TECHNICAL MEMORANDUM

G.V. SABOL

14 JANUARY 1992

UNIT HYDROGRAPHS FOR AGRICULTURAL FIELDS

AND

NEW LAG RELATION FOR UNIT HYDROGRAPHS

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TECHNICAL MEMORANDUM

TO: Tim Murphy (Contract FCD 90-69)
Steve Waters (Contract FCD 90-20)

FROM: G.V. Sabol

DATE: 14 January 1992

SUBJECT: 1.) Unit hydrographs for agricultural fields, and
2.) New Lag relation for unit hydrographs.

REFERENCE: Contract FCD 90-69, Buckeye FIS
Contract FCD 90-20, Hydrology/Hydraulics Advisory Services

INTRODUCTION

This study was initiated as part of the Buckeye FIS Project (Tasks 3.13.A and 3.13.B). However, the work effort and results extend beyond that required by the Buckeye FIS, and some portion of this work was undertaken under contract FCD 90-20 as additional unit hydrograph development for the Manual.

This memorandum presents the following:

1. development of a new Lag relation for unit hydrographs,
2. comparison of four unit hydrographs for four selected subbasins from the Buckeye FIS watershed model,
3. comparison and evaluation of using the new Lag relation with the Phoenix Valley and the Phoenix Mountain S-Graphs for seven watersheds that were used in verification of the Maricopa County Hydrologic Design Manual (Manual),
4. conclusions from these comparisons and evaluations,
5. recommendations, and
6. suggested studies to be undertaken before implementing the recommendations.

DEVELOPMENT OF NEW Lag RELATION

Theory

The general relation for basin Lag as a function of watershed characteristics that is traditionally used is given by Equation 1.

The theoretical justification for Equation 1 is not known but was probably an extension of the results of Snyder's (1940) investigations, wherein he

$$Lag = C\left(\frac{L \times LCA}{S^{1/2}}\right)^{m} \tag{1}$$

determined the following equation for Lag:

$$Lag = C_t\,(L \times LCA)^{.30} \tag{2}$$

The value of the exponent, m, in Equation 1, generally has been assigned within the range 0.30 to 0.38. The USBR (Flood Hydrology Manual (Cudworth, 1989)) recommends that m = 0.33 regardless of the location of the drainage basin. The Corps of Engineers typically uses m = 0.38. The coefficient, C, appears to be related to the hydraulic efficiency of the direct storm runoff through the drainage network. For a value of m = 0.33, the USBR recommends that C = 26 K_n, and the Corps uses C = 24 K_n with m = 0.38, where K_n is a resistance coefficient representing the average resistance to flow through the drainage network. The traditional Lag equations in use are:

$$Lag = 26K_n\left(\frac{L \times LCA}{S^{1/2}}\right)^{.33} \qquad \textit{by the USBR} \tag{3}$$

$$Lag = 24K_n\left(\frac{L \times LCA}{S^{1/2}}\right)^{.38} \qquad \textit{by the Corps} \tag{4}$$

It should be noted that there are numerous definitions for Lag. Horner and Flynt (1936) originally defined Lag as the time from center of mass of rainfall to center of mass of runoff. Lag, as defined by Snyder (1940), is the time between the center of mass of rainfall excess of a specified type of storm and the occurrence of peak discharge at the location being studied. This definition indicates that Lag will vary depending on the type of storm or rainfall characteristics such as intensity. The SCS definition of Lag is the

same as that used by Snyder. Lag of Equation 1 is determined from an S-graph analysis and is defined as the time from the start of a continuous series of unit rainfall excess increments to the time when the resulting runoff hydrograph reaches 50 percent of the ultimate discharge. The ultimate discharge is an equilibrium rate achieved at the time when the entire drainage basin is contributing runoff at the concentration point from the continuous series of unit rainfall excess increments.

These equations and others for Lag have been developed from data for gaged watersheds and these empirical equations are used to estimate Lag for ungaged watersheds. Theoretically, the equations should satisfy hydraulic similitude for gravity flow with the gaged watersheds being considered as models and the ungaged watersheds as prototypes. The resulting Lag equations should satisfy Froude Number similitude and accordingly the time relation for model to prototype conversion is:

$$T_R \propto L_R^{.5} \tag{5}$$

where T_R is the time ratio and L_R is the scale ratio. The model to prototype time relation of Equation 1 should agree with Equation 5. Therefore the exponent m should be 0.25 as shown in Equation 6:

$$Lag \propto (L \times LCA)^{.25} \tag{6}$$

The relation of Lag to watershed slope is a means of incorporating the runoff velocity, V, in the Lag equation and

$$Lag \propto \frac{1}{V} \tag{7}$$

According to equations of gravity flow

$$V \propto S^{1/2} \tag{8}$$

and therefore

$$Lag \propto \frac{1}{S^{1/2}} \tag{9}$$

which deviates significantly from either Equation 3 or 4.

Combining Equations 6 and 9 results in

$$Lag = CL \left(\frac{L \times LCA}{S^2} \right)^{.25} \tag{10}$$

Where CL is a coefficient.

Lag is a function of many variables that describe the watershed characteristics and possibly also variables that describe the rainfall characteristics as suggested by Snyder (1940). Sufficient data for gaged watersheds are not available to document all the watershed and rainfall characteristics that may be of interest, and certain variables may be too subjective, such as K_n in Equations 3 and 4, to be reliable and reproducible for use in a prediction equation. Therefore, CL may be a surrogate to account for all the <u>unknown</u> and <u>unmeasured</u> variables affecting Lag. For this reason, it may not be possible to develop a CL equation that is dimensionlessly homogeneous using only available and readily obtainable watershed characteristics and measured Lag data. Therefore, empirical equations were developed for CL from available data.

CL Relations

Data on watershed characteristics and Lag as determined by S-graph analysis was obtained from the files of the USBR that was used by the USBR in developing Tables 4-1 through 4-6 of its Flood Hydrology Manual. These data were classified into six categories by the USBR as follows:

1. Great Plains (Table 4-1),
2. Rocky Mountains (Table 4-2),
3. Southwest Desert, Great Basin, and Colorado Plateau (Table 4-3),
4. Sierra Nevada (Table 4-4),
5. Coast and Cascade Ranges of California, Oregon, and Washington, (Table 4-5), and
6. Urbanized basins (Table 4-6).

The data sets for deserts (Table 4-3), the Rocky Mountains (Table 4-2), and urban basins (Table 4-6) are applicable to Arizona and these data are shown in Appendix A. Previous investigations indicated that the desert and Rocky Mountain Lag data are compatible for analysis as a single set. The watershed characteristic data and measured Lag for the desert and Rocky Mountain watersheds that were obtained from the USBR are shown in Table 1. Figure 1 shows a graph of measured Lag versus L x LCA/S^2. Lines are shown in Figure 1 with a slope of 0.25 indicating agreement with the theoretically derived exponent m = 0.25. The lines are for CL of 5, 10 and 15, and the data indicate that CL ranges from slightly less than 5 to about 18 with most CLs between 10 and 15.

Multiple regression analyses were performed using the data of Table 1 in an attempt to develop a prediction equation for CL. About 40 CL equations were developed from various combinations of independent variables. The variables were inspected in both untransformed and transformed (log and power functions) states.

Four CL prediction equations were selected for further inspection. These being:

$$CL1 = 11.75 + .006\ DA - .21\ LWR \qquad (11)$$

$$R^2 = 0.70$$

$$CL2 = -18.03 + 3.3 \log DA + 10.5 \log S \quad (12)$$

$$R^2 = 0.69$$

$$CL3 = -14.24 + 3.02 \log DA + 9.04 \log S \quad (13)$$

$$R^2 = 0.68$$

$$CL4 = antilog\ (.1816 + .103 \log DA + .307 \log S) \quad (14)$$

$$R^2 = 0.65$$

where LWR is watershed length to width ration (L^2/DA),
DA is drainage area in square miles, and
S is watercourse slope in feet/mile.

The square of the multiple correlation coefficient (R^2) measures the portion of total variation about the mean (in this case the mean value of CL) that is explained by the regression equation. A $R^2 = 1.0$ indicates that the regression equation explains 100% of the total variation (the ideal, but virtually never achieved situation). Larger values of R^2 means that the equation better explains variation in the data. R^2 in the 0.5 to 0.8 range are common for hydrologic data. R^2 larger than 0.8 is exceptional. The R^2 for the above equations are reasonable for the type of data that are analyzed. There are many more variables that are needed to "accurately" estimate Lag, but the identification and measurement of these other variables is beyond our present ability.

The CL that is estimated by Equations 11 through 14 are listed in Table 1 and these were plotted against the measured CL in Figures 2 through 5, respectively. These graphs indicate that the four CL prediction equations provide reasonable values for CL.

The results from the four CL prediction equations were used in Equation 10 (the new Lag relation) to estimate Lag for the watersheds that were used to develop the CL prediction equations. The estimated Lag with CL estimated by Equations 11 through 14 are listed in Table 1 and these were plotted against the measured Lag in Figures 6 through 9, respectively.

Inspection of Figures 2 through 9 does not lead to a clearly superior estimator of CL or Lag. However, CL1 seems to be weak at estimating low CLs and short Lags, but seems to be stronger than other CL equations for longer Lags.

Some independent Lag data is identified in the S-Graph Report that was prepared for the Flood Control District of Maricopa County (Sabol, 1987). That data is shown in Table 2. In Table 2, values of Lag are shown for numerous Arizona watersheds that were developed from data for the storms of December 1967, September 1970, and June 1972. Descriptions of those storms are shown in Appendix B. Notice that different values of Lag are shown in Table 2 depending on the storm. This illustrates that Lag is not only a function of watershed characteristics but is also a function of storm characteristics as suggested by Snyder.

Estimated values of Lag by Equation 10 and CL by Equations 11 through 14 were calculated and these are shown in Table 2 and are compared to the measured values of Lag in Figures 10 through 13. Notice in these figures that the Lags for the December 1967 storms are usually longer than the Lag for the September 1970 and June 1972 storms. The December 1967 storm was a general winter storm with lower rainfall intensity than the large local storm of September 1972 and the smaller local storm of June 1972. This indicates that estimated values of Lag should be larger for the same watershed for lower rainfall intensities. These figures also indicate that the Lag and CL prediction equations perform reasonably well for watersheds that were <u>not</u> used to develop the CL prediction equations.

Quantitative analyses could not distinguish a clearly superior CL prediction equation and a qualitative evaluation of Equations 11 through 14 was performed. Equations 12 and 13 could result in negative values of CL for some combinations of area (DA) and slope (S) and therefore these equations were rejected. Equation 11 seems to be weak for watersheds with low CL values which could yield some unconservative results. Therefore Equation 14 is recommended for use in estimating CL for undeveloped (natural) watersheds of deserts and mountains in Arizona.

A similar analysis was performed for urban watersheds using USBR data (Appendix A) as shown in Table 3. An additional watershed characteristic, impervious area (RTIMP), was included for urban watersheds. A graph of L x LCA/S^2 versus measured Lag for urban watersheds is shown in Figure 14, and that graph illustrates that the theoretical value of m = 0.25 is appropriate and that CL ranges from about 1.0 to 5.0 for urban watersheds. A multiple regression analysis of the urban watershed data resulted in one clearly superior equation to predict CL for such watersheds:

$$CL = antilog\,(0.31 + 0.0955 \log DA + 0.3560 \log S - 0.3610 \log RTIMP)$$

$$R^2 = 0.67 \qquad (15)$$

A comparison of the estimated CL and measured CL is shown in Figure 15 and a comparison of the estimated Lag and measured Lag is shown in Figure 16.

One more general type of watershed exists in Arizona that needs to be considered besides desert/mountain and urban; that being irrigated agricultural watersheds. This was identified by the District prior to initiation of the Buckeye FIS contract. Such watersheds have very flat slopes and may have high resistance to flow due to tillage and vegetation growth. Such watersheds may also be representative of large turf areas such as golf courses and parks. Data are not available to develop a CL prediction equation for such watersheds, therefore, the desert/mountain CL equation was modified based on other considerations as follows: Resistance factors for overland flow are provided in the September 1990 HEC-1 Manual and SCS TR-55 (Appendix C). The ratio of resistance factors for various surfaces to the resistance factor for rangeland (natural) from TR-55 are as follows:

Surface	Ratio of Resistance Factors (Rangeland n = 0.13)
Cultivated, residue greater than 20%	1.3
Dense grass	1.8
Bermuda grass	3.2

The ratio of resistance factors for various surfaces to the resistance factor for rangeland (20% cover) from HEC-1 are as follows:

Surface	Ratio of Resistance Factors	
	n = 0.05	n = 0.25
Conventional tillage with residue	3.2 - 4.4	.6 - .9
Dense grass	3.4 - 16.0	.7 - 3.2
Bermuda grass	6.0 - 9.6	1.2 - 1.9

Although there is tremendous variability in these ratios, a composite ratio of agricultural/grass resistance factors to a rangeland (natural) resistance factor of 3.0 seems reasonable. Therefore, the Lag for agricultural/grass watersheds would be about 3 times larger than the Lag for a comparable rangeland watershed. The CL prediction equation for agricultural/grass watersheds is:

$$CL = 3 \times antilog\ (.1816 + .103 \log DA + .307 \log S) \tag{16}$$

Summary of CL and Lag for use in Arizona

The recommended Lag equation is:

$$Lag = CL\left(\frac{L \times LCA}{S^2}\right)^{.25} \tag{10}$$

where CL is estimated by Equation 14 for desert and mountain watersheds, by Equation 16 for agricultural/grass watersheds, and by Equation 15 for urban watersheds. Those equations, rewritten in more convenient form are:

desert and mountain watersheds,

$$CL = 1.5\ A^{.1}\ S^{.3} \tag{17}$$

agricultural/grass watersheds,

$$CL = 4.5\ A^{.1}\ S^{.3} \tag{18}$$

urban watersheds,

$$CL = \frac{2.0\ A^{.1}\ S^{.36}}{RTIMP^{.36}} \tag{19}$$

where A is drainage area in square miles,
S is watershed slope in feet/mile, and
RTIMP is impervious area in %.

Adjustment of Lag for Return Period

It is assumed that the Lag that is estimated by Equation 10 with CL estimated by Equations 17, 18 and 19 provides an estimate of Lag for severe storms that produce floods of approximately the 100-yr return period. The Lag should be increased for less severe storms and should be decreased for use in estimating floods larger than the 100-yr. Data are not available to provide definitive guidance for adjusting Lag for flood return period. Previous flood studies (Tucson Arroyo) for the District indicate that the following Lag frequency factors may be appropriate:

Return Period years	F_f
100	1.0
50	1.25
25	1.50
10	1.75
2	2.0

Additional testing of this method using gaged watershed data could be used to confirm or modify the use of flood frequency factors.

Adjustment of Lag for use with SCS Unit Hydrographs

As previously discussed, there are several definitions of Lag and the definition of Lag as used herein is not the same as the SCS definition of Lag used with its unit hydrographs. Appendix D provides a comparison of this definition of Lag to the SCS Lag. The SCS Lag can be estimated by

$$Lag\ (SCS) = 0.77\ Lag \tag{20}$$

where Lag is calculated by Equation 10.

COMPARISON OF UNIT HYDROGRAPHS FOR SELECTED BUCKEYE FIS SUBBASINS

Four subbasins from the Buckeye FIS watershed model were selected and unit hydrographs by four methods were calculated for each. These four subbasins are shown in Figure 17, and the watershed characteristics are shown in Table 4. Three of the subbasins (#50, #37 and #48) are agricultural fields, and one subbasin (#1) is desert.

The four unit hydrograph procedures are:

1. Clark with parameters according to the Manual,
2. Phoenix Valley S-graph with Lag by the traditional method(procedure in the Manual),
3. Phoenix Valley S-graph with Lag by the new Lag relation, and
4. SCS Dimensionless unit hydrograph with Lag = .77 x new Lag.

The calculated unit hydrograph parameters are shown in Table 4, and graphical comparisons of the unit hydrographs for the four subbasins are shown in Figures 18 through 21.

Discussion of the comparisons is as follows:

1. The Clark unit hydrograph procedure was developed from a data base that did not include irrigated agricultural fields, and that procedure, as defined in the Manual, probably should not be applied to such watersheds or subbasins. The Clark unit hydrographs shown in Figures 18, 19 and 20 do not look appropriate for the very flat sloped agricultural subbasins (the peaks are too high and the times to peak are too short).
2. In Table 4, the traditional Lag (Column 10) and the new Lag (Column 12) are quite comparable for all four watersheds.
3. For the three agricultural subbasins (#50, #37 and #48), the unit hydrographs by the S-graphs, by both traditional Lag and the new Lag, and the SCS Dimensionless unit hydrograph, agree fairly well for hydrologic estimation purposes.
4. For the desert subbasin (#1), both the S-graph by the traditional Lag and the Clark yield nearly identical results. This indicates that for small desert/rangeland watersheds that the two methods should yield similar

results, and this is reassuring.

5. For subbasin #1, all four unit hydrographs are comparable. Accuracy of one method over another cannot be judged, but the four methods would probably produce similar Q_p's when used with a 6-hr or longer storm. Previous verifications have indicated that the existing Clark and S-graph procedures yield good results and therefore, by extension, the other two methods using the new Lag relation should yield similar results for small desert/rangeland watersheds.

EVALUATION OF NEW LAG USING WATERSHED DATA FROM PREVIOUS VERIFICATIONS

The procedures in the manual have been verified against gaged data for seven watersheds. Those watersheds are:

ID Code	Name and Location	Type of Watershed
AFT	Agua Fria R. trib., Youngtown, AZ	urban
TA	Tucson Arroyo, Tucson, AZ	urban/commercial
AA	Academy Acres, Albuquerque, NM	urban
WG11	Walnut Gulch 63.011, Tombstone, AZ	rangeland
WG8	Walnut Gulch 63.008, Tombstone, AZ	rangeland
CC	Cave Creek, Cave Creek, AZ	desert/mountain
UAFR	Agua Fria River, Mayer, AZ	mountain

That watershed data was used to compare the estimates of 100-yr flood peak discharges using the two unit hydrograph procedures in the Manual with the results that are obtained by using the new Lag relation with an S-graph.

The watershed characteristics and unit hydrograph parameters for each of the three unit hydrograph procedures are listed in Table 5. The Clark unit hydrograph parameters (T_c and R) were calculated by the MCUHP1 Program using the Maricopa County 6-hr rainfall distribution and the appropriate Green and Ampt parameters from the verification studies (see the Documentation/ Verification Report). The Clark unit hydrograph was not calculated for the Cave Creek (CC) and the Agua Fria River (UAFR) watersheds because the drainage areas for those two watersheds exceed the size limit for application of the Clark parameter estimation equations. The Clark unit hydrograph should not be applied to the Walnut Gulch 63.008 watershed (WG8) because the calculated T_c (1.5 hr) exceeds the duration of rainfall excess (1.0 hr). The Clark parameters for WG8 are shown for comparison purposes <u>only</u>.

CLARK doesn't work.

The S-graph Lag was calculated by two methods; (1) the traditional Lag

requiring the selection of K_n from the best available information and use of either the Corps or the USBR Lag equation as shown in Table 5, and (2) the new Lag relation with CL calculated by Equation 17 for desert and mountain watersheds and Equation 19 for urban watersheds. The calculated Lag for each watershed is shown in Table 5, column 11 by the traditional Lag method, and Column 14 by the new Lag relation. The Phoenix Mountain S-graph was used for CC and UAFR watersheds and the Phoenix Valley S-graph was used for the other five watersheds.

The Lag by the new Lag relation is greater than the Lag by the traditional method for the five smaller watersheds (AFT, TA, AA, WG11 and WG8), and was less for the two larger watersheds (CC and UAFR). Accuracy of either Lag calculation cannot be determined for any of the watersheds except UAFR for which the two Lags (one for a local storm and one for a general storm) were measured from actual runoff data (see the S-Graph Report). The new Lag relation provides a reasonable estimate of Lag for that watershed.

Those unit hydrograph parameters were used with HEC-1 models of the watersheds to estimate the 100-yr flood peak discharges (Table 6). Input to the models was according to the Manual and the 6-hr storm distribution was used for all of the watersheds except UAFR for which the SCS Type II distribution was used because of the watershed size (588 square miles).

Discussion of the model results from Table 6 is as follows:

1. The Clark unit hydrograph procedure is intended to be used with small watersheds or subbasins (less than 5 square miles), and was primarily developed for urban applications although it is also applicable for undeveloped watersheds. Therefore, the Clark is most appropriately applied to AFT, AA and WG11, and the Clark model results are the best for those watersheds.
2. The TA watershed exceeds the 5 square mile size recommendation but not the 10 square mile limit for application of the Clark, and the Clark again has the best model results for TA. However, the S-graph with the new Lag relation yields very good results that are better than the S-graph with the traditional Lag.
3. None of the HEC-1 models are particularly good at reproducing the flood

frequency relations for WG8 or WG11. Although an event simulation using rainfall and runoff data for WG8 has verified that the Maricopa County procedures with the Clark unit hydrograph do very accurately reproduce both the rainfall losses and the runoff response for this watershed. It is possible that the flood frequency relation for these watersheds is weak. Nonetheless, the S-graph with the new Lag relation produces results that are comparable with the other two unit hydrograph procedures.

4. The new Lag relation produces results that agree very well with the traditional Lag equation for the two larger watersheds (CC and UAFR) for which S-graphs are intended to be applied.

CONCLUSIONS

1. The new Lag relation of Equation 10 is a theoretical improvement over the traditional Lag equations. This by itself may have value to the theoretical hydrologist, but offers little to the practicing hydrologist. The main advantage of the new Lag relation is that Lag is more sensitive to slope than the traditional equations. This greater sensitivity to slope should lead to improved estimates of Lag.
2. Three equations are provided for estimating CL in the new Lag equation; Equation 17 for deserts and mountains, Equation 18 for agricultural fields, and Equation 19 for urbanized areas. These equations can be applied by using readily obtainable watershed characteristics without subjective decisions, such as selection of K_n in the traditional Lag equations.
3. Use of Equation 10 for Lag along with Equations 17, 18 and 19 for CL should produce estimates of Lag that are reproducible for all significantly representative watersheds in Maricopa County.
4. The SCS Dimensionless unit hydrograph with Lag estimated by Equations 10 and 18 (times 0.77 to correct for the different definitions of Lag), probably provides as good a representation of runoff from agricultural fields as does the Phoenix Valley S-graph with Lag estimated by either the traditional method or the new Lag relation.
5. The Clark unit hydrograph procedure in the Manual was not developed for agricultural fields and should not be applied for those applications without additional development. Given that other unit hydrograph methods

are available that may be appropriate for agricultural fields, there does not seem to be justification for developing modifications to the Clark procedure for agricultural areas.

6. A major weakness of the Lag equations is that they do not account for changes in hydraulic efficiency of the watershed due to varying rainfall intensity; that is, Lag should increase with decreasing rainfall intensity (rainfall return period). Frequency factors to be applied to Lag are suggested based on some limited verifications that were previously performed.

RECOMMENDATIONS

1. Consider adoption of the new Lag relation (Equation 10) along with the CL estimators (Equations 17, 18 and 19) in the Manual in place of the traditional Lag equations.
2. Consider adoption of the SCS Dimensionless unit hydrograph with Lag = 0.77 x new Lag, and the new Lag estimated by Equations 10 and 18, for use with agricultural fields.
3. Consider adoption of the SCS Dimensionless unit hydrograph with Lag = 0.77 x new Lag, and the new Lag estimated by Equations 10 and 17, for use on small, desert/rangeland subbasins of models.
4. Continue to use the Phoenix Valley and Phoenix Mountain S-graphs (with the new Lag relation) for large (maybe larger than 25 square miles) modeling basins and subbasins.
5. Continue to use the Clark unit hydrograph, as defined in the Manual, for urban and urbanizing areas.
6. Consider development and/or adoption of Lag frequency factors.

IMPLEMENTATION

The Recommendations, if adopted, would have long-term implications on how hydrology is performed in Maricopa County. Therefore, the consequences need to be carefully evaluated before adoption. The following studies should be conducted as part of that evaluation:

1. Perform a more extensive comparison of the various unit hydrograph options:
   a. Clark,
   b. S-Graph with traditional Lag,
   c. S-Graph with new Lag, and
   d. SCS Dimensionless with new Lag.

   Perform these comparisons for a larger and more diverse selection of watershed types. Data is probably available for this from previously performed AMDS and FIS projects. Compare the unit hydrograph parameters, unit hydrograph shapes, and Q_{100} estimates for the selected subbasins.
2. Use the existing verification data for the TA, WG8, WG11, and CC watersheds to further test and refine the suggested frequency factor table for adjustment of Lag for various return periods.

eristics

S ft/mi	LAG hrs measured	L*LCA over S**	CL measured	CL1 estimated	LAG1 hrs estimated	CL2 estimated	LAG2 hrs estimated	CL3 estimated	LAG3 hrs estimated	CL4 estimated	LAG4 hrs estimated
47.00	16.00	3.938433680	11.36	11.02	15.52	11.53	16.24	11.86	16.71	11.74	16.54
46.40	12.00	2.401345125	9.64	11.23	13.98	11.03	13.73	11.41	14.20	11.33	14.10
104.60	8.50	0.061830738	13.04	11.86	5.91	12.52	6.24	12.57	6.27	12.39	6.18
87.10	5.40	0.077507016	10.23	11.64	6.14	11.48	6.06	11.67	6.16	11.55	6.09
350.00	3.30	0.002196898	15.24	13.15	2.85	15.97	3.46	15.43	3.34	15.50	3.35
450.00	1.60	0.000192889	13.58	14.00	1.65	15.13	1.78	14.60	1.72	14.51	1.71
690.00	1.10	0.000030456	14.81	15.24	1.13	15.19	1.13	14.54	1.08	14.44	1.07
440.00	1.50	0.000213223	12.41	13.43	1.62	13.72	1.66	13.31	1.61	13.11	1.58
600.00	1.30	0.000089222	13.38	14.17	1.38	14.37	1.40	13.83	1.34	13.65	1.33
1017.00	1.20	0.000017113	18.66	17.42	1.12	17.60	1.13	16.65	1.07	17.03	1.10
140.00	5.60	0.029020408	13.57	11.82	4.88	12.92	5.33	12.86	5.31	12.68	5.23
150.00	3.70	0.013057778	10.95	11.81	3.99	12.16	4.11	12.15	4.11	11.99	4.05
105.00	7.30	0.091791383	13.26	11.69	6.44	12.46	6.86	12.52	6.89	12.34	6.80
85.00	9.50	0.290541176	12.94	11.20	8.22	11.70	8.59	11.87	8.71	11.73	8.62
700.00	0.80	0.000008878	14.66	15.18	0.83	13.04	0.71	12.57	0.69	12.37	0.68
290.00	2.50	0.001310702	13.14	12.90	2.45	14.13	2.69	13.79	2.62	13.63	2.59
95.00	4.00	0.031042659	9.53	11.61	4.88	10.47	4.39	10.71	4.50	10.72	4.50
145.00	3.50	0.008133175	11.65	12.12	3.64	11.86	3.56	11.89	3.57	11.75	3.53
315.00	2.40	0.001209373	12.87	11.94	2.23	12.97	2.42	12.71	2.37	12.51	2.33
140.00	0.60	0.000277551	4.65	11.90	1.54	6.13	0.79	6.64	0.86	7.78	1.00
75.00	2.40	0.038341333	5.42	10.75	4.76	7.96	3.52	8.48	3.75	8.99	3.98
29.00	21.50	11.059453032	11.79	10.66	19.43	8.72	15.90	9.41	17.16	9.69	17.67
32.00	20.60	9.394531250	11.77	10.17	17.80	8.67	15.17	9.34	16.34	9.63	16.86
65.00	10.30	0.674319527	11.37	10.56	9.57	10.57	9.58	10.90	9.88	10.88	9.86
141.00	3.10	0.009855641	9.84	11.32	3.57	10.57	3.33	10.71	3.37	10.71	3.37
145.00	3.70	0.015006897	10.57	11.30	3.96	11.04	3.87	11.14	3.90	11.07	3.88
83.00	5.30	0.143028016	8.62	9.70	5.97	9.62	5.91	9.97	6.13	10.11	6.22
89.00	2.40	0.022219417	6.22	11.28	4.35	8.41	3.25	8.85	3.42	9.26	3.57
159.00	8.00	0.034808750	18.52	12.16	5.25	14.56	6.29	14.33	6.19	14.23	6.14
295.00	0.90	0.000031026	12.06	12.79	0.95	8.97	0.67	9.06	0.68	9.40	0.70
480.00	1.00	0.000021484	14.69	13.96	0.95	11.88	0.81	11.60	0.79	11.47	0.78
709.00	0.70	0.000004914	14.87	15.42	0.73	12.28	0.58	11.87	0.56	11.71	0.55
310.00	2.40	0.001219043	12.84	12.99	2.43	14.61	2.73	14.21	2.66	14.08	2.63
100.00	5.10	0.040600000	11.36	11.67	5.24	10.94	4.91	11.13	5.00	11.07	4.97
49.00	11.00	1.366097459	10.17	10.77	11.65	9.77	10.56	10.24	11.07	10.33	11.17

S ft/mi	LAG hrs measured	L*LCA over S**	CL measured	CL1 estimated	LAG1 hrs estimated	CL2 estimated	LAG2 hrs estimated	CL3 estimated	LAG3 hrs estimated	CL4 estimated	LAG4 hrs estimated
83.40	8.85	0.141659334	14.43	9.71	5.95	9.64	5.91	9.99	6.13	10.13	6.21
83.40	5.38	0.141659334	8.77	9.71	5.95	9.64	5.91	9.99	6.13	10.13	6.21
101.90	2.95	0.016780291	8.20	11.35	4.09	9.03	3.25	9.38	3.38	9.65	3.47
101.90	2.19	0.016780291	6.08	11.35	4.09	9.03	3.25	9.38	3.38	9.65	3.47
75.90	4.99	0.053256400	10.39	10.18	4.89	7.80	3.75	8.33	4.00	8.89	4.27
75.90	5.88	0.053256400	12.24	10.18	4.89	7.80	3.75	8.33	4.00	8.89	4.27
67.00	0.86	0.000250613	6.84	11.23	1.41	0.18	0.02	1.38	0.17	5.15	0.65
67.00	0.95	0.000250613	7.55	11.23	1.41	0.18	0.02	1.38	0.17	5.15	0.65
67.00	0.79	0.000250613	6.28	11.23	1.41	0.18	0.02	1.38	0.17	5.15	0.65
16.00	0.96	0.001173047	5.19	10.89	2.02	-8.31	-1.54	-6.03	-1.12	2.88	0.53
16.00	1.00	0.001173047	5.40	10.89	2.02	-8.31	-1.54	-6.03	-1.12	2.88	0.53
141.40	2.59	0.009799960	8.23	11.33	3.56	10.58	3.33	10.72	3.37	10.72	3.37
141.40	2.50	0.009799960	7.95	11.33	3.56	10.58	3.33	10.72	3.37	10.72	3.37
121.60	4.25	0.021971304	11.04	10.80	4.16	10.24	3.94	10.45	4.02	10.49	4.04
121.60	2.72	0.021971304	7.06	10.80	4.16	10.24	3.94	10.45	4.02	10.49	4.04
64.20	8.02	0.091400510	14.59	11.00	6.05	8.05	4.43	8.60	4.73	9.08	4.99
64.20	7.31	0.091400510	13.29	11.00	6.05	8.05	4.43	8.60	4.73	9.08	4.99
64.20	3.10	0.091400510	5.64	11.00	6.05	8.05	4.43	8.60	4.73	9.08	4.99
73.60	10.59	0.211059340	15.62	10.19	6.91	9.85	6.68	10.21	6.92	10.31	6.99
73.60	6.90	0.211059340	10.18	10.19	6.91	9.85	6.68	10.21	6.92	10.31	6.99
68.90	10.68	0.349510555	13.89	11.08	8.52	10.70	8.22	11.00	8.46	10.97	8.43
68.90	7.80	0.349510555	10.14	11.08	8.52	10.70	8.22	11.00	8.46	10.97	8.43
42.10	9.20	1.730609735	8.02	11.40	13.08	10.23	11.74	10.70	12.27	10.72	12.29
41.00	11.20	2.171564545	9.23	9.89	12.01	8.09	9.82	8.74	10.62	9.19	11.16
310.00	0.64	0.000676171	3.97	12.59	2.03	12.84	2.07	12.59	2.03	12.40	2.00
72.40	12.90	1.119425536	12.54	10.44	10.74	11.84	12.18	12.04	12.38	11.89	12.23
312.00	1.00	0.000223537	8.18	12.38	1.51	10.93	1.34	10.84	1.33	10.81	1.32

TABLE 3
Watershed characteristics and lag data for urban watersheds

Ref. No.	Station and Location	A sq.mi.	L miles	LCA miles	LWR	S ft/mi	LAG hrs measured	L*LCA over S**	CL measured	CL estimated	LAG hrs estimated	RTIMP
1	Alhambra Wash above Short St., Monterey Park, CA	14.00	9.50	4.60	6.45	85.00	0.60	0.006048443	2.15	3.42	0.95	40
2	San Jose Cr. at Workman Mill Rd., Whittier, CA	81.30	23.70	9.10	6.91	75.00	2.40	0.038341333	5.42	4.09	1.81	35
3	Broadway Drain at Raymond Dike, CA	2.50	3.40	1.70	4.62	100.00	0.30	0.000578000	1.93	2.92	0.45	45
4	Compton Cr. below Hooper Ave. Storm Drain, L.A., CA	19.50	8.80	4.20	3.97	14.60	1.80	0.173390880	2.79	1.62	1.04	60
5	Ballona Cr. at Sawtelle Blvd., L.A., CA	88.60	11.80	5.60	1.57	64.00	1.20	0.016132813	3.37	3.71	1.32	40
6	Brays Bayou, Houston, TX	88.40	23.30	10.40	6.14	4.10	2.10	14.415229030	1.08	1.38	2.69	40
7	White Oak Bayou, Houston, TX	92.00	23.10	12.80	5.80	5.00	3.10	11.827200000	1.67	1.56	2.89	35
8	Boneyard Cr., Austin, TX	4.50	2.80	1.30	1.74	9.50	0.80	0.040332410	1.79	1.42	0.64	37
9	Waller Cr., Austin, TX	4.10	5.20	1.90	6.60	48.00	1.00	0.004288194	3.91	2.83	0.72	27
10	Beargrass Cr., Louisville, KY	9.70	5.60	2.50	3.23	6.30	0.90	0.352733686	1.17	1.05	0.81	70
11	17th Street Sewer, Louisville, KY	0.20	0.90	0.30	4.05	48.00	0.15	0.000117188	1.44	1.34	0.14	93
12	Northwest Trunk, Louisville, KY	1.90	3.00	1.10	4.74	19.00	0.40	0.009141274	1.29	1.51	0.47	50
13	Southern Outfall, Louisville, KY	6.40	6.40	2.50	6.40	13.00	0.70	0.094674556	1.26	1.50	0.83	48
14	Southwest Outfall, Louisville, KY	7.50	6.50	2.70	5.63	18.50	0.50	0.051278305	1.05	1.99	0.95	33
15	Beargrass Cr., Louisville, KY	6.30	4.00	1.80	2.54	4.50	1.00	0.355555556	1.30	1.41	1.09	20
16	Tripps Run nr. Falls Church, VA	4.60	4.10	1.90	3.65	52.00	0.90	0.002880917	3.88	2.91	0.67	28
17	Tripps Run at Falls Church, VA	1.80	2.30	1.00	2.94	79.00	0.50	0.000368531	3.61	3.21	0.44	25
18	Four Mile Run at Alexandria, VA	14.40	7.80	3.50	4.23	43.00	1.40	0.014764738	4.02	3.44	1.20	20
19	Little Pimmit Run at Arlington, VA	2.30	2.20	1.00	2.10	77.00	0.40	0.000371058	2.88	3.53	0.49	20
20	Piney Branch at Vienna, VA	0.30	0.50	0.20	0.83	87.00	0.20	0.000013212	3.32	2.60	0.16	30
21	Walker Avenue Drain at Baltimore, MD	0.20	1.00	0.40	5.00	83.00	0.20	0.000058064	2.29	2.37	0.21	33

TABLE 4

Comparison of unit hydrograph parameters for selected subbasins from the Buckeye FIS watershed model

Subbasin	Type[a]	Watershed Characteristics				Unit Hydrograph Parameters							
						Clark		Traditional Lag[b]		New Lag[c]			SCS Lag[d]
		A	L	LCA	S								
		sq.mi.	mi.	mi.	ft/mi.	T_c hr	R hr	K_n	Lag hr	CL eq'n	CL	Lag hr	hr
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
#50	A	1.0	1.98	.99	31	.89	.56	.2	3.23	18	12.61	2.67	2.06
#37	A	.725	1.82	.91	38	.76	.53	.2	2.91	18	12.98	2.41	1.86
#48	A	.486	.49	.25	22	.60	.31	.2	1.56	18	10.58	1.59	1.22
#1	D	1.672	2.15	1.3	28	1.00	.51	.05	.94	17	4.29	1.05	.81

a - A, agricultural
D, desert

b - Lag = $24\ K_n(L \times LCA/S^{1/2})^{.38}$

c - Lag = $CL(L \times LCA/S^2)^{.25}$

d - SCS Lag = .77 x new Lag

TABLE 5

Comparison of unit hydrograph parameters for watersheds that were used to verify the Maricopa County Hydrologic Design Manual

Watershed	Type[a]	Watershed Characteristics					Unit Hydrograph Parameters						
							Clark		Traditional Lag		New Lag[g]		
		A	L	LCA	S	RTIMP	T_c	R	K_n	Lag	CL	CL	Lag
		sq.mi.	mi.	mi.	ft/mi.	%	hr	hr		hr	eq'n		hr
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
AFT	U	.13	1.023	.5	5.8	25	.73	.85	.015	.23[e]	19	.96	.34
TA	U	8.12	6.18	2.7	37.7	20.2	.93	.45	.015	.54[e]	19	3.09	1.01
AA	U	.124	.90	.52	105	28	.24	.23	.015	.14[e]	19	2.61	.21
WG11	R	3.18	4.0	1.8	100	0	.64	.35	.03	.70[e]	17	6.70	1.10
WG8	R	5.98	8.0	3.6	75	0	1.53[b]	1.13	.03	1.16[e]	17	6.55	1.75
CC	D/M	126	28.3	19.4	103	20	---	---	.045	4.92[f]	17	9.77	4.66
UAFR	M	588	42.0	14.0	87.1	0	---	---	.043[c] .059[d]	4.99[f] 6.84[f]	17	10.84	5.72

a - U, urban
R, rangeland
D/M, desert and mountain
M, mountain

b - T_c exceeds duration of rainfall excess, therefore the Clark should not be used (comparison only)

c - Ref., S-Graph Report, Table 7, #21 (local storm)

d - Ref., S-Graph Report, Table 7, #22 (general storm)

e - Lag = $26\ K_n(L \times LCA/S^{1/2})^{.33}$ (Corps)

f - Lag = $24\ K_n(L \times LCA/S^{1/2})^{.38}$ (USBR)

g - Lag = $CL(L \times LCA/S^{2})^{.25}$

TABLE 6

Comparison of 100-yr flood peak discharge estimates using the selected unit hydrograph procedures

