 25 MINUTES (0.42 HOURS) AND THE DIRECTLY CONNECTED IMPERVIOUS AREA AMOUNTS TO 15% (0.15) OF THE BASIN.

SOLUTION: 1) LOAD PROGRAM (BOTH SIDES OF MAGNETIC CARD)

2) INITIALIZE, PRESS D, READ 0.00

3) 245 , STO 1 — 10 , STO A

0.15, STO 2 — 1.0, STO B

0.25, STO 3 — 3.4, STO C

0.42, STO 4

4) PRESS E, READ 0.00000000 (SEVERAL MINUTES RUNNING TIME REQUIRED)

5) ENTER RAINFALL INCREMENTS, THEN SUCCESSIVE ZEROS

INPUT-RAINFALL (IN.)		OUTPUT-HYDROGRAPH ORDINATES (CFS)
.09	PRESS R/S	0
.09	PRESS R/S	2.70
.10	PRESS R/S	7.53
.13	PRESS R/S	11.83
.14	PRESS R/S	15.51
.14	PRESS R/S	17.83
.24	PRESS R/S	22.47
.26	PRESS R/S	29.02
.93	PRESS R/S	183.32
.99	PRESS R/S	431.37
.26	PRESS R/S	416.57
.26	PRESS R/S	245.41
.21	PRESS R/S	150.05
.21	PRESS R/S	95.38
.15	PRESS R/S	63.77
.13	PRESS R/S	43.96
.13	PRESS R/S	32.56
.11	PRESS R/S	25.72
.11	PRESS R/S	21.34
.11	PRESS R/S	18.97
.11	PRESS R/S	17.68
.10	PRESS R/S	16.65
.10	PRESS R/S	15.76
.10	PRESS R/S	15.27
0	PRESS R/S	11.64
0	PRESS R/S	6.30
0	PRESS R/S	3.41
0	PRESS R/S	1.85
0	PRESS R/S	1.00
0	PRESS R/S	0.54
0	PRESS R/S	0.29
0	PRESS R/S	0.16
0	PRESS R/S	0.09
0	PRESS R/S	0.05
0	PRESS R/S	0.03

User Instructions

SANTA BARBARA URBAN HYDROGRAPH METHOD

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Load Program (Sides 1 & 2)				
2.	Initialize (clear all registers)			D	0.00
3.	Input Known Values				
	a) Watershed Area	A (Acres)	STO	1	
	b) Impervious Portion Watershed	I (Decimal)	STO	2	
	c) Time Increment	Δt (Hours)	STO	3	
	d) Time of Concentration	Tc (Hours)	STO	4	
	e) Initial Infiltration Rate	fo (In/Hr)	STO	A	
	f) Final Infiltration Rate	fc (In/Hr)	STO	B	
	g) Accumulated Infiltration	F (Inches)	STO	C	
4.	Start Program			E	0.00000000
5.	Place First Rainfall Increment	P(t) (In/Δt)		R/S	Q_1 cfs
	in X-Register				
6.	Continue to place successive	P(t) (In/Δt)		R/S	Q cfs
	Rainfall Increments P(t) in X-Register				
	one at a time untill all entered. Then				
	successive zeros.				
7.	To compute new hydrograph, go to Step 2				

Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001 ✳	f LBL E	31 25 15	
	RCL A	34 11	f_o
	RCL B	34 12	f_c
	−	51	$(f_o - f_c)$
	STO D	33 14	$(f_o - f_c)$ in RD
	.	83	.
	0	00	0
	1	01	1
	STO + 8	33 61 08	$t = \Sigma\Delta t$ in R8
010	RCL 8	34 08	$t = \Sigma\Delta t$
	2 (=K)	02	K
	X	71	Kt
	CHS	42	−Kt
	$g e^x$	32 52	e^{-Kt}
	RCL D	34 14	$(f_o - f_c)$
	X	71	$f - f_c = (f_o - f_c)e^{-Kt}$
	STO E	33 15	
	.	83	.
	0	00	0 } = Δt
020	1	01	1
	X	71	$(f - f_c)\Delta t$
	STO + 9	33 61 09	$\Sigma(f - f_c)\Delta t$ in R9
	RCL 9	34 09	$\Sigma(f - f_c)\Delta t$
	RCL C	34 13	F
	g X>Y	32 81	
	GTO E	22 15	(YES)
	RCL E	34 15	(NO) $f - f_c$
	RCL B	34 12	f_c
	+	61	f_1
030	STO C	33 13	f_1 in RC
	0	00	
	DSP 9	22 09	
✳	f LBL 1	31 25 01	
	R/S	84	
	STO 7	33 07	P(t) in R7
	DSP 2	23 02	
	1	01	
	1	01	
	h STI	35 33	
040	RCL (i)	34 24	$\Sigma P(t)$
	.	83	.
	1	01	1
	0	00	0
	g X>Y	32 81	
	GTO A	22 11	(YES)
	GTO B	22 12	(NO)
	f LBL A	31 25 11	
	RCL 7	34 07	P(t)
	STO + (i)	33 61 24	P(t) in R11
050	RCL (i)	34 24	$\Sigma P(t)$
	.	83	.
	1	01	1
	0	00	0
	g X>Y	32 81	
	GTO C	22 13	(YES)
	−	51	(NO)

