APPENDIX A-2

PEAK DISCHARGES

NRCS CHART METHOD

INTRODUCTION

A quick and reliable method of computing peak discharges from drainage areas 1 to 2,000 acres in size is given in Figures A-2.3 through A-2.5, p. A-2-3 through A-2-5. The charts were prepared for the solution of the general relationships and are based on type-II rainfall distribution.

Type-II storms occur in regions where the high rates of runoff from small areas are usually generated from summer thunderstorms.

This chapter presents a method of adjusting peak discharges obtained from the charts to reflect the increase in peak discharge due to urbanization. Additional methods for interpolating or adjusting peak discharges for conditions not found on the charts or not represented by the general equations in this chapter are given later in this chapter.

MODIFICATION OF PEAK DISCHARGE DUE TO URBANIZATION

Research in the area of urban hydrology is developing rapidly. Research to date has been sufficient to identify the parameters that are affected by urbanization and to derive limited empirical relationships between those parameters for both agriculture and urban watersheds. The time to peak for urban watersheds is affected by a decrease in lag or time of concentration as described in TR-55 (Appendix A-1).

Figures A-2.1 and A-2.2 give factors for adjusting peaks calculated from Figures A-2.3 to A-2.5 based on the same parameters that affect watershed lag and time of concentration. The factors are applied to the peak using future-condition runoff curve numbers as follows:

Q_{MOD} = Q [Factor $_{IMP}$] [Factor $_{HLM}$] (Eq. A-2.1)

where

Q_{MOD} = modified discharge due to urbanization

Q = Discharge for future CN using charts (Figures A-2.3, A-2.4 or A-2.5)

$Factor_{IMP}$ = adjustment factor for percent impervious areas

$Factor_{HLM}$ = adjustment factor for percent of hydraulic length modified.

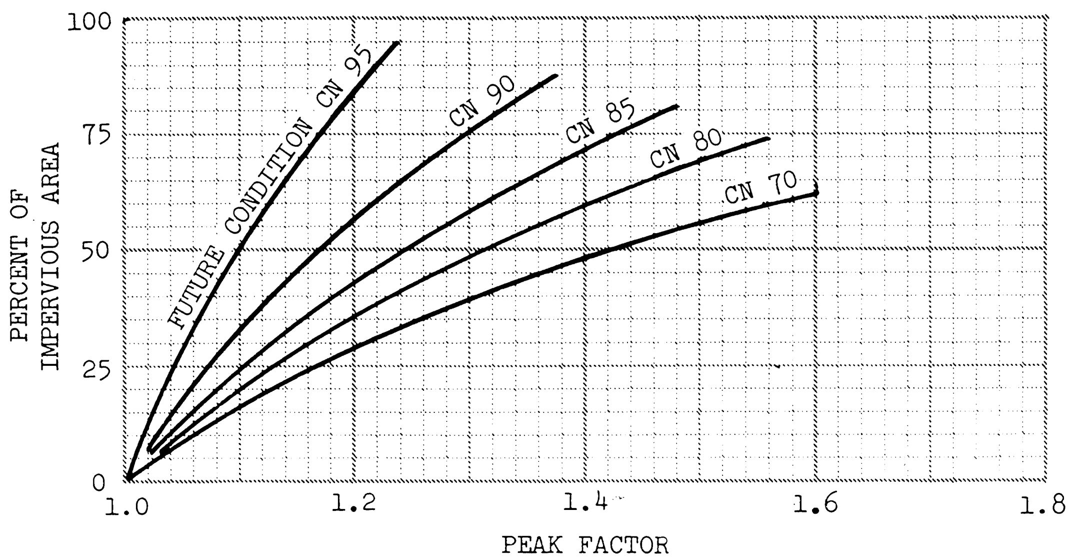


Figure A-2.1 – Factors for adjusting peak discharges for a given future-condition runoff curve number based on the percentage of impervious area in the watershed.