Watershed	Flood Frequency Best Estimate	Q_{100} from HEC-1 models		
		Clark	S-Graph Traditional Lag	S-Graph New Lag
	cfs	cfs	cfs	cfs
(1)	(2)	(3)	(4)	(5)
AFT	190	120	370	310
TA	7,600	7,400	9,670	6,890
AA	190	200	300	260
WG11	6,500	4,380	4,230	3,170
WG8	6,200	3,820[a]	5,290	3,880
CC	14,600	-----[b]	9,360	10,350
UAFR[c]	37,000	-----[b]	56,600[d]	64,500

a - calculated T_c (1.5 hr) exceeds duration of rainfall excess (1.0 hr)

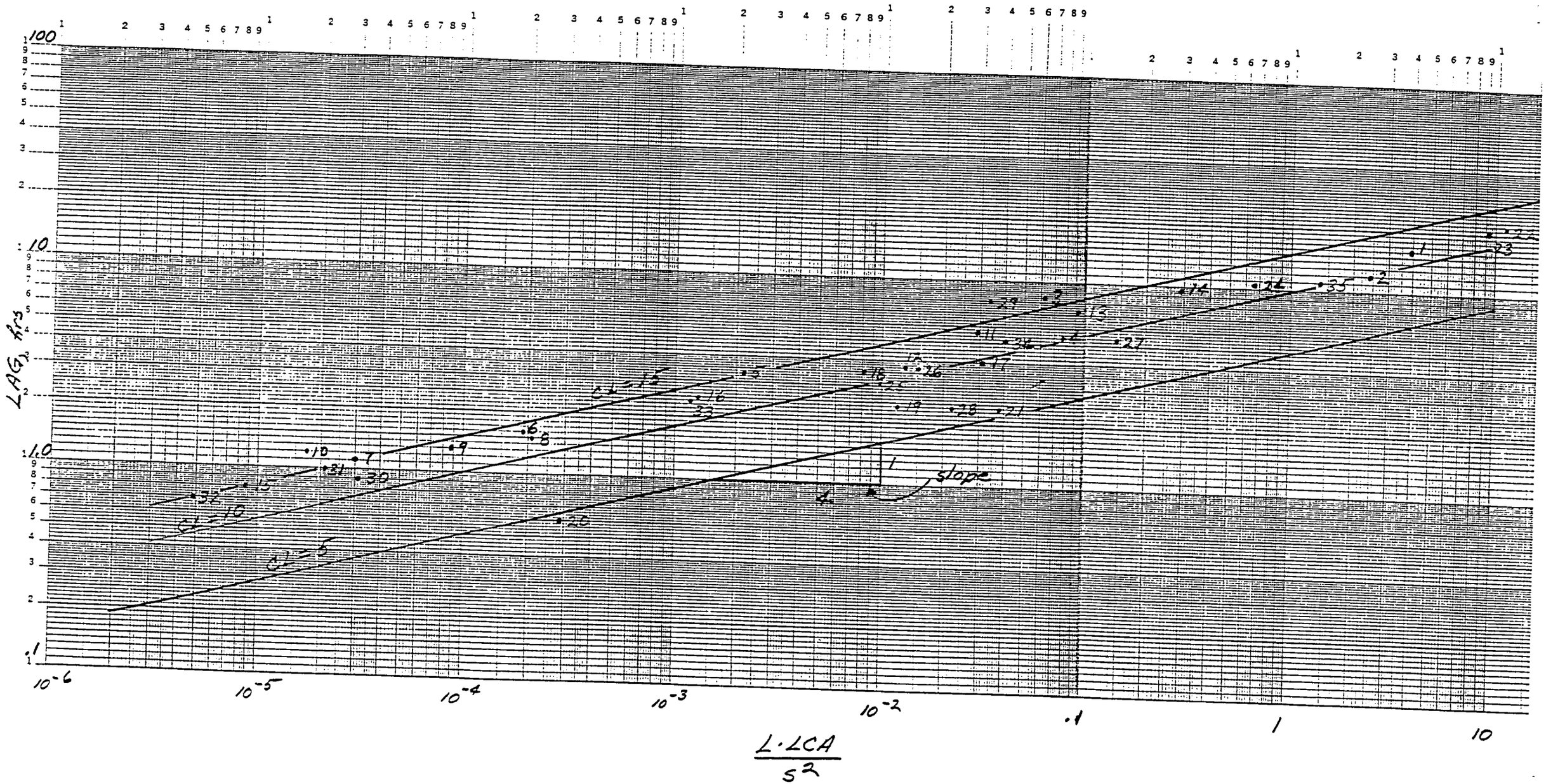
b - watershed too large to apply the Clark unit hydrograph as described in the Manual

c - SCS 24-hr rainfall distribution was used

d - calculated with Lag = 6.84 hr from a K_n = .059 for a general storm

FIGURE 1

LAG versus $\frac{L \cdot LCA}{S^2}$ for Desert & Rocky Mtn watersheds



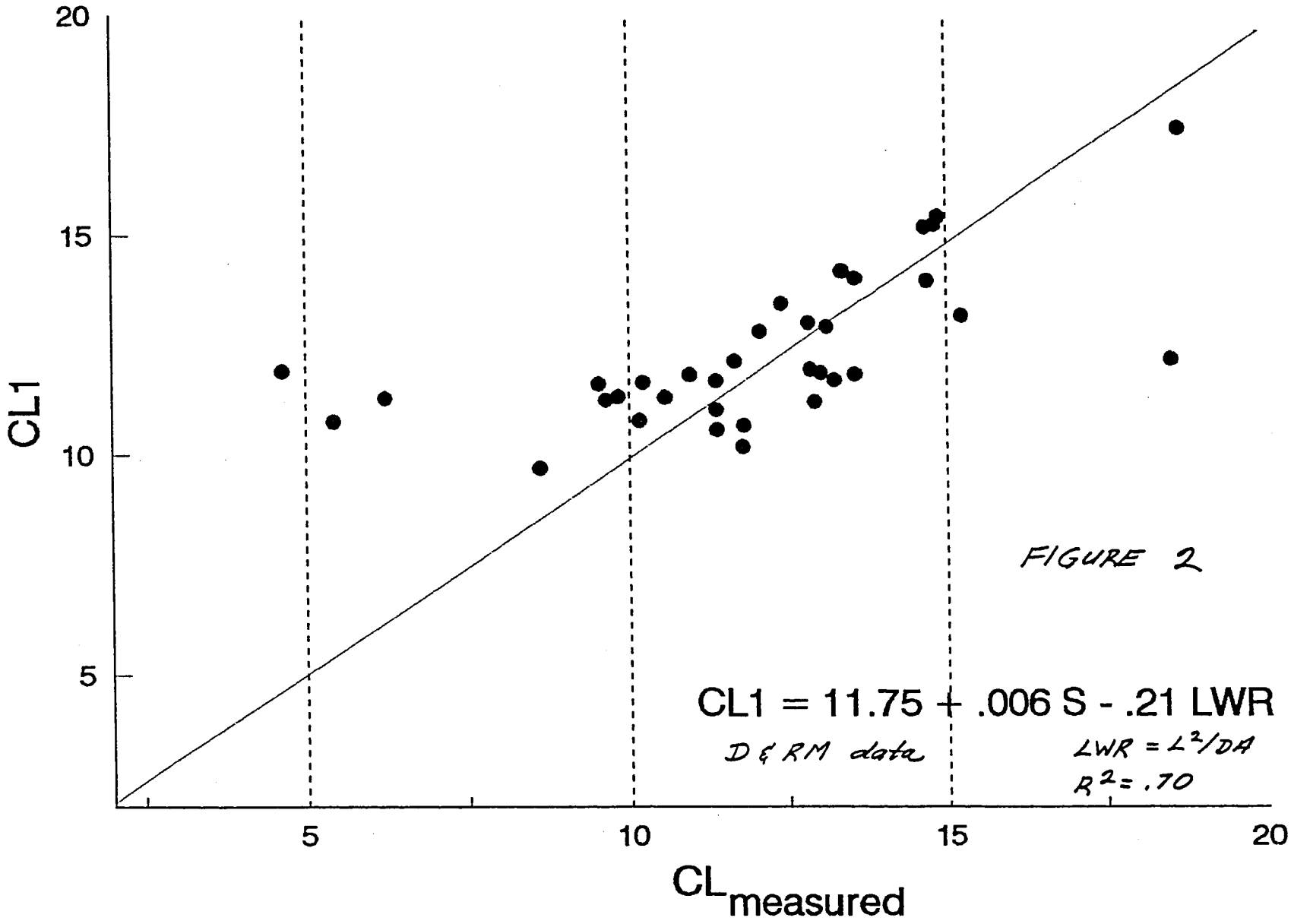

20
15
10
5
CL1
5
10
15
20
CLmeasured
CL1 = 11.75 + .006 S - .21 LWR
D & RM data
LWR = L²/DA
R² = .70

FIGURE 2

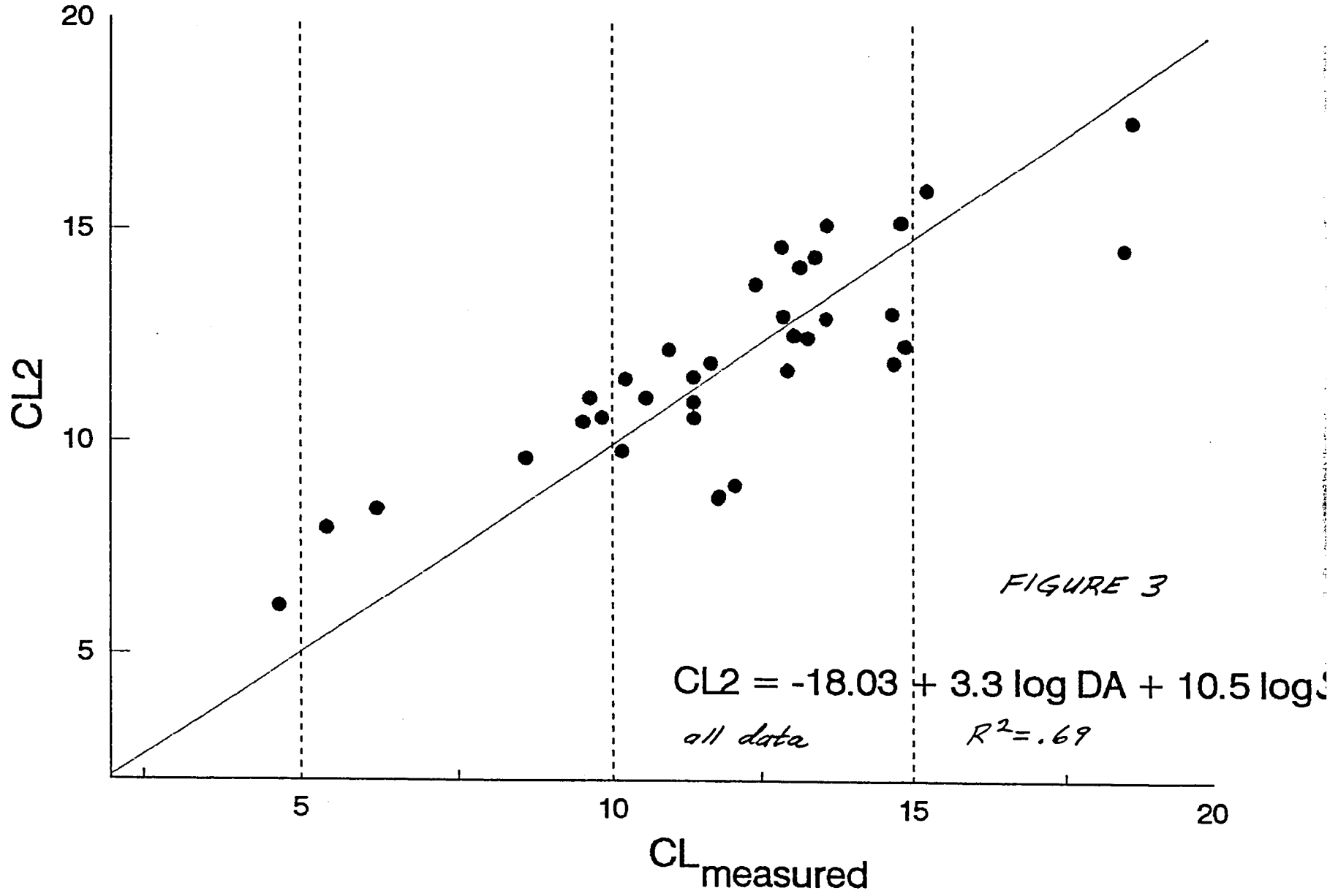

20
15
10
5
CL2
5
10
15
20
CLmeasured
CL2 = -18.03 + 3.3 log DA + 10.5 log
all data
R2=.69

FIGURE 3

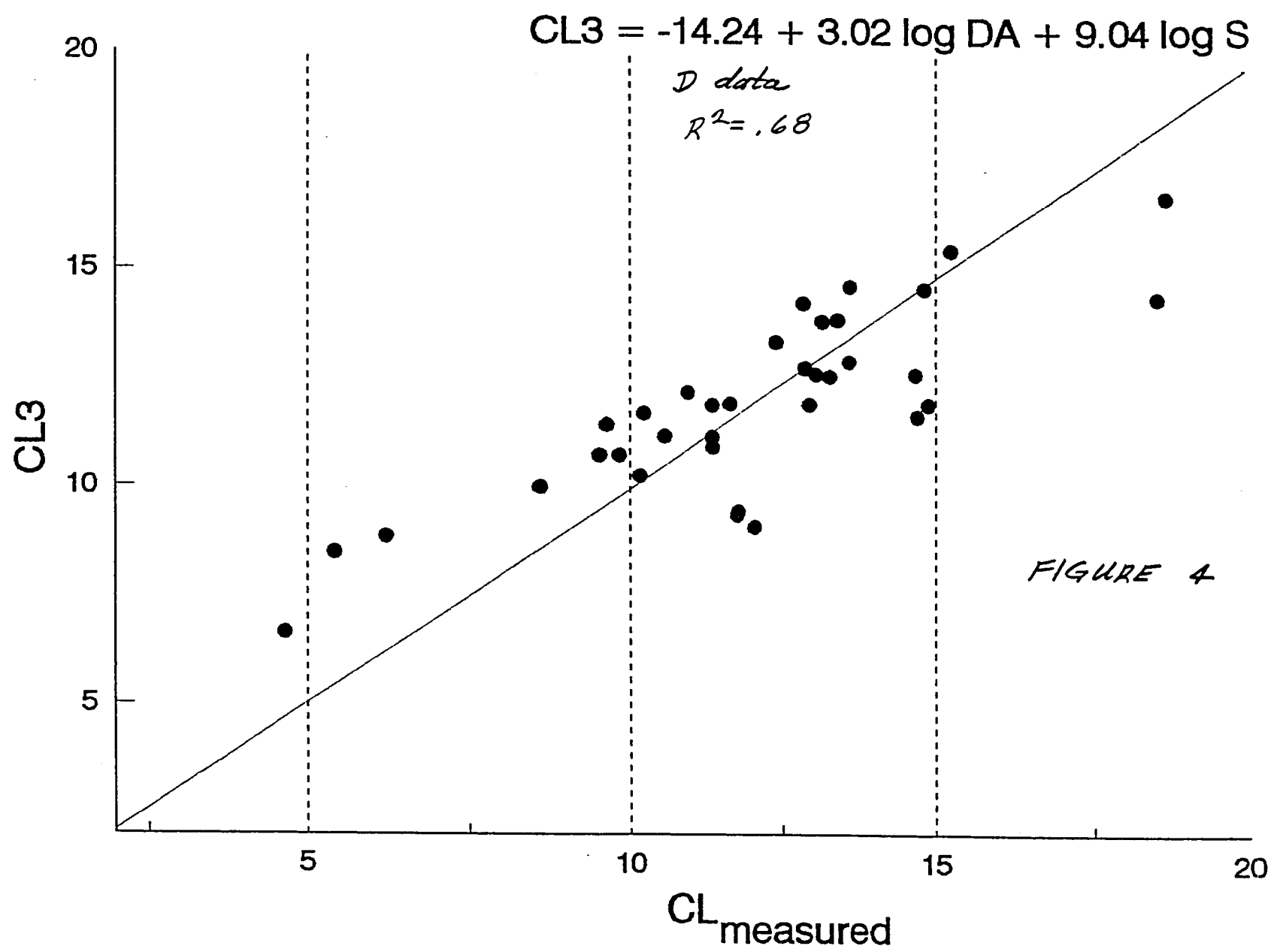

CL3 = -14.24 + 3.02 log DA + 9.04 log S
D data
R^2= .68
CL3
20
15
10
5
5
10
15
20
$CL_{measured}$

FIGURE 4

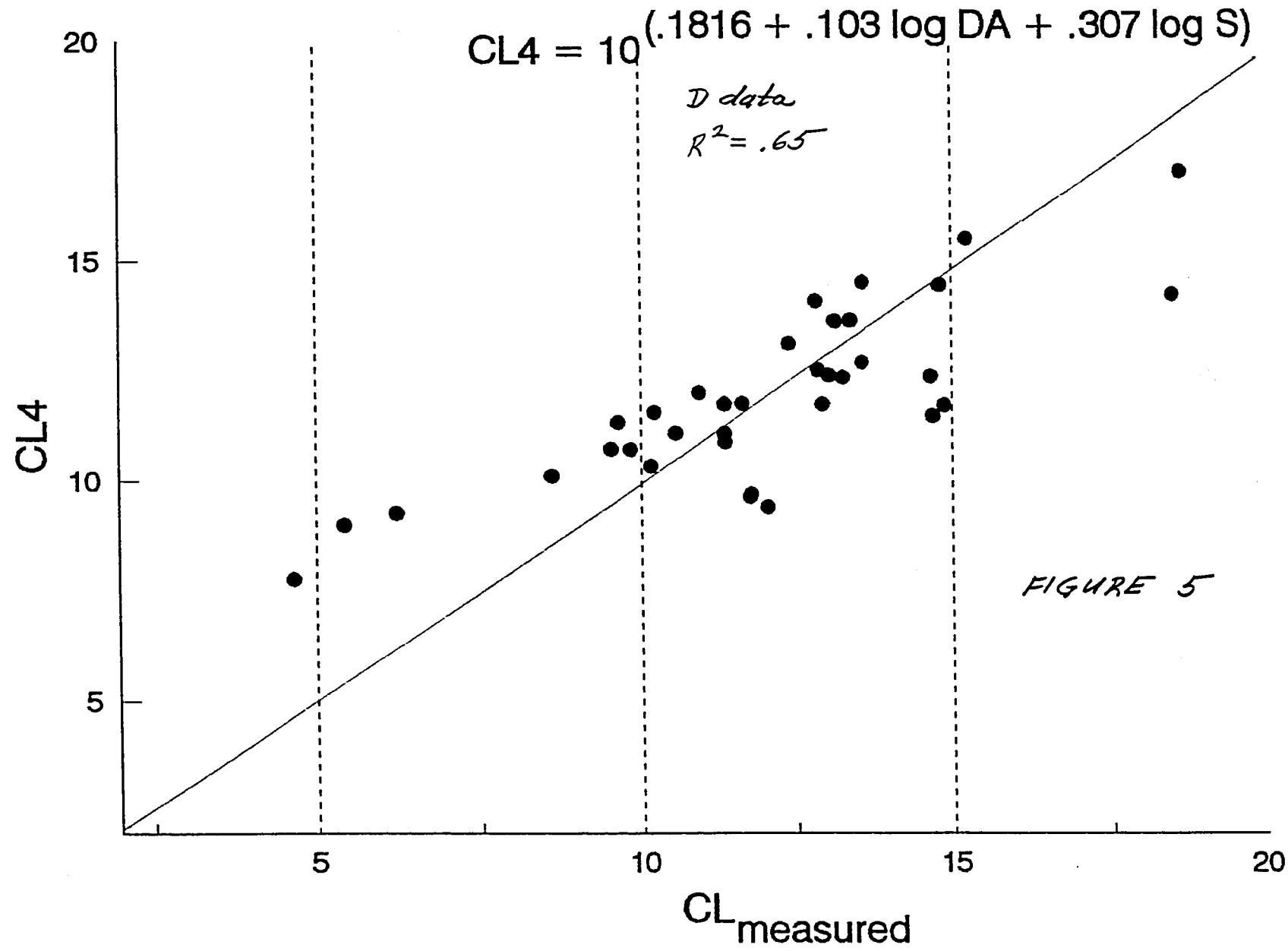

CL4 = 10(.1816 + .103 log DA + .307 log S)
D data
R^2 = .65
CL4
20
15
10
5
5
10
15
20
CLmeasured

FIGURE 5

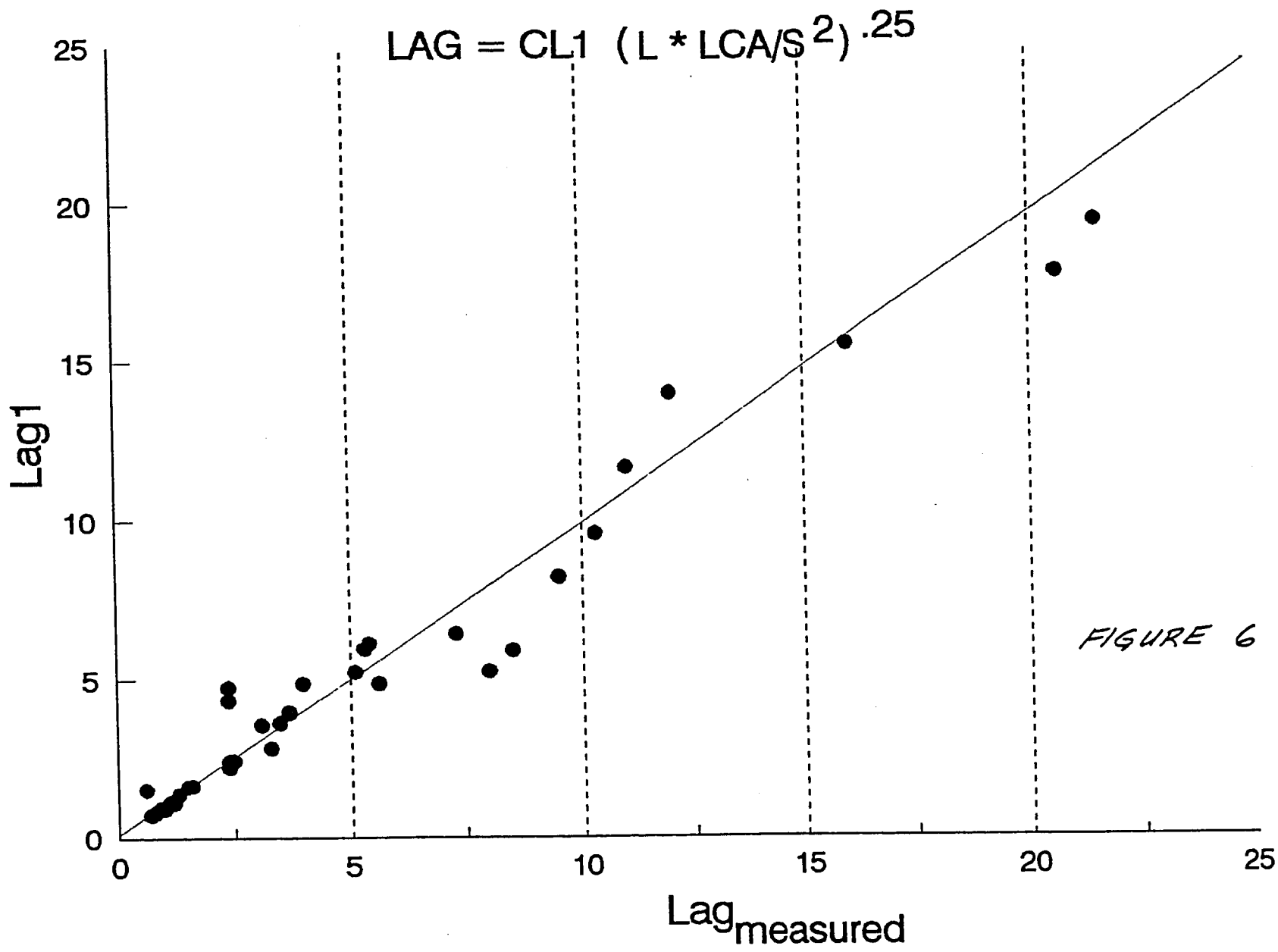


FIGURE 6

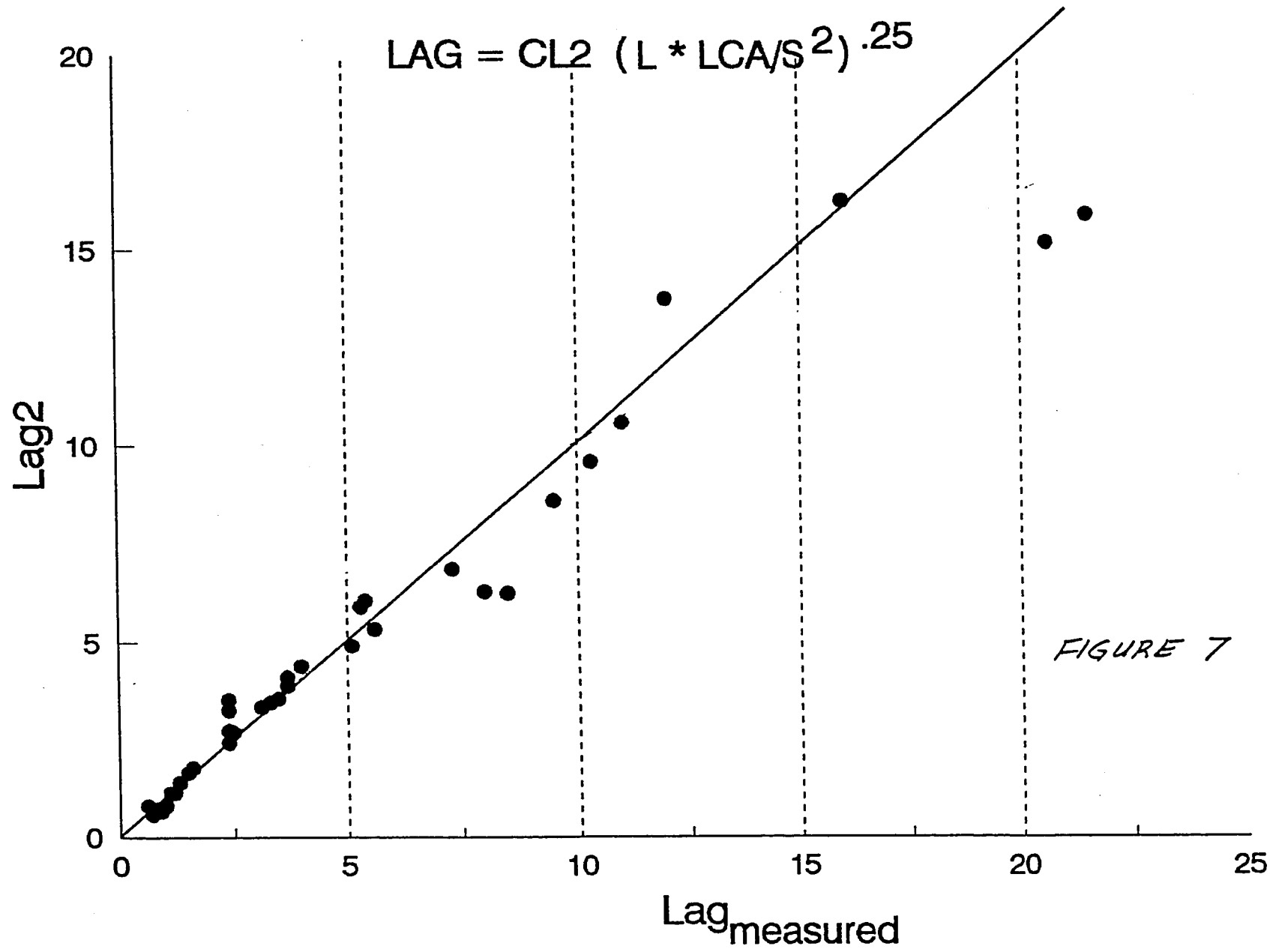


FIGURE 7

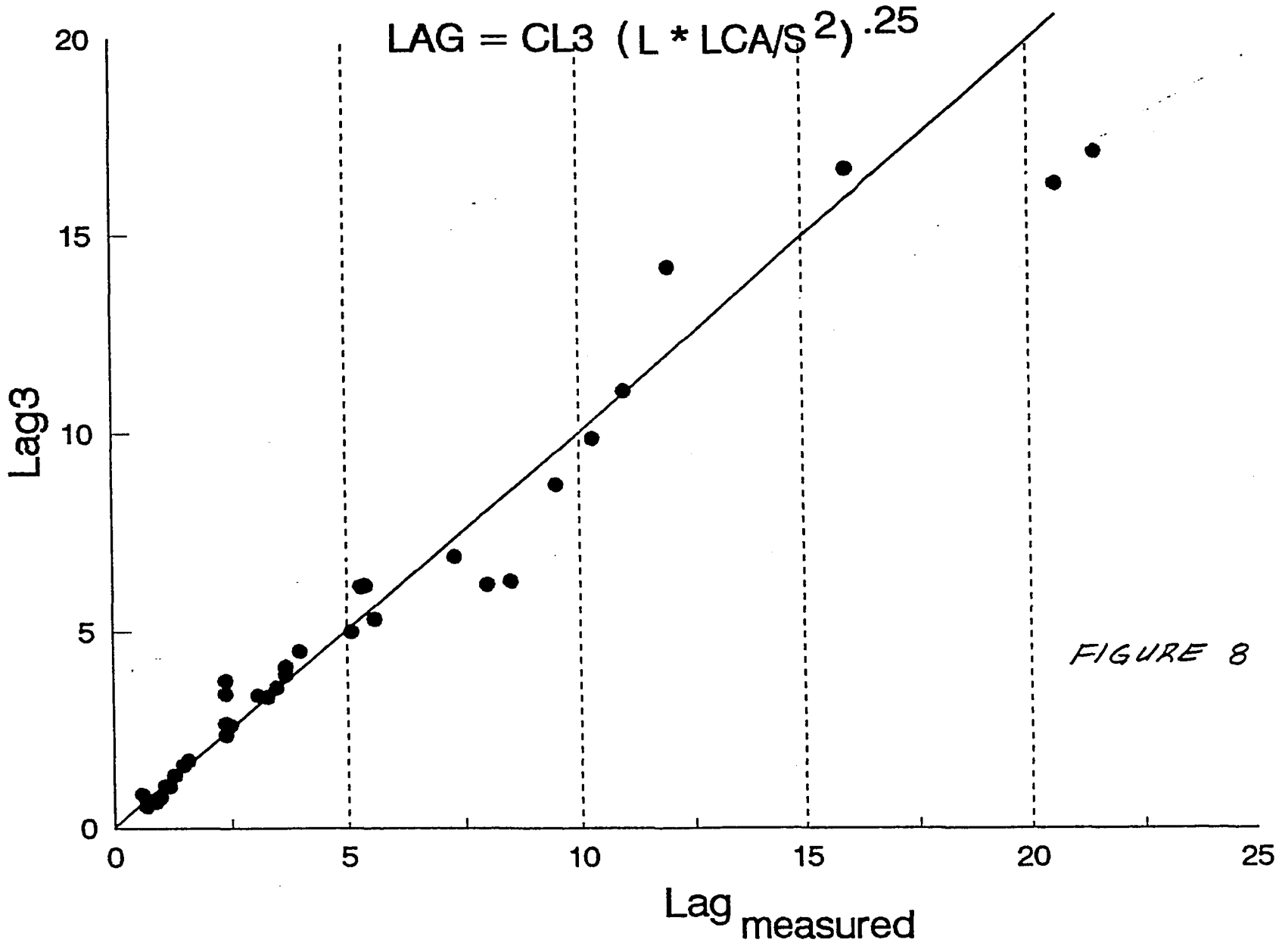


FIGURE 8

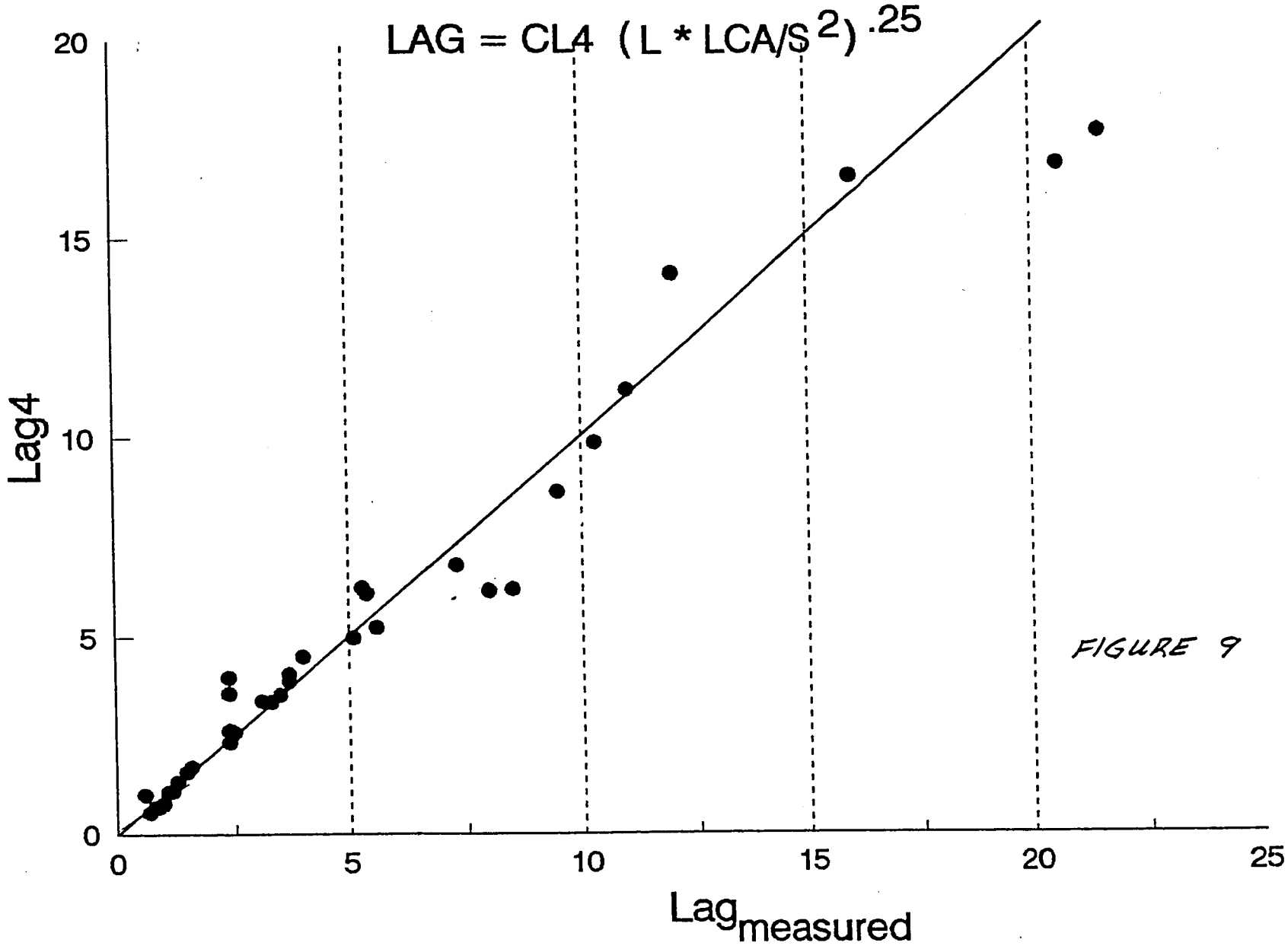


FIGURE 9

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG1 = CL1 \left(\frac{L \cdot LCA}{S^2} \right)^{.25}$$

$$CL1 = 11.75 + .006\,S - .21\,LWR$$

• for Sept 70, June 72 and undated data

⊙ for Dec 67 data

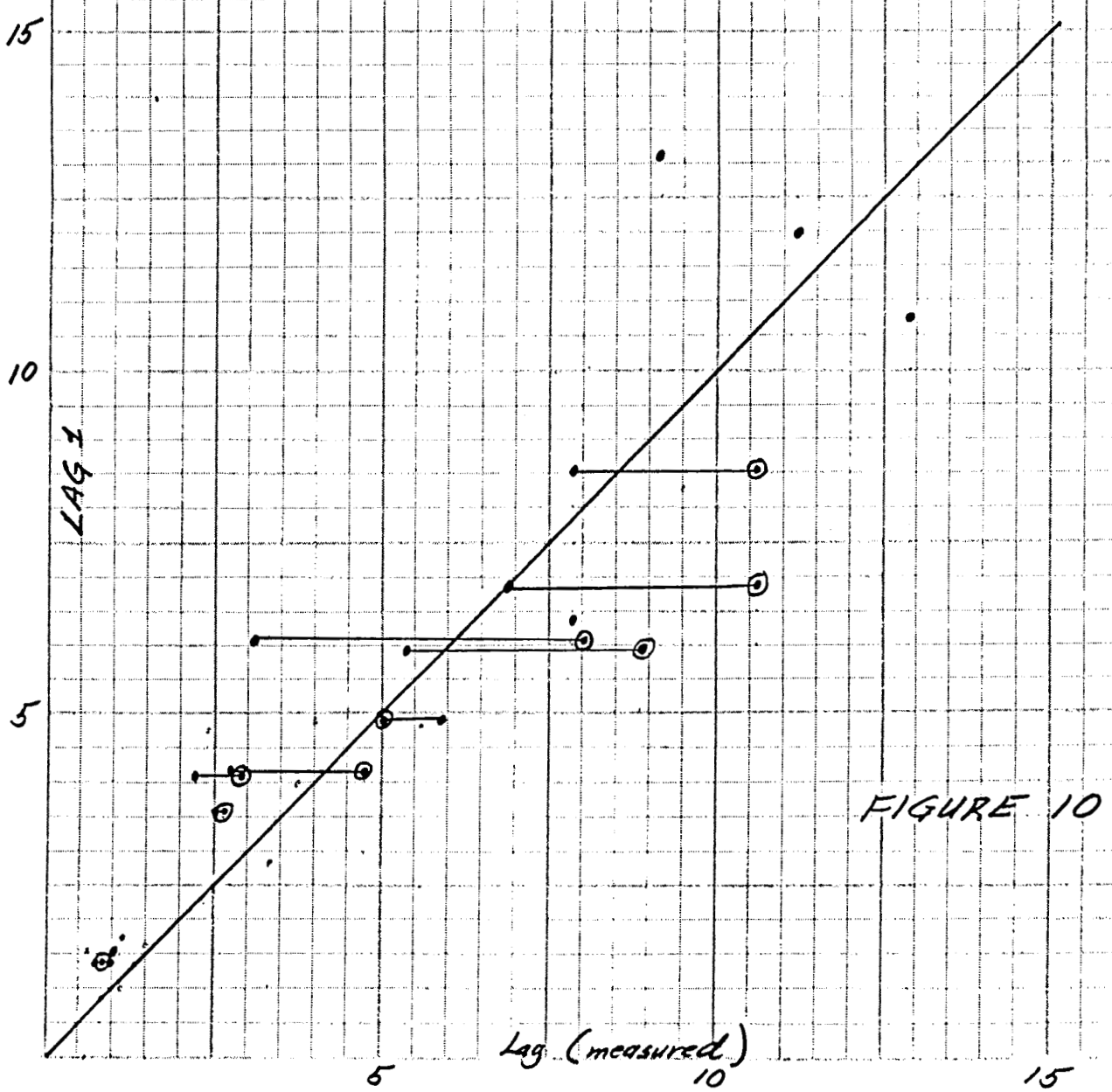


FIGURE 10

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG2 = CL2\left(\frac{L \cdot LCA}{S^2}\right)^{.25}$$