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	STO 7	33 07	P(t)
	f LBL B	31 25 12	
	RCL 3	34 03	Δt
060	STO + 8	33 61 08	$t = \Sigma\Delta t$ in R8
	RCL 8	34 08	t
	2 (=K)	02	K
	X	71	Kt
	CHS	42	−Kt
	$g e^x$	32 52	e^{-Kt}
	RCL D	34 14	$(f_o - f_c)$
	X	71	$f - f_c = (f_o - f_c)e^{-Kt}$
	RCL B	34 12	f_c
	+	61	$f_2 = f_c + (f_o - f_c)e^{-Kt}$
070	STO E	33 15	f_2 in RE
	RCL C	34 13	f_1
	+	61	$f_1 + f_2$
	2	02	2
	÷	81	$(f_1 + f_2)/2 = f$
	RCL 3	34 03	Δt
	X	71	f in Δt $(= f \cdot \Delta t)$
	STO 5	33 05	f in R5
	RCL E	34 15	f_2
	STO C	33 13	f_2 becomes f_1
080	RCL 7	34 07	P(t)
	RCL 5	34 05	f
	−	51	P(t) − f
	1	01	1
	RCL 2	34 02	I
	−	51	(1 − I)
	X	71	[P(t) − f](1 − I) = R1
	f x<0	31 71	
	GTO 2	22 02	
	RCL 7	34 07	P(t)
090	RCL 2	34 02	I
	X	71	P(t) · I = R0
	+	61	R(t) = R0 + R1
	GTO 3	22 03	
	f LBL 2	31 25 02	
	RCL 7	34 07	P(t)
	RCL 2	34 02	I
	X	71	R(t) = P(t) · I
	f LBL 3	31 25 03	
	RCL 1	34 01	A
100	X	71	R(t) · A
	RCL 3	34 03	Δt
	÷	81	I(t) = R(t) · A/Δt
	STO 7	33 07	I(t) in R7
	RCL 6	34 06	I(t−1)
	+	61	I(t−1) + I(t)
	RCL 0	34 00	Q(t−1)
	2	02	2
	X	71	2Q(t−1)
	−	51	[I(t−1) + I(t) − 2Q(t−1)]
110	RCL 4	34 04	Tc
	2	02	2
	X	71	2Tc

REGISTERS

0	1	2	3	4	5	6	7	8	9
USED	A	I	Δt	Tc	f = f·Δt	I(t−1)	P(t)	ΣΔt	(f − fc)Δt
S0 10 −	S1 11 ΣP(t)	S2	S3	S4	S5	S6	S7	S8	S9

12	B 13	C 14	D 15	E 16	I
f_o	f_c	F and f	$f_o - f_c$	$(f - f_c)$ or f_2	

Program Listing II

STEP	KEY ENTRY	KEY CODE	COMMENTS
113	RCL 3	34 03	Δt
	+	61	$2T_c + \Delta t$
	RCL 3	34 03	Δt
	h X⇄Y	35 52	$2T_c + \Delta t$
	÷	81	$\overline{K} = \Delta t / 2T_c + \Delta t$
	X	71	$\overline{K}[I(t-1) + I(t) - 2Q(t-1)] = X$
	RCL 0	34 00	$Q(t-1)$
120	+	61	$Q(t) = Q(t-1) + X$
	STO 0	33 00	$Q(t)$ in R0
	RCL 7	34 07	$I(t)$
	STO 6	33 06	$I(t)$ in R6
	RCL 0	34 00	$Q(t)$
	GTO 1	22 01	
	f LBL C	31 25 13	
	0	00	
	GTO 1	22 01	
	f LBL D	31 25 14	INITIALIZATION ROUTINE
130	CLX	44	
	f CL REG	31 43	
	f P≷S	31 42	
	f CL REG	31 43	
	h RTN	35 22	
140			
150			
160			
170			
180			
190			
200			
210			
220			

LABELS					FLAGS
A	B	C	D	E	0
a	b	c	d	e	1
0	1	2	3	4	2
5	6	7	8	9	3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 2	

From these frequency curves, values of C for recurrence intervals of 1 yr and 10 yr were obtained using Eq. 7. These are presented in Table 3. Since the average increase from $C_{1\,yr}$ to $C_{10\,yr}$ for six of these areas amounts to only 10%, from a practical view it seems reasonable that, pending a better approach to the problem of estimating design runoff rates for urban areas, constant values of C, equivalent to $C_{5\,yr}$ or perhaps $C_{10\,yr}$, would be adequate for design use.

One of the major criticisms of the Rational Method arises because the observed C for individual storms usually varies from storm to storm. This variation is sufficiently great that the Rational Method should not be used to estimate the peak runoff rates for a particular storm. A method which would accomplish this would have to involve antecedent conditions and other variables of both the drainage area and the rainstorm that caused the C to be different for each storm.

A statistical analysis was made of the apparent convergence of rainfall and runoff frequency curves. It was first assumed that both C and I could be

TABLE 3.—C-FACTORS CORRESPONDING TO 1- AND 10-YEAR RECURRENCE INTERVALS[a]

Drainage Area (1)	C_{1yr} (2)	C_{10yr} (3)	Percentage Increase (4)
Gray Haven	0.42	0.46	10
Newark 9	0.91	0.99	9
Newark 12	0.69	0.76	10
Northwood	0.66	0.67	2
Swansea	0.58	0.61	5
Yorkwood South	0.44	0.54	23
		Average	10

[a] The assumption that $t_a = t_l$ was made in determining the values of C in this table.

regarded as random variables. Previously it was found that log I was approximately normally distributed. A study of the data for 36 storms on the Swansea drainage area suggests that log C also may be approximately normal. If both log I and log C were normally distributed, and if I and C were statistically independent, then log Q also would be normally distributed. The variance of log Q (which determines the slope of the runoff frequency curve) would then be given by the relation

$$\mathrm{Var}(\log Q) = \mathrm{Var}(\log C) + \mathrm{Var}(\log I) \quad \ldots\ldots\ldots\ldots \quad (8)$$

The Swansea data were studied to see if Eq. 8 could predict Var(log Q). The value obtained for Var(log Q) from Eq. 8 was 0.0497, and the value obtained from the runoff data for Var(log Q) was 0.0434. Because there is a slight correlation in the data between C and I, these values are not expected to agree exactly.