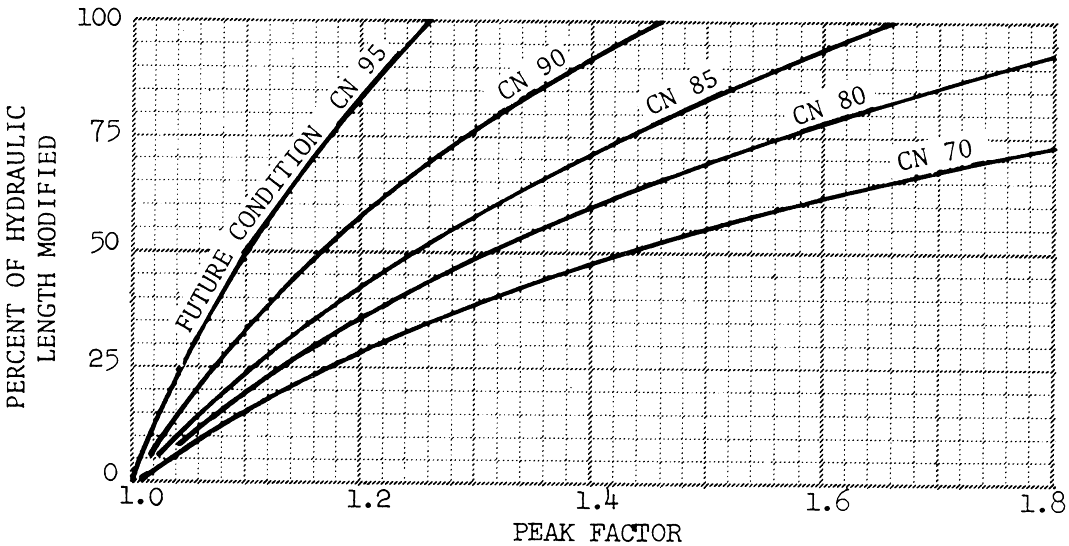


Figure A-2.2 – Factors for adjusting peak discharges for a given future-condition runoff curve number based on the percentage of hydraulic length modified.

Example A-2.1

A 300-acre watershed is to be developed. The runoff curve number for the proposed development is computed to be 80. Approximately 60 percent of the hydraulic length will be modified by the installation of street gutters and storm drains to the watershed outlet. Approximately 30 percent of the watershed will be impervious. The average watershed slope is estimated to be 4 percent. Compute the present-condition and anticipated future-condition peak discharge for a 50-year/24-hour storm event with 5 inches of rainfall. The present-condition runoff curve number is 75.

1. From TR-55, Table 2-1 (Appendix A-1), the runoff for present condition is 2.45 inches and for future conditions is 2.89 inches.
2. From the chart for moderate slope in Figure A-2.4 (CN = 75), the present condition peak discharge is 120 cfs (cubic feet per second) per inch of runoff. The peak discharge is then 120 x 2.45 or 294 cfs.
3. From the chart for moderate slope in Figure A-2.4 (CN = 80), the future-condition base discharge for (CN = 80) is 133 cfs per inch of runoff. The base discharge is then 133 x 2.89 or 384 cfs.
4. From Figure A-2.1 with 30 percent impervious area and future runoff curve number of 80, read peak factor = 1.16.
5. From Figure A-2.2, with 60 percent of the hydraulic length modified and future-condition curve number of 80, read peak factor = 1.42.
6. Future-condition peak discharge is:

   384 (1.16)(1.42) = 633 cfs

7. The effect of this proposal development is to increase the peak discharge from 294 to 633 cfs.

ADJUSTMENT FACTORS FOR PEAKS DETERMINED USING FIGURES A-2.3 THROUGH A-2.5

This section describes methods for adjusting peak rates of discharge for ranges of flat, moderate, and steep slopes; for conditions where swamps or ponding areas exist; and for conditions where the watershed shape factor (l/w) varies significantly from that used in the development of the charts of Figures A-2.3 through A-2.5.