$$CL2 = -18.0 + 3.3 \log DA + 10.5 \log S$$

• for Sept 70, June 72 and undated data

⊙ for Dec 67 data

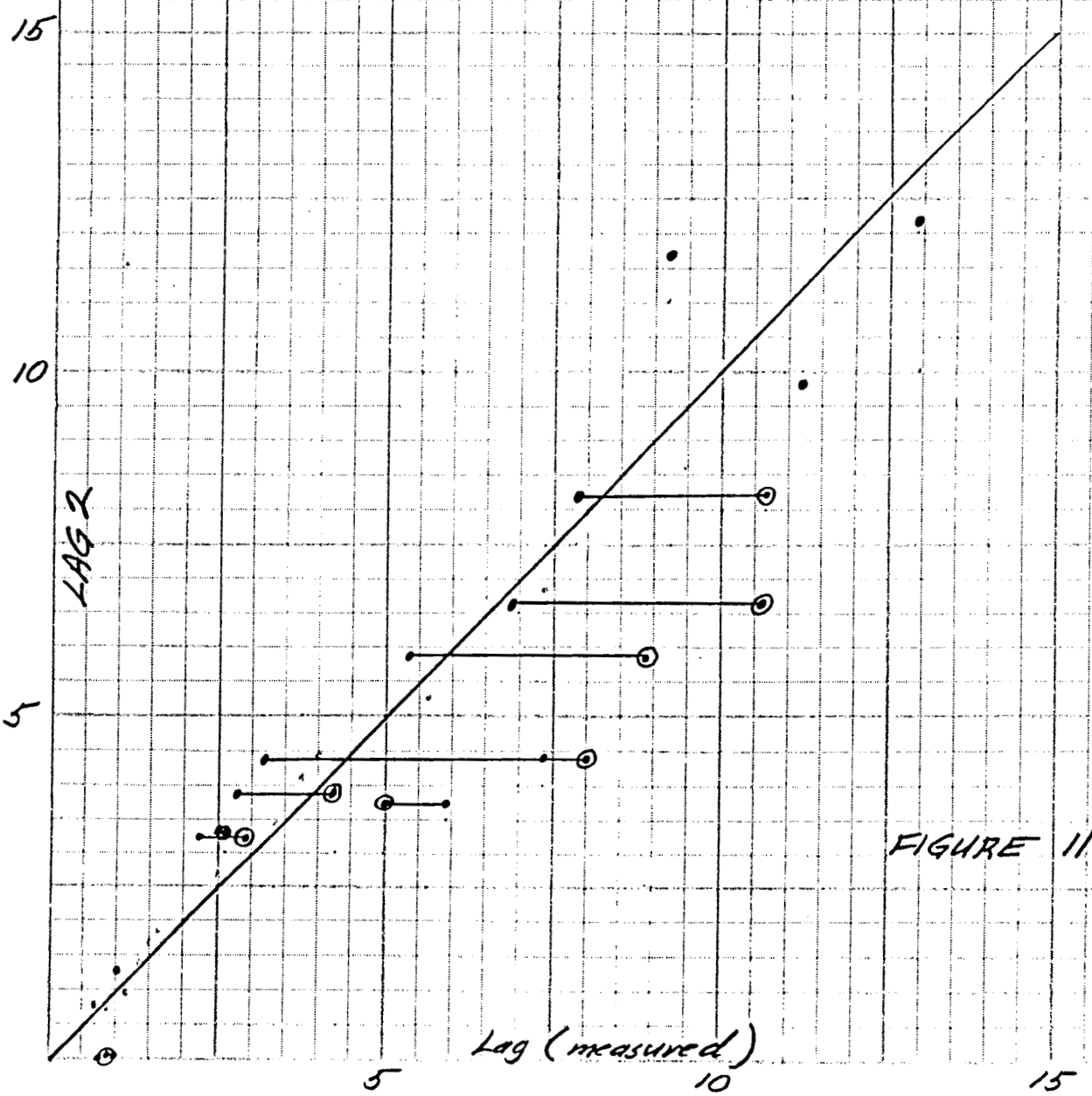


FIGURE 11

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG3 = CL3 \left(\frac{L \cdot LCA}{S^2} \right)^{.25}$$

$$CL3 = -14.2 + 3.0 \log DA + 9.0 \log S$$

• for Sept 70, June 72 and undated data

⊙ for Dec 67 data

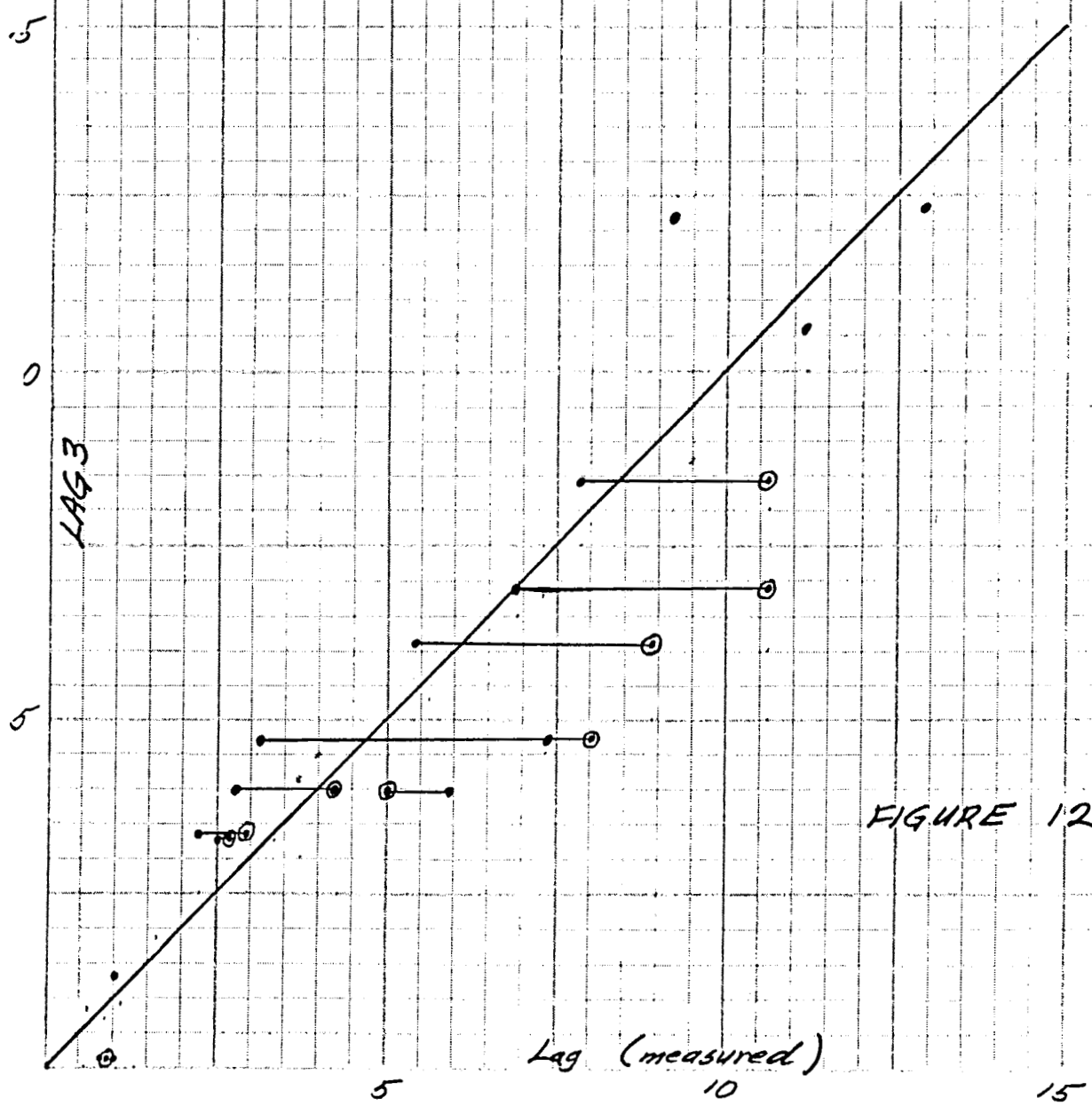


FIGURE 12

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG4 = CL4\left(\frac{L \cdot LCA}{S^2}\right)^{.25}$$

$$CL4 = 10^{(.18 + .10 \log DA + .31 \log S)}$$

• for Sept 70, June 72, and undated data

⊙ for Dec 67 data

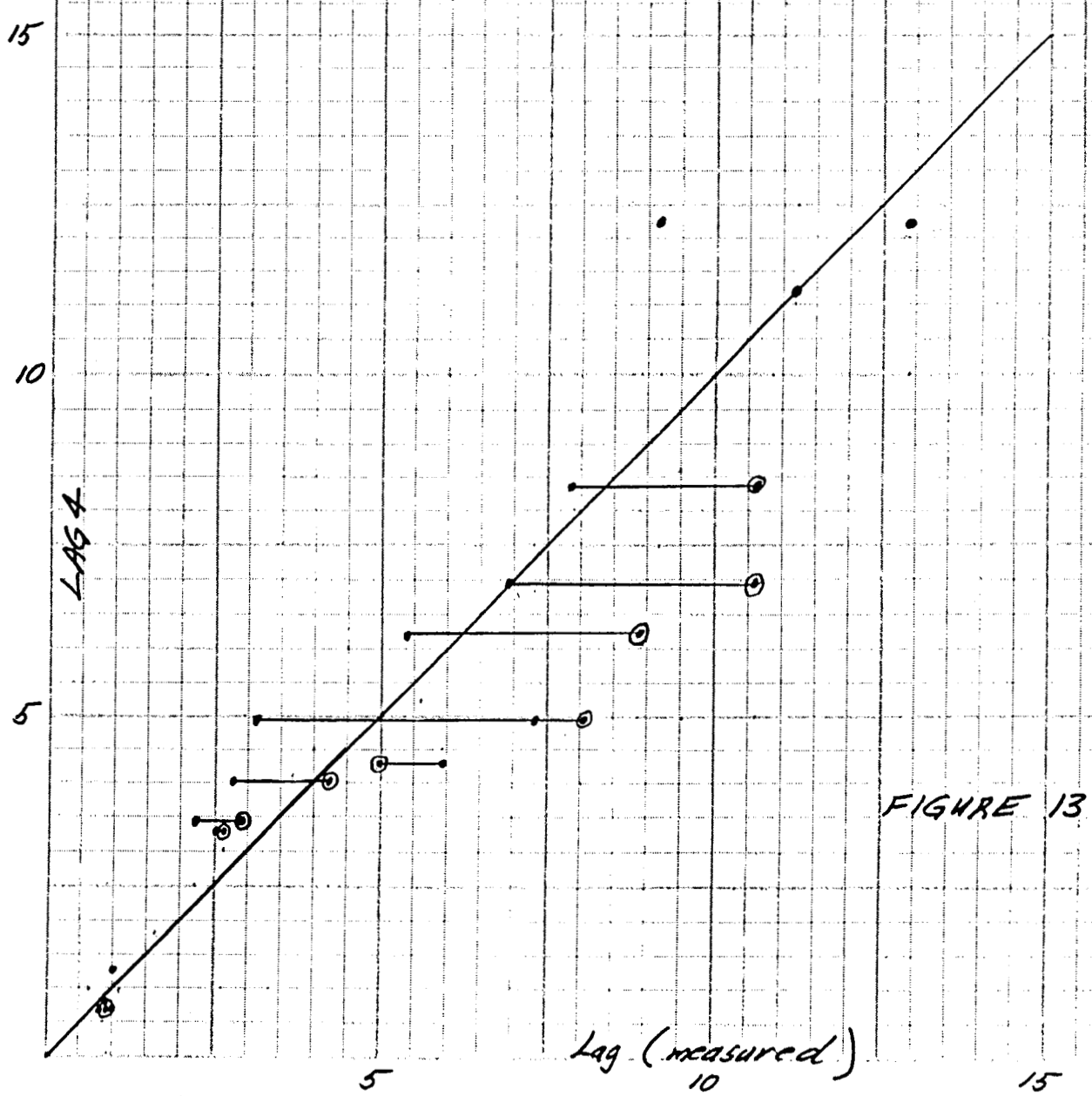
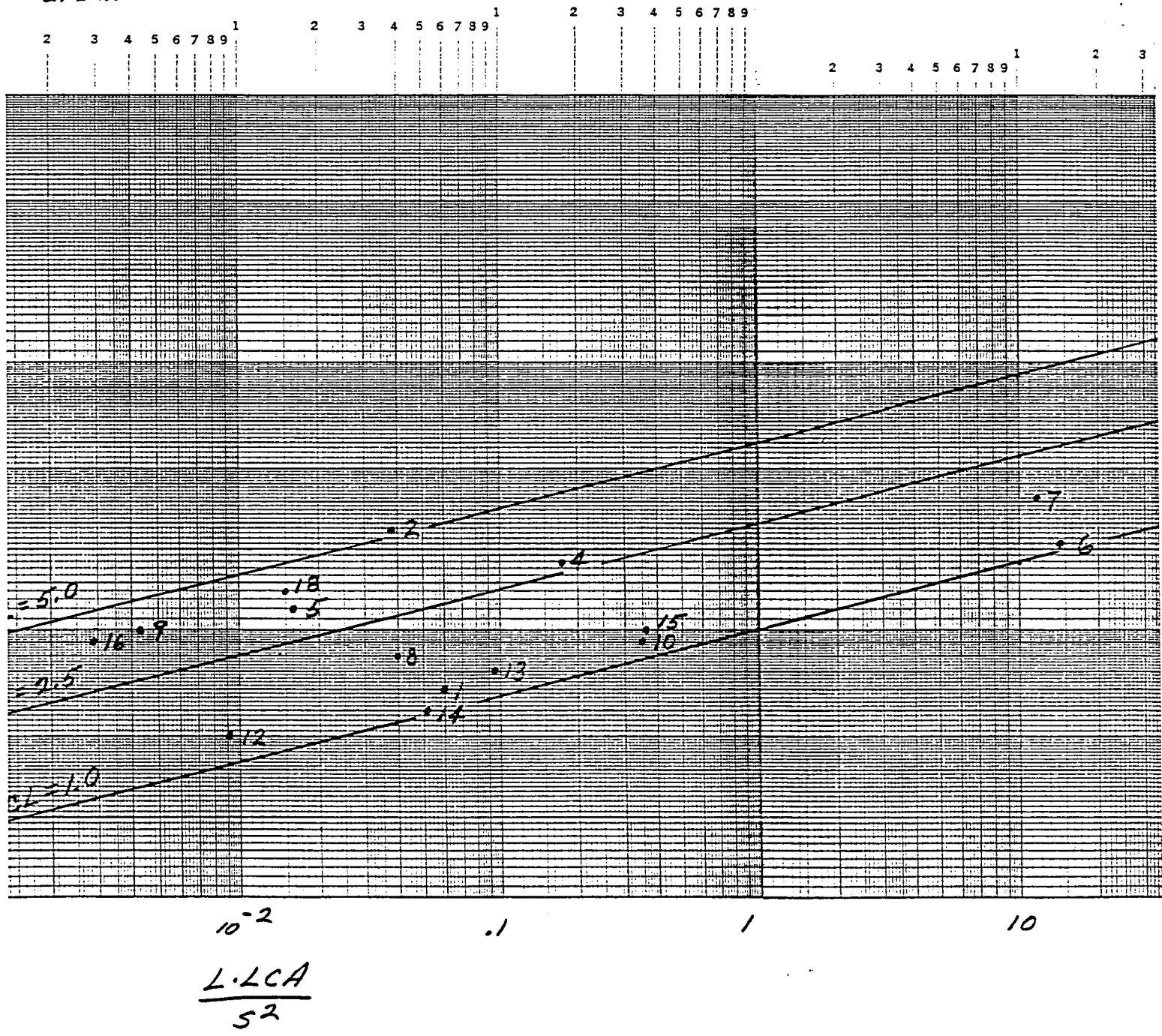


FIGURE 13

FIGURE 14

- urban watersheds



Urban Watersheds

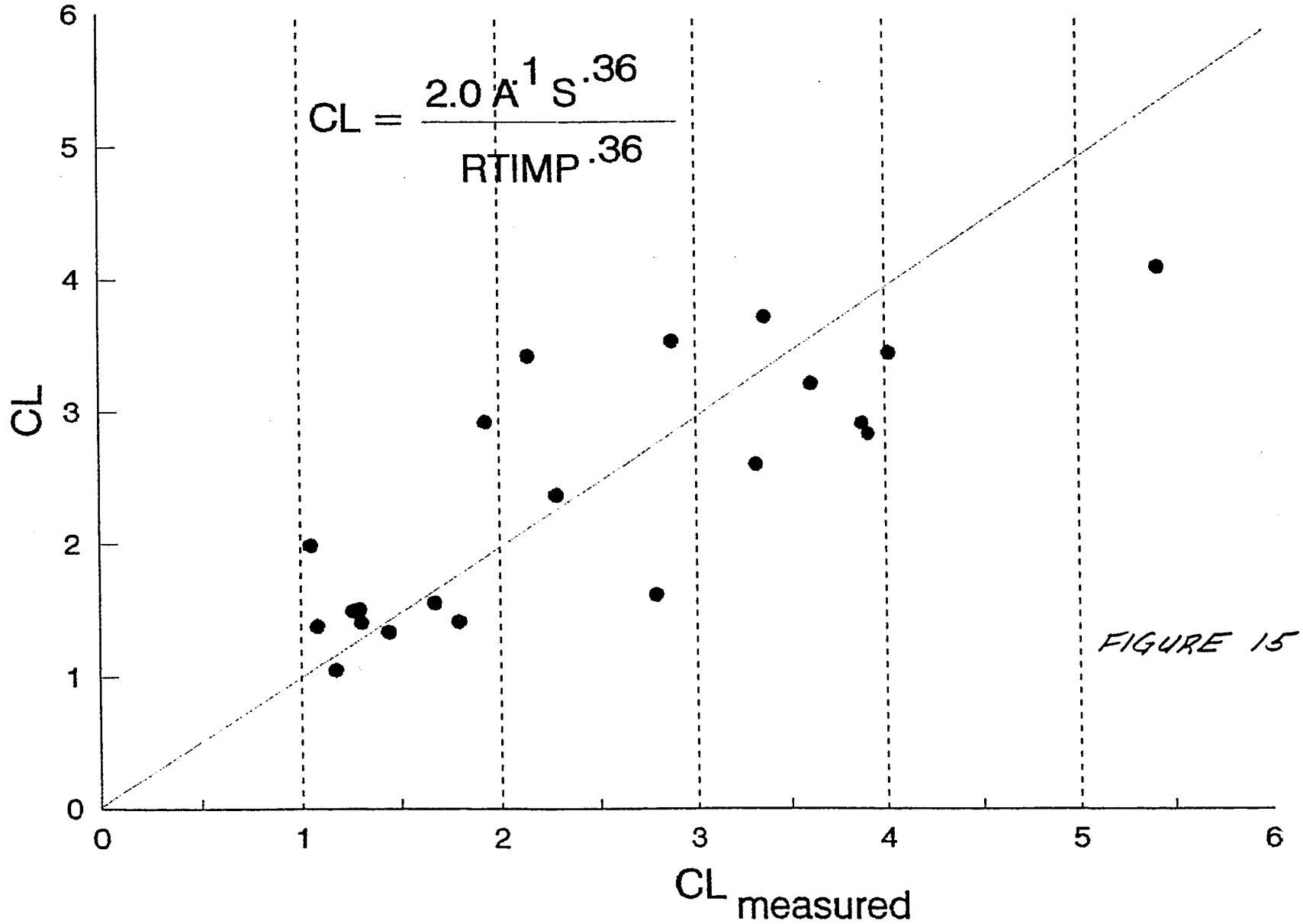


FIGURE 15

Urban Watersheds

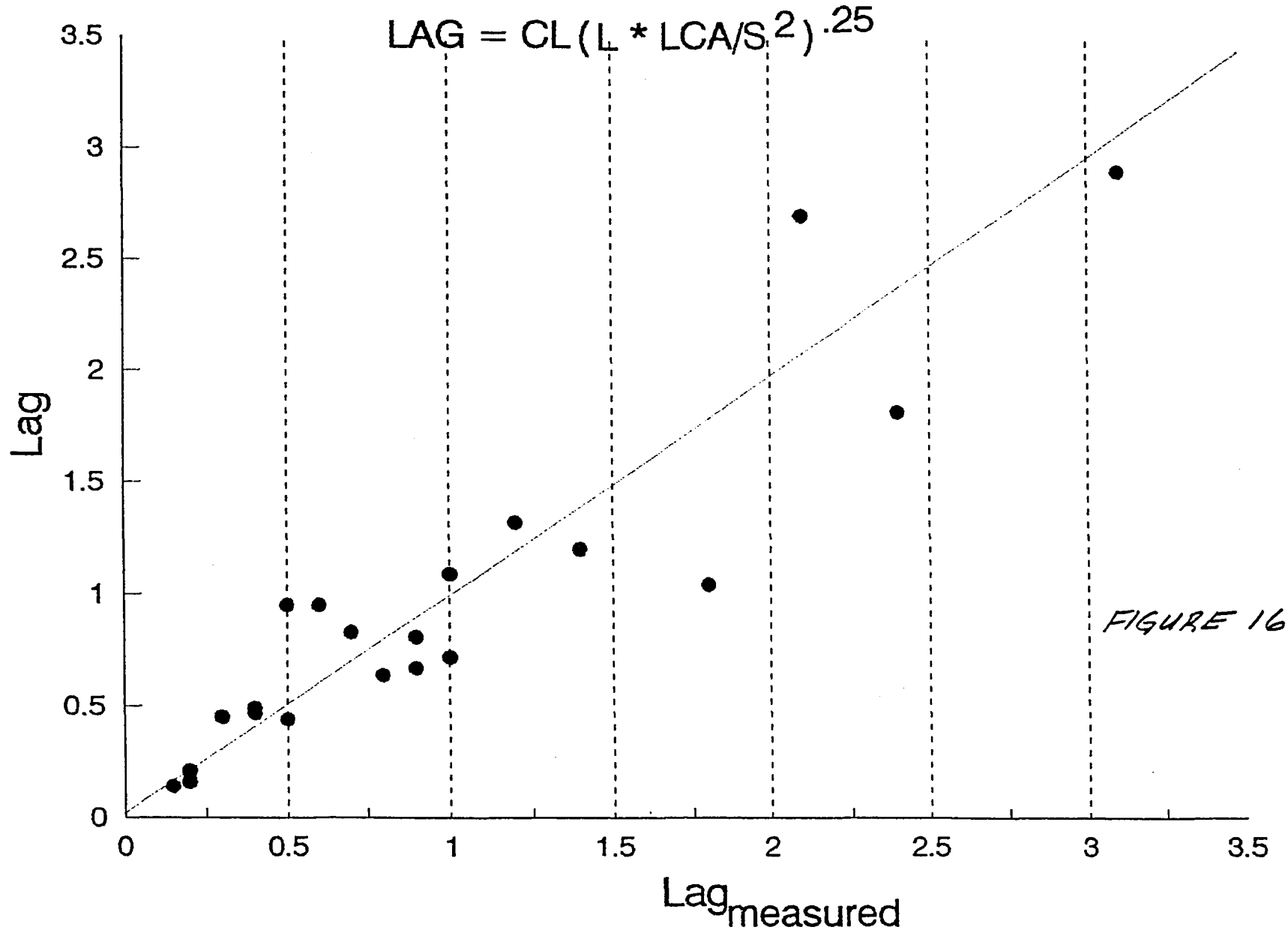


FIGURE 16

FIGURE 17

4 subbasins from the Buckeye FIS watershed model that were selected for unit hydrograph comparisons

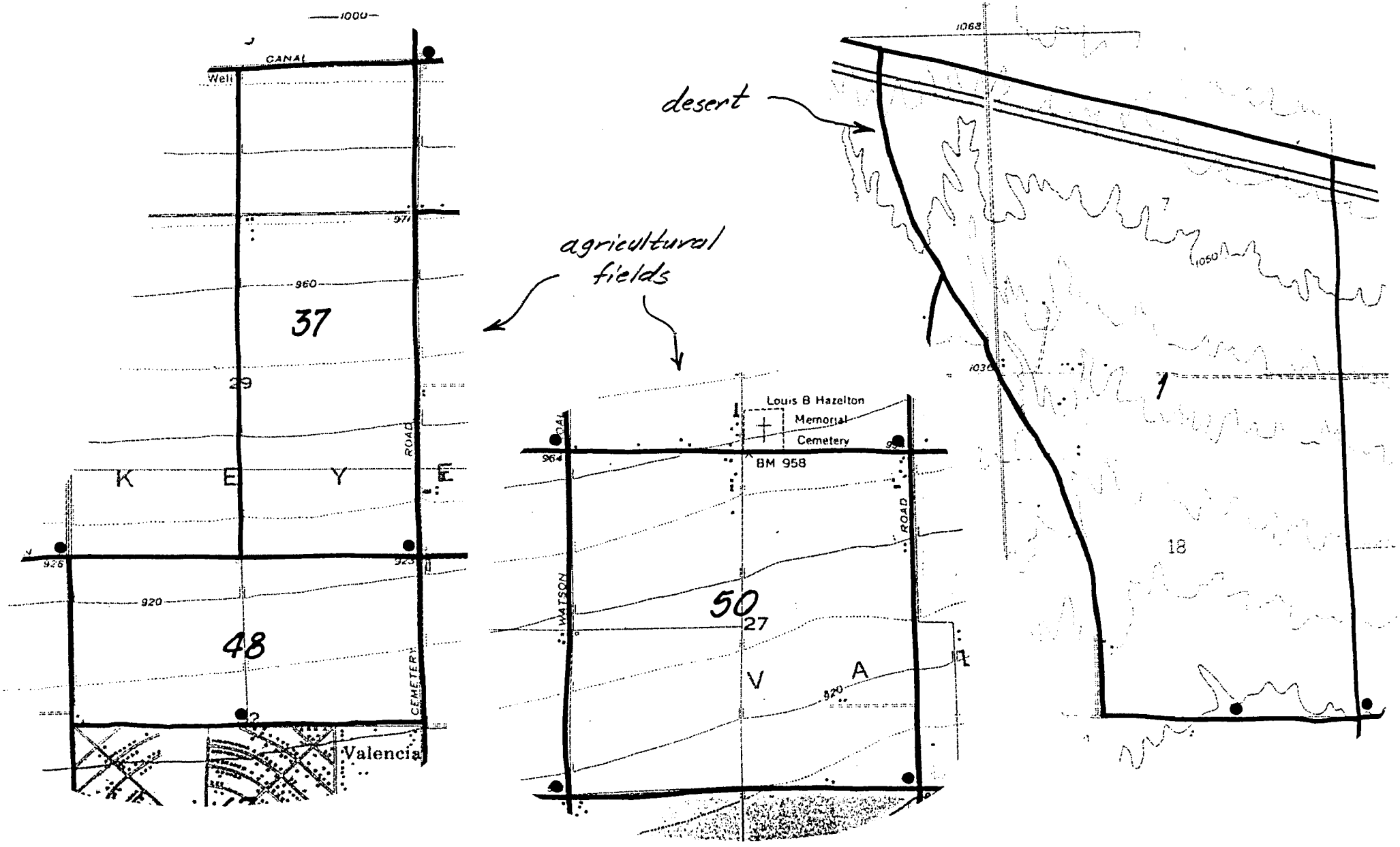
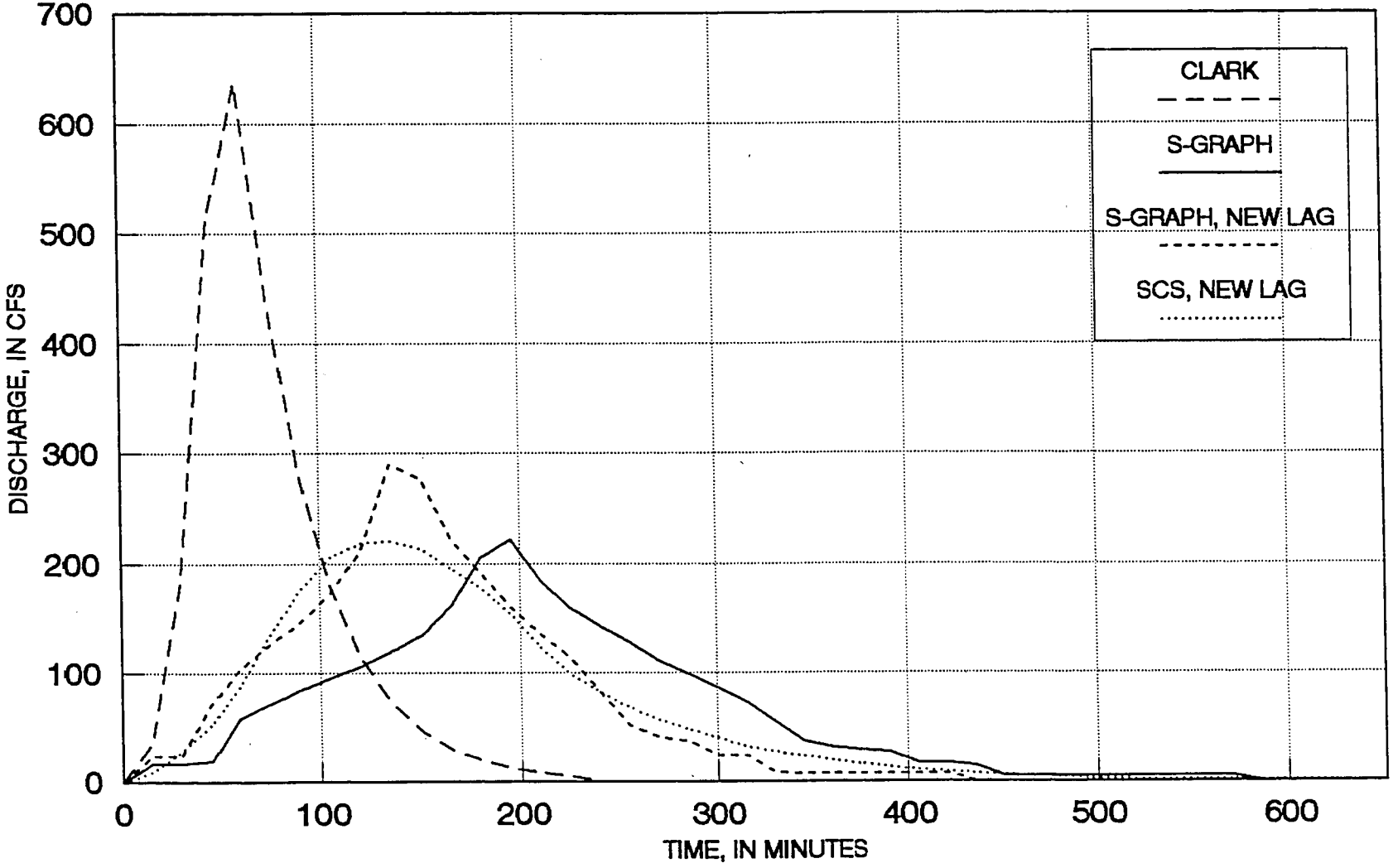


FIGURE 18

SUBBASIN #50
COMPARISON OF UNIT-HYDROGRAPHS

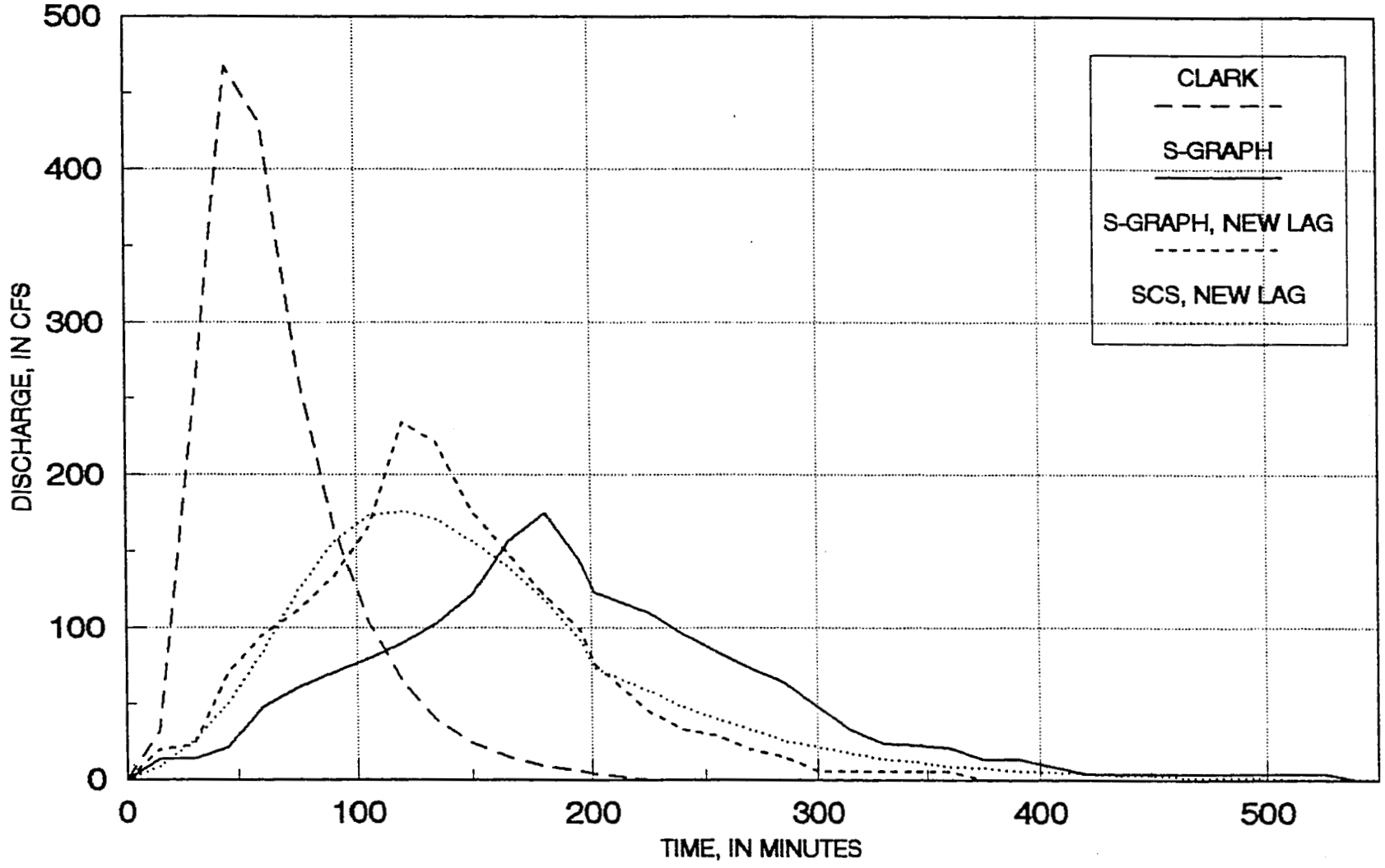


DURATION (NMIN) = 15 MINUTES

FIGURE 19

SUBBASIN #37

COMPARISON OF UNIT-HYDROGRAPHS

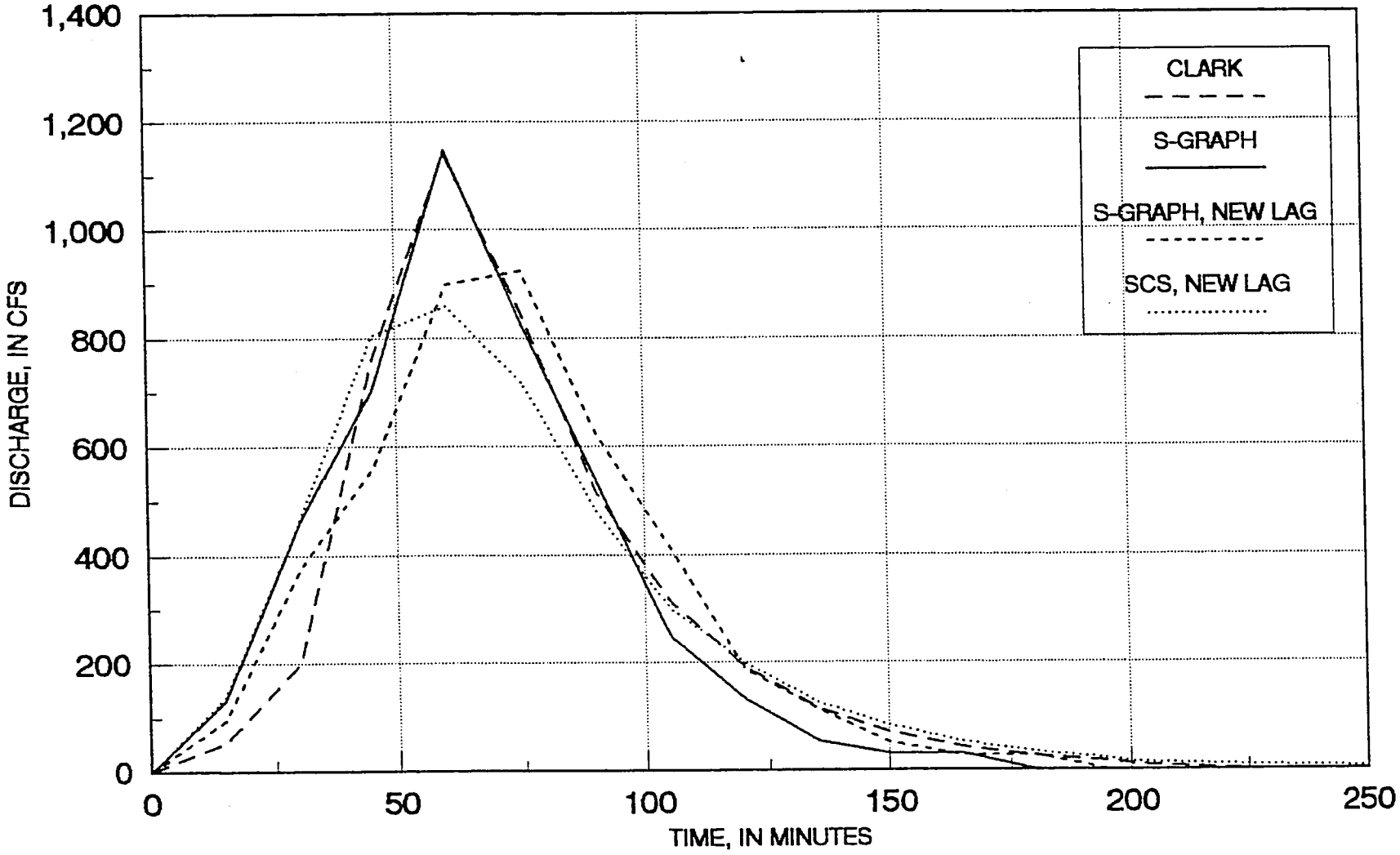


DURATION (NMIN) = 15 MINUTES

FIGURE 21

SUBBASIN #1

COMPARISON OF UNIT-HYDROGRAPHS

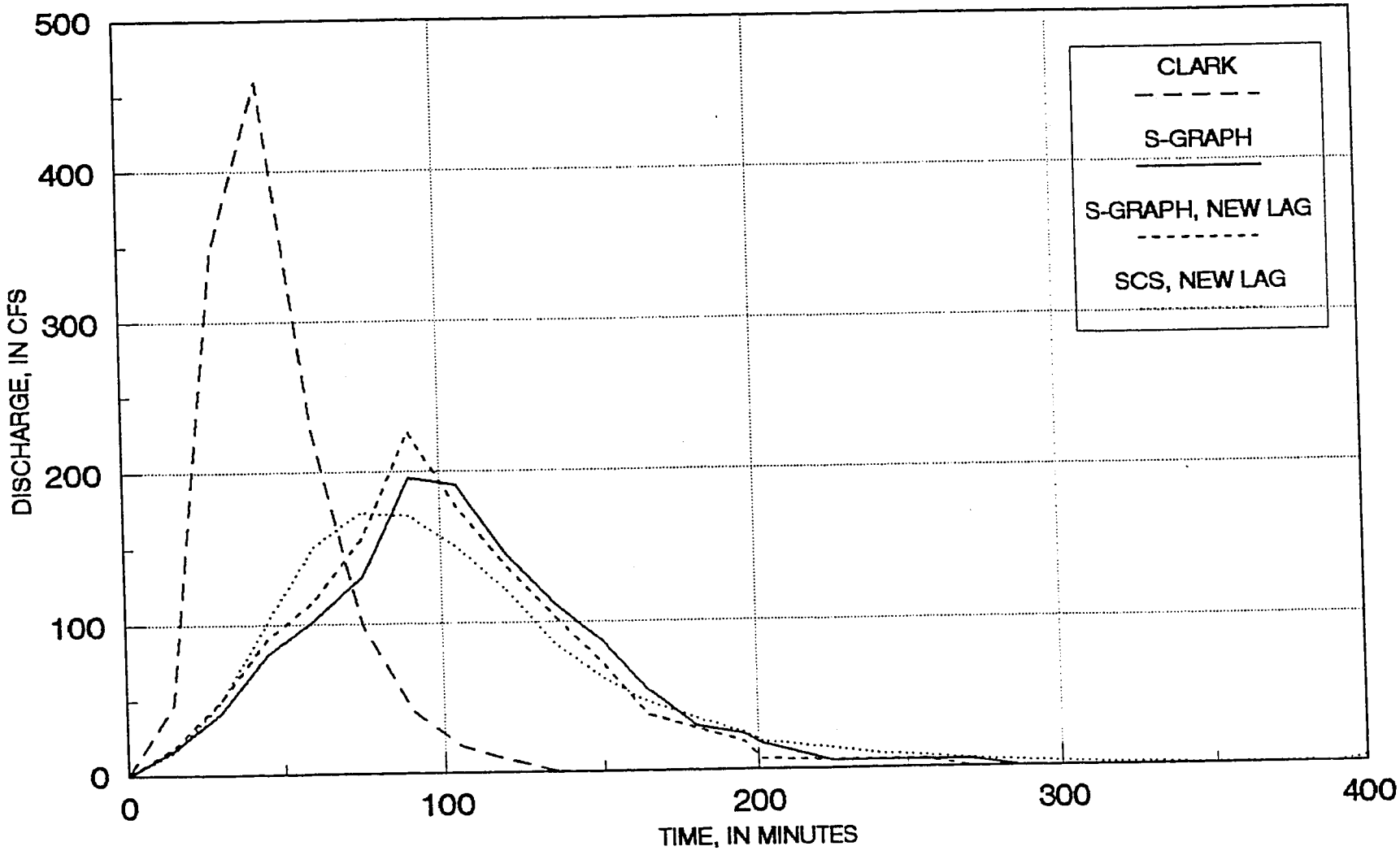


DURATION (NMIN) = 15 MINUTES

FIGURE 20

SUBBASIN #48

COMPARISON OF UNIT-HYDROGRAPHS



DURATION (NMIN) = 15 MINUTES

APPENDIX A

Table 4-3.—Unit hydrograph lag data for the Southwest Desert, Great Basin, and Colorado Plateau.