The average values of C for storms having 5 min average rainfall intensities greater than 3 in. per hr are presented in Table 4. For comparison

values of $C_{5\,yr}$ also have been included in Table 4 for those areas where frequency distributions could be plotted.

It should be noted that the C in Eq. 7 is a function both of t_l and T. It was observed above that C may be assumed to be nearly constant for a range of values of T. Because C also is a function of t_l, the values of C presented in Table 2 depend on the assumption that $t_a = t_l$. If some other time variable, rather than t_l, had been used to estimate t_a, different values of C would have

TABLE 4.—AVERAGE OBSERVED C-FACTORS FOR THE GAGED DRAINAGE AREAS[a]

Drainage Area	Average C-Factor	C_{5yr}
Gray Haven	0.45	0.45
Hamilton Hills 2	0.42	—
Hamilton Hills 3	0.40	—
Hamilton Hills 4	1.02	—
Hamilton Hills 5	0.45	—
Midwood 5	0.51	—
Montebello 2	0.29	—
Montebello 3	0.54	—
Montebello 4	0.58	—
Montebello 5	0.66	—
Newark 9	1.01	0.97
Newark 12	0.76	0.74
Northwood	0.76	0.65
South Parking Lot 1	0.83	—
South Parking Lot 2	0.83	—
Swansea	0.61	0.60
Uplands	0.69	—
Walker Avenue	0.37	—
Yorkwood	0.56	0.51

[a] The assumption that $t_a = t_l$ was made in determining the values of C in this table.

been obtained. It is therefore emphasized that the values of C in Table 2 are not equivalent to the values of C usually used in design practice.

RELATIONSHIP BETWEEN t_l AND THE PHYSICAL CHARACTERISTICS OF THE DRAINAGE AREAS

The average time lag between the centroid of the rainfall hyetograph and the centroid of the runoff hydrograph will vary from area to area, depending on average slopes in the area, length of the main channel, the nature of the surface of the drainage area, and certainly many other factors which have not been considered herein. A relationship to estimate the average value of t_l for a drainage area is indicated by

$$t_l = f(\mathrm{Imp},\ L,\ S) \quad \ldots\ldots\ldots\ldots \quad (9)$$

in which t_l = the average lag time, in minutes, Imp = the imperviousness of the drainage area, L = the length of the main drainage channel, and S = the

slope of the main channel. For inlet areas, the length of the main drainage channel was measured from the storm water inlet upstream to the end of the paved gutter. For composite areas the length was measured from the downstream point of interest, proceeding upstream in the direction of the largest drain to an upstream inlet. To this length was added the length of paved gutter contributing to the storm water inlet. The slope, as a percentage, was found by dividing the difference in elevation between the upstream and downstream ends of the main channel by the length of the channel in hundreds of feet.

The imperviousness of the drainage area is included in the functional relationship for t_l because it represents a measure of the nature of the surface of the drainage area. It appears reasonable to believe that factors which affect the time required for runoff to appear downstream, such as the average length of flow path before reaching a paved surface, average roughness of the various flow paths throughout a drainage area, etc., are correlated with the imperviousness of the drainage area. Hence it would be expected that the imperviousness of the drainage area would be correlated with t_l.

A multiple regression analysis of the data for 19 gaged urban drainage areas was made to obtain an equation for t_l. The Cincinnati area was not included because sufficient data were not available for this area. An equation of the form

$$t_l = K\, L^a\, S^b\, \mathrm{Imp}^c \qquad (10)$$

was assumed. The regression analysis was made using this equation rewritten as

$$\log t_l = \log K + a \log L + b \log S + c \log \mathrm{Imp} \qquad (11)$$

and values for log K, a, b, and c were obtained from the regression. The equation which resulted was

$$t_l = \frac{1.05\, L^{0.24}}{S^{0.16}\, \mathrm{Imp}^{0.26}} \qquad (12)$$

A slightly different equation for t_l appears in Technical Report No. 1 of the Storm Drainage Research Project.[8] Additional information was used to obtain Eq. 10 given here. The multiple correlation coefficient between the estimated and observed values of t_l was 0.85. About two-thirds of the estimates of t_l from Eq. 12 are expected to be between -22% and +13% of the true value of t_l.

The range of values on which the equation for t is based are: (1) Imperviousness of the drainage area greater than 8%; (2) average slope of the main drainage channel greater than 0.5% and not greater than 6%; (3) length of the main drainage channel greater than 150 ft and less than 6,000 ft; (4) gutters draining to storm water inlets were paved; and (5) house roofs were not connected directly to the storm drain.

Eq. 12 should be used only within these limitations. The values thus obtained for t_l are estimates of the average value of t_l that would be obtained from a number of storms. Values observed for individual storms are dependent on

[8] Schaake, J. C. Jr., Geyer, J. C., and Knapp, J. W., "Runoff Estimates by the Rational Method," Technical Report No. 1, The Storm Drainage Research Project, Dept. of Sanitary Engrg. and Water Resources, The Johns Hopkins Univ., Baltimore, Md., 1964.

the nature of the individual storm and will not necessarily equal the average value.

RELATIONSHIP BETWEEN C AND THE PHYSICAL CHARACTERISTICS OF THE DRAINAGE AREAS

The average observed C-factors given in Table 4 are highly correlated with the imperviousness of the gaged drainage areas. (The simple correlation coefficient between sample values of C and Imp was 0.91.) A linear equation relating these variables was fitted to observations of C and Imp from 18 gaged areas. The resulting equation accounted for 83% (0.91^2) of the total variation of the C-factor, and the standard error of estimate was found to be 0.09. That is, about two-thirds of the estimates of C from this equation would be expected to agree with ± 0.09 of the true C value.