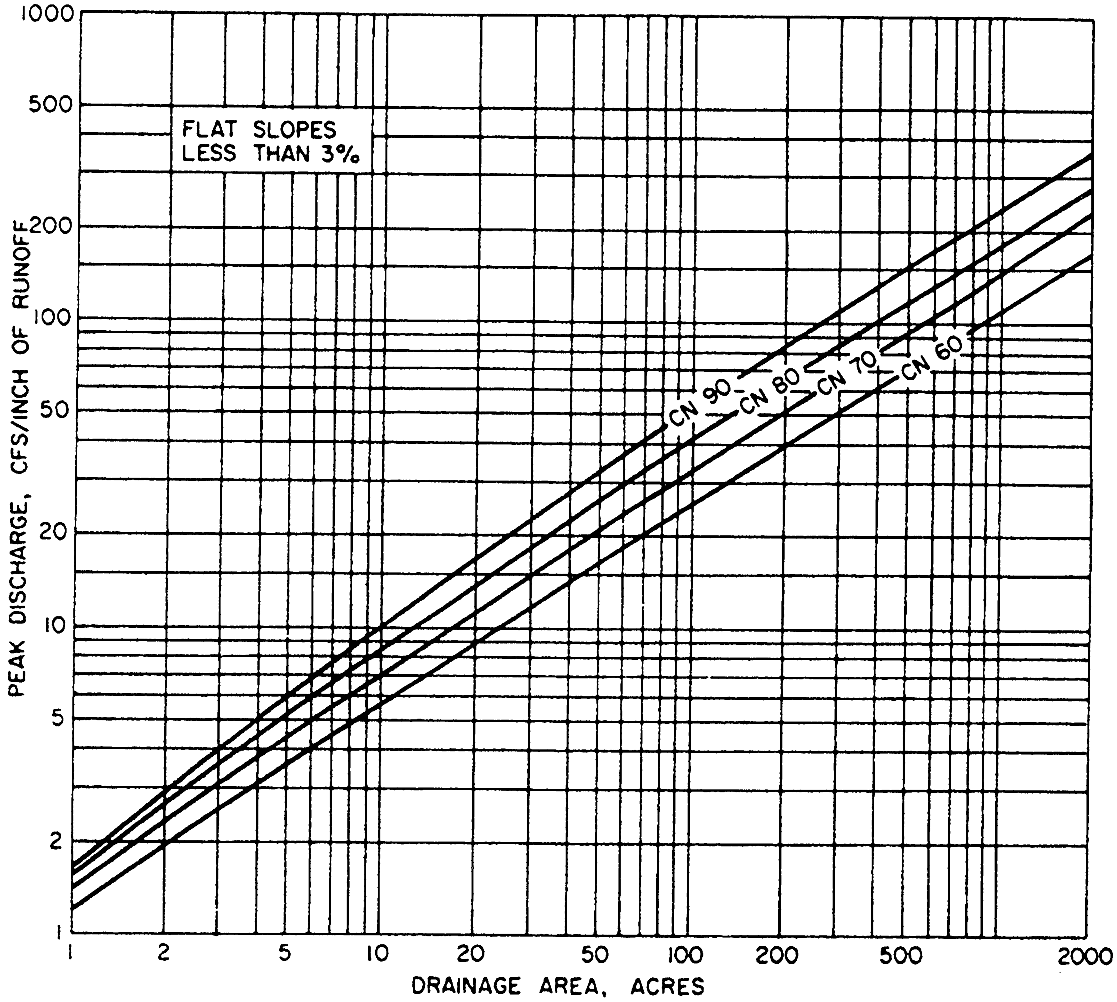
SLOPE INTERPOLATION

Table A-2.1 provides interpolation factors to be used in determining peak rates of discharge for specific slopes within ranges of flat, moderate, and steep slopes for a range of drainage areas. Figure A-2.3, for FLAT slopes is based on 1-percent slope, Figure A-2.4, for MODERATE slopes on 4-percent slope, and Figure A-2.5 for STEEP slopes on 16-percent slope. For slopes other than 1, 4, and 16 percent, use the factors shown in Table A-2.1 to modify the peak discharges.