Index No.	Station and location	Drainage area, mi²	Basin factor, $LL_{ca}/S^{0.5}$	Lag time, L_g, hours	K_n	C_t
1	Salt River at Roosevelt, AZ	4341.0	1261.0	16.0	0.058	1.51
2	Verde R. above E. Verde and below Jerome, AZ	3190.0	760.0	12.0	.052	1.35
3	Tonto Cr. above Gun Cr., AZ	678.0	66.3	6.5	.063	1.64
4	Agua Fria R. nr. Mayer, AZ	590.0	63.2	5.4	.053	1.38
5	San Gabriel R. at San Gabriel Dam, CA	162.0	14.4	3.3	.053	1.38
6	West Fk. San Gabriel R. at Cogswell Dam, CA	40.4	1.8	1.6	.051	1.33
7	Santa Anita Cr. at Santa Anita Dam, CA	10.8	0.6	1.1	.050	1.30
8	Sand Dimas Cr. at San Dimas Dam, CO	16.2	2.0	1.5	.046	1.20
9	Eaton Wash at Eaton Wash Dam, CA	9.5	1.3	1.3	.046	1.20
10	San Antonio Cr. nr. Claremont, CA	16.9	0.6	1.2	.055	1.43
11	Santa Clara R. nr. Saugus, CA	355.0	48.2	5.6	.060	1.56
12	Temecula Cr. at Pauba Canyon, CA	168.0	24.1	3.7	.050	1.30
13	Santa Margarita R. nr. Fallbrook, CA	645.0	99.2	7.3	.062	1.61
14	Santa Margarita R. at Ysidora, CA	740.0	228.0	9.5	.061	1.59
15	Live Oak Cr. at Live Oak Dam, CA	2.3	0.2	0.8	.052	1.35
16	Tujunga Cr. at Big Tujunga Dam, CA	81.4	6.5	2.5	.052	1.35
17	Murrieta Cr. at Temecula, CA	220.0	28.9	4.0	.051	1.33
18	Los Angeles R. at Sepulveda Dam, CA	152.0	14.3	3.5	.056	1.46
19	Pacoima Wash at Pacoima Dam, CA	27.8	6.8	2.4	.049	1.27
20	East Fullerton Cr. at Fullerton Dam, CA	3.1	0.5	0.6	.029	0.75
21	San Jose Cr. at Workman Mill Rd. CA	81.3	24.8	2.4	.032	0.83
22	San Vincente Cr. at Foster, CA	75.0	12.8	3.2	.053	1.38
23	San Diego R. nr. Santee, CA	380.0	95.4	9.2	.078	2.03
24	Deep Cr. nr. Hesperia, CA	137.0	28.1	2.8	.036	0.94
25	Bill Williams R. at Planet, AZ	4730.0	1476.0	16.2	.056	1.46
26	Gila R. at Conner No. 4 Damsite, AZ	2840.0	1722.0	21.5	.071	1.85
27	San Francisco R. at Jct. with Blue R., AZ	2000.0	1688.0	20.6	.068	1.77
28	Blue R., nr. Clifton, AZ	790.0	352.0	10.3	.057	1.48
29	Moencopi Wash nr. Tuba City, AZ	2490.0	473.0	9.2	.046	1.20
30	Clear Cr. nr. Winslow, AZ	607.0	570.0	11.2	.053	1.38
31	Puerco R. nr. Admana, AZ	2760.0	1225.0	15.9	.058	1.51
32	Plateau Cr. nr. Cameo, CO	604.0	89.9	7.9	.069	1.79
33	White R. nr. Watson, UT	4020.0	1473.0	15.7	.054	1.40
34	Paria R. at Lees Ferry, AZ	1570.0	296.0	10.2	.060	1.56
35	New River at Rock Springs, AZ	67.3	16.5	3.1	.047	1.22
36	New River at New River, AZ	85.7	26.3	3.7	.048	1.25
37	New R. at Bell Road nr. Phoenix, AZ	187.0	108.0	5.3	.043	1.12
38	Skunk Cr. nr. Phoenix, AZ	64.6	18.7	2.4	.035	0.91

BY	DATE	PROJECT: DESIGN OF SMALL DAMS	SHEET 1 OF 3
CHKD BY	DATE	FEATURE: CHAPTER 2, FLOOD STUDIES	

DETAILS: ULC LAG DATA - SOUTHWEST DESERT, GREAT BASIN, AND COLORADO PLATEAU.

No	Stream & Location	DA (1)	L (2)	LCA (3)	S (4)	√S	LCA/√S	LAG (6)	KN (5)	Class	Data Source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	Salt River at Roosevelt, Ariz	4341	145.	60.	47.	6.9	1261.	16.0	0.058	Desert Mtn	D.L.M. Study
2	Verde R. abv. East Verde and below Jerome, Ariz.	3190.	110.	47.	46.4	6.8	760.	12.0	0.052	Desert Mtn.	D.L.M Study
3	Tonto Cr. abv. Gun Cr., Ariz.	678.	41.	16.5	104.6	10.2	66.3	6.5	0.063	Desert Mtn	D.L.M. Study
4	Agua Fria R. nr. Mayer, Ariz.	590.	42.	14.0	87.1	9.3	63.2	5.4	0.053	Desert Hills	D.L.M Study
5	San Gabriel R. at San Gabriel Dam, Calif	162.	23.2	11.6	350.	18.7	16.4	3.3	0.053	San Gab. Calif	C.E.
6	West Fk. San Gabriel R. at Cogswell Dam, Calif.	40.4	9.3	4.2	450.	21.2	1.8	1.6	0.051	San Gab Calif	C.E.
7	Santa Anita Cr. at Santa Anita Dam, Calif	10.8	5.8	2.5	690.	26.3	0.6	1.1	0.050	San Gab Calif	C.E.
8	San Dimas Cr. at San Dimas Dam, Calif	16.2	8.6	4.8	440.	21.0	2.0	1.5	0.046	San Gab. Calif	C.E
9	Eaton Wash at Eaton Wash Dam, Calif	9.5	7.3	4.4	600.	24.5	1.3	1.3	0.046	San Gab Calif	C.E.
10	San Antonio Cr. nr. Claremont, Calif.	16.9	5.9	3.0	1017.	31.9	0.6	1.2	0.055	San Gab Calif	CE
11	Santa Clara R. nr. Saugus, Calif	355.	36.0	15.8	140.	11.8	48.2	5.6	0.060	San Diego Mtns Cal.	CE
12	Temecula Cr at Pauba Canyon Calif	168.	26.0	11.3	150.	12.2	24.1	3.7	0.050		CE
13	Santa Margarita R. nr. Fallbrook, Calif	645.	46.0	22.0	105.	10.2	99.2	7.3	0.062	San Diego Mtns	C.E.

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 2 OF 3
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UNIT LAG DATA - SOUTHWEST DESERT, GREAT BASIN, AND COLORADO PLATEAU.

	No	Stream & Location	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L L_{CA}}{\sqrt{S}}$	Lag	K_N	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
14	14	Santa Margarita R. at Ysidora, Calif.	740.	61.2	34.3	85.	9.2	228.	9.5	0.061	San Diego Mtns	C.E.
15	15	Live Oak Cr. at Live Oak Dam, Calif.	2.3	2.9	1.5	700.	26.5	0.2	0.8	0.052	San Gab	C.E.
16	16	Tujunga Cr. at Big Tujunga Dam, Calif.	81.4	15.1	7.3	290.	17.0	6.5	2.5	0.052	San Gab	C.E.
17	17	Murrieta Cr. at Temecula, Calif.	220.	27.2	10.3	95.	9.7	28.9	4.0	0.051		C.E.
18	18	Los Angeles R. at Sepulveda Dam, Calif.	152	19.0	9.0	145.	12.0	14.3	3.5	0.056	San Gab	C.E.
19	19	Pacoima Wash at Pacoima Dam, Calif.	27.8	15.0	8.0	315.	17.7	6.8	2.4	0.049	San Gab	C.E.
20	20	East Fullerton Cr. at Fullerton Dam, Calif.	3.1	3.2	1.7	140.	11.8	0.5	0.6	0.029	San Gab. Partial	C.E.
21	21	San Jose Cr. at Workman Mill Road, Calif.	81.3	23.7	9.1	75.	8.7	24.8	2.4	0.032	San Gab Ft. Hills Partial	C.E.
	22	San Vincente Cr. at Foster, Calif.	75.0					12.8	3.2	0.053		C.E.
	23	San Diego R. nr. Santee, Calif.	380.					95.4	9.2	0.078	San Diego Mtn	C.E.
	24	Deep Cr. nr. Hesperia, Calif.	137					28.1	2.8	0.036	San Gab Backsite	C.E.
	25	Bill Williams R. at Planet, Ariz.	4730					1476.	16.2	0.056	Desert	C.E.
22	26	Gila R. at Conner #4 Damsite, Ariz.	2840	131.	71.	29.	5.4	1722.	21.5	0.071	Desert Mtn	C.E.

BY	DATE	PROJECT	SHEET 3 OF 3
CHKD BY	DATE	FEATURE	

DETAILS: UNIT LAG DATA - SOUTHWEST DESERT, GREAT BASIN, AND COLORADO PLATEAU.

No.	Stream & Location	DA	L	L_{CA}	S	TE	$\frac{L L_{CA}}{TE}$	LAG	K_N	Class	Data Source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
27	San Francisco R. at Jct. with Blue R., Ariz.	2000	130.	74.	32.	5.7	1688.	20.6	.068	Desert	C.E.
28	Blue R. nr. Clifton, Ariz.	790.	77.	37.	65.	8.1	352.	10.3	0.057	Desert	C.E.
29	Moencopi Wash nr. Tuba City, Ariz.	2490.					473.	9.2	0.046	Desert	C.E.
30	Clear Cr. nr. Winslow, Ariz.	607.					570.	11.2	0.053	Desert	C.E.
31	Puerco R. nr. Adamana, Ariz.	2760.					1225.	15.9	0.058	Desert	C.E.
32	Plateau Cr. nr. Cameo, Colo.	604.					89.9	7.9	0.069	Colo. West. Desert	C.E.
33	White R. nr. Watson, Ut.	4020.					1473.	15.7	0.054	Colo. West Desert	C.E.
34	Paria R. at Lees Ferry, Ariz.	1570.					296.	10.2	0.060	Desert	C.E.
35	New River at Rock Springs, Ariz.	67.3	20.2	9.7	141.	11.9	16.5	3.1	0.047	Desert	C.E.
36	New River at New River, Ariz.	85.7	23.2	13.6	145.	12.0	26.3	3.7	0.048	Desert	C.E.
37	New R. at Bell Road nr. Phoenix, Ariz.	187.	27.6	20.7	83.	9.1	108.	5.3	0.043	Desert	C.E.
38	Skunk Cr. nr. Phoenix, Ariz.	64.6	17.6	10.0	89.	9.4	18.7	2.4	0.035	Desert	C.E.

Table 4-2.—Unit hydrograph lag data for the Rocky Mountains, New Mexico, Colorado, Utah, Wyoming, Montana, Idaho, and Oregon.

Index No.	Station and location	Drainage area, mi²	Basin factor, $LL_{ca}/S^{0.5}$	Lag time, L_g, hours	K_n	C_t
1	Purgatoire R. at Trinidad, CO	742.0	69.8	8.0	0.076	1.98
2	Wood R. nr. Meeteetse, WY	194.0	41.9	21.5	.241	6.27
3	Grey Bull R. nr. Meeteetse, WY	681.0	68.3	34.0	.324	8.42
4	San Miguel R. at Naturita, CO	1080.0	174.0	34.0	.238	6.19
5	Uncompaghre R. at Delta, CO	1110.0	216.0	36.0	.235	6.11
6	Dry Gulch nr. Estes Park, CO	2.1	0.2	0.9	.059	1.53
7	Rabbit Gulch nr. Estes Park, CO	3.4	0.2	1.0	.065	1.69
8	North Fk. Big Thompson R. nr. Glen Haven, CO	1.3	0.1	0.7	.058	1.51
9	Uintah R. nr. Neola, UT	181.0	59.0	32.0	.324	8.42
10	South Fk. Payette R. nr. Garden Valley, ID	779.0	123.0	30.0	.236	6.14
11	Malheur R. nr. Drewsey, OR	910.0	114.0	30.0	.242	6.29
12	Weiser R. above Craney Cr. nr. Weiser, ID	1160.0	310.0	37.0	.214	5.56
13	Madison R. nr. Three Forks, MT	2511.0	2060.0	50.0	.155	4.03
14	Gallatin R. at Logan, MT	1795.0	443.0	38.0	.196	5.10
15	Surface Cr. at Cedaredge, CO	43.0	11.3	11.3	.195	5.07
16	South Piney Cr. at Willow Park, WY	28.9	3.8	10.5	.260	6.76
17	Piney Cr. at Kearney, WY	106.0	29.0	16.5	.209	5.43
18	Coal Cr. nr. Cedar City, UT	92.0	6.6	2.4	.050	1.30
19	Sevier R. nr. Hatch, UT	260.0	41.0	5.1	.058	1.51
20	Sevier R. nr. Kingston, UT	1110.0	469.0	11.0	.056	1.46
21	Centerville Cr. nr. Centerville, UT	3.9	0.4	2.4	.124	3.22
22	Parrish Cr. nr. Centerville, UT	2.0	0.3	2.2	.126	3.28
23	Florida R. nr. Hermosa, CO	69.4	12.5	15.5	.259	6.73
24	Dolores R. nr. McPhee, CO	793.0	193.0	9.0	.061	1.59
25	Los Pinos R. nr. Bayfield, CO	284.0	35.0	28.5	.339	8.81

BY	DATE	PROJECT: DESIGN OF SMALL DAMS	SHEET 1 OF 2
CHKD BY	DATE	FEATURE: CHAPTER 3, FLOOD STUDIES	
DETAILS: UHG LAG DATA - ROCKY MOUNTAINS			

	No	Stream & Location	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L L_{CA}}{\sqrt{S}}$	L_{CG}	K_N	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
29	1	Purgatoire R. at Trinidad, Colo.	742.	44.0	20.0	159.	12.6	69.8	8.0	0.076	Southern Rockies E. Slope	B.R.
30	2.	Wood R. nr. Meeteetse, Wyo.	194.	32.1	18.0	190.	13.8	41.9	21.5	0.241	North Rockies E. Slope	B.R.
31	3.	Grey Bull R. nr. Meeteetse, Wyo.	681.	43.6	18.8	144.	12.0	68.3	34.0	0.324	North. Rockies E. Slope	B.R.
	4.	San Miguel R at Naturita, Colo.	1080.					174	34.0	0.238	South. Rockies W. Slope	B.R.
	5	Uncompaghre R. at Delta, Colo	1110					216.	36.0	0.235	South Rockies W. Slope	B.R.
32	6	Dry Gulch nr. Estes Park, Colo	2.1	2.7	1.0	295.	17.1	0.2	0.9	0.059	Central Rockies E. Slope	B.R.
33	7	Rabbit Gulch nr. Estes Park, Colo	3.4	3.3	1.5	480.	21.9	0.2	1.0	0.065	Central Rockies E. Slope	B.R
34	8	North Fk. Big Thompson R. nr. Glen Haven, Colo.	1.3	1.9	1.3	709.	26.6	0.1	0.7	0.058	Central Rockies E. Slope	B.R
	9	Uintah R. nr Neola, Ut.	181.					57.	32.	0.324	~~[illegible]~~ Uintah Mtns	B.R.
	10	South Fk. Payette R. nr. Gordon Valley, Ore.	779.					123.	30.	0.236	North Rockies W. Slope	B.R
	11	Malheur R. nr. Drewsey, Ore	910.					114.	30.	0.242	North Rockies W. Slope	B.R
	12	Weiser R. abv. Cranney Cr. nr Weiser, Ore	1160.					310.	37.	0.214	North Rockies W. Slope	B.R
	13.	Madison R. nr. Three Forks, Mont.	2511.					2060.	50.	0.155	North Rockies E. Slope	B.R

Bureau of Reclamation

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 2 OF 2
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	
DETAILS UHG LAG DATA - ROCKY MOUNTAINS			

	No	Stream & Location	DA	L	Lca	S	TE	Lca/TE	Lag	Kn	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	14	Gallitin R. at Logan, Mont.	1745.					443.	38.	0.196	North Rockies E. Slope	BR, DLM.
	15	Surface Cr. at Cedaredge, Colo.	43.					11.3	11.3	0.195	Central Rockies W. Slope	J.F.L. File
	16	South Piney Cr. at ~~Kearney, Wyo.~~ Willow Park, Wyo	28.9					3.8	10.5	0.260		J.L. File
	17	Piney Cr. at Kearney, Wyo	106.					29.	16.5	0.209		J.L. File
35	18	Coal Cr nr. Cedar City, Ut.	92.	16.5	7.1	310	17.6	6.6	2.4	0.050	South Ut Mtns	J.F.L. File
36	19	Sevier R. nr Hatch, Ut.	260.	29.	14.	100.	10.0	41.	5.1	0.058	So. Ut. Mtns	JFL File
37	20	Sevier R. nr Kingston, Ut.	110.	82.	40.	49.	7.0	469.	11.0	0.056	So. Ut. Mtns	J.L. File.
	21	Centerville Cr. nr Centerville, Ut.	3.9					0.4	2.4	0.126	Wasatch W. Face	J.L. File
	22	Parrish Cr. nr Centerville, Ut	2.0					0.3	2.2	0.126	Wasatch W. Face	J.L. File
	23	Florida R. nr Hermosa, Colo	694					12.5	15.5	0.259	South Rockies W. Slope	J.L. File
	24	Dolores R. nr McPhee, Colo.	793.					193.	9.0	0.061	South. Rockies W. Slope	J.L. File
	25	Los Pinos R. nr Bayfield Colo	284.					35.	28.5	0.339	South Rockies W. Slope	J.L. File

Table 4-6.—Unit hydrograph lag data for urban basins.

Index No.	Station and location	Drainage area, mi²	Basin factor, $LL_{ca}/S^{0.5}$	Lag time, L_g, hours	K_n	C_t
1	Alhambra Wash above Short St., Monterey Park, CA	14.0	4.8	0.6	0.011	0.29
2	San Jose Cr. at Workman Mill Rd., Whittier, CA	81.3	24.8	2.4	.032	0.83
3	Broadway Drain at Raymond Dike, CA	2.5	0.6	0.3	.014	0.36
4	Compton Cr. below Hooper Ave. Storm Drain, L.A., CA	19.5	9.7	1.8	.033	0.86
5	Ballona Cr. at Sawtelle Blvd., L.A., CA	88.6	8.3	1.2	.023	0.60
6	Brays Bayou, Houston, TX	88.4	121.0	2.1	.017	0.44
7	White Oak Bayou, Houston, TX	92.0	134.0	3.1	.024	0.62
8	Boneyard Cr., Austin, TX	4.5	1.2	0.8	.029	0.75
9	Waller Cr., Austin, TX	4.1	1.4	1.0	.034	0.88
10	Beargrass Cr., Louisville, KY	9.7	5.6	0.9	.020	0.52
11	17th Street Sewer, Louisville, KY	0.2	0.04	0.15	.017	0.44
12	Northwest Trunk, Louisville, KY	1.9	0.8	0.4	.014	0.36
13	Southern Outfall, Louisville, KY	6.4	4.4	0.7	.017	0.44
14	Southwest Outfall, Louisville, KY	7.5	4.1	0.50	.012	0.31
15	Beargrass Cr., Louisville, KY	6.3	3.4	1.0	.026	0.68
16	Tripps Run nr. Falls Church, VA	4.6	1.1	0.9	.033	0.86
17	Tripps Run at Falls Church, VA	1.8	0.26	0.5	.030	0.78
18	Four Mile Run at Alexandria, VA	14.4	4.2	1.4	.034	0.88
19	Little Pimmit Run at Arlington, VA	2.3	0.25	0.4	.024	0.62
20	Piney Branch at Vienna, VA	0.3	0.01	0.2	.035	0.91
21	Walker Avenue Drain at Baltimore, MD	0.2	0.04	0.2	.022	0.57

Bureau of Reclamation

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 1 OF
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UHG LAG DATA - URBANIZED DRAINAGES

	ID	STREAM & LOCATION	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L L_{CA}}{\sqrt{S}}$	LAG	K_N	CLASS	DATA SOURCE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
77	1	ALHAMBRA WASH ABV SHORT ST, CALIF	14.0	9.5	4.6	85.	9.2	4.8	0.6	0.011	40% IMP	C.E.
78	2.	SAN JOSE CR AT WORKMAN MILL RD, CALIF.	81.3	23.7	9.1	75.	8.7	24.8	2.4	0.032	35% IMP	C.E.
79	3	BROADWAY DRAIN AT RAYMOND DIKE, CALIF	2.5	3.4	1.7	100	10.0	0.6	0.3	0.014	45% IMP	C.E.
80	4	COMPTON CR. BEL. HOOPER AVE. STORM DRAIN, L.A. CALIF.	19.5	8.8	4.2	14.6	3.8	9.7	1.8	0.033	60% IMP	CE
81	5	BALLONA CR. AT SANTELLE BLVD, L.A., CALIF	88.6	11.8	5.6	64.	8.0	8.3	1.2	0.023	40% IMP	CE.
82	6.	BRAY'S BAYOU, HOUSTON TEX.	88.4	23.3	10.4	4.1	2.0	121.	2.1	0.017	40% IMP	AGC
83	7	WHITE OAK BAYOU, HOUSTON, TEX.	92.0	23.1	12.8	5.0	2.2	134.	3.1	0.024	35% IMP	AGC
84	8.	BOWEYARD CR., AUSTIN TEX.	4.5	2.8	1.3	9.5	3.1	1.2	0.8	0.029	37% IMP	AGC
85	9	WALLER CR, AUSTIN TEX.	4.1	5.2	1.9	48.	6.9	1.4	1.0	0.034	27% IMP	AGC
86	10	BEARGRASS CR, LOUISVILLE KY	9.7	5.6	2.5	6.3	2.5	5.6	0.9	0.020	70% IMP	AGC
87	11	17TH STREET SEWER, LOUISVILLE, KY.	0.2	0.9	0.3	48	6.9	0.04	0.15	0.017	93% IMP	AGC
88	12	NORTHWEST TRUNK, LOUISVILLE, KY.	1.9	3.0	1.1	19.	4.4	0.8	0.4	0.014	50% IMP	AGC
89	13	SOUTHERN OUTFALL LOUISVILLE, KY.	6.4	6.4	2.5	13.	3.6	4.4	0.7	0.017	48% IMP	AGC

Bureau of Reclamation

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 2 OF
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UHG LAG DATA - URBAN DRAINAGES

No	STREAM & LOCATION	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L L_{CA}}{\sqrt{S}}$	LAG	K_N	CLASS	DATA SOURCE
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
14	SOUTHWEST OUTFALL, LOUISVILLE, KY.	7.5	6.5	2.7	18.5	4.3	4.1	0.50	0.012	33% IMP	A.G.C.
15	BEARGRASS CR, LOUISVILLE, KY.	6.3	4.0	1.8	4.5	2.1	3.4	1.0	0.026	60% IMP	AGC
16	TRIPPS RUN NR. FALLS CHURCH, VA.	4.6	4.1	1.9	52.	7.2	1.1	0.9	0.053	20% IMP	AGC
17	TRIPPS RUN AT FALLS CHURCH, VA.	1.8	2.3	1.0	79.	8.9	0.26	0.5	0.030	25% IMP	AGC
18	FOUR MILE RUN AT ALEXANDRIA, VA.	14.4	7.8	3.5	43.	6.5	4.2	1.4	0.034	20% IMP	AGC
19	LITTLE PIMMIT RUN AT ARLINGTON, VA	2.3	2.2	1.0	77.	8.8	0.25	0.4	0.024	20% IMP	A.G.C.
20	PINEY BRANCH AT VIENNA, VA	0.3	0.5	0.2	87.	9.3	0.01	0.2	0.035	30% IMP	AGC
21	WALKER AVENUE DRAIN AT BALTIMORE, MD	0.2	1.0	0.4	83.	9.1	0.04	0.2	0.022	33% IMP	AGC

APPENDIX B

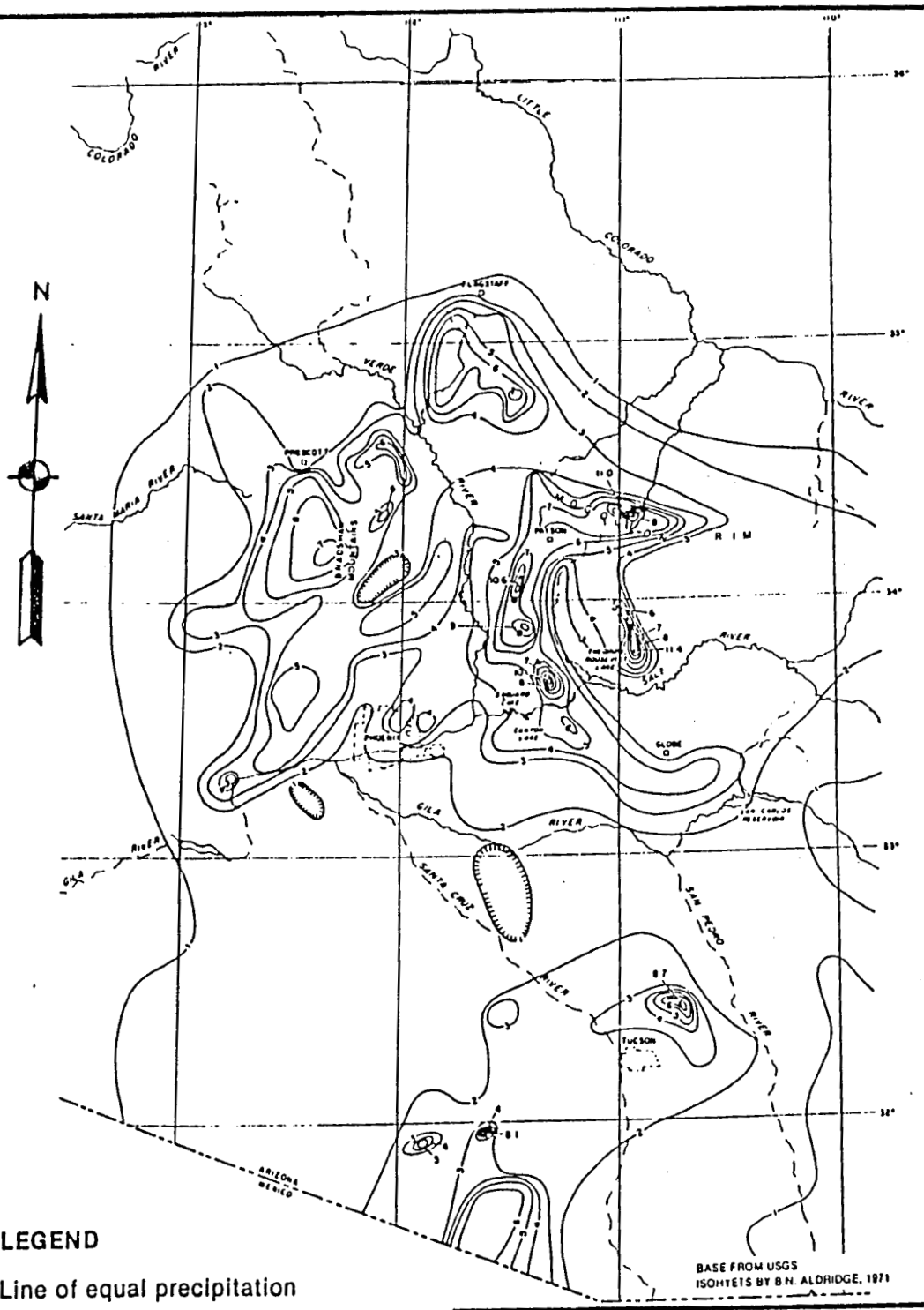
Description of the Storm and Flood of 12-21 December 1967
(Los Angeles District, 1974)

Storm and Flood of December 12-21, 1967. This storm period consisted of two general storm systems - one during December 12 through 16, and the other during December 17 through 21. During December 12 and 13, very cold air invaded Arizona from the north while a deepening upper level low pressure center off the southern California coast brought strong southerly winds aloft to Arizona and caused widespread substantial precipitation over much of the state. Snow fall was very heavy in the mountain areas with some stations reporting unprecedented snow depths and the snow level dropped to as low as 1,000 feet on December 13 and14. Precipitation from this first storm system generally diminished from December 15 through December 17, as the storm began moving to the east. A strong flow of warm moist air from the south began invading Arizona ahead of the second storm system and rainfall over the area began to increase with the snow level rising to around 5,000 feet. Around mid-day on December 19, precipitation became quite heavy over the Phoenix area as a cold front moved through the region from the northwest and a considerable amount of melting snow was added to the runoff. Precipitation intensities diminished and the snow level lowered once again late on December 19, after the passage of the cold front. New December precipitation records were set at several Arizona stations during December 1967, including 16.21 inches at Crown King, 7.30 inches at Flagstaff, and 3.92 inches at Phoenix. All of the months' precipitation fell during the 10 day period of December 12-21 in central Arizona. The heaviest daily precipitation occurred on December 19, with Crown King measuring 6.00 inches and Bumble Bee reporting 4.61 inches. With approximately 5 days of antecedent rainfall during the period December 13-18, the ground conditions were ripe to produce sizeable floods in the Phoenix area during the higher intensity rainfall which occurred during December 19. The New River-Skunk Creek system produced a peak of 19,800 c.f.s. near Glendale (323 square miles).

Description of the Storm and Flood of 3-7 September 1970
(Los Angeles District, 1982)

Isohyetal map on following page.

Storm and Flood of 3-7 September 1970. The storm began on 3 September in southern Arizona as moisture outflow from tropical storm Norma, west of Baja California, began to move into Arizona from the south. Showers pushed northward across the state on 4 September, becoming heavy at times. On 5 September, a strong cold front moved across Arizona from the west, triggering a 12- to 24-hour period of rain that reached unprecedented intensities at some stations. Precipitation tapered off rapidly late on 5 September, and only a few light showers lingered on 6-7 September. Total storm precipitation in central Arizona ranged from less than 1 inch around Coolidge Dam (San Carlos Reservoir) to nearly 12 inches in the Sierra Ancha Mountains northeast of Roosevelt Dam. Workman Creek, with a storm total of 11.92 inches, measured 11.4 inches in 24-hours—exceeding the previous all-time Arizona 24-hour record by more than 5 inches. Numerous other stations recorded from 5 to 8 inches during the heaviest 24 hours (mostly on 5 September). In and near the Agua Fria River drainage the storm total ranged from 1.78 inches at Prescott to 7.01 inches at Crown King. The latter station recorded 4.50 inches in the 24 hours ending at 6:00 p.m. on the 5th. A large portion of the maximum 24-hour precipitation fell within 4 to 6 hours. Total storm isohyets for 4-6 September are shown on plate 11. Much of central Arizona had received substantial precipitation during the first 3 to 4 weeks of August 1970. Thus, the ground was partially saturated in most areas at the beginning of the September storm. By the time of the heaviest burst of rain on 5 September conditions were favorable for heavy runoff. The high intensity rain that occurred on the 5th resulted in extensive flooding, with some streams recording all-time maximum discharges. On the New River USGS measurements at the gages near Rock Springs and at New River list peak discharges for 5 September of 18,600 and 19,500 ft^3/s, respectively. On the Agua Fria River near Rock Springs the peak discharge on 5 September was 40,100 ft^3/s (table 9). On the Hassayampa River at Box Damsite, near Wickenburg, the 58,000 ft^3/s recorded on 5 September is more than twice the previous known maximum of 27,000 ft^3/s, which is estimated to have occurred in February 1927 and which occurred again in August 1951.



LEGEND

-2- Line of equal precipitation

3 Hactures indicate less rainfall than value shown

11.4 X Shows maximum rainfall where all Isohyets cannot be shown.

NOTE: Some rainfall near the Mexican boundary occured before midnight on September 3.