A study of the errors obtained from this initial equation revealed low estimates for areas having steep slopes (slope of the main drainage channel) and conversely for areas having flat slopes. This might have been anticipated since the simple correlation of S and Imp was only 0.01.

It was apparent that improved accuracy could be obtained by including the slope parameter in the equation for C. A linear equation

$$C = a + b\,(\mathrm{Imp}) + c\,(S) \qquad (13)$$

was fitted to the observed data. The equation obtained from the regression was

$$C = 0.14 + 0.65\,(\mathrm{Imp}) + 0.05\,(S) \qquad (14)$$

The multiple correlation coefficient obtained was 0.95, which means that more than 89% of the total variation of C has been accounted for by the regression. The standard error of estimate of C was found to be 0.074.

The possibility of obtaining improved accuracy by considering terms involving $(\mathrm{Imp})^2$, $(S)^2$, and $(\mathrm{Imp})(S)$ was investigated, but the multiple correlation coefficient could not be increased above 0.95 nor the standard error reduced below 0.07.

Because it is possible that Eq. 14 is valid only for the type of storm patterns occurring in the Baltimore area, it should be used with caution elsewhere. Also, values of C from Eq. 14 should not be used in the Rational Method without also using Eq. 12 to estimate $t_a = t_l$. The values of C estimated by this equation are not the same as values of C usually used in design practice, since the assumption that $t_a = t_l$ has been used in obtaining values of C for the gaged areas.

COMPARISONS WITH DESIGN PEAK RUNOFF RATES ESTIMATED BY THE RATIONAL METHOD

The estimates made using the Rational Method are compared, for six gaged drainage areas, with runoff values from frequency curves. Because only a few years of record was available (3 to 5 yr) the frequency curves have wide confidence limits. However, the rainfall intensities obtained from the rainfall frequency distributions at each gage for a recurrence interval of 5 yr are within ±15% of the values obtained from the 70-yr record of rainfall at the U. S. Weather Bureau gage in Baltimore.

Rational Method estimates of the 5 yr runoff for each of the six areas were made using values of C and $t_a = t_c$ selected by five storm drain designers in accordance with their usual design procedures. These estimates, referred to as $\hat{q}$(5 yr), are presented in Table 5. For each area the 5-yr runoff values from runoff frequency curves are presented in the tabulated data for each area

TABLE 5.—COMPARISON OF ESTIMATES OF $\hat{q}$(5YR) OBTAINED BY THE RATIONAL METHOD USING VALUES OF C AND t_a REPORTED BY VARIOUS AGENCIES FOR SIX GAGED DRAINAGE AREAS

Gaged Area (1)	Agency (2)	Value of C (3)	Value of t_a, in minutes (4)	Rainfall Intensity, I(5yr), in inches per hour (5)	Rational Method Estimate, q(5yr), in cubic feet per second per acre (6)	Percentage Error (7)
Gray Haven						
A = 23.3 acres	a	0.56	13.0	4.87	2.73	+ 2
Q(5yr) = 59.5 cfs	c	0.71	5.1	6.06	4.30	+61
q(5yr) = 2.67 cfs per acre	d	0.55	10.3	5.38	2.96	+11
n = 3 yr	e	0.52	14.6	4.59	2.39	-10
N = 12 storms	f	0.53	7.5	6.21	3.29	+23
Newark (N9)						
A = 0.64 acres	a	0.85	5.0	5.68	4.83	-23
Q(5yr) = 4.01 cfs	b	0.90	5.0	5.68	5.11	-19
q(5yr) = 6.27 cfs per acre	c	1.00	5.0	5.68	5.68	- 9
n = 3 yr	d	0.95	6.1	5.15	4.89	-22
N = 37 storms	e	0.90	3.5	6.31	5.68	- 9
	f	0.97	3.6	6.26	6.07	- 3
Newark (N12)						
A = 0.96 acres	a	0.85	5.0	5.25	4.46	+11
Q(5yr) = 3.87 cfs	b	0.90	5.0	5.25	4.73	+17
q(5yr) = 4.03 cfs per acre	c	1.00	5.0	5.25	5.25	+30
n = 3 yr	d	0.95	9.9	4.16	3.95	- 2
N = 32 storms	e	0.90	7.5	4.70	4.23	+ 5
	f	0.83	5.0	5.25	4.36	+ 8
Northwood						
A = 47.4 acres	a	0.66	14.0	4.53	2.99	-28
Q(5yr) = 197 cfs	b	0.80	10.0	5.17	4.14	0
q(5yr) = 4.15 cfs per acre	d	0.74	12.2	4.78	3.54	-15
n = 4 yr	e	0.71	11.4	4.91	3.49	-16
N = 37 storms	f	0.74	6.3	6.20	4.58	+11
Swansea						
A = 47.3 acres	a	0.51	13.0	4.34	2.21	-45
Q(5yr) = 189 cfs	c	0.67	10.9	4.73	3.17	-21
q(5yr) = 3.99 cfs per acre	d	0.50	13.0	4.34	2.17	-46
n = 5 yr	e	0.54	11.9	4.50	2.43	-39
N = 36 storms	f	0.59	7.0	5.79	3.42	-14
Yorkwood South						
A = 10.4 acres	a	0.60	6.5	6.23	3.19	-11
Q(5yr) = 37.5 cfs	d	0.60	10.1	5.33	3.20	-11
q(5yr) = 3.60 cfs per acre	e	0.53	8.1	5.64	2.99	-17
n = 5 yr	f	0.60	5.9	6.38	3.83	+ 6
N = 20 storms						

in Col. 1. The letters a, b, c, d, e, f in Col. 2 refer to the various storm drai designers. Rainfall intensities used in the Rational Method to obtain the var- ious estimates of q(5 yr) were obtained from rainfall time-intensity-frequen curves from the rainfall record at each gage.