SCALE 0 10 20 30 40 50 MILES

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

ISOHYETAL MAP
STORM OF SEPT. 4-6, 1970

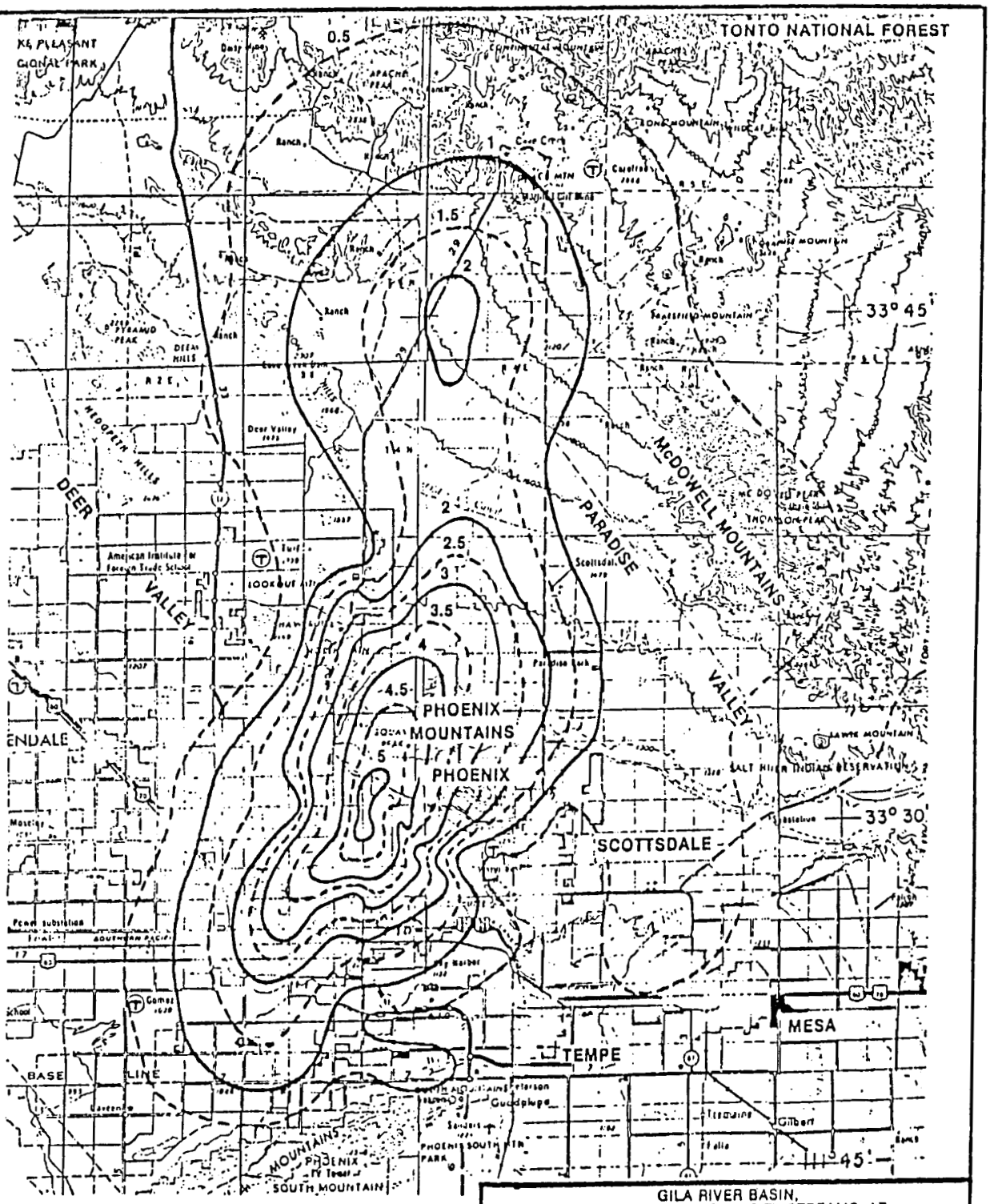
US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

Description of the Storm and Flood of 22 June 1972

(Los Angeles District, 1982)

Isohyetal map on following page.

Storm and Flood of 22 June 1972. The heavy thunderstorm that occurred over northeastern Phoenix and adjacent communities on the morning of 22 June 1972 was a part of a series of early summer thunderstorms over the entire southwestern United States from 20 through 23 June 1972 that resulted from a deep flow of very moist, tropical air into the region from off the west coast of Mexico. In Phoenix the unofficial maximum rainfall was 5.25 inches during an estimated 2 hours near 4th Street and Camelback Road. Bucket survey amounts of 4.87 inches at 24th Street and Indianola Avenue and 4.8 inches at 28th Street and Indian School Road were confirmed by the National Weather Service. The maximum recording-gage intensity was 3.85 inches in 80 minutes at 18th Street and Turney Avenue. Large hail also fell in the area. The storm was highly localized, with only 10 square miles having greater than 4 inches of rainfall and only 200 square miles with more than 2 inches. Total storm isohyets for 21-22 June are shown on plate 12. Estimates of peak discharges for 22 June made by the USGS include: Shea Wash at Shea Boulevard (1.79 square miles), 945 ft^3/s; Cudia City Wash 1000 feet upstream from McDonald Drive (2.16 square miles), 4200 ft^3/s; Dreamy Draw at 16th Street (1.62 square miles), 860 ft^3/s; Indian Bend Wash (at Indian Bend Road) near Scottsdale (142 square miles), 21,000 ft^3/s.



N

SCALE IN MILES

1 0 4 8

LEGEND

— 2 — LINE OF EQUAL PRECIPITATION IN INCHES

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

ISOHYETAL MAP
STORM OF JUNE 21-22, 1972

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

Point Rainfalls for the December 1967 Storm

Gage Location (1)	Rainfall Depth inches (2)	Type of Gage Recording (R) Nonrecording (N) (3)
Black Canyon 4NE	3.53	R
Carefree	2.75	R
New River	2.70	R
Rock Springs	3.19	R
Thunderbird Airport	1.42	R
Skunk Creek	3.59	R
Youngtown	2.35	R
Phoenix 11 NNW	1.89	R
Castle Hot Springs	4.07	N
Lake Pleasant	2.26	N
Cave Creek Dam	2.83	N
Beardsley	1.99	N
Paradise Valley	1.93	N
Litchfield Park	2.03	N
Alhambra 2NE	1.86	N
Arizona Falls	1.45	N
Tolleson 1E	1.77	N
T3N, R3E, Sec 34	2.46	N
T3N, R5E, Sec 15	2.67	N
T3N, R5E, Sec 16	2.02	N

Point Rainfalls for the September 1970 Storm

Black Canyon 4NE	2.82	R
Rock Springs	2.81	R
New River	5.39	R
Carefree	2.12	R
Skunk Creek	2.53	R
Youngtown	4.24	R
Phoenix	1.92	R
Thunderbird Airport	3.07	N
Lake Pleasant	4.11	N
Horseshoe Dam	3.94	N
Castle Hot Springs	4.56	N
Beardsley	5.04	N
Litchfield Park	3.09	N
Tolleson 1E	2.00	N

Point Rainfalls for the June 1972 Storm

Phoenix	3.13	R
Thunderbird Airport	.87	R
Carefree	.80	R

TR-55

Table 3-1.—Roughness coefficients (Manning's n) for sheet flow

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

HEC-1

Table 3.5

Resistance Factor for Overland Flow

Surface	N value	Source
Asphalt/Concrete*	0.05 - 0.15	a
Bare Packed Soil Free of Stone	0.10	c
Fallow - No Residue	0.008 - 0.012	b
Convential Tillage - No Residue	0.06 - 0.12	b
Convential Tillage - With Residue	0.16 - 0.22	b
Chisel Plow - No Residue	0.06 - 0.12	b
Chisel Plow - With Residue	0.10 - 0.16	b
Fall Disking - With Residue	0.30 - 0.50	b
No Till - No Residue	0.04 - 0.10	b
No Till (20-40 percent residue cover)	0.07 - 0.17	b
No Till (60-100 percent residue cover)	0.17 - 0.47	b
Sparse Rangeland with Debris:		
0 Percent Cover	0.09 - 0.34	b
20 Percent Cover	0.05 - 0.25	b
Sparse Vegetation	0.053 - 0.13	f
Short Grass Prairie	0.10 - 0.20	f
Poor Grass Cover On Moderately Rough	0.30	c
Bare Surface		
Light Turf	0.20	a
Average Grass Cover	0.4	c
Dense Turf	0.17 - 0.80	a,c,e,f
Dense Grass	0.17 - 0.30	d
Bermuda Grass	0.30 - 0.48	d
Dense Shrubbery and Forest Litter	0.4	a

Legend: a) Harley (1975), b) Engman (1986), c) Hathaway (1945), d) Palmer (1946), e) Ragan and Duru (1972), f) Woolhiser (1975). (See Hjemfelt, 1986)

*Asphalt/Concrete n value for open channel flow 0.01 - 0.016

APPENDIX C

APPENDIX D

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET ____ OF ____

CLIENT ATRC/ADOT

DATE 10 oct 91

PROJECT Hydro. Manual

BY GVS

SUBJECT Comparison of SCS lag & S-graph lag

PROJECT NO. S-15

Definitions:

Lag_s = S-graph lag

= time at 50% runoff volume

L = SCS dimensionless u-hg lag

For the SCS dimensionless u-hg:

$$Lag_s = 1.17\,T_p \qquad (1)$$

$$T_p = \frac{\Delta D}{2} + L \qquad (2)$$

$$\Delta D \approx .2\,T_p \qquad (3)$$

(1) & (3) into (2):

$$T_p = \frac{.2T_p}{2} + L$$

$$.9\,T_p = L$$

$$.9\left(\frac{Lag_s}{1.17}\right) = L$$

$$.77\,Lag_s = L \qquad (4)$$

Therefore, when using an S-graph lag equation to estimate lag for the SCS dimensionless u-hg, we should apply Equation 4.

Elements of a Unit Hydrograph

The dimensionless curvilinear unit hydrograph (figure 16.1) has 37.5% of the total volume in the rising side, which is represented by one unit of time and one unit of discharge. This dimensionless unit hydrograph also can be represented by an equivalent triangular hydrograph having the same units of time and discharge, thus having the same percent of volume in the rising side of the triangle (figure 16.2).

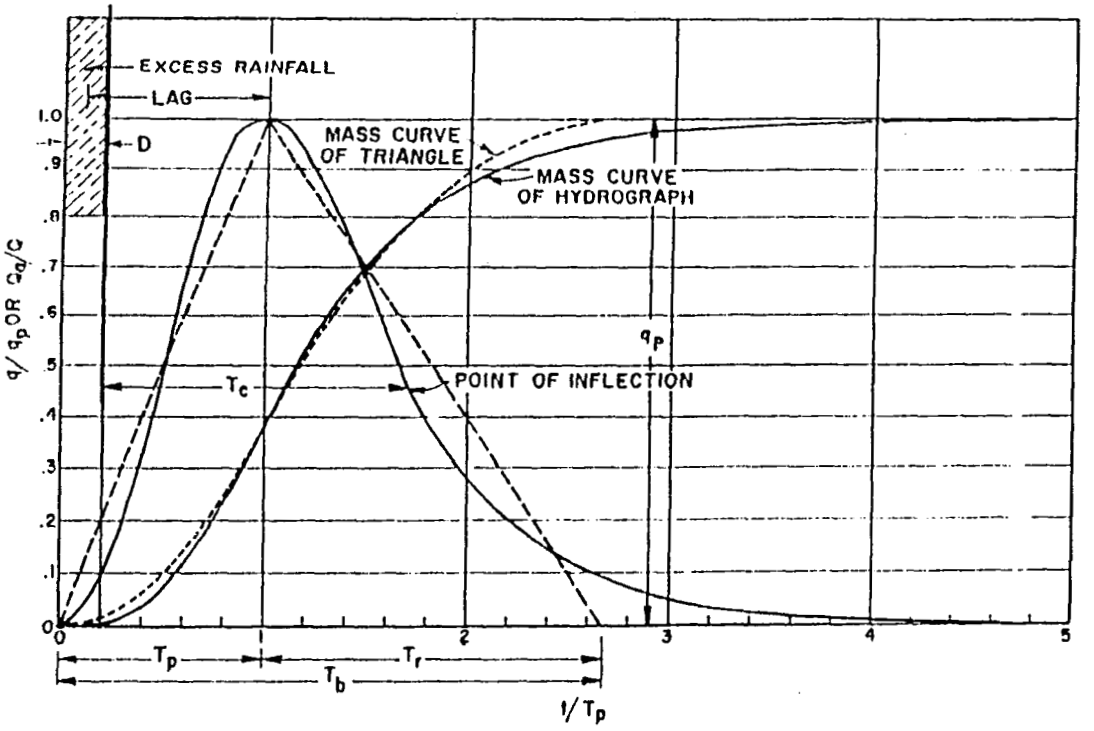
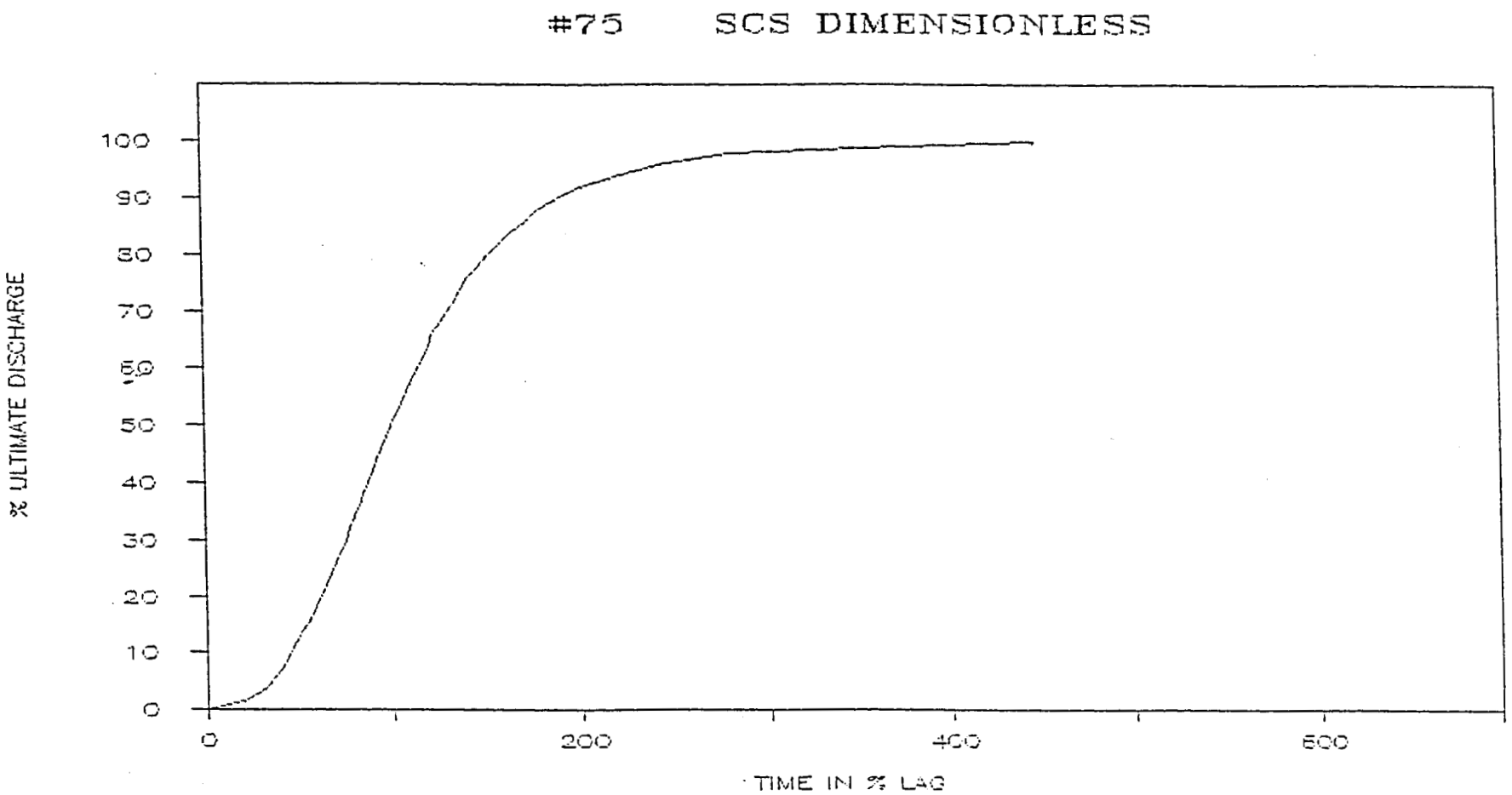


Figure 16.2 Dimensionless curvilinear unit hydrograph and equivalent triangular hydrograph

Table 16.1 Ratios for dimensionless unit hydrograph and mass curve.

Time Ratios (t/T_p)	% Lag	Discharge Ratios (q/q_p)	Mass Curve Ratios (Q_a/Q)
0		.000	.000
.1	9	.030	.001
.2	17	.100	.006
.3	26	.190	.012
.4	34	.310	.035
.5	43	.470	.065
.6	51	.660	.107
.7	60	.820	.163
.8	68	.930	.228
.9	77	.990	.300
1.0	85	1.000	.375
1.1	94	.990	.450 ← .50
$t/T_p = 1.17$ > 1.2	100	.930	.522
1.3	103	.860	.589
1.4	111	.780	.650
1.5	120	.680	.700
1.6	128	.560	.751
1.7	137	.460	.790
1.8	145	.390	.822
1.9	154	.330	.849
2.0	162	.280	.871
2.2	171	.207	.908
2.4	188	.147	.934
2.6	205	.107	.953
2.8	222	.077	.967
3.0	239	.055	.977
3.2	256	.040	.984
3.4	274	.029	.989
3.6	291	.021	.993
3.8	308	.015	.995
4.0	325	.011	.997
4.5	342	.005	.999
5.0	425	.000	1.000


#75 SCS DIMENSIONLESS
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

PC Shell Version 7 Directory Print ID = None

Path=B:\

Bullseye subbasins

Name	Ext	Size	#Clu	Date	Time	Attributes
1C	DAT	269	1	1-03-92	4:10p	A
1C	OUT	9410	19	1-03-92	4:10p	A
1S	DAT	1020	2	1-03-92	6:04p	A
1S	OUT	11211	22	1-03-92	6:04p	A
1SCS	DAT	167	1	1-03-92	3:49p	A
1SCS	OUT	8691	17	1-03-92	3:49p	A
1SN	DAT	1033	3	1-03-92	6:07p	A
1SN	OUT	11221	22	1-03-92	6:07p	A
37C	DAT	270	1	1-03-92	4:04p	A
37C	OUT	9410	19	1-03-92	4:05p	A
37S	DAT	1220	3	1-14-92	2:02p	A
37SCS	DAT	168	1	1-03-92	3:45p	A
37SCS	OUT	8925	18	1-03-92	3:45p	A
37SN	DAT	1154	3	12-11-91	11:10a	A
48C	DAT	270	1	1-03-92	4:07p	A
48C	OUT	9338	19	1-03-92	4:08p	A
48S	DAT	1072	3	12-11-91	11:19a	A
48SCS	DAT	168	1	1-03-92	3:47p	A
48SCS	OUT	8783	18	1-03-92	3:47p	A
48SN	DAT	1072	3	12-11-91	11:21a	A
50C	DAT	309	1	1-03-92	3:59p	A
50C	OUT	9637	19	1-03-92	3:59p	A
50S	DAT	1162	3	1-14-92	2:03p	A
50SCS	DAT	207	1	1-03-92	3:40p	A
50SCS	OUT	9194	18	1-03-92	3:40p	A
50SN	DAT	1098	3	12-10-91	5:30p	A

1, 37, 48 & 50 are subbasin nos.

C- Clark

S- S-graph

SCS- SCS Dim. u-hg

SN- S-graph, new tag

verification watershed comparisons

AAC	DAT	790	2	1-06-92	9:22a	A
AAC	OUT	8443	17	1-06-92	9:22a	A
AAS	DAT	938	2	1-06-92	9:29a	A
AAS	OUT	8553	17	1-06-92	9:29a	A
AASN	DAT	947	2	1-06-92	9:31a	A
AASN	OUT	8553	17	1-06-92	9:31a	A
AFTC	DAT	510	1	1-06-92	8:56a	A
AFTS	DAT	939	2	1-06-92	8:57a	A
AFTS	OUT	8553	17	1-06-92	8:57a	A
AFTSN	DAT	1030	3	1-06-92	8:59a	A
AFTSN	OUT	8663	17	1-06-92	9:00a	A
CCS	DAT	1680	4	1-06-92	10:19a	A
CCS	OUT	9543	19	1-06-92	10:20a	A
CCSG	DAT	1714	4	12-24-91	9:48a	A
CCSG	OUT	16623	33	1-06-92	10:19a	A
CCSN	DAT	1605	4	1-06-92	10:29a	A
CCSN	OUT	9433	19	1-06-92	10:29a	A
~~PARMS~~	~~DAT~~	~~62~~	~~1~~	~~1-14-92~~	~~2:05p~~	~~A~~
TAC	DAT	509	1	1-06-92	9:11a	A
TAC	OUT	8003	16	1-06-92	9:11a	A
TAS	DAT	746	2	1-06-92	9:02a	A
TAS	OUT	8223	17	1-06-92	9:04a	A
TASN	DAT	1193	3	1-06-92	9:20a	A
TASN	OUT	8883	18	1-06-92	9:20a	A
UAFRS	DAT	1170	3	1-06-92	10:03a	A
UAFRS	OUT	8773	18	1-06-92	10:03a	A
UAFRSN	DAT	1302	3	1-06-92	10:11a	A
UAFRSN	OUT	8993	18	1-06-92	10:11a	A
WG11C	DAT	791	2	1-06-92	9:39a	A
WG11C	OUT	8443	17	1-06-92	9:34a	A
WG11S	DAT	1104	3	1-06-92	9:47a	A
WG11S	OUT	8773	18	1-06-92	9:47a	A
WG11SN	DAT	1277	3	1-06-92	9:49a	A
WG11SN	OUT	8993	18	1-06-92	9:49a	A
WG8C	DAT	792	2	1-06-92	9:51a	A
WG8C	OUT	8443	17	1-06-92	9:51a	A
WG8S	DAT	1267	3	1-06-92	9:57a	A
WG8S	OUT	8993	18	1-06-92	9:57a	A
WG8SN	DAT	1440	3	1-06-92	9:59a	A
WG8SN	OUT	9213	18	1-06-92	9:59a	A

Academy Acres

Agua Fria R. trib.

Cave Ck.

Tucson Arroyo

upper Agua Fria R.

Walnut Gulch 63.011

Walnut Gulch 63.008

66 files LISTed 302,382 byte 66 files in subdir = 302,382 byte

s 0 files SELECTed 0 bytes Available on volume = 1,138,176 byte

GEORGE V. SABOL CONSULTING ENGINEERS, INC.
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(602) 275-1490
FAX (602) 273-1637

16 March 1992

Mr. Steve Waters
Hydrologist
Flood Control District of Maricopa County
2801 W. Durango
Phoenix, Arizona

Dear Steve:

Enclosed is a copy of a report on the new Lag relation that was developed as part of the Buckeye FIS Project. This report is extracted from the information that is contained in my Technical Memorandum of 14 January 1992. The report was prepared so that this information can be submitted to various individuals with the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers for their review and comment. I deleted some of the material from the Technical Memorandum that was written specifically for the Buckeye FIS Project.

I am sending copies of the report to the following individuals:

Mr. Art Cudworth, retired USBR (author of the USBR Flood Hydrology Manual)
Mr. Joseph Evelyn, Corps of Engineers, LA District
Mr. Dennis Marfice, Corps of Engineers, LA District
Mr. John Pedersen, Corps of Engineers, LA District
Mr. Dave Sveum, USBR, Denver

I will inform you of comments that I may receive from those individuals.

Sincerely yours,
George V. Sabol Consulting Engineers, Inc.

George V. Sabol

Copy: Mr. Tim Murphy, FCDMC w/Enclosure

Enclosure: Report on New Lag Relation for Arizona

FLOOD CONTROL DISTRICT
RECEIVED
MAR 19 1992

	CH ENG		P & PM
	DEP		HYDRO
	ADMIN		DIRECT
	FINANCE		FILE
	O & O	CC	SDW
	ENGR		TMM

REMARKS

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PHOENIX, ARIZONA 85008
(602) 275-1490
FAX (602) 273-1637

16 March 1992

Mr. Art Cudworth
Box 3766
Estes Park, Colorado 80517

Dear Mr. Cudworth:

Enclosed is a report on the development of a new Lag relation for S-graphs. This work was done for the Flood Control District of Maricopa County, Phoenix, Arizona. I am sending copies of this report to:

Mr. Art Cudworth, USBR retired
Mr. Joseph Evelyn, Corps of Engineers, LA District
Mr. Dennis Marfice, Corps of Engineers, LA District
Mr. John Pedersen, Corps of Engineers, LA District
Mr. Dave Sveum, USBR, Denver

This may be of interest to you and I would appreciate any comments and suggestions that you may want to make. Please call me at the Denver office (303) 295-7016 if you wish to discuss this, or send your comments. Thank you.

Sincerely yours,
George V. Sabol Consulting Engineers, Inc.

George V. Sabol

Copy: Mr. Steve Waters, FCDMC
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Enclosure: New Lag Relation for Arizona

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

NEW Lag RELATION FOR ARIZONA

George V. Sabol Consulting Engineers, Inc.
Denver, Colorado
and
Phoenix, Arizona

March 1992

INTRODUCTION

The use of S-graphs as a unit hydrograph technique in flood hydrology requires the estimation of Lag. The traditional equations that are used to estimate Lag contain a watershed resistance coefficient, K_n, and the selection of K_n can be a tenuous process, often resulting in disparity in Lag estimates when performed by different individuals or agencies. S-graphs have a long history of use by the U.S. Bureau of Reclamation (USBR) and the U.S. Army Corps of Engineers (Corps), and the flood hydrologists of those agencies may have adequate experience for the selection of K_n for many watersheds. However, there is a renewed interest in S-graphs as a unit hydrograph procedure. The Flood Control District of Maricopa County and several county flood control districts in southern California have adopted S-graphs for performing flood hydrology studies within those agency boundaries. Furthermore, the 1987 edition of Design of Small Dams by the USBR presents S-graphs and this will increase the interest and use of S-graphs by flood hydrologists other than those of the USBR and the Corps.

Guidance in the use of S-graphs and in the selection of K_n is provided in Design of Small Dams and the Flood Hydrology Manual of the USBR and in various project reports by the Corps (particularly the Los Angeles District of the Corps). However, that guidance is often difficult to apply to watersheds that are not representative of the watersheds for which K_n values have been determined through hydrograph analysis. Therefore, there is a practical need to either provide expanded guidance for the selection of K_n or an alternative form of the Lag equation that does not require the selection of K_n.

Another concern about the traditional form of the Lag equation is that the basin factor ($L \times LCA/S^{1/2}$) uses the square root of the watershed slope. This tends to reduce the sensitivity of slope in the Lag equation which may not be desirable for many flat, alluvial basins in the Southwest United States.

Because of the above two concerns (difficulty in selecting K_n, and lack of sensitivity to watershed slope), the Lag equation was investigated and an alternative form of the Lag equation was developed. The following presents the new Lag relation that was developed.

This research and development was performed for the Flood Control District of Maricopa County, Phoenix, Arizona. The Lag equations were developed for use with watersheds that are representative of Maricopa County and Arizona (Rocky Mountains, Southwest Desert, and Urbanized basins). These equations are probably appropriate for other regions that share these physiographic characteristics. A similar approach could probably be used to develop Lag equations

for other regions (Great Plains, Sierra Nevada, and Coast and Cascade Ranges of California, Oregon and Washington).

DEVELOPMENT OF NEW Lag RELATION

Theory

The general relation for basin Lag as a function of watershed characteristics that is traditionally used is given by Equation 1.

$$Lag = C \left[\frac{L \times LCA}{S^{1/2}} \right]^{m} \tag{1}$$

The theoretical justification for Equation 1 is not known but was probably an extension of the results of Snyder's (1940) investigations, wherein he determined the following equation for Lag:

$$Lag = C_t \left(L \times LCA \right)^{.30} \tag{2}$$

The value of the exponent, m, in Equation 1, generally has been assigned within the range 0.30 to 0.38. The USBR (Flood Hydrology Manual (Cudworth, 1989)) recommends that m = 0.33 regardless of the location of the drainage basin. The Corps of Engineers typically uses m = 0.38. The coefficient, C, appears to be related to the hydraulic efficiency of the direct storm runoff through the drainage network. For a value of m = 0.33, the USBR recommends that C = 26 K_n, and the Corps uses C = 24 K_n with m = 0.38, where K_n is a resistance coefficient representing the average resistance to flow through the drainage network. The traditional Lag equations in use are:

$$Lag = 26K_n \left[\frac{L \times LCA}{S^{1/2}} \right]^{.33} \qquad \textit{by the USBR} \tag{3}$$

$$Lag = 24K_n \left[\frac{L \times LCA}{S^{1/2}} \right]^{.38} \qquad \textit{by the Corps} \tag{4}$$

It should be noted that there are numerous definitions for Lag. Horner and Flynt (1936) originally defined Lag as the time from center of mass of rainfall to center of mass of runoff. Lag,

as defined by Snyder (1940), is the time between the center of mass of rainfall excess of a specified type of storm and the occurrence of peak discharge at the location being studied. This definition indicates that Lag will vary depending on the type of storm or rainfall characteristics such as intensity. The SCS definition of Lag is the same as that used by Snyder. Lag of Equation 1 is determined from an S-graph analysis and is defined as the time from the start of a continuous series of unit rainfall excess increments to the time when the resulting runoff hydrograph reaches 50 percent of the ultimate discharge. The ultimate discharge is an equilibrium rate achieved at the time when the entire drainage basin is contributing runoff at the concentration point from the continuous series of unit rainfall excess increments.

These equations and others for Lag have been developed from data for gaged watersheds and these empirical equations are used to estimate Lag for ungaged watersheds. Theoretically, the equations should satisfy hydraulic similitude for gravity flow with the gaged watersheds being considered as models and the ungaged watersheds as prototypes. The resulting Lag equations should satisfy Froude Number similitude and accordingly the time relation for model to prototype conversion is:

$$T_R \propto L_R^{.5} \tag{5}$$

where T_R is the time ratio and L_R is the scale ratio. The model to prototype time relation of Equation 1 should agree with Equation 5. Therefore the exponent m should be 0.25 as shown in Equation 6:

$$Lag \propto (L \times LCA)^{.25} \tag{6}$$

The relation of Lag to watershed slope is a means of incorporating the runoff velocity, V, in the Lag equation and

$$Lag \propto \frac{1}{V} \tag{7}$$

According to equations of gravity flow

$$V \propto S^{1/2} \tag{8}$$

and therefore

$$Lag \propto \frac{1}{S^{1/2}} \tag{9}$$

which deviates significantly from either Equation 3 or 4.

Combining Equations 6 and 9 results in

$$Lag = CL \left[\frac{L \times LCA}{S^2}\right]^{.25} \tag{10}$$

where CL is a coefficient.

Lag is a function of many variables that describe the watershed characteristics and possibly also variables that describe the rainfall characteristics as suggested by Snyder (1940). Sufficient data for gaged watersheds are not available to document all the watershed and rainfall characteristics that may be of interest, and certain variables may be too subjective, such as K_n in Equations 3 and 4, to be reliable and reproducible for use in a prediction equation. Therefore, CL may be a surrogate to account for all the unknown and unmeasured variables affecting Lag. For this reason, it may not be possible to develop a CL equation that is dimensionlessly homogeneous using only available and readily obtainable watershed characteristics and measured Lag data. Therefore, empirical equations were developed for CL from available data.

CL Relations

Data on watershed characteristics and Lag as determined by S-graph analysis was obtained from the files of the USBR that was used by the USBR in developing Tables 4-1 through 4-6 of its Flood Hydrology Manual. These data were classified into six categories by the USBR as follows:

1. Great Plains (Table 4-1),
2. Rocky Mountains (Table 4-2),
3. Southwest Desert, Great Basin, and Colorado Plateau (Table 4-3),
4. Sierra Nevada (Table 4-4),
5. Coast and Cascade Ranges of California, Oregon, and Washington, (Table 4-5), and
6. Urbanized basins (Table 4-6).

The data sets for deserts (Table 4-3), the Rocky Mountains (Table 4-2), and urban basins (Table 4-6) are applicable to Arizona and these data are shown in Appendix A. Previous investigations indicated that the desert and Rocky Mountain Lag data are compatible for analysis as a single set. The watershed characteristic data and measured Lag for the desert and Rocky Mountain watersheds that were obtained from the USBR are shown in Table 1.
Figure 1 shows a graph of measured Lag versus L x LCA/S^2. Lines are shown in Figure 1 with a slope of 0.25 indicating agreement with the theoretically derived exponent m = 0.25. The lines are for CL of 5, 10 and 15, and the data indicate that CL ranges from slightly less than 5 to about 18 with most CLs between 10 and 15.

Multiple regression analyses were performed using the data of Table 1 in an attempt to develop a prediction equation for CL. About 40 CL equations were developed from various combinations of independent variables. The variables were inspected in both untransformed and transformed (log and power functions) states.

Four CL prediction equations were selected for further inspection. These being:

$$CL1 = 11.75 + .006\ DA - .21\ LWR \tag{11}$$

$$R^2 = 0.70$$

$$CL2 = -18.03 + 3.3 \log DA + 10.5 \log S \tag{12}$$

$$R^2 = 0.69$$

$$CL3 = -14.24 + 3.02 \log DA + 9.04 \log S \tag{13}$$

$$R^2 = 0.68$$

$$CL4 = antilog\ (.1816 + .103 \log DA + .307 \log S\ ) \tag{14}$$

$$R^2 = 0.65$$

where LWR is watershed length to width ration (L^2/DA),
DA is drainage area in square miles, and
S is watercourse slope in feet/mile.

The square of the multiple correlation coefficient (R^2) measures the portion of total variation about the mean (in this case the mean value of CL) that is explained by the regression equation. A R^2 = 1.0 indicates that the regression equation explains 100% of the total variation (the ideal, but

virtually never achieved situation). Larger values of R^2 means that the equation better explains variation in the data. R^2 in the 0.5 to 0.8 range are common for hydrologic data. R^2 larger than 0.8 is exceptional. The R^2 for the above equations are reasonable for the type of data that are analyzed. There are many more variables that are needed to "accurately" estimate Lag, but the identification and measurement of these other variables is beyond our present ability.

The CL that is estimated by Equations 11 through 14 are listed in Table 1 and these were plotted against the measured CL in Figures 2 through 5, respectively. These graphs indicate that the four CL prediction equations provide reasonable values for CL.

The results from the four CL prediction equations were used in Equation 10 (the new Lag relation) to estimate Lag for the watersheds that were used to develop the CL prediction equations. The estimated Lag with CL estimated by Equations 11 through 14 are listed in Table 1 and these were plotted against the measured Lag in Figures 6 through 9, respectively.

Inspection of Figures 2 through 9 does not lead to a clearly superior estimator of CL or Lag. However, CL1 seems to be weak at estimating low CLs and short Lags, but seems to be stronger than other CL equations for longer Lags.

Some independent Lag data is identified in the S-Graph Report that was prepared for the Flood Control District of Maricopa County (Sabol, 1987). That data is shown in Table 2. In Table 2, values of Lag are shown for numerous Arizona watersheds that were developed from data for the storms of December 1967, September 1970, and June 1972. Descriptions of those storms are shown in Appendix B. Notice that different values of Lag are shown in Table 2 depending on the storm. This illustrates that Lag is not only a function of watershed characteristics but is also a function of storm characteristics as suggested by Snyder.

Estimated values of Lag by Equation 10 and CL by Equations 11 through 14 were calculated and these are shown in Table 2 and are compared to the measured values of Lag in Figures 10 through 13. Notice in these figures that the Lags for the December 1967 storms are usually longer than the Lag for the September 1970 and June 1972 storms. The December 1967 storm was a general winter storm with lower rainfall intensity than the large local storm of September 1972 and the smaller local storm of June 1972. This indicates that estimated values of Lag should be larger for the same watershed for lower rainfall intensities. These figures also indicate that the Lag and CL prediction equations perform reasonably well for watersheds that were <u>not</u> used to develop the CL prediction equations.

Quantitative analyses could not distinguish a clearly superior CL prediction equation and a qualitative evaluation of Equations 11 through 14 was performed. Equations 12 and 13 could result in negative values of CL for some combinations of area (DA) and slope (S) and therefore these equations were rejected. Equation 11 seems to be weak for watersheds with low CL values which could yield some unconservative results. Therefore Equation 14 is recommended for use in estimating CL for undeveloped (natural) watersheds of deserts and mountains in Arizona.

A similar analysis was performed for urban watersheds using USBR data (Appendix A) as shown in Table 3. An additional watershed characteristic, impervious area (RTIMP), was included for urban watersheds. A graph of L x LCA/S^2 versus measured Lag for urban watersheds is shown in Figure 14, and that graph illustrates that the theoretical value of m = 0.25 is appropriate and that CL ranges from about 1.0 to 5.0 for urban watersheds. A multiple regression analysis of the urban watershed data resulted in one clearly superior equation to predict CL for such watersheds:

$$CL = antilog\ (0.31 + 0.0955 \log DA + 0.3560 \log S - 0.3610 \log RTIMP)$$

$$R^2 = 0.67 \qquad (15)$$

A comparison of the estimated CL and measured CL is shown in Figure 15 and a comparison of the estimated Lag and measured Lag is shown in Figure 16.

One more general type of watershed exists in Arizona that needs to be considered besides desert/mountain and urban; that being irrigated agricultural watersheds. Such watersheds have very flat slopes and may have high resistance to flow due to tillage and vegetation growth. Such watersheds may also be representative of large turf areas such as golf courses and parks. Data are not available to develop a CL prediction equation for such watersheds, therefore, the desert/mountain CL equation was modified based on other considerations as follows: Resistance factors for overland flow are provided in the September 1990 HEC-1 Manual and SCS TR-55 (Appendix C). The ratio of resistance factors for various surfaces to the resistance factor for rangeland (natural) from TR-55 are as follows:

Surface	Ratio of Resistance Factors (Rangeland n = 0.13)
Cultivated, residue greater than 20%	1.3
Dense grass	1.8
Bermuda grass	3.2

The ratio of resistance factors for various surfaces to the resistance factor for rangeland (20% cover) from HEC-1 are as follows:

Surface	Ratio of Resistance Factors	
	n = 0.05	n = 0.25
Conventional tillage with residue	3.2 - 4.4	.6 - .9
Dense grass	3.4 - 16.0	.7 - 3.2
Bermuda grass	6.0 - 9.6	1.2 - 1.9

Although there is tremendous variability in these ratios, a composite ratio of agricultural/grass resistance factors to a rangeland (natural) resistance factor of 3.0 seems reasonable. Therefore, the Lag for agricultural/grass watersheds would be about 3 times larger than the Lag for a comparable rangeland watershed. The CL prediction equation for agricultural/grass watersheds is:

$$CL = 3 \times antilog\ (.1816 + .103 \log DA + .307 \log S) \tag{16}$$

Summary of CL and Lag for use in Arizona

The recommended Lag equation (Equation 10) is:

$$Lag = CL \left[\frac{L \times LCA}{S^2} \right]^{.25}$$

where CL is estimated by Equation 14 for desert and mountain watersheds, by Equation 16 for agricultural/grass watersheds, and by Equation 15 for urban watersheds. Those equations, rewritten in more convenient form are:

desert and mountain watersheds,

$$CL = 1.5\ A^{.1}\ S^{.3} \tag{17}$$

agricultural/grass watersheds,

$$CL = 4.5\ A^{.1}\ S^{.3} \tag{18}$$

urban watersheds,

$$CL = \frac{2.0\ A^{.1}\ S^{.36}}{RTIMP^{.36}} \tag{19}$$

where A is drainage area in square miles,
S is watershed slope in feet/mile, and
RTIMP is impervious area in %.

The expansion of Equation 10 with the appropriate substitution of CL from Equations 17, 18 or 19, respectively, results in the following equations:

desert and mountain watersheds,

$$Lag = 1.5\ A^{.1}\ S^{-.2}\ L^{.25}\ LCA^{.25} \tag{20}$$

agricultural/grass watersheds,

$$Lag = 4.5\ A^{.1}\ S^{-.2}\ L^{.25}\ LCA^{.25} \tag{21}$$

urban watersheds,

$$Lag = 2.0\ RTIMP^{-.36}\ A^{.1}\ S^{-.14}\ L^{.25}\ LCA^{.25} \tag{22}$$

Notice in the expanded forms of these Lag equations that the exponent on S is approximately the same as Equation 1 (exponent equals -.15 for m=.30 and -.19 for m=.38). This indicates that the total sensitivity to slope (S) is about the same whether either the traditional Lag or the new Lag equations are used.

Adjustment of Lag for Return Period

It is assumed that the Lag that is estimated by Equation 10 with CL estimated by Equations 17, 18 and 19 provides an estimate of Lag for severe storms that produce floods of approximately the 100-yr return period. The Lag should be increased for less severe storms and should be decreased for use in estimating floods larger than the 100-yr. Data are not available to provide definitive guidance for adjusting Lag for flood return period. Previous flood studies (Tucson Arroyo)

for the Flood Control District of Maricopa County indicate that the following Lag frequency factors may be appropriate:

Return Period years	F_f
100	.0
50	1.25
25	1.50
10	1.75
2	2.0

Additional testing of this method using gaged watershed data could be used to confirm or modify the use of flood frequency factors.

CONCLUSIONS

1. The new Lag relation of Equation 10 has a theoretical justification that may be lacking from the traditional Lag equation.
2. Published Lag and watershed characteristic data were used to develop CL equations for desert/mountain watersheds (Equation 17) and for urban watersheds (Equation 19).
3. A CL equation for agricultural/grass watersheds (Equation 18) was developed from a consideration of the relative resistance to flow in typical agricultural/grass fields to the resistance in typical undeveloped rangelands. This CL equation can not be applied with the same confidence as the CL equation for desert/mountain, however, adequate data for agricultural/grass fields do not appear to be available for the development of a data-based CL equation.
4. The three CL equations can be used with easily obtained watershed characteristics, and Lag can be estimated without subjective selection of watershed characteristics.
5. The use of the new Lag relation (Equation 10 along with Equation 17, 18 and 19 or the expanded form in Equations 20, 21 and 22) should produce estimates of Lag that are reproducible for all significantly representative watersheds in Arizona.
6. A major weakness of the Lag equations is that they do not account for changes in hydraulic efficiency of the watershed due to varying rainfall intensity; that is, Lag should increase with decreasing rainfall intensity (rainfall return period). Frequency factors to be applied to Lag are suggested based on some limited verifications that were performed previously.
7. This new form of the Lag equation (Equation 10) may provide better estimates of Lag than the traditional equations (Equations 3 and 4) by estimating CL from a selection of K_n. This would offer the advantage of the existing experience base by the hydrologists of the USBR

and the Corps (and possibly other hydrologists) in selecting K_n along with a basin factor that is more sensitive to watercourse slope.

acteristics

R	S ft/mi	LAG hrs measured	L*LCA over S**	CL measured	CL1 estimated	LAG1 hrs estimated	CL2 estimated	LAG2 hrs estimated	CL3 estimated	LAG3 hrs estimated	CL4 estimated	LAG4 hrs estimated
.84	47.00	16.00	3.938433680	11.36	11.02	15.52	11.53	16.24	11.86	16.71	11.74	16.54
.79	46.40	12.00	2.401345125	9.64	11.23	13.98	11.03	13.73	11.41	14.20	11.33	14.10
.48	104.60	8.50	0.061830738	13.04	11.86	5.91	12.52	6.24	12.57	6.27	12.39	6.18
.99	87.10	5.40	0.077507016	10.23	11.64	6.14	11.48	6.06	11.67	6.16	11.55	6.09
.32	350.00	3.30	0.002196898	15.24	13.15	2.85	15.97	3.46	15.43	3.34	15.50	3.35
.14	450.00	1.60	0.000192889	13.58	14.00	1.65	15.13	1.78	14.60	1.72	14.51	1.71
.11	690.00	1.10	0.000030456	14.81	15.24	1.13	15.19	1.13	14.54	1.08	14.44	1.07
.57	440.00	1.50	0.000213223	12.41	13.43	1.62	13.72	1.66	13.31	1.61	13.11	1.58
.61	600.00	1.30	0.000089222	13.38	14.17	1.38	14.37	1.40	13.83	1.34	13.65	1.33
.06	1017.00	1.20	0.000017113	18.66	17.42	1.12	17.60	1.13	16.65	1.07	17.03	1.10
.65	140.00	5.60	0.029020408	13.57	11.82	4.88	12.92	5.33	12.86	5.31	12.68	5.23
.02	150.00	3.70	0.013057778	10.95	11.81	3.99	12.16	4.11	12.15	4.11	11.99	4.05
.28	105.00	7.30	0.091791383	13.26	11.69	6.44	12.46	6.86	12.52	6.89	12.34	6.80
.06	85.00	9.50	0.290541176	12.94	11.20	8.22	11.70	8.59	11.87	8.71	11.73	8.62
.66	700.00	0.80	0.000008878	14.66	15.18	0.83	13.04	0.71	12.57	0.69	12.37	0.68
.80	290.00	2.50	0.001310702	13.14	12.90	2.45	14.13	2.69	13.79	2.62	13.63	2.59
.36	95.00	4.00	0.031042659	9.53	11.61	4.88	10.47	4.39	10.71	4.50	10.72	4.50
.38	145.00	3.50	0.008133175	11.65	12.12	3.64	11.86	3.56	11.89	3.57	11.75	3.53
.09	315.00	2.40	0.001209373	12.87	11.94	2.23	12.97	2.42	12.71	2.37	12.51	2.33
.30	140.00	0.60	0.000277551	4.65	11.90	1.54	6.13	0.79	6.64	0.86	7.78	1.00
.91	75.00	2.40	0.038341333	5.42	10.75	4.76	7.96	3.52	8.48	3.75	8.99	3.98
.04	29.00	21.50	11.059453032	11.79	10.66	19.43	8.72	15.90	9.41	17.16	9.69	17.67
.45	32.00	20.60	9.394531250	11.77	10.17	17.80	8.67	15.17	9.34	16.34	9.63	16.86
.51	65.00	10.30	0.674319527	11.37	10.56	9.57	10.57	9.58	10.90	9.88	10.88	9.86
.06	141.00	3.10	0.009855641	9.84	11.32	3.57	10.57	3.33	10.71	3.37	10.71	3.37
.28	145.00	3.70	0.015006897	10.57	11.30	3.96	11.04	3.87	11.14	3.90	11.07	3.88
12	83.00	5.30	0.143028016	8.62	9.70	5.97	9.62	5.91	9.97	6.13	10.11	6.22
80	89.00	2.40	0.022219417	6.22	11.28	4.35	8.41	3.25	8.85	3.42	9.26	3.57
61	159.00	8.00	0.034808750	18.52	12.16	5.25	14.56	6.29	14.33	6.19	14.23	6.14
47	295.00	0.90	0.000031026	12.06	12.79	0.95	8.97	0.67	9.06	0.68	9.40	0.70
20	480.00	1.00	0.000021484	14.69	13.96	0.95	11.88	0.81	11.60	0.79	11.47	0.78
78	709.00	0.70	0.000004914	14.87	15.42	0.73	12.28	0.58	11.87	0.56	11.71	0.55
96	310.00	2.40	0.001219043	12.84	12.99	2.43	14.61	2.73	14.21	2.66	14.08	2.63
23	100.00	5.10	0.040600000	11.36	11.67	5.24	10.94	4.91	11.13	5.00	11.07	4.97
06	49.00	11.00	1.366097459	10.17	10.77	11.65	9.77	10.56	10.24	11.07	10.33	11.17

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R	S ft/mi	LAG hrs measured	L*LCA over S**	CL measured	CL1 estimated	LAG1 hrs estimated	CL2 estimated	LAG2 hrs estimated	CL3 estimated	LAG3 hrs estimated	CL4 estimated	LAG4 hrs estimated
.12	83.40	8.85	0.141659334	14.43	9.71	5.95	9.64	5.91	9.99	6.13	10.13	6.21
.12	83.40	5.38	0.141659334	8.77	9.71	5.95	9.64	5.91	9.99	6.13	10.13	6.21
.80	101.90	2.95	0.016780291	8.20	11.35	4.09	9.03	3.25	9.38	3.38	9.65	3.47
.80	101.90	2.19	0.016780291	6.08	11.35	4.09	9.03	3.25	9.38	3.38	9.65	3.47
.66	75.90	4.99	0.053256400	10.39	10.18	4.89	7.80	3.75	8.33	4.00	8.89	4.27
66	75.90	5.88	0.053256400	12.24	10.18	4.89	7.80	3.75	8.33	4.00	8.89	4.27
41	67.00	0.86	0.000250613	6.84	11.23	1.41	0.18	0.02	1.38	0.17	5.15	0.65
41	67.00	0.95	0.000250613	7.55	11.23	1.41	0.18	0.02	1.38	0.17	5.15	0.65
41	67.00	0.79	0.000250613	6.28	11.23	1.41	0.18	0.02	1.38	0.17	5.15	0.65
56	16.00	0.96	0.001173047	5.19	10.89	2.02	-8.31	-1.54	-6.03	-1.12	2.88	0.53
56	16.00	1.00	0.001173047	5.40	10.89	2.02	-8.31	-1.54	-6.03	-1.12	2.88	0.53
06	141.40	2.59	0.009799960	8.23	11.33	3.56	10.58	3.33	10.72	3.37	10.72	3.37
06	141.40	2.50	0.009799960	7.95	11.33	3.56	10.58	3.33	10.72	3.37	10.72	3.37
01	121.60	4.25	0.021971304	11.04	10.80	4.16	10.24	3.94	10.45	4.02	10.49	4.04
01	121.60	2.72	0.021971304	7.06	10.80	4.16	10.24	3.94	10.45	4.02	10.49	4.04
40	64.20	8.02	0.091400510	14.59	11.00	6.05	8.05	4.43	8.60	4.73	9.08	4.99
40	64.20	7.31	0.091400510	13.29	11.00	6.05	8.05	4.43	8.60	4.73	9.08	4.99
40	64.20	3.10	0.091400510	5.64	11.00	6.05	8.05	4.43	8.60	4.73	9.08	4.99
34	73.60	10.59	0.211059340	15.62	10.19	6.91	9.85	6.68	10.21	6.92	10.31	6.99
34	73.60	6.90	0.211059340	10.18	10.19	6.91	9.85	6.68	10.21	6.92	10.31	6.99
.8	68.90	10.68	0.349510555	13.89	11.08	8.52	10.70	8.22	11.00	8.46	10.97	8.43
.8	68.90	7.80	0.349510555	10.14	11.08	8.52	10.70	8.22	11.00	8.46	10.97	8.43
7	42.10	9.20	1.730609735	8.02	11.40	13.08	10.23	11.74	10.70	12.27	10.72	12.29
2	41.00	11.20	2.171564545	9.23	9.89	12.01	8.09	9.82	8.74	10.62	9.19	11.16
5	310.00	0.64	0.000676171	3.97	12.59	2.03	12.84	2.07	12.59	2.03	12.40	2.00
1	72.40	12.90	1.119425536	12.54	10.44	10.74	11.84	12.18	12.04	12.38	11.89	12.23
4	312.00	1.00	0.000223537	8.18	12.38	1.51	10.93	1.34	10.84	1.33	10.81	1.32

LWR	S ft/mi	LAG hrs measured	L*LCA over S**	CL measured	CL estimated	LAG hrs estimated	RTIMP
6.45	85.00	0.60	0.006048443	2.15	3.42	0.95	40
6.91	75.00	2.40	0.038341333	5.42	4.09	1.81	35
4.62	100.00	0.30	0.000578000	1.93	2.92	0.45	45
3.97	14.60	1.30	0.173390880	2.79	1.62	1.04	60
1.57	64.00	1.20	0.016132813	3.37	3.71	1.32	40
6.14	4.10	2.10	14.415229030	1.08	1.38	2.69	40
5.80	5.00	3.10	11.827200000	1.67	1.56	2.89	35
1.74	9.50	0.80	0.040332410	1.79	1.42	0.64	37
6.60	48.00	1.00	0.004288194	3.91	2.83	0.72	27
3.23	6.30	0.90	0.352733686	1.17	1.05	0.81	70
4.05	48.00	0.15	0.000117188	1.44	1.34	0.14	93
4.74	19.00	0.40	0.009141274	1.29	1.51	0.47	50
6.40	13.00	0.70	0.094674556	1.26	1.50	0.83	48
5.63	18.50	0.50	0.051278305	1.05	1.99	0.95	33
2.54	4.50	1.00	0.355555556	1.30	1.41	1.09	20
3.65	52.00	0.90	0.002880917	3.88	2.91	0.67	28
2.94	79.00	0.50	0.000368531	3.61	3.21	0.44	25
4.23	43.00	1.40	0.014764738	4.02	3.44	1.20	20
2.10	77.00	0.40	0.000371058	2.88	3.53	0.49	20
0.83	87.00	0.20	0.000013212	3.32	2.60	0.16	30
5.00	83.00	0.20	0.000058064	2.29	2.37	0.21	33

KEUFFEL & ESSER CO. MADE IN U.S.A.

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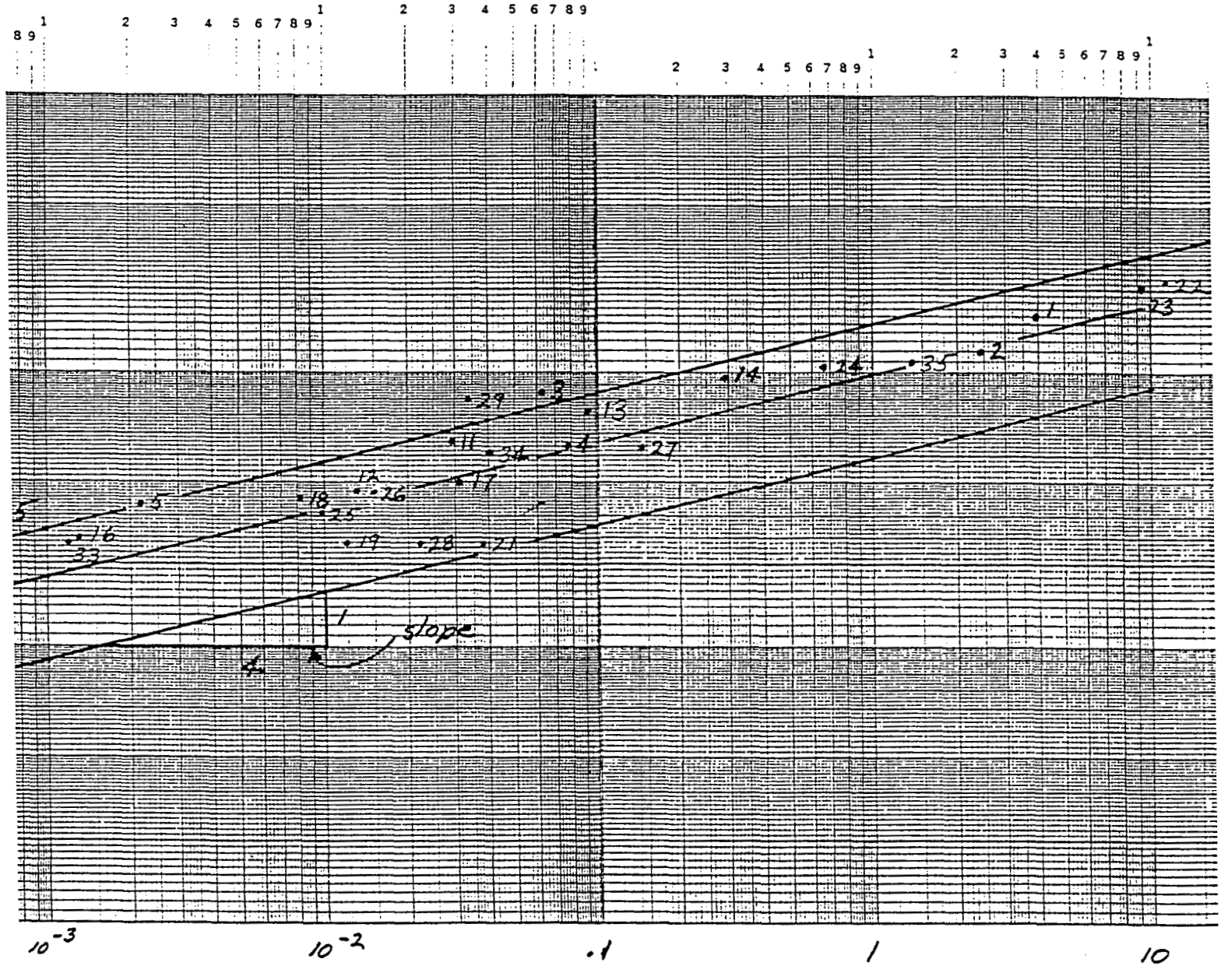
y Mtn watersheds



$$\frac{L \cdot LCA}{S^2}$$

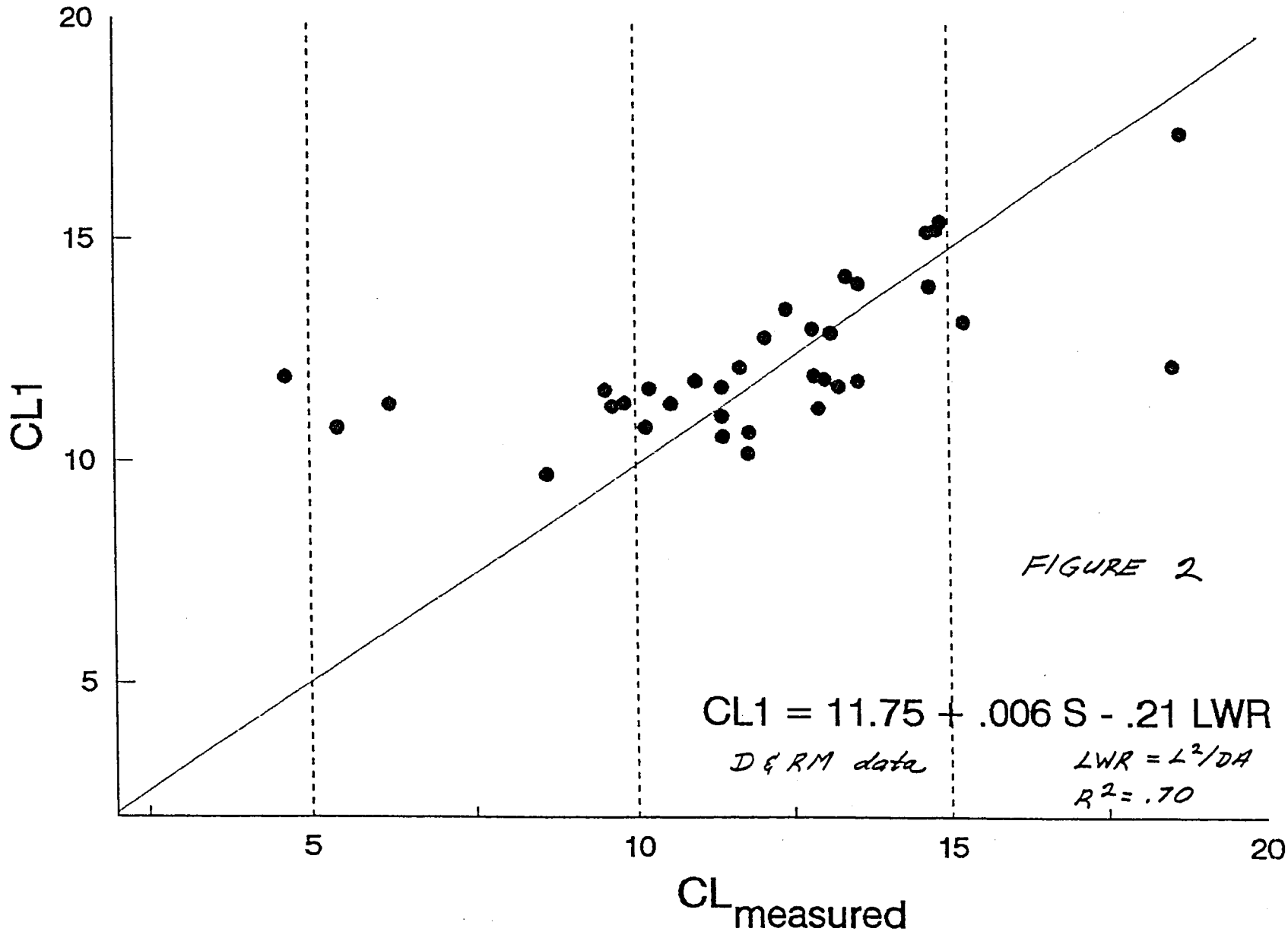

20
15
10
5
CL1
5
10
15
20
CLmeasured
CL1 = 11.75 + .006 S - .21 LWR
D & RM data
LWR = L²/DA
R² = .70

FIGURE 2

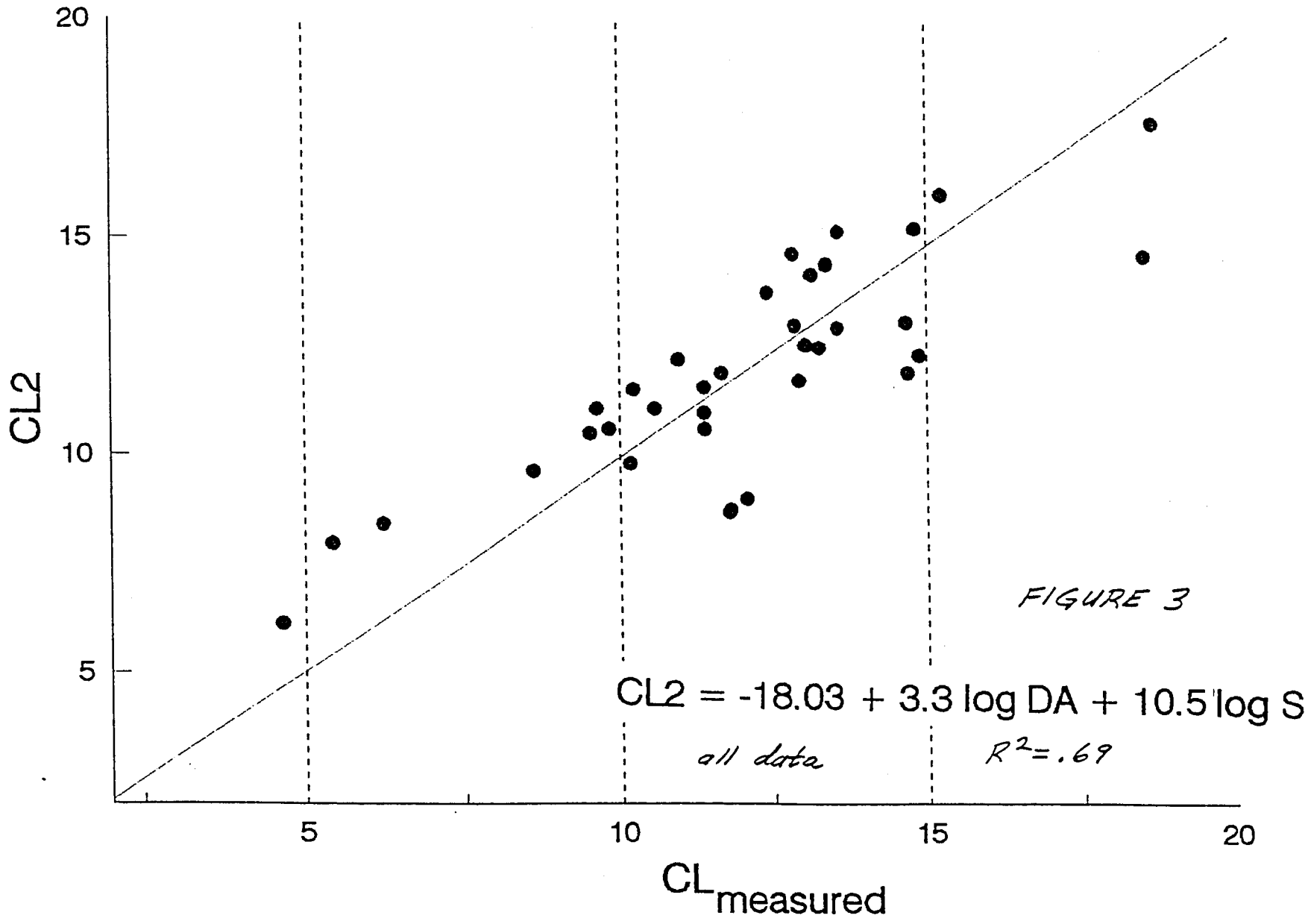

20
15
10
5
CL2
5
10
15
20
CLmeasured
CL2 = -18.03 + 3.3 log DA + 10.5 log S
all data
R2=.69

FIGURE 3

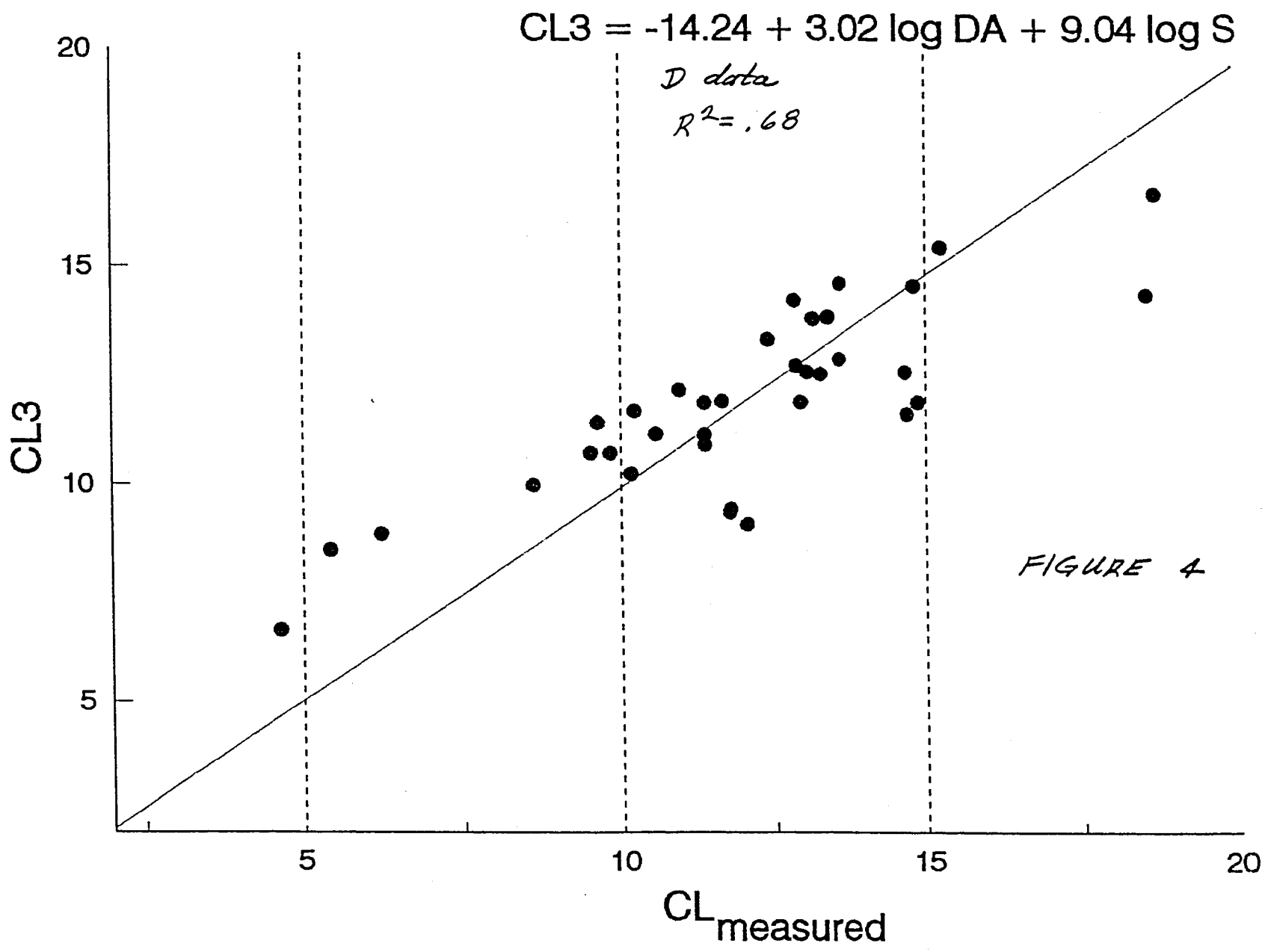

CL3 = -14.24 + 3.02 log DA + 9.04 log S
D data
R^2 = .68
CL3
20
15
10
5
5
10
15
20
$CL_{measured}$

FIGURE 4

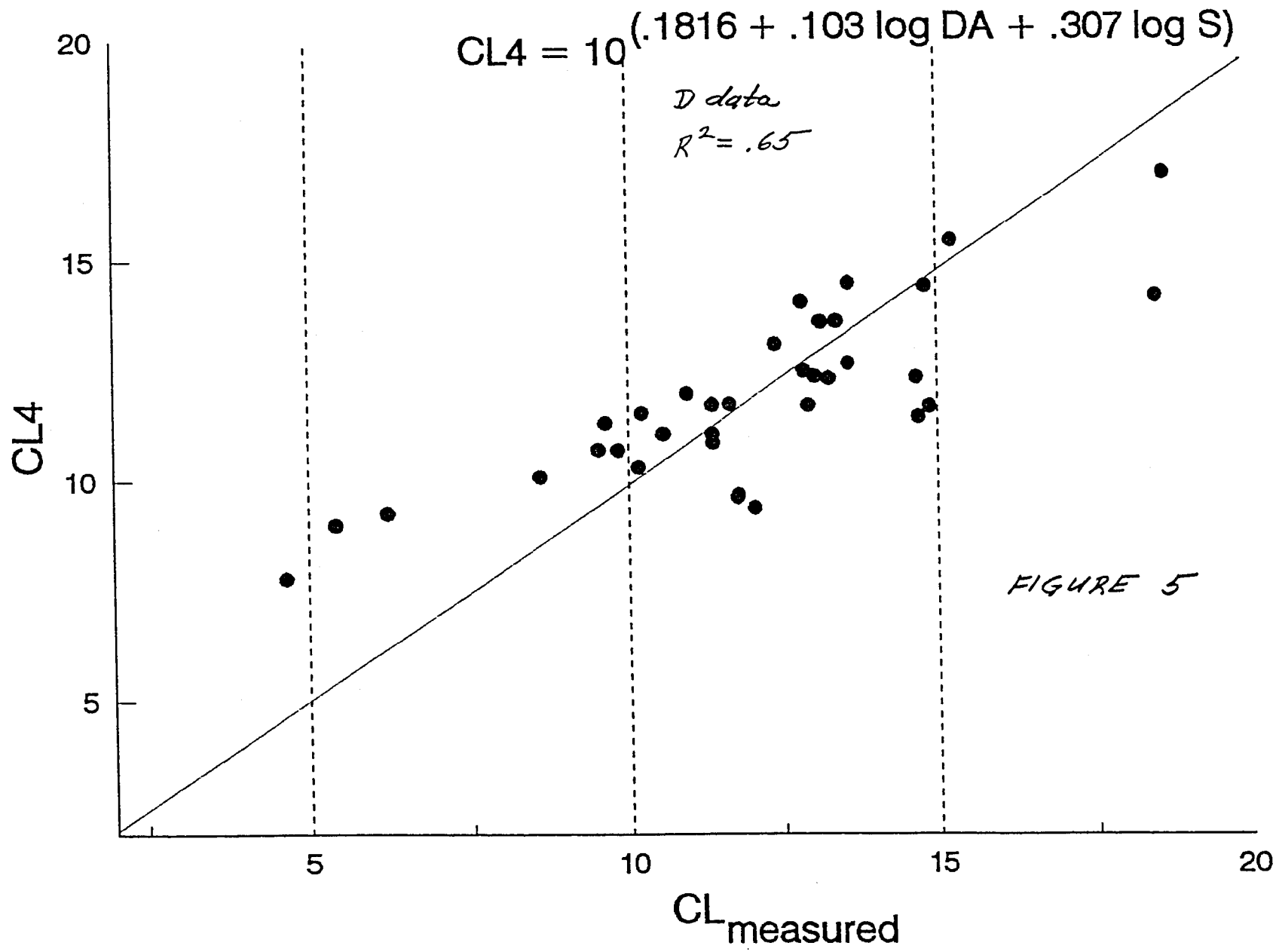

CL4 = 10(.1816 + .103 log DA + .307 log S)
D data
R^2 = .65
CL4
20
15
10
5
5
10
15
20
CLmeasured