The percentage differences between Rational Method estimates of runo

and corresponding values obtained from runoff frequency curves are given in Table 5.

In Fig. 10 a comparison is presented of runoff estimates from the Rational Method with values of q(5 yr) obtained from runoff frequency curves for each agency participating in the study. Considerable variability is observed in estimates obtained by usual design procedures. More than 20% of the designers'

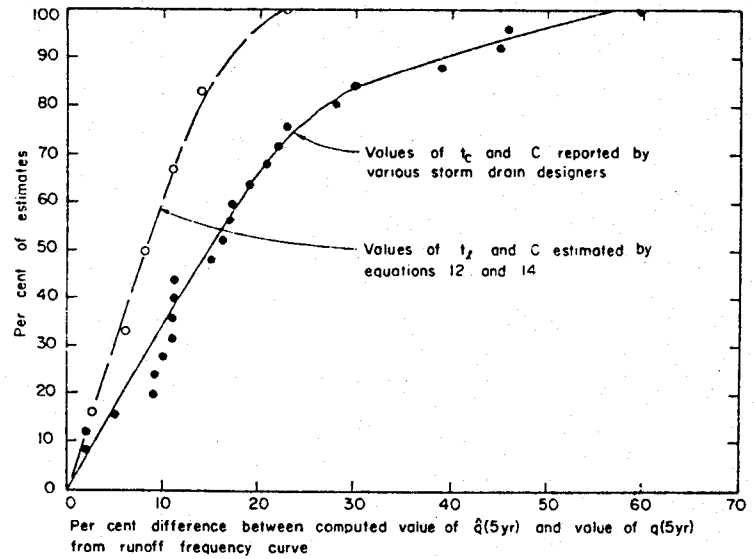

FIG. 10.—COMPARISON OF VALUES OF $\hat{q}$ (5 YR) COMPUTED BY THE RATIONAL METHOD WITH VALUES OF q (5 YR) OBTAINED FROM RUNOFF FREQUENCY CURVES

estimates differed by 25% or more from values obtained from runoff frequency curves.

CONCLUSIONS

Experimental rainfall and runoff data collected in Baltimore, Md., from 20 gaged urban drainage areas ranging in size up to 150 acres have been used in an examination of the Rational Method. Although sufficiently long records were not available to judge the Rational Method on a statistical basis, a report of this examination of the Rational Method is believed worth while on the grounds it may lead to a better understanding of the method by those who use it.

An attempt was made to study the assumption, implicity in the method as it is now used, that the frequency of occurrence of the computed design peak runoff rate is the same as the frequency of the rainfall intensity selected by the designer. The results suggest that this assumption is approximately correct.

Empirical equations have been presented for computing the values of C and the "rainfall intensity averaging time" from the physical characteristics of the

drainage area. Because the data used to develop these equations have been collected in the Baltimore area, they may not be applicable to other urban areas. The purpose in presenting these equations is to demonstrate the possibility of developing similar equations suitable for design use if sufficient data were collected from many gaged urban areas throughout the United States.

Rational Method estimates of runoff were made by five storm drain designers in accordance with their normal design procedures, and these are compared with runoff values from runoff frequency curves for six of the gaged areas. It was found from this comparison that for every five Rational Method estimates, one of them, on the average, may be in error by more than 25%.

APPENDIX.—NOTATION

The following symbols have been adopted for use in this paper:

A = drainage area size, in acres;
a = coefficient;
b = coefficient;
C = ratio of peak runoff rate, in cubic feet per second per acre, to the maximum rainfall intensity averaged over the time t_a;
c = coefficient;
I = maximum average rainfall intensity, in inches per hour, averaged over the time t_a;
Imp = ratio of impervious area to total area;
K = coefficient;
L = length of the main drainage channel, in feet;
m = an integer used to denote the rank of an element in a sequence;
N = number of years of data;
n = number of storms observed during N years of data;
P = percentage of sample values exceeding in magnitude the value of the mth value in a sequence of observations;
Q = peak runoff rate in cubic feet per second;
q = runoff rate in cubic feet per second per acre ($\hat{q}$ = estimate of q);
S = slope of the main drainage channel, as percentage or feet per 100 feet;
T = return interval, in years;
t_a = rainfall intensity averaging time, here defined as the length of time during which the instantaneous rainfall intensity is averaged to obtain an average rainfall intensity;
t_c = time of concentration; and
t_l = time lag between the centroid of the rainfall hyetograph and the centroid of the runoff hydrograph.

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SYNTHETIC COEFFICIENTS FOR STREAMFLOW ROUT

By José A. Buil,[1] A. M. ASCE

INTRODUCTION

In connection with hydrologic studies on the Missouri River B tributaries below Rulo, Nebr., attempts were made to systematiz opment of streamflow routing coefficients for the better utiliza electronic computer. Routing coefficients for nearly 150 chan were involved. At present, there are no available techniques to c nel routing coefficients in the absence of runoff data. Effective pr available routing coefficients were determined. Graphical relati these properties and physical channel characteristics of reach le channel capacity, and the degree of channel improvement were from actual data and tested for effectiveness. A graph was develo senting required travel times for various discharge regimes in the graph checked well with the results of recent independent expe travel times on the Missouri and Smoky Hill Rivers using dyes. grams proved to be more practical, and as effective in the deter channel routing coefficients as rigorous and lengthy analyses of fl graphs and trial-and-error methods previously used, and result siderable savings of time. A direct application can be made on reac no discharge records are available.