FIGURE 5

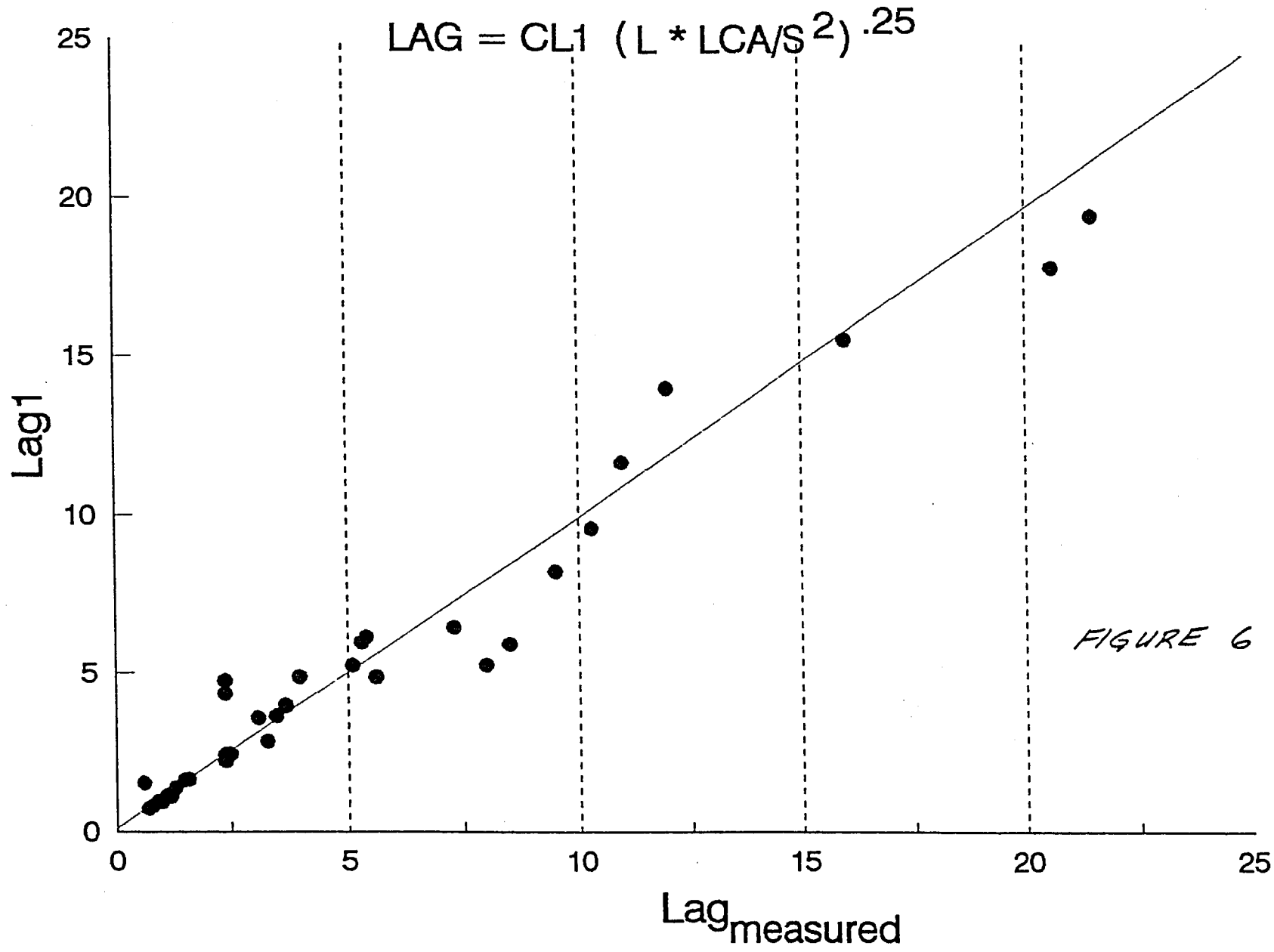


FIGURE 6

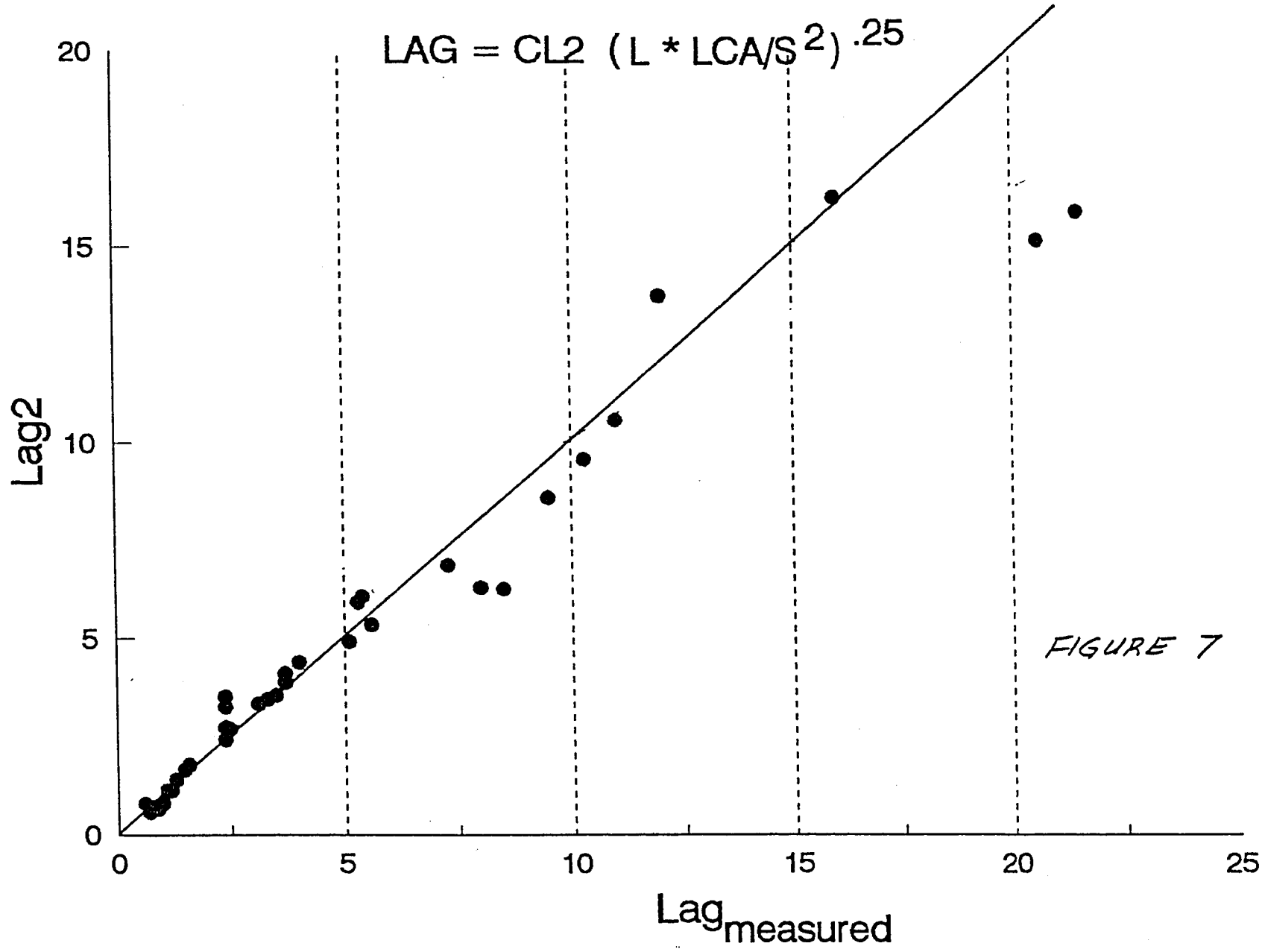


FIGURE 7

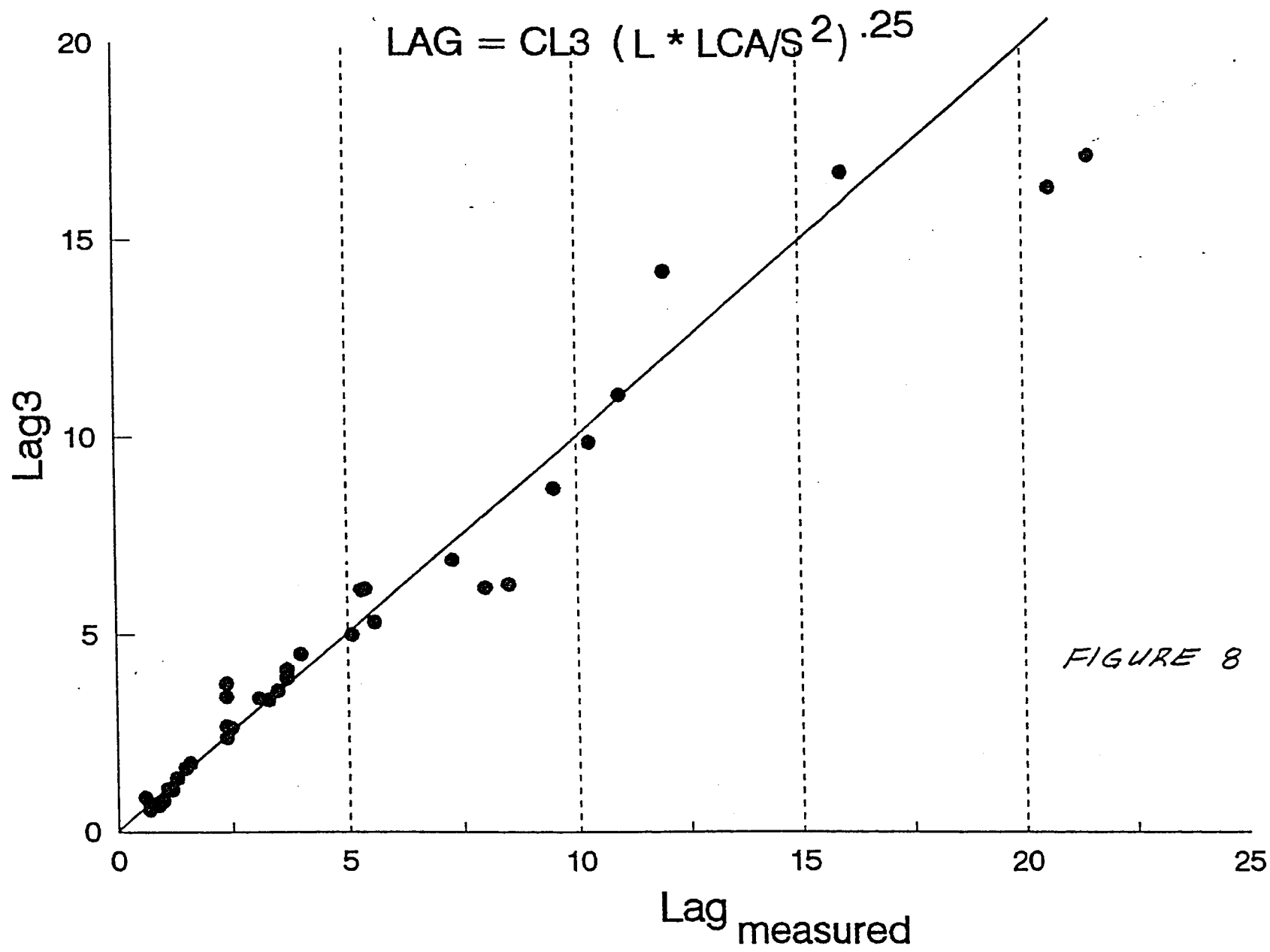


FIGURE 8

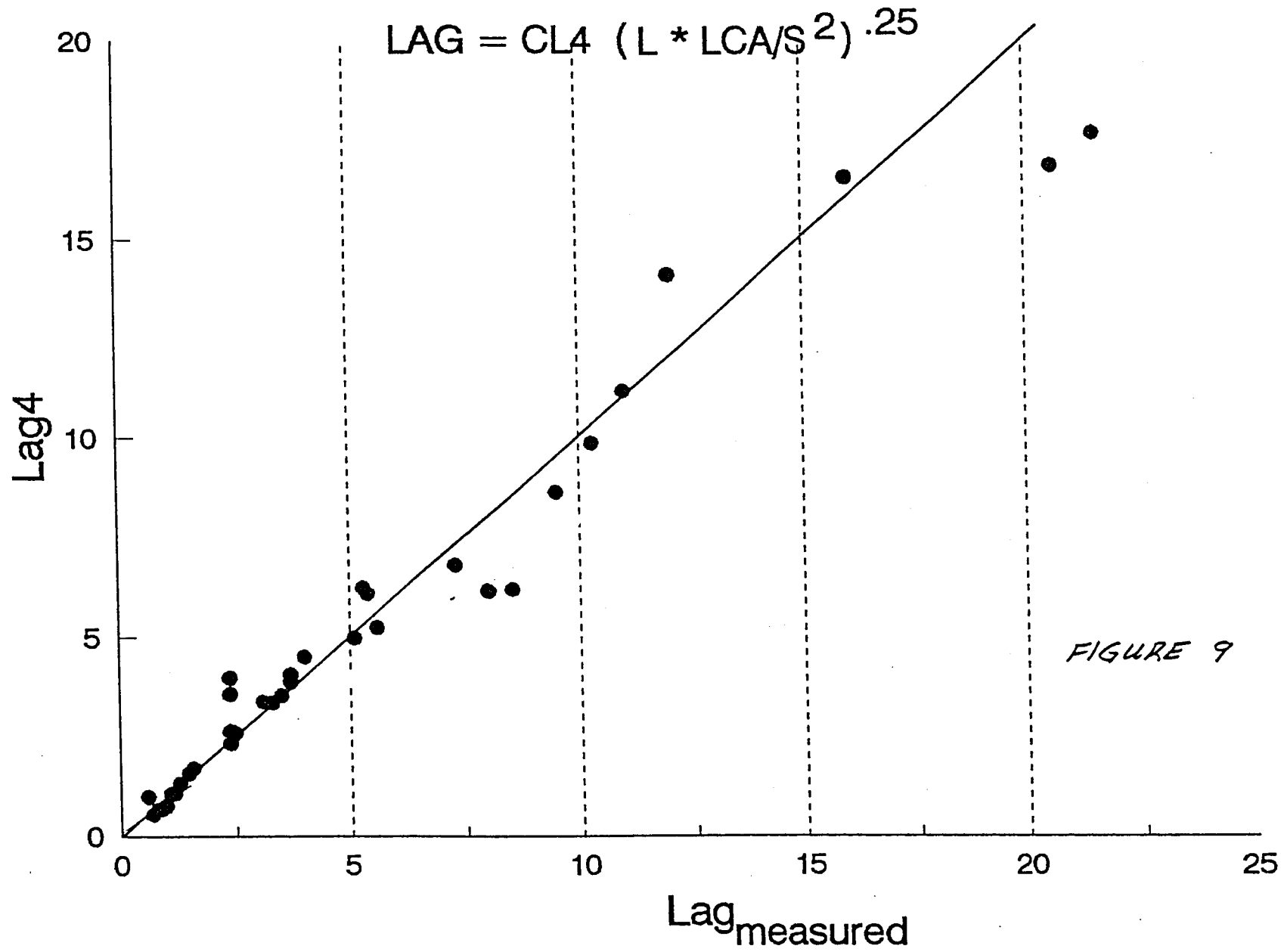


FIGURE 9

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG1 = CL1 \left(\frac{L \cdot LCA}{S^2} \right)^{.25}$$

$$CL1 = 11.75 + .006\,S - .21\,LWR$$

• for Sept 70, June 72 and undated data

⊙ for Dec 67 data

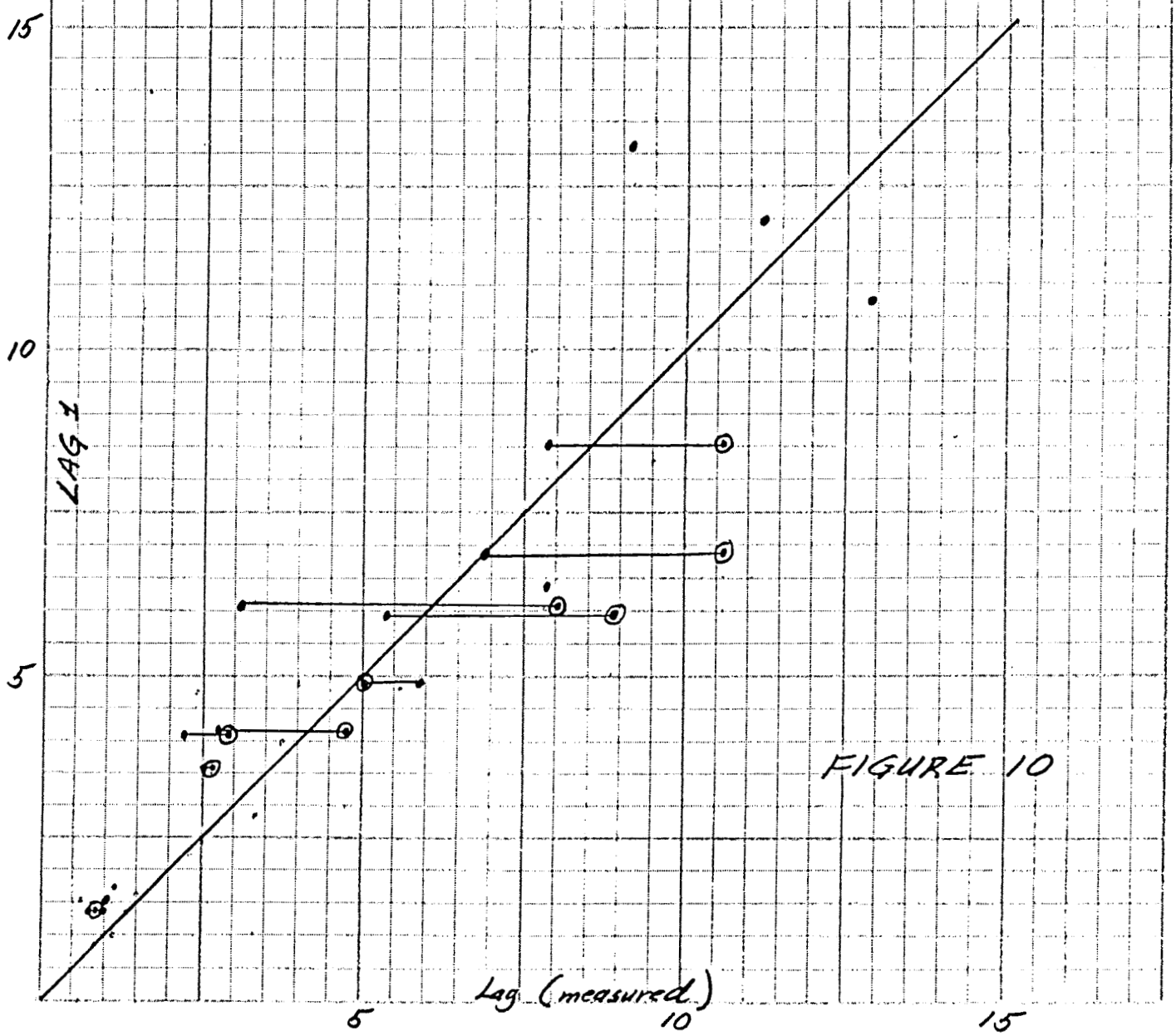


FIGURE 10

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG2 = CL2\left(\frac{L \cdot LCA}{S^2}\right)^{.25}$$

$$CL2 = -18.0 + 3.3 \log DA + 10.5 \log S$$

• for Sept 70, June 72 and undated data

⊙ for Dec 67 data

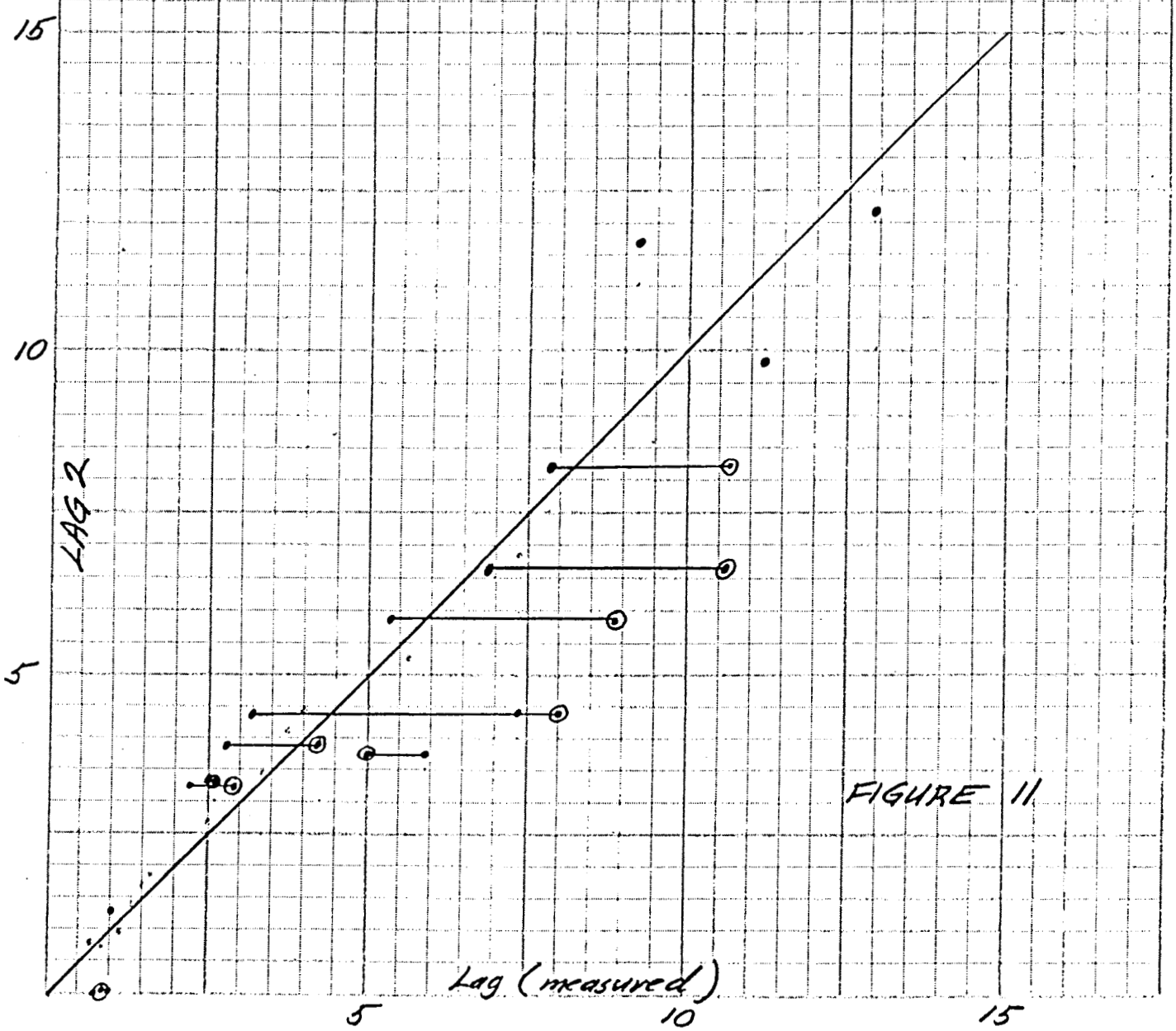


FIGURE 11

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG3 = CL3 \left(\frac{L \cdot LCA}{S^2} \right)^{.25}$$

$$CL3 = -14.2 + 3.0 \log DA + 9.0 \log S$$

• for Sept 70, June 72 and undated data

⊙ for Dec 67 data

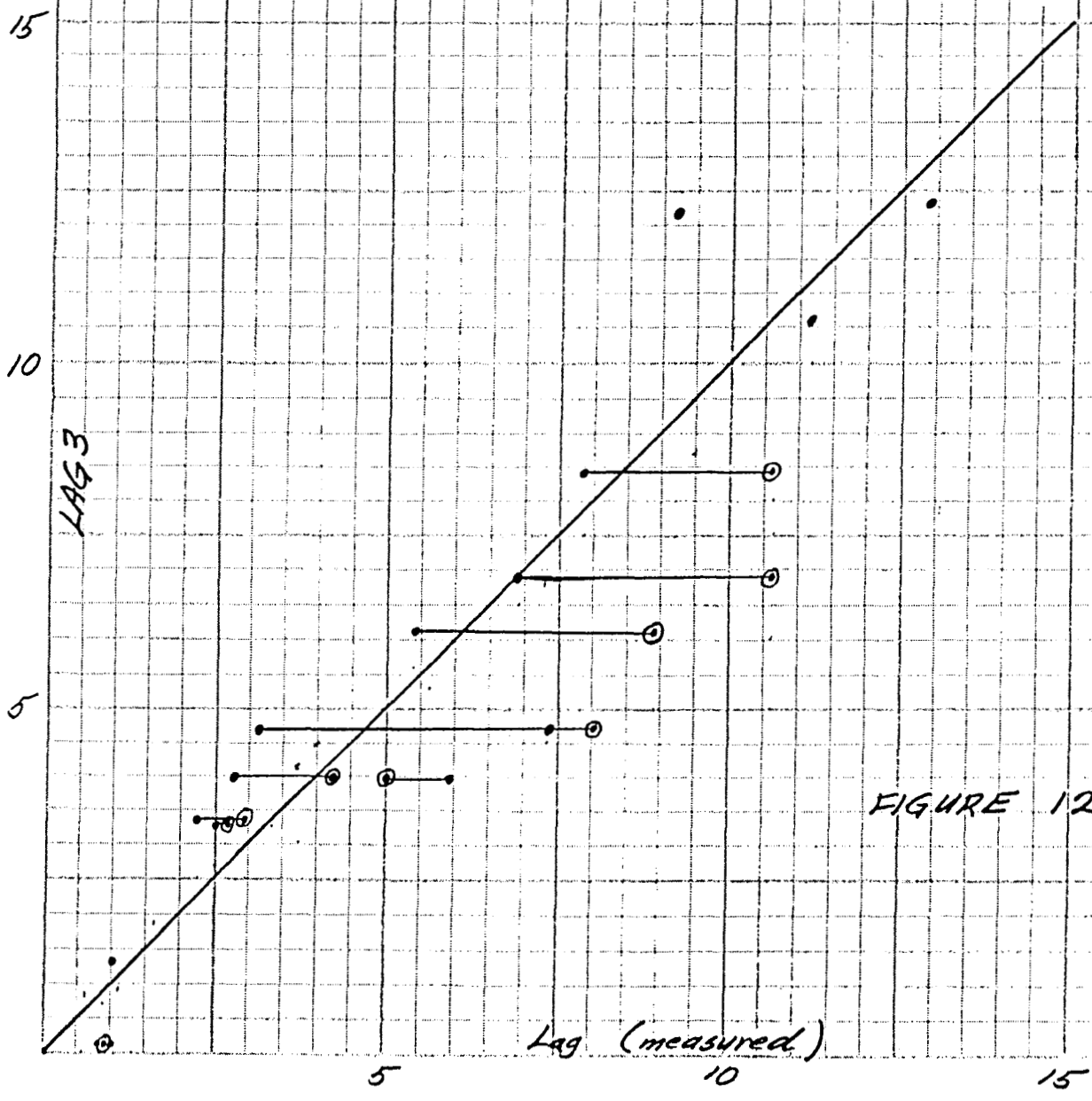


FIGURE 12

GEORGE V. SABOL CONSULTING ENGINEERS, INC.

SHEET _____ OF _____

CLIENT _____ DATE _____

PROJECT _____ BY _____

SUBJECT _____ PROJECT NO. _____

$$LAG4 = CL4\left(\frac{L \cdot LCA}{S^2}\right)^{.25}$$

$$CL4 = 10^{(.18 + .10 \log DA + .31 \log S)}$$

• for Sept 70, June 72, and undated data

⊙ for Dec 67 data

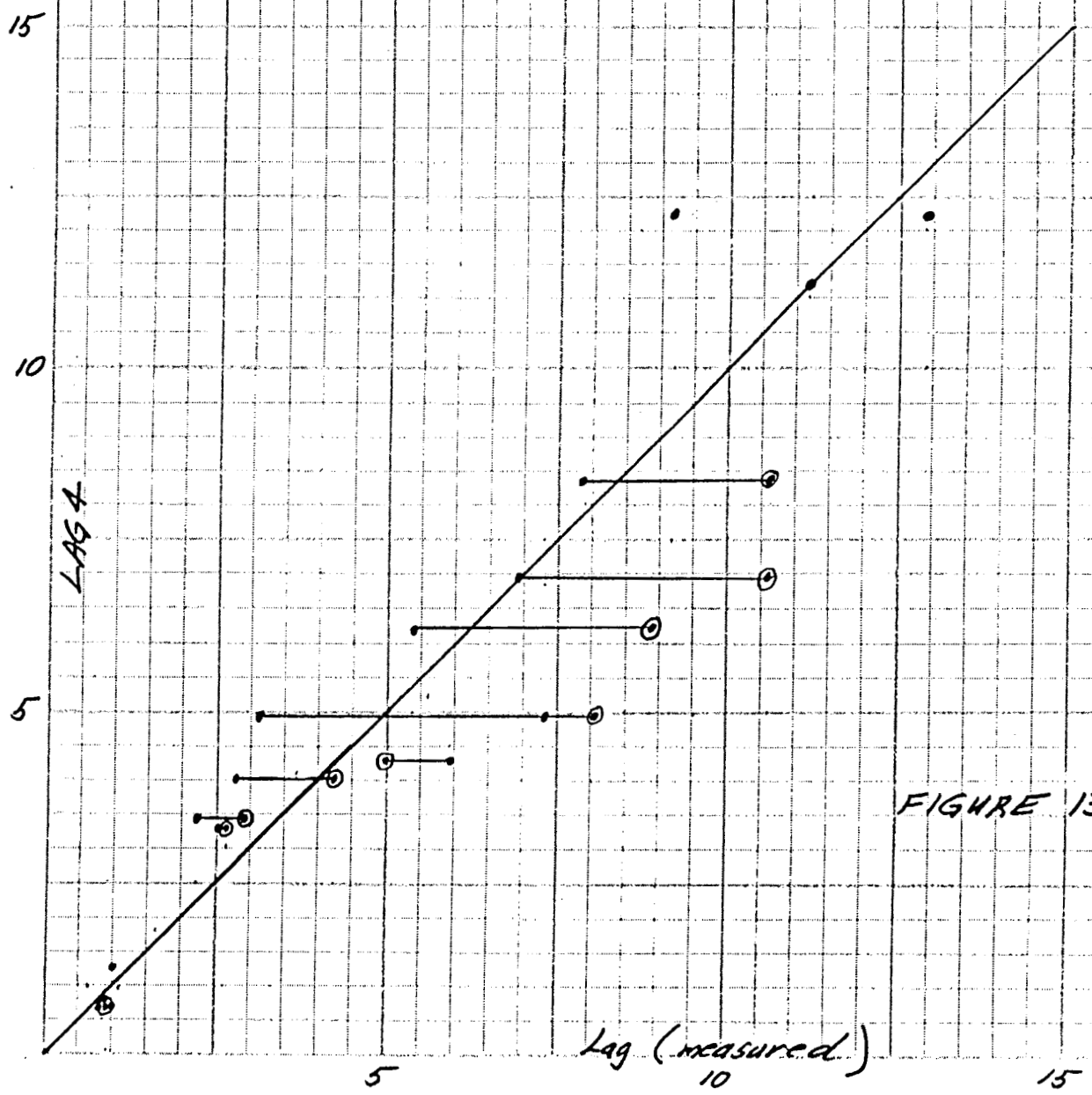


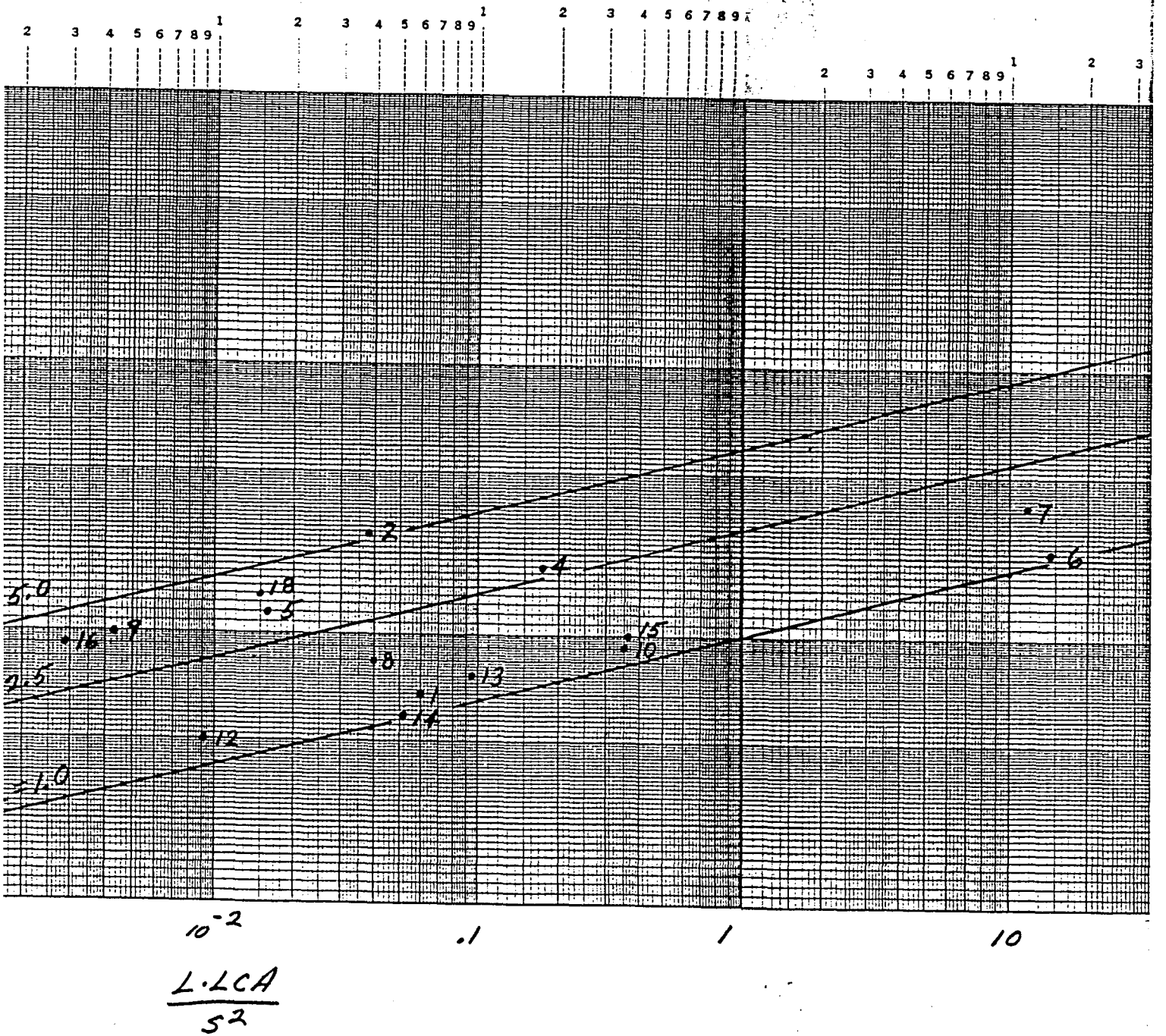
FIGURE 13

46 7522

K+E LOGARIT

FIGURE 14

urban watersheds



Urban Watersheds

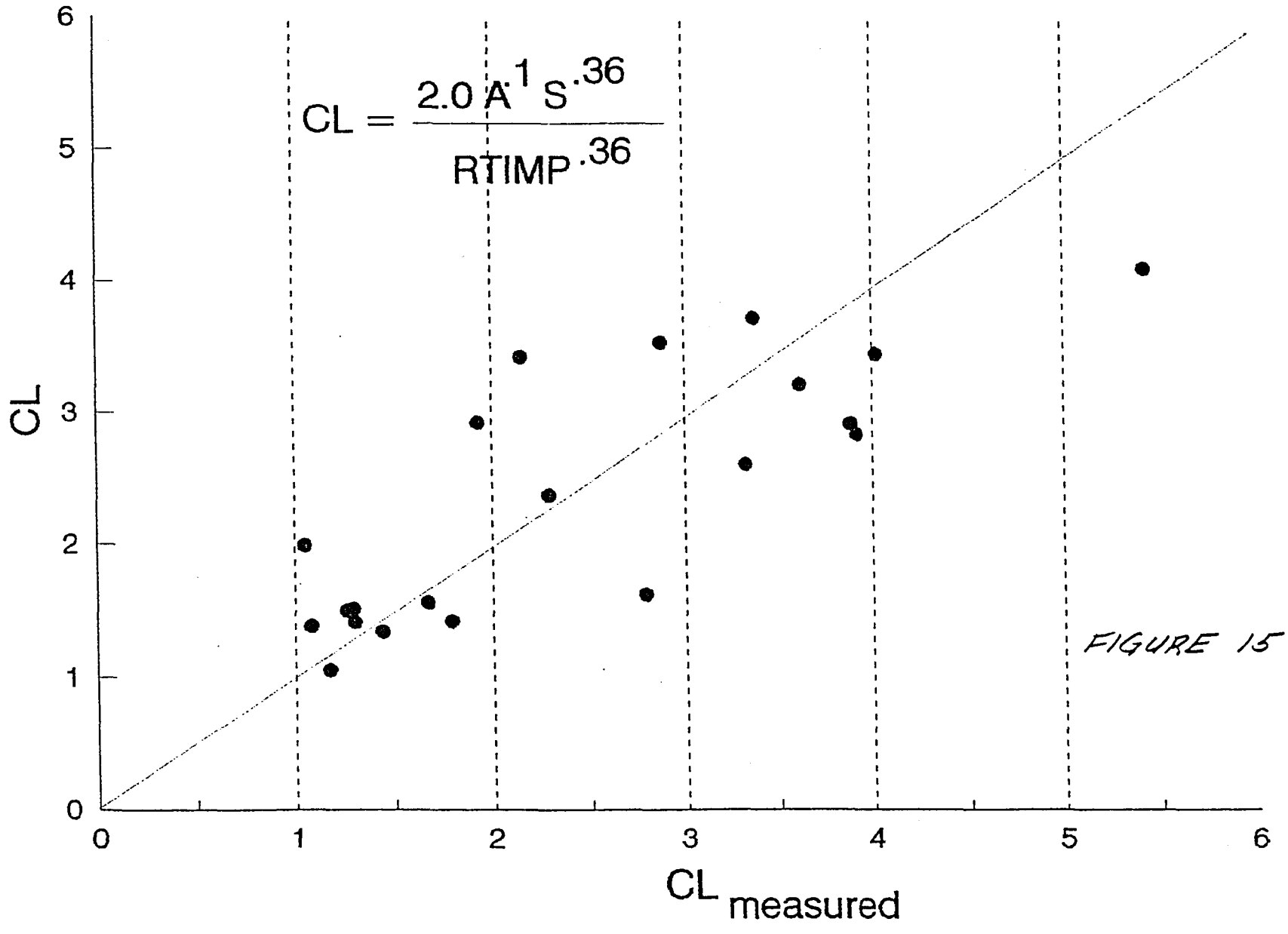


FIGURE 15

Urban Watersheds

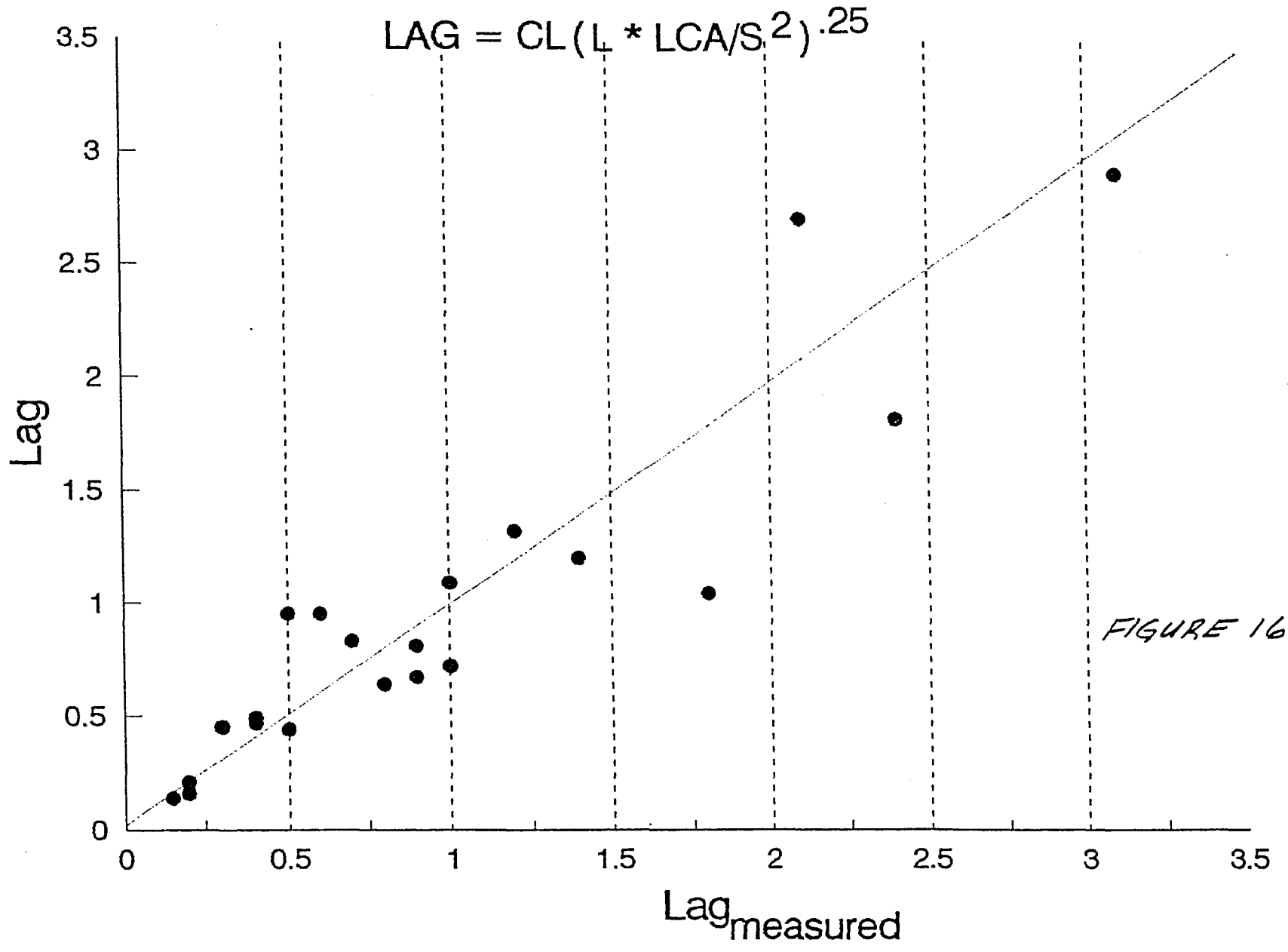


FIGURE 16

APPENDIX A

Table 4-3.—Unit hydrograph lag data for the Southwest Desert, Great Basin, and Colorado Plateau.

Index No.	Station and location	Drainage area, mi²	Basin factor, $LL_{ca}/S^{0.5}$	Lag time, L_g, hours	K_n	C_t
1	Salt River at Roosevelt, AZ	4341.0	1261.0	16.0	0.058	1.51
2	Verde R. above E. Verde and below Jerome, AZ	3190.0	760.0	12.0	.052	1.35
3	Tonto Cr. above Gun Cr., AZ	678.0	66.3	6.5	.063	1.64
4	Agua Fria R. nr. Mayer, AZ	590.0	63.2	5.4	.053	1.38
5	San Gabriel R. at San Gabriel Dam, CA	162.0	14.4	3.3	.053	1.38
6	West Fk. San Gabriel R. at Cogswell Dam, CA	40.4	1.8	1.6	.051	1.33
7	Santa Anita Cr. at Santa Anita Dam, CA	10.8	0.6	1.1	.050	1.30
8	Sand Dimas Cr. at San Dimas Dam, CO	16.2	2.0	1.5	.046	1.20
9	Eaton Wash at Eaton Wash Dam, CA	9.5	1.3	1.3	.046	1.20
10	San Antonio Cr. nr. Claremont, CA	16.9	0.6	1.2	.055	1.43
11	Santa Clara R. nr. Saugus, CA	355.0	48.2	5.6	.060	1.56
12	Temecula Cr. at Pauba Canyon, CA	168.0	24.1	3.7	.050	1.30
13	Santa Margarita R. nr. Fallbrook, CA	645.0	99.2	7.3	.062	1.61
14	Santa Margarita R. at Ysidora, CA	740.0	228.0	9.5	.061	1.59
15	Live Oak Cr. at Live Oak Dam, CA	2.3	0.2	0.8	.052	1.35
16	Tujunga Cr. at Big Tujunga Dam, CA	81.4	6.5	2.5	.052	1.35
17	Murrieta Cr. at Temecula, CA	220.0	28.9	4.0	.051	1.33
18	Los Angeles R. at Sepulveda Dam, CA	152.0	14.3	3.5	.056	1.46
19	Pacoima Wash at Pacoima Dam, CA	27.8	6.8	2.4	.049	1.27
20	East Fullerton Cr. at Fullerton Dam, CA	3.1	0.5	0.6	.029	0.75
21	San Jose Cr. at Workman Mill Rd. CA	81.3	24.8	2.4	.032	0.83
22	San Vincente Cr. at Foster, CA	75.0	12.8	3.2	.053	1.38
23	San Diego R. nr. Santee, CA	380.0	95.4	9.2	.078	2.03
24	Deep Cr. nr. Hesperia, CA	137.0	28.1	2.8	.036	0.94
25	Bill Williams R. at Planet, AZ	4730.0	1476.0	16.2	.056	1.46
26	Gila R. at Conner No. 4 Damsite, AZ	2840.0	1722.0	21.5	.071	1.85
27	San Francisco R. at Jct. with Blue R., AZ	2000.0	1688.0	20.6	.068	1.77
28	Blue R., nr. Clifton, AZ	790.0	352.0	10.3	.057	1.48
29	Moencopi Wash nr. Tuba City, AZ	2490.0	473.0	9.2	.046	1.20
30	Clear Cr. nr. Winslow, AZ	607.0	570.0	11.2	.053	1.38
31	Puerco R. nr. Admana, AZ	2760.0	1225.0	15.9	.058	1.51
32	Plateau Cr. nr. Cameo, CO	604.0	89.9	7.9	.069	1.79
33	White R. nr. Watson, UT	4020.0	1473.0	15.7	.054	1.40
34	Paria R. at Lees Ferry, AZ	1570.0	296.0	10.2	.060	1.56
35	New River at Rock Springs, AZ	67.3	16.5	3.1	.047	1.22
36	New River at New River, AZ	85.7	26.3	3.7	.048	1.25
37	New R. at Bell Road nr. Phoenix, AZ	187.0	108.0	5.3	.043	1.12
38	Skunk Cr. nr. Phoenix, AZ	64.6	18.7	2.4	.035	0.91

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 1 OF 3
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UNIT LAG DATA - SOUTHWEST DESERT, GREAT BASIN, AND COLORADO PLATEAU.