DEVELOPMENT OF FUNDAMENTAL PHILOSOPHY

Basis for Development.—The Muskingum method developed by M was used as a basis for the lower Missouri River Tributary stud

Note.—Discussion open until April 1, 1968. To extend the closing date on written request must be filed with the Executive Secretary, ASCE. This pa of the copyrighted Journal of the Hydraulics Division, Proceedings of the Society of Civil Engineers, Vol. 93, No. HY6, November, 1967. Manuscrip mitted for review for possible publication on May 9, 1967.

[1] Hydr. Engr., U. S. Engr. Dist., Kansas City, Mo.

[2] McCarthy, G. T., "Engineering Procedure as Applied to Flood Control R with Reference to the Muskingum Flood Control Project. Appendix IV," The School, Fort Belvoir, Va., 1936.

BLANK HYDROLOGIC DATA SHEETS
(For User Copying Purposes)

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: _____

2. Drainage Concentration Point: _____

3. *Watershed Area (A) at Drainage Concentration Point: _____ acres.

4. Length of Hydraulically Longest Watercourse (L_c): _____ ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: _____ ft.

6. Change in Length Factors - ft. | Change in Elevation Factors - ft.

a. ΔL_1: _____ $(\Delta L_1)^3$ _____ ΔH_1: _____ $\Delta L_1^3/\Delta H_1$ _____

b. ΔL_2: _____ $(\Delta L_2)^3$ _____ ΔH_2: _____ $\Delta L_2^3/\Delta H_2$ _____

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = _____ + _____ + _____ = _____

8. Mean Slope (S_c) = $(L_c/I)^2$ = (_____)^2 = _____ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	_____ (_____)	_____ (_____)	
10. Basin Factor (n_b):	_____	_____	n_{bw} = _____
11. Imperviousness (%):	_____	_____	I_w = _____
12. Runoff Coefficient (C_w):	_____	_____	C_w = _____

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = _____ (future)

14. **Time of Concentration (T_c), determined from Table III: _____ minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = _____ inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = _____ x _____ x _____ = _____ cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	_____	_____	_____	_____
Q (cubic feet/second):	_____	_____	_____	_____

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: _____ Company: _____ Date: _____

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: _____

2. Drainage Concentration Point: _____

3. *Watershed Area (A) at Drainage Concentration Point: _____ acres.

4. Length of Hydraulically Longest Watercourse (L_c): _____ ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: _____ ft.

6. Change in Length Factors - ft. | Change in Elevation Factors - ft.

a. ΔL_1: _____ $(\Delta L_1)^3$ _____ ΔH_1: _____ $\Delta L_1^3/\Delta H_1$ _____

b. ΔL_2: _____ $(\Delta L_2)^3$ _____ ΔH_2: _____ $\Delta L_2^3/\Delta H_2$ _____

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = _____ + _____ + _____ = _____

8. Mean Slope (S_c) = $(L_c/I)^2$ = (_____)^2 = _____ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	_____ (_____)	_____ (_____)	
10. Basin Factor (n_b):	_____	_____	n_{bw} = _____
11. Imperviousness (%):	_____	_____	I_w = _____
12. Runoff Coefficient (C_w):	_____	_____	C_w = _____

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = _____ (future)

14. **Time of Concentration (T_c), determined from Table III: _____ minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = _____ inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = _____ x _____ x _____ = _____ cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	_____	_____	_____	_____
Q (cubic feet/second):	_____	_____	_____	_____

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Prepared by: _____ Company: _____ Date: _____

City of Tucson

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Ratio to 100-year Peak:	_____	_____	_____	_____
Q (cubic feet/second):	_____	_____	_____	_____

---

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: _____ Company: _____ Date: _____

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: _____

2. Drainage Concentration Point: _____

3. *Watershed Area (A) at Drainage Concentration Point: _____ acres.

4. Length of Hydraulically Longest Watercourse (L_c): _____ ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: _____ ft.

6. Change in Length Factors - ft. | Change in Elevation Factors - ft.

a. ΔL_1: _____ $(\Delta L_1)^3$ _____ ΔH_1: _____ $\Delta L_1^3/\Delta H_1$ _____

b. ΔL_2: _____ $(\Delta L_2)^3$ _____ ΔH_2: _____ $\Delta L_2^3/\Delta H_2$ _____

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = _____ + _____ + _____ = _____

8. Mean Slope (S_c) = $(L_c/I)^2$ = (_____)^2 = _____ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type (s) (% of Total Area):	_____ (_____)	_____ (_____)	
10. Basin Factor (n_b):	_____	_____	n_{bw} = _____
11. Imperviousness (%):	_____	_____	I_w = _____
12. Runoff Coefficient (C_w):	_____	_____	C_w = _____

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = _____ (future)

14. **Time of Concentration (T_c), determined from Table III: _____ minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = _____ inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = _____ x _____ x _____ = _____ cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	_____	_____	_____	_____
Q (cubic feet/second):	_____	_____	_____	_____

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: _____ Company: _____ Date: _____

City of Tucson

Hydrologic Data Sheet for Computing 100-Year Peak Discharge (Q_p^{100})

1. Project Name and Location: _____

2. Drainage Concentration Point: _____

3. *Watershed Area (A) at Drainage Concentration Point: _____ acres.

4. Length of Hydraulically Longest Watercourse (L_c): _____ ft.

5. Length from center of Watershed Area (L_{ca}), along L_c: _____ ft.

6. Change in Length Factors - ft. | Change in Elevation Factors - ft.

a. ΔL_1: _____ $(\Delta L_1)^3$ _____ ΔH_1: _____ $\Delta L_1^3/\Delta H_1$ _____

b. ΔL_2: _____ $(\Delta L_2)^3$ _____ ΔH_2: _____ $\Delta L_2^3/\Delta H_2$ _____

c. ΔL_3: _____ $(\Delta L_3)^3$ _____ ΔH_3: _____ $\Delta L_3^3/\Delta H_3$ _____

7. $I = \left(\frac{\Delta L_1^3}{\Delta H_1}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_2^3}{\Delta H_2}\right)^{\frac{1}{2}} + \left(\frac{\Delta L_3^3}{\Delta H_3}\right)^{\frac{1}{2}}$ = _____ + _____ + _____ = _____

8. Mean Slope (S_c) = $(L_c/I)^2$ = (_____)^2 = _____ ft./ft.

	Subarea 1	Subarea 2	Weighted Watershed Average
9. Watershed Type(s) (% of Total Area):	_____ (_____)	_____ (_____)	
10. Basin Factor (n_b):	_____	_____	n_{bw} = _____
11. Imperviousness (%):	_____	_____	I_w = _____
12. Runoff Coefficient (C_w):	_____	_____	C_w = _____

13. Z-Factor (Z) = $0.444 n_{bw} (L_c L_{ca})^{0.3} / (S_c C_w)^{0.4}$ = _____ (future)

14. **Time of Concentration (T_c), determined from Table III: _____ minutes (future)

15. At T_c, 100-year Rainfall Intensity (i) = $12/(1+0.05T_c)$ = _____ inches/hour

16. 100-year Flood Peak (Q_p^{100}) = $C_w iA$ = _____ x _____ x _____ = _____ cfs (future)

17. For Other Return Periods:

	2-Year	10-Year	25-Year	50-Year
Ratio to 100-year Peak:	_____	_____	_____	_____
Q (cubic feet/second):	_____	_____	_____	_____

* A may not exceed 1,280 acres (2 square miles) in size.

** T_c may not be less than five (5) minutes nor greater than sixty (60) minutes.

Prepared by: _____ Company: _____ Date: _____

HP-41 USER INSTRUCTIONS AND OPTIONAL PROGRAM LISTING

Program COTFP

Program COTFP computes peak discharge rates by utilizing a simplification of a method by the Pima County Department of Transportation and Flood Control District. The simplified method is applicable to a small watershed (drainage area less than 2 square miles) with a time of concentration greater than 5 minutes and less than 60 minutes. An error message is printed if the time of concentration is out of range.

Program Execution

1. Set SIZE: 13
2. XEQ COTFP
3. R/S advances user through program
4. Input basin parameters and hydrologic values when prompted.

Input Data

AREA - basin area in acres.

LC - length of the basin along the centerline of the channel, in feet.

LCA - length along channel from concentration point to centroid (area) of basin, in feet.

DELTA # L - horizontal length of slope increment, in feet.

DELTA # H - change in elevation of slope increment, in feet.

NB - basin factor

CW - weighted runoff coefficient (dimensionless).

Q2 = Q100 x ? = input for ratio to 100-year Q for Q2

Q10 = Q100 x ? = input ratio to 100-year Q for Q10

Q25 = Q100 x ? = input ratio to 100-year Q for Q25

Q50 = Q100 x ? = input ratio to 100-year Q for Q50.

5. Program Output

I = a factor which represents the summation of slope increments for mean channel slope determination.

Z = Z-factor, a coefficient which relates the physical characteristics of a watershed to its time of concentration.

TC = Time of concentration in minutes

RAIN.I = 100-year rainfall intensity in inches/hour

Q100 = 100-year flood peak in cubic feet/second

Q2 = 2-year flood peak in cubic feet/second

Q10 = 10-year flood peak in cubic feet/second

Q25 = 25 year flood peak in cubic feet/second

Q50 = 50 year flood peak in cubic feet/second

6. Press R/S to repeat peak discharge calculations for different basin/watershed conditions or concentration points.

PROGRAM COTFP EXAMPLE PROBLEM

INPUT DATA FOR EXAMPLE PROBLEM

Area = 100 acres

Length of channel (LC) = 4500 feet

Length along channel to centroid of basin (LCA) = 2200 feet.

Number of slopes = 3

First horizontal slope increment (Delta 1 L) = 1300 feet.

First vertical slope increment (Delta 1 H) = 9 feet.

Second horizontal slope increment (Delta 2L) = 1900 feet.

Second vertical slope increment (Delta 2H) = 15 feet.

Third horizontal slope increment (Delta 3L) = 1300 feet

Third vertical slope increment (Delta 3H) = 8 feet.

Basin factor (NB) = .022

Weighted runoff coefficient = .75

Ratio to 100-year Q for Q2 (Q2 = Q100 x ?) = .20

Ratio to 100-year Q for Q10 (Q10 = Q100 x ?) = .45

Ratio to 100-year Q for Q25 (Q25 = Q100 x ?) = .65

Ratio to 100-year Q for Q50 (Q50 = Q100 x ?) = .85

PROGRAM COTFP EXAMPLE

Set Printer on MAN

KEYSTROKE	DISPLAY
XEQ(Alpha)COTFP (Alpha)	AREA ACRES ?
100 R/S	INPUT LC ? Hydraulically Longest Watercourse, Ft
4500 R/S	INPUT LCA ? Ft. to Center of Area.
2200 R/S	NO. SLOPES ?
3 R/S	DELTA 1. L ? 1
1300 R/S	DELTA 1. H ?
9 R/S	DELTA 2. L ?
1900 R/S	DELTA 2. H ?
15 R/S	DELTA 3. L ?
1300 R/S	DELTA 3. H ?
8 R/S	I = 53,580
R/S	SLOPE = .0071
R/S	INPUT NB ?
.022 R/S	INPUT CW ?
.75 R/S	Z = 9.9793
R/S	(Beep) TC = 12.0000
R/S	(Beep) RAINF.I = 7.5000 $= \frac{12}{(1+0.05T_c)}$ inch/hr.
R/S	(Beep) Q100 = 562.50
R/S	Q2 = Q100 x ?
.2 R/S	Q2 = 112.50
R/S	Q10 = Q100 x ?
.45 R/S	Q10 = 253.13
R/S	Q25 = Q100 x ?
.65 R/S	Q25 = 365.63
R/S	Q50 = Q100 x ?
.85 R/S	Q50 = 478.13
R/S	AREA ACRES ? (beginning)