No	STREAM & LOCATION	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L_{CA}}{\sqrt{S}}$	LAG	K_N	CLASS	DATA SOURCE
		1	2	3	4			6	5		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	SALT RIVER AT ROOSEVELT, ARIZ	4341	145.	60.	47.	6.9	1261.	16.0	0.058	DESERT MTN	D.L.M. STUDY
2	VERDE R. ABV. EAST VERDE AND BELOW JEROME, ARIZ.	3190.	110.	47.	46.4	6.8	760.	12.0	0.052	DESERT MTN.	D.L.M STUDY
3	TONTO CR. ABV. GUN CR., ARIZ.	678.	41.	16.5	104.6	10.2	66.3	6.5	0.063	DESERT MTN	D.L.M. STUDY
4	AGUA FRIA R. NR. MAYOR, ARIZ.	590.	42.	14.0	87.1	9.3	63.2	5.4	0.053	DESERT HILLS	D.L.M STUDY
5	SAN GABRIEL R. AT SAN GABRIEL DAM, CALIF	162.	23.2	11.6	350	18.7	14.4	3.3	0.053	SAN GAB. CALIF	C.E.
6	WEST FK. SAN GABRIEL R. AT COGSWELL DAM, CALIF.	40.4	9.3	4.2	450.	21.2	1.8	1.6	0.051	SAN GAB CALIF	C.E.
7	SANTA ANITA CR. AT SANTA ANITA DAM, CALIF	10.8	5.8	2.5	690.	26.3	0.6	1.1	0.050	SAN GAB CALIF	C.E.
8	SAN DIMAS CR. AT SAN DIMAS DAM, CALIF	16.2	8.6	4.8	440.	21.0	2.0	1.5	0.046	SAN GAB. CALIF	C.E
9	EATON WASH AT EATON WASH DAM, CALIF	9.5	7.3	4.4	600.	24.5	1.3	1.3	0.046	SAN GAB CALIF	C.E.
10	SAN ANTONIO CR. NR. CLAREMONT, CALIF.	16.9	5.9	3.0	1017.	31.9	0.6	1.2	0.055	SAN GAB CALIF	C.E
11	SANTA CLARA R. NR. SAUGUS, CALIF	355.	36.0	15.8	140.	11.8	46.2	5.6	0.060	SAN DIEGO MTNS CAL.	C.E
12	TEMECULA CR AT PAUBA CANYON CALIF	168.	26.0	11.3	150.	12.2	24.1	3.7	0.050		C.E
13	SANTA MARGARITA R. NR. FALLBROOK, CALIF	645.	46.0	22.0	105.	10.2	99.2	7.3	0.062	SAN DIEGO MTNS	C.E.

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 2 OF 3
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UNIT LAG DATA - SOUTHWEST DESERT, GREAT BASIN, AND COLORADO PLATEAU.

	No	Stream & Location	DA	L	Lca	S	$\sqrt{S}$	$\frac{L_{ca}}{\sqrt{S}}$	Lag	K_n	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
14	14	Santa Margarita R. at Ysidora, Calif.	740.	61.2	34.3	85.	9.2	228.	9.5	0.061	San Diego Mtns	C.E.
15	15	Live Oak Cr. at Live Oak Dam, Calif.	2.3	2.9	1.5	700.	26.5	0.2	0.8	0.052	San Gab	C.E.
16	16	Tujunga Cr. at Big Tujunga Dam, Calif.	81.4	15.1	7.3	290.	17.0	6.5	2.5	0.052	San Gab	C.E.
17	17	Murrieta Cr. at Temecula, Calif.	220.	27.2	10.3	95.	9.7	28.9	4.0	0.051		C.E.
18	18	Los Angeles R. at Sepulveda Dam, Calif.	152	19.0	9.0	145.	12.0	14.3	3.5	0.056	San Gab	C.E.
19	19	Pacoima Wash at Pacoima Dam, Calif.	27.8	15.0	8.0	315.	17.7	6.8	2.4	0.049	San Gab	C.E.
20	20	East Fullerton Cr. at Fullerton Dam, Calif.	3.1	3.2	1.7	140.	11.8	0.5	0.6	0.029	San Gab. Part UCB.	C.E.
21	21	San Jose Cr. at Workman Mill Road, Calif.	81.3	23.7	9.1	75.	8.7	24.8	2.4	0.032	San Gab Ft. Hills Part UCB	C.E.
22	22	San Vincente Cr. at Foster, Calif.	75.0					12.8	3.2	0.053		C.E.
23	23	San Diego R. nr. Santee, Calif.	380.					95.4	9.2	0.078	San Diego Mtn	C.E.
24	24	Deep Cr. nr. Hesperia, Calif.	137					28.1	2.8	0.036	San Gab Backsim.	C.E.
25	25	Bill Williams R. at Planet, Ariz.	4730					1476.	16.2	0.056	Desert	C.E.
22	26	Gila R. at Cannon #4 Damsite, Ariz.	2840	131.	71.	29.	5.4	1722.	21.5	0.071	Desert Mtn	C.E.

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 3 OF 3
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UNIT LAG DATA - SOUTHWEST DESERT, GREAT BASIN, AND COLORADO PLATEAU.

	No	Stream & Location	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L L_{CA}}{\sqrt{S}}$	Lag	K_N	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
23	27	San Francisco R. at Jct. with Blue R., Ariz.	2000	130.	74.	32.	5.7	1688.	20.6	.068	Desert	C.E
24	28	Blue R. nr. Clifton, Ariz	790.	77.	37.	65.	8.1	352.	10.3	0.057	Desert	C.E.
	29	Moencopi Wash nr. Tuba City, Ariz	2490.					473.	9.2	0.046	Desert	C.E
	30	Clear Cr. nr. Winslow, Ariz.	607.					570.	11.2	0.053	Desert	C.E.
	31	Puerco R. nr. Adamana, Ariz.	2760.					1225.	15.9	0.058	Desert	C.E.
	32	Plateau Cr. nr. Cameo, Colo	604.					89.9	7.9	0.069	Colo. West. Desert	C.E
	33	White R. nr. Watson, Ut.	4020.					1473.	15.7	0.054	Colo West Desert	C.E
	34	Paria R. at Lees Ferry, Ariz	1570.					596.	10.2	0.060	Desert	C.E
25	35	New River at Rock Springs, Ariz	67.3	20.2	9.7	141.	11.9	16.5	3.1	0.047	Desert	C.E.
26	36	New River at New River, Ariz	85.7	23.2	13.6	145.	12.0	26.3	3.7	0.048	Desert	C.E.
27	37	New R. at Bell Road nr Phoenix, Ariz.	187.	27.6	20.7	83.	9.1	108.	5.3	0.043	Desert	C.E.
28	38	Skunk Cr. nr. Phoenix, Ariz.	64.6	17.6	10.0	89.	9.4	18.7	2.4	0.035	Desert	C.E

Table 4-2.—Unit hydrograph lag data for the Rocky Mountains, New Mexico, Colorado, Utah, Wyoming, Montana, Idaho, and Oregon.

Index No.	Station and location	Drainage area, mi²	Basin factor, $LL_{ca}/S^{0.5}$	Lag time, L_g, hours	K_n	C_t
1	Purgatoire R. at Trinidad, CO	742.0	69.8	8.0	0.076	1.98
2	Wood R. nr. Meeteetse, WY	194.0	41.9	21.5	.241	6.27
3	Grey Bull R. nr. Meeteetse, WY	681.0	68.3	34.0	.324	8.42
4	San Miguel R. at Naturita, CO	1080.0	174.0	34.0	.238	6.19
5	Uncompaghre R. at Delta, CO	1110.0	216.0	36.0	.235	6.11
6	Dry Gulch nr. Estes Park, CO	2.1	0.2	0.9	.059	1.53
7	Rabbit Gulch nr. Estes Park, CO	3.4	0.2	1.0	.065	1.69
8	North Fk. Big Thompson R. nr. Glen Haven, CO	1.3	0.1	0.7	.058	1.51
9	Uintah R. nr. Neola, UT	181.0	59.0	32.0	.324	8.42
10	South Fk. Payette R. nr. Garden Valley, ID	779.0	123.0	30.0	.236	6.14
11	Malheur R. nr. Drewsey, OR	910.0	114.0	30.0	.242	6.29
12	Weiser R. above Craney Cr. nr. Weiser, ID	1160.0	310.0	37.0	.214	5.56
13	Madison R. nr. Three Forks, MT	2511.0	2060.0	50.0	.155	4.03
14	Gallatin R. at Logan, MT	1795.0	443.0	38.0	.196	5.10
15	Surface Cr. at Cedaredge, CO	43.0	11.3	11.3	.195	5.07
16	South Piney Cr. at Willow Park, WY	28.9	3.8	10.5	.260	6.76
17	Piney Cr. at Kearney, WY	106.0	29.0	16.5	.209	5.43
18	Coal Cr. nr. Cedar City, UT	92.0	6.6	2.4	.050	1.30
19	Sevier R. nr. Hatch, UT	260.0	41.0	5.1	.058	1.51
20	Sevier R. nr. Kingston, UT	1110.0	469.0	11.0	.056	1.46
21	Centerville Cr. nr. Centerville, UT	3.9	0.4	2.4	.124	3.22
22	Parrish Cr. nr. Centerville, UT	2.0	0.3	2.2	.126	3.28
23	Florida R. nr. Hermosa, CO	69.4	12.5	15.5	.259	6.73
24	Dolores R. nr. McPhee, CO	793.0	193.0	9.0	.061	1.59
25	Los Pinos R. nr. Bayfield, CO	284.0	35.0	28.5	.339	8.81

Bureau of Reclamation

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 1 OF 2
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	
DETAILS UHG LAG DATA - ROCKY MOUNTAINS			

	No	Stream & Location	DA	L	L_{CA}	S	$\sqrt{S}$	$\frac{L L_{CA}}{\sqrt{S}}$	Lag	K_N	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
29	1	Purgatoire R. at Trinidad, Colo.	742.	44.0	20.0	159.	12.6	69.8	8.0	0.076	Southern Rockies E. Slope	B.R.
30	2.	Wood R. nr. Meeteetse, Wyo.	194.	32.1	18.0	190.	13.8	41.9	21.5	0.241	North Rockies E. Slope	B.R.
31	3.	Grey Bull R. nr. Meeteetse, Wyo.	681.	43.6	18.8	144.	12.0	68.3	34.0	0.324	North. Rockies E. Slope	B.R.
	4.	San Miguel R at Naturita, Colo.	1080.					174.	34.0	0.258	South. Rockies W. Slope	B.R.
	5	Uncompahgre R. at Delta, Colo	1110					216.	36.0	0.235	South Rockies W. Slope	B.R.
32	6	Dry Gulch nr. Estes Park, Colo	2.1	2.7	1.0	295.	17.1	0.2	0.9	0.059	Central Rockies E. Slope	B.R.
33	7	Rabbit Gulch nr. Estes Park, Colo	3.4	3.3	1.5	280.	21.9	0.2	1.0	0.065	Central Rockies E. Slope	B.R
34	8	North Fk. Big Thompson R. nr. Glen Haven, Colo.	1.3	1.9	1.3	709.	26.6	0.1	0.7	0.058	Central Rockies E. Slope	B.R
	9	Uintah R. nr Neola, Ut.	181.					57.	32.	0.324	~~[illegible]~~ Uintah Mtns	B.R.
	10	South Fk. Payette R. nr. Garden Valley, Ore.	779.					123.	30.	0.236	North Rockies W. Slope	B.R
	11	Malheur R. nr. Drewsey, Ore	910.					114.	30.	0.242	North Rockies W. Slope	B.R
	12	Weiser R. abv. Cranney Cr. nr Weiser, Ore	1160.					310.	37.	0.214	North Rockies W. Slope	B.R
	13.	Madison R. nr. Three Forks, Mont.	2511.					2060.	50.	0.155	North Rockies E. Slope	B.R

Bureau of Reclamation

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 2 OF 2
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	
DETAILS UHG LAG DATA - ROCKY MOUNTAINS			

No	STREAM & LOCATION	DA	L	L_{CA}	S	TE	$\frac{L_{CA}}{TE}$	LAG	K_N	CLASS	DATA SOURCE
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
14	GALLITIN R. AT LOGAN, MONT.	1795.					443.	38.	0.196	NORTH ROCKIES E. SLOPE	BR, DLM.
15	SURFACE CR. AT CEDAREDGE, COLO.	43.					11.3	11.3	0.195	CENTRAL ROCKIES W. SLOPE	J.F.L. FILE
16	SOUTH PINEY CR. AT ~~[illegible]~~ WILLOW PARK, WYO	28.9					3.8	10.5	0.260		J.L. FILE
17	PINEY CR. AT KEARNEY, WYO	106.					29.	16.5	0.209		J.L. FILE
35 18	COAL CR NR. CEDAR CITY, UT.	92.	16.5	7.1	310	176	6.6	2.4	0.050	SOUTH UT MTNS	J.F.L. FILE
36 19	SEVIER R. NR. HATCH, UT.	260.	29.	14.	100.	10.0	41.	5.1	0.058	SO. UT. MTNS	JFL FILE
37 20	SEVIER R. NR KINGSTON, UT.	1110.	82.	40.	49.	7.0	469.	11.0	0.056	SO. UT. MTNS	J.L. FILE.
21	CENTERVILLE CR. NR. CENTERVILLE, UT.	3.9					0.4	2.4	0.126	WASATCH W. FACE	J.L. FILE
22	PARRISH CR. NR CENTERVILLE, UT	2.0					0.3	2.2	0.126	WASATCH W. FACE	J.L. FILE
23	FLORIDA R. NR HERMOSA, COLO	694					12.5	15.5	0.259	SOUTH ROCKIES W. SLOPE	J.L. FILE
24	DOLORES R. NR McPHEE, COLO.	793.					193.	9.0	0.061	SOUTH. ROCKIES W. SLOPE	J.L. FILE
25	LOS PINOS R. NR BAYFIELD COLO	284.					35.	28.5	0.339	SOUTH ROCKIES W. SLOPE	J.L. FILE

Table 4-6.—Unit hydrograph lag data for urban basins.

Index No.	Station and location	Drainage area, mi²	Basin factor, $LL_{ca}/S^{0.5}$	Lag time, L_g, hours	K_n	C_t
1	Alhambra Wash above Short St., Monterey Park, CA	14.0	4.8	0.6	0.011	0.29
2	San Jose Cr. at Workman Mill Rd., Whittier, CA	81.3	24.8	2.4	.032	0.83
3	Broadway Drain at Raymond Dike, CA	2.5	0.6	0.3	.014	0.36
4	Compton Cr. below Hooper Ave. Storm Drain, L.A., CA	19.5	9.7	1.8	.033	0.86
5	Ballona Cr. at Sawtelle Blvd., L.A., CA	88.6	8.3	1.2	.023	0.60
6	Brays Bayou, Houston, TX	88.4	121.0	2.1	.017	0.44
7	White Oak Bayou, Houston, TX	92.0	134.0	3.1	.024	0.62
8	Boneyard Cr., Austin, TX	4.5	1.2	0.8	.029	0.75
9	Waller Cr., Austin, TX	4.1	1.4	1.0	.034	0.88
10	Beargrass Cr., Louisville, KY	9.7	5.6	0.9	.020	0.52
11	17th Street Sewer, Louisville, KY	0.2	0.04	0.15	.017	0.44
12	Northwest Trunk, Louisville, KY	1.9	0.8	0.4	.014	0.36
13	Southern Outfall, Louisville, KY	6.4	4.4	0.7	.017	0.44
14	Southwest Outfall, Louisville, KY	7.5	4.1	0.50	.012	0.31
15	Beargrass Cr., Louisville, KY	6.3	3.4	1.0	.026	0.68
16	Tripps Run nr. Falls Church, VA	4.6	1.1	0.9	.033	0.86
17	Tripps Run at Falls Church, VA	1.8	0.26	0.5	.030	0.78
18	Four Mile Run at Alexandria, VA	14.4	4.2	1.4	.034	0.88
19	Little Pimmit Run at Arlington, VA	2.3	0.25	0.4	.024	0.62
20	Piney Branch at Vienna, VA	0.3	0.01	0.2	.035	0.91
21	Walker Avenue Drain at Baltimore, MD	0.2	0.04	0.2	.022	0.57

Bureau of Reclamation

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 1 OF
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD STUDIES	

DETAILS
UHG LAG DATA - URBANIZED DRAINAGES

	ID	STREAM & LOCATION	DA	L	LCA	S	TS	LLCA/TS	LAG	KN	CLASS	DATA SOURCE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
77	1	ALHAMBRA WASH ABV SHORT ST, CALIF	14.0	9.5	4.6	85.	9.2	4.8	0.6	0.011	40% IMP	C.E.
78	2.	SAN JOSE CR AT WORKMAN MILL RD, CALIF.	81.3	23.7	9.1	75	8.7	24.8	2.4	0.032	35% IMP	C.E.
79	3	BROADWAY DRAIN AT RAYMOND DIKE, CALIF	2.5	3.4	1.7	100	10.0	0.6	0.3	0.014	45% IMP	C.E.
80	4	COMPTON CR. BEL. HOOPER AVE. STORM DRAIN, L.A. CALIF.	19.5	8.8	4.2	14.6	3.8	9.7	1.8	0.033	60% IMP	CE
81	5	BALLONA CR. AT SAWTELLE BLVD, L.A., CALIF.	88.6	11.8	5.6	4.	8.0	8.3	1.2	0.023	40% IMP	CE.
82	6.	BRAY'S BAYOU, HOUSTON TEX.	88.4	23.3	10.4	4.1	2.0	121.	2.1	0.017	40% IMP	AGC
83	7	WHITE OAK BAYOU, HOUSTON, TEX.	42.0	23.1	12.8	5.0	2.2	134.	3.1	0.024	35% IMP	AGC
84	8.	BONEYARD CR., AUSTIN TEX.	4.5	2.8	1.3	9.5	3.1	1.2	0.8	0.029	37% IMP	AGC
85	9	WALLER CR, AUSTIN TEX.	4.1	5.2	1.9	48.	6.9	1.4	1.0	0.034	27% IMP	AGC
86	10	BEARGRASS CR, LOUISVILLE KY	9.7	5.6	2.5	6.3	2.5	5.6	0.9	0.020	70% IMP	AGC
87	11	17TH STREET SEWER, LOUISVILLE, KY.	0.2	0.9	0.3	46	6.9	0.04	0.15	0.017	93% IMP	AGC
88	12	NORTHWEST TRUNK, LOUISVILLE, KY.	1.9	3.0	1.1	19.	4.4	0.8	0.4	0.014	50% IMP	AGC
89	13	SOUTHERN OUTFALL LOUISVILLE, KY.	6.4	6.4	2.5	13.	3.6	4.4	0.7	0.017	48% IMP	AGC

BY	DATE	PROJECT DESIGN OF SMALL DAMS	SHEET 2 OF
CHKD BY	DATE	FEATURE CHAPTER 5, FLOOD ROUTES	

DETAILS
UHG LAG DATA - URBAN DRAINAGES

	No	Stream & Location	DA	L	L_{CA}	S	T_E	$\frac{L L_{CA}}{T_E}$	LAG	K_N	Class	Data Source
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
70	14	Southwest Outfall, Louisville, Ky.	7.5	6.5	2.7	18.5	4.3	4.1	0.50	0.012	33% imp	A.G.C.
71	15	Beargrass Cr, Louisville, Ky.	6.3	4.0	1.8	4.5	2.1	3.4	1.0	0.026	60% imp	AGC
72	16	Tripps Run nr. Falls Church, Va.	4.6	4.1	1.9	52.	7.2	1.1	0.9	0.053	20% imp	AGC
73	17	Tripps Run at Falls Church, Va.	1.8	2.3	1.0	79.	8.9	0.26	0.5	0.030	25% imp	AGC
74	18	Four Mile Run at Alexandria, Va.	14.4	7.8	3.5	13.	6.5	4.2	1.4	0.034	26% imp	AGC
75	19	Little Pimmit Run at Arlington, Va	2.3	2.2	1.0	77.	8.8	0.25	0.4	0.024	20% imp	A.G.C.
76	20	Piney Branch at Vienna, Va	0.3	0.5	0.2	87.	9.3	0.01	0.2	0.035	30% imp	AGC
77	21	Walker Avenue Drain at Baltimore, Md	0.2	1.0	0.4	83.	9.1	0.04	0.2	0.022	33% imp	AGC

APPENDIX B

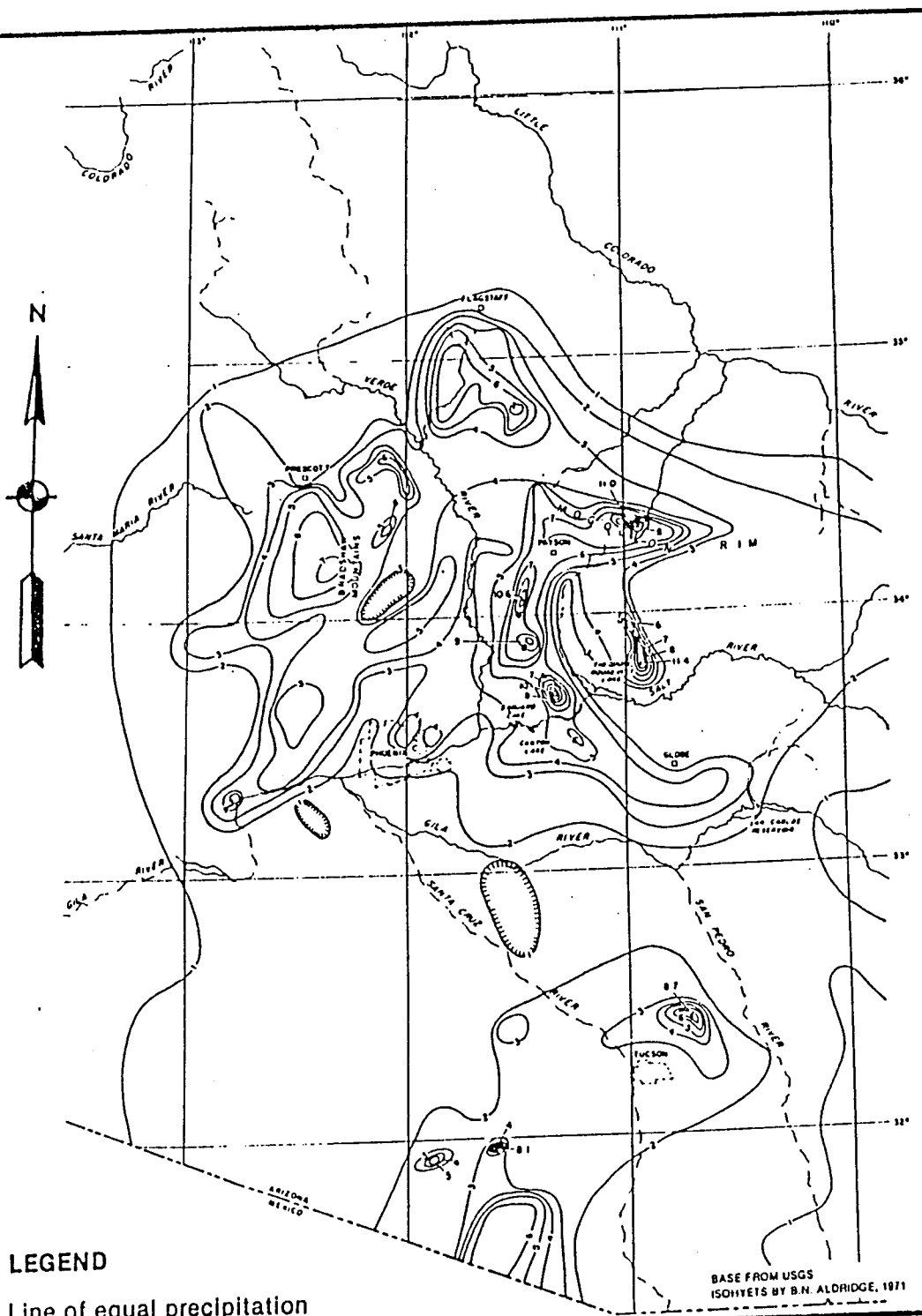
Description of the Storm and Flood of 12-21 December 1967
(Los Angeles District, 1974)

Storm and Flood of December 12-21, 1967. This storm period consisted of two general storm systems - one during December 12 through 16, and the other during December 17 through 21. During December 12 and 13, very cold air invaded Arizona from the north while a deepening upper level low pressure center off the southern California coast brought strong southerly winds aloft to Arizona and caused widespread substantial precipitation over much of the state. Snow fall was very heavy in the mountain areas with some stations reporting unprecedented snow depths and the snow level dropped to as low as 1,000 feet on December 13 and14. Precipitation from this first storm system generally diminished from December 15 through December 17, as the storm began moving to the east. A strong flow of warm moist air from the south began invading Arizona ahead of the second storm system and rainfall over the area began to increase with the snow level rising to around 5,000 feet. Around mid-day on December 19, precipitation became quite heavy over the Phoenix area as a cold front moved through the region from the northwest and a considerable amount of melting snow was added to the runoff. Precipitation intensities diminished and the snow level lowered once again late on December 19, after the passage of the cold front. New December precipitation records were set at several Arizona stations during December 1967, including 16.21 inches at Crown King, 7.30 inches at Flagstaff, and 3.92 inches at Phoenix. All of the months' precipitation fell during the 10 day period of December 12-21 in central Arizona. The heaviest daily precipitation occurred on December 19, with Crown King measuring 6.00 inches and Bumble Bee reporting 4.61 inches. With approximately 5 days of antecedent rainfall during the period December 13-18, the ground conditions were ripe to produce sizeable floods in the Phoenix area during the higher intensity rainfall which occurred during December 19. The New River-Skunk Creek system produced a peak of 19,800 c.f.s. near Glendale (323 square miles).

Description of the Storm and Flood of 3-7 September 1970
(Los Angeles District, 1982)

Isohyetal map on following page.

Storm and Flood of 3-7 September 1970. The storm began on 3 September in southern Arizona as moisture outflow from tropical storm Norma, west of Baja California, began to move into Arizona from the south. Showers pushed northward across the state on 4 September, becoming heavy at times. On 5 September, a strong cold front moved across Arizona from the west, triggering a 12- to 24-hour period of rain that reached unprecedented intensities at some stations. Precipitation tapered off rapidly late on 5 September, and only a few light showers lingered on 6-7 September. Total storm precipitation in central Arizona ranged from less than 1 inch around Coolidge Dam (San Carlos Reservoir) to nearly 12 inches in the Sierra Ancha Mountains northeast of Roosevelt Dam. Workman Creek, with a storm total of 11.92 inches, measured 11.4 inches in 24-hours—exceeding the previous all-time Arizona 24-hour record by more than 5 inches. Numerous other stations recorded from 5 to 8 inches during the heaviest 24 hours (mostly on 5 September). In and near the Agua Fria River drainage the storm total ranged from 1.78 inches at Prescott to 7.01 inches at Crown King. The latter station recorded 4.50 inches in the 24 hours ending at 6:00 p.m. on the 5th. A large portion of the maximum 24-hour precipitation fell within 4 to 6 hours. Total storm isohyets for 4-6 September are shown on plate 11. Much of central Arizona had received substantial precipitation during the first 3 to 4 weeks of August 1970. Thus, the ground was partially saturated in most areas at the beginning of the September storm. By the time of the heaviest burst of rain on 5 September conditions were favorable for heavy runoff. The high intensity rain that occurred on the 5th resulted in extensive flooding, with some streams recording all-time maximum discharges. On the New River USGS measurements at the gages near Rock Springs and at New River list peak discharges for 5 September of 18,600 and 19,500 ft^3/s, respectively. On the Agua Fria River near Rock Springs the peak discharge on 5 September was 40,100 ft^3/s (table 9). On the Hassayampa River at Box Damsite, near Wickenburg, the 58,000 ft^3/s recorded on 5 September is more than twice the previous known maximum of 27,000 ft^3/s, which is estimated to have occurred in February 1927 and which occurred again in August 1951.



LEGEND

-2- Line of equal precipitation

3 Hactures indicate less rainfall than value shown

11.4 X Shows maximum rainfall where all isohyets cannot be shown.

NOTE: Some rainfall near the Mexican boundary occured before midnight on September 3.

SCALE 0 10 20 30 40 50 MILES

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

ISOHYETAL MAP
STORM OF SEPT. 4-6, 1970

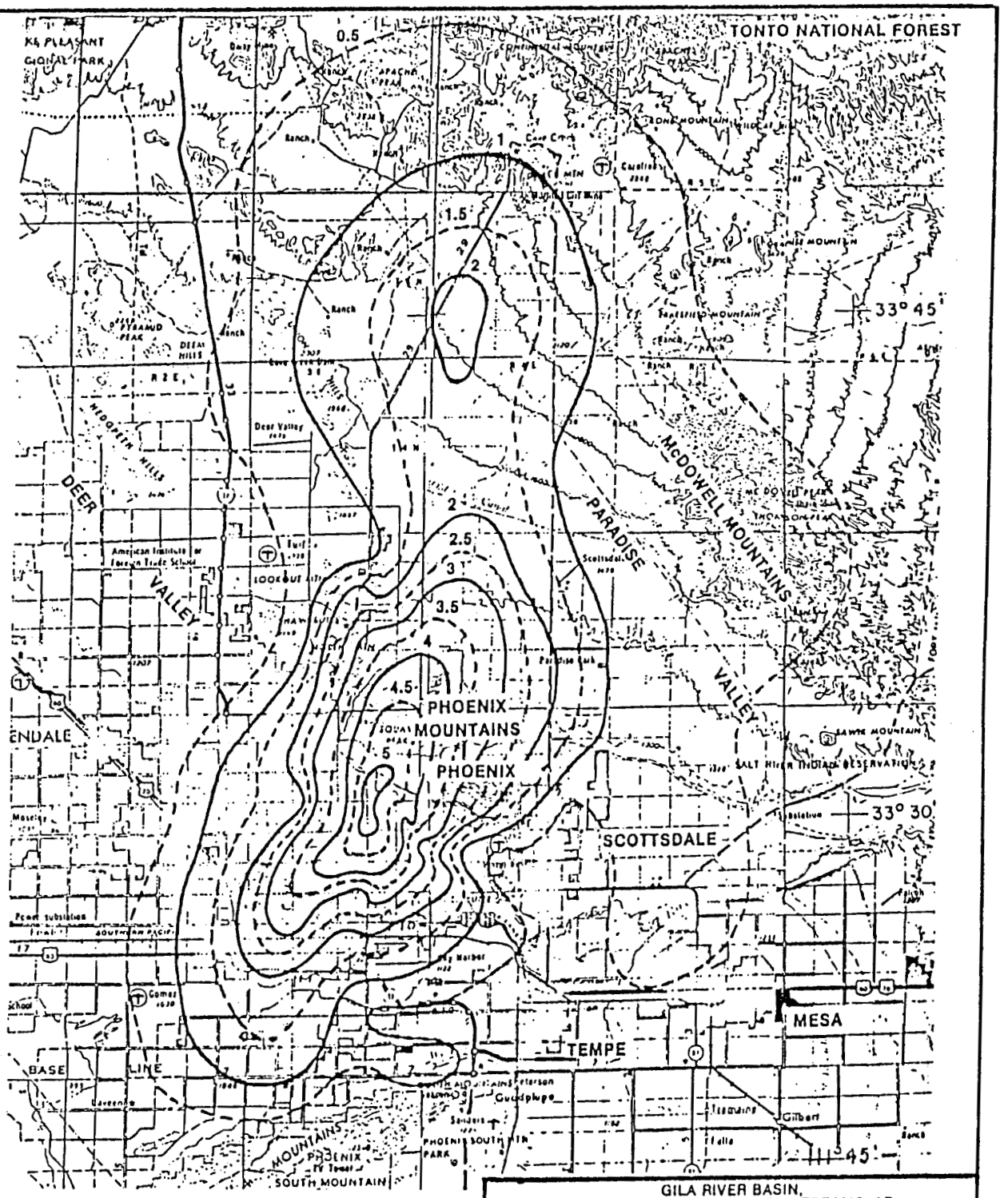
US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

Description of the Storm and Flood of 22 June 1972

(Los Angeles District, 1982)

Isohyetal map on following page.

Storm and Flood of 22 June 1972. The heavy thunderstorm that occurred over northeastern Phoenix and adjacent communities on the morning of 22 June 1972 was a part of a series of early summer thunderstorms over the entire southwestern United States from 20 through 23 June 1972 that resulted from a deep flow of very moist, tropical air into the region from off the west coast of Mexico. In Phoenix the unofficial maximum rainfall was 5.25 inches during an estimated 2 hours near 4th Street and Camelback Road. Bucket survey amounts of 4.87 inches at 24th Street and Indianola Avenue and 4.8 inches at 28th Street and Indian School Road were confirmed by the National Weather Service. The maximum recording-gage intensity was 3.85 inches in 80 minutes at 18th Street and Turney Avenue. Large hail also fell in the area. The storm was highly localized, with only 10 square miles having greater than 4 inches of rainfall and only 200 square miles with more than 2 inches. Total storm isohyets for 21-22 June are shown on plate 12. Estimates of peak discharges for 22 June made by the USGS include: Shea Wash at Shea Boulevard (1.79 square miles), 945 ft^3/s; Cudia City Wash 1000 feet upstream from McDonald Drive (2.16 square miles), 4200 ft^3/s; Dreamy Draw at 16th Street (1.62 square miles), 860 ft^3/s; Indian Bend Wash (at Indian Bend Road) near Scottsdale (142 square miles), 21,000 ft^3/s.



N

SCALE IN MILES

1 0 4 8

LEGEND

— 2 — LINE OF EQUAL PRECIPITATION IN INCHES

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

ISOHYETAL MAP
STORM OF JUNE 21-22, 1972

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

Point Rainfalls for the December 1967 Storm

Gage Location (1)	Rainfall Depth inches (2)	Type of Gage Recording (R) Nonrecording (N) (3)
Black Canyon 4NE	3.53	R
Carefree	2.75	R
New River	2.70	R
Rock Springs	3.19	R
Thunderbird Airport	1.42	R
Skunk Creek	3.59	R
Youngtown	2.35	R
Phoenix 11 NNW	1.89	R
Castle Hot Springs	4.07	N
Lake Pleasant	2.26	N
Cave Creek Dam	2.83	N
Beardsley	1.99	N
Paradise Valley	1.93	N
Litchfield Park	2.03	N
Alhambra 2NE	1.86	N
Arizona Falls	1.45	N
Tolleson 1E	1.77	N
T3N, R3E, Sec 34	2.46	N
T3N, R5E, Sec 15	2.67	N
T3N, R5E, Sec 16	2.02	N

Point Rainfalls for the September 1970 Storm

Black Canyon 4NE	2.82	R
Rock Springs	2.81	R
New River	5.39	R
Carefree	2.12	R
Skunk Creek	2.53	R
Youngtown	4.24	R
Phoenix	1.92	R
Thunderbird Airport	3.07	N
Lake Pleasant	4.11	N
Horseshoe Dam	3.94	N
Castle Hot Springs	4.56	N
Beardsley	5.04	N
Litchfield Park	3.09	N
Tolleson 1E	2.00	N

Point Rainfalls for the June 1972 Storm

Phoenix	3.13	R
Thunderbird Airport	.87	R
Carefree	.80	R

TR-55

Table 3-1.—Roughness coefficients (Manning's n) for sheet flow

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

HEC-1

Table 3.5

Resistance Factor for Overland Flow

Surface	N value	Source
Asphalt/Concrete*	0.05 - 0.15	a
Bare Packed Soil Free of Stone	0.10	c
Fallow - No Residue	0.008 - 0.012	b
Convential Tillage - No Residue	0.06 - 0.12	b
Convential Tillage - With Residue	0.16 - 0.22	b
Chisel Plow - No Residue	0.06 - 0.12	b
Chisel Plow - With Residue	0.10 - 0.16	b
Fall Disking - With Residue	0.30 - 0.50	b
No Till - No Residue	0.04 - 0.10	b
No Till (20-40 percent residue cover)	0.07 - 0.17	b
No Till (60-100 percent residue cover)	0.17 - 0.47	b
Sparse Rangeland with Debris:		
0 Percent Cover	0.09 - 0.34	b
20 Percent Cover	0.05 - 0.25	b
Sparse Vegetation	0.053 - 0.13	f
Short Grass Prairie	0.10 - 0.20	f
Poor Grass Cover On Moderately Rough	0.30	c
Bare Surface		
Light Turf	0.20	a
Average Grass Cover	0.4	c
Dense Turf	0.17 - 0.80	a,c,e,f
Dense Grass	0.17 - 0.30	d
Bermuda Grass	0.30 - 0.48	d
Dense Shrubbery and Forest Litter	0.4	a

Legend: a) Harley (1975), b) Engman (1986), c) Hathaway (1945), d) Palmer (1946), e) Ragan and Duru (1972), f) Woolhiser (1975). (See Hjemfelt, 1986)

*Asphalt/Concrete n value for open channel flow 0.01 - 0.016

APPENDIX C