SIZE 013

STORAGE REGISTER CONTENTS

STO 00 - Temporary

STO 01 - LC

STO 02 - LCA

STO 03 - NB

STO 04 - SLOPE

STO 05 - Not used

STO 06 - CW

STO 07 - AREA

STO 08 - Temporary

STO 09 - TC

STO 10 - (RAINF.I)

STO 11 - Number of slopes (counter)

STO 12 - Temporary

HP-41 COMPUTER PROGRAM LISTING FOR CITY OF TUCSON
"SIMPLIFIED METHOD FOR ESTIMATING FLOOD PEAKS"
"COTFP"

```
PRP "COTFP"

01♦LBL "COTFP"
02 CLRG
03 SF 21
04 "COT 100YR PEAK:"
05 FS? 55
06 PRA
07 ADV
08 ADV

09♦LBL 10
10 "AREA ACRES?"
11 XEQ 99
12 STO 07
13 ADV
14 "INPUT LC?"
15 XEQ 99
16 STO 01
17 ADV
18 "INPUT LCA?"
19 XEQ 99
20 STO 02
21 ADV
22 "NO. SLOPES?"
23 XEQ 99
24 1 E3
25 /
26 1
27 +
28 STO 11
29 FIX 0

30♦LBL 16
31 "DELTA "
32 ARCL 11
33 "⊢ L?"
34 XEQ 99
35 3
36 Y↑X
37 STO 12
38 "DELTA "
39 ARCL 11
40 "⊢ H?"
41 XEQ 99
42 RCL 12
43 X<>Y
44 /
45 .5
46 Y↑X
47 ST+ 08
48 ISG 11
49 GTO 16
50♦LBL 20
51 RCL 08
52 "I="
53 XEQ 98
54 FIX 4
55 RCL 01
56 RCL 00
57 /
58 X↑2
59 STO 04
60 "SLOPE="
61 XEQ 98
62 ADV
63 "INPUT NB?"
64 XEQ 99
65 STO 03
66 ADV
67 "INPUT CW?"
68 XEQ 99
69 STO 06
70 RCL 04
71 RCL 06
72 *
73 .4
74 Y↑X
75 STO 00
76 RCL 01
77 RCL 02
78 *
79 .3
80 Y↑X
81 RCL 03
82 *
83 .444
84 *
85 RCL 00
86 /
87 STO 00
88 ADV
89 "Z="
90 XEQ 98
91 STO 08

92♦LBL 30
93 RCL 08
94 .05
95 *
96 1
97 +
98 .4
99 Y↑X
100 RCL 00
101 *
102 STO 09
103 RCL 08
104 -
105 ABS
106 .5
107 X<>Y
108 X<=Y?
109 GTO 40
110 RCL 09
111 STO 08
112 GTO 30
```

HP-41 COMPUTER PROGRAM LISTING FOR CITY OF TUCSON
"SIMPLIFIED METHOD FOR ESTIMATING FLOOD PEAKS"
"COTFP"

```
113♦LBL 40
114 RCL 09
115 5
116 X>Y?
117 GTO 50
118 RCL 09
119 60
120 X<Y?
121 GTO 50
122 RCL 09
123 FRC
124 .5
125 X>Y?
126 GTO 70
127 RCL 09
128 1
129 +
130 INT
131 STO 09

132♦LBL 70
133 RCL 09
134 INT
135 STO 09
136 TONE 0
137 ADV
138 "TC="
139 XEQ 98
140 GTO 60

141♦LBL 50
142 "TC OUT OF RANGE"
143 XEQ 98

144♦LBL 60
145 RCL 09
146 .05
147 *
148 1
149 +
150 STO 10
151 12
152 RCL 10
153 /
154 STO 10
155 TONE 0
156 ADV
157 "RAINF. I="
158 XEQ 98
159 RCL 06
160 *
161 RCL 07
162 *
163 STO 00
164 FIX 2
165 TONE 0
166 ADV
167 "Q100="
168 XEQ 98
169 "**************"
170 FS? 55
171 PRA
172 ADV
173 "LESSER PEAKS:"
174 FS? 55
175 PRA
176 ADV
177 ADV
178 "Q2=Q100X ?"
179 XEQ 99
180 XEQ 95
181 "Q2="
182 XEQ 98
183 ADV
184 "Q10=Q100X ?"
185 XEQ 99
186 XEQ 95
187 "Q10="
188 XEQ 98
189 ADV
190 "Q25=Q100X ?"
191 XEQ 99
192 XEQ 95
193 "Q25="
194 XEQ 98
195 ADV
196 "Q50=Q100X ?"
197 XEQ 99
198 XEQ 95
199 "Q50="
200 XEQ 98
201 "**************"
202 FS? 55
203 PRA
204 ADV
205 GTO 10

206♦LBL 95
207 RCL 00
208 *
209 RTN

210♦LBL 98
211 ARCL X
212 AVIEW
~~213 STOP~~
213 RTN

214♦LBL 99
215 PROMPT
216 "⊢ "
217 ARCL X
218 FS? 55
219 PRA
220 RTN
221 END
```