Example A-2.2

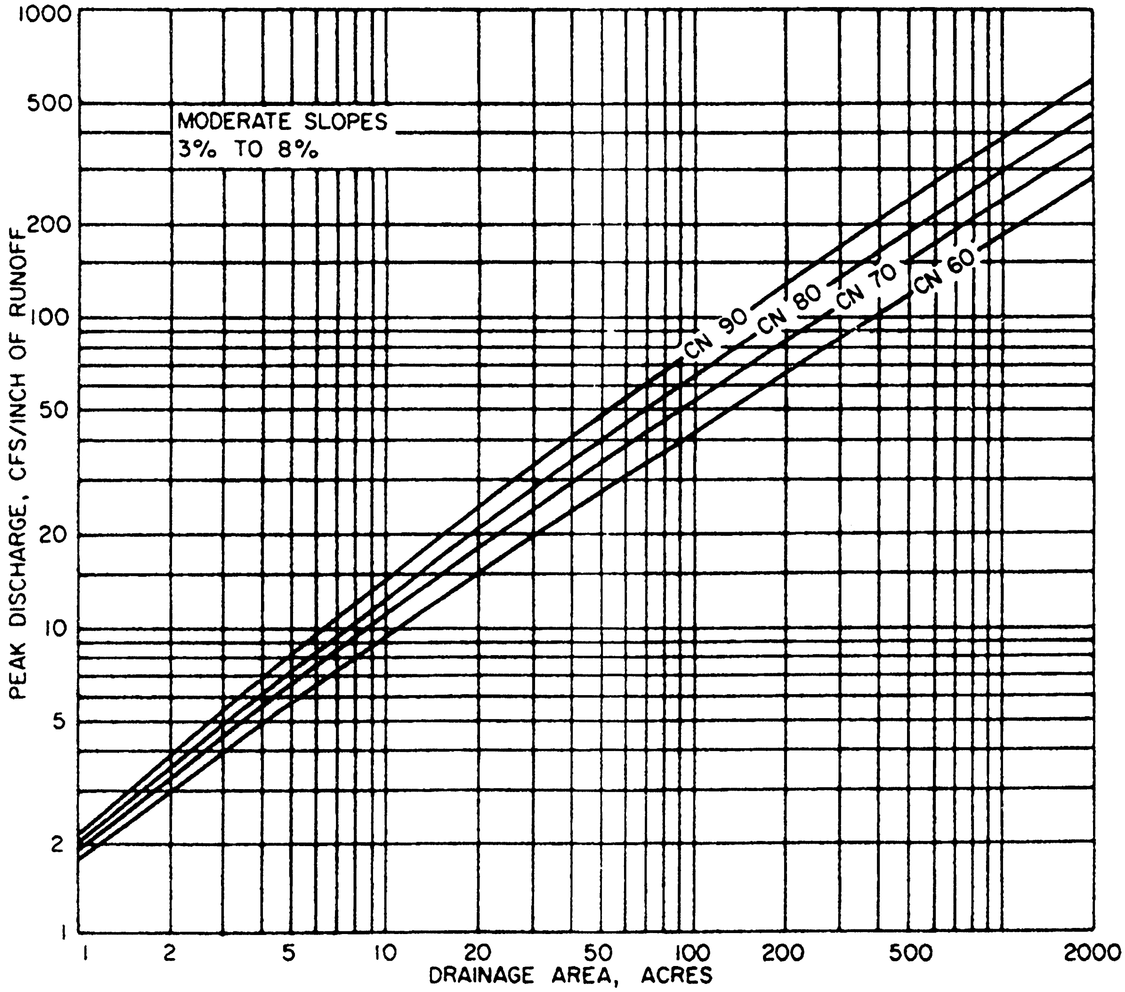
Compute the peak discharge for a 1,000-acre watershed with an average watershed slope of 7 percent and a runoff curve number (CN) of 80 for central Lee County, 2-year/24-hour storm.

1. Determine the peak discharge for a watershed with a moderate slope (4 percent). From Figure A-2.4, read a peak discharge of 295 cfs per inch of runoff for 1,000 acres and a CN of 80. From Figure A-2.8, Lee County has a P value of 4.0 inches. From TR-55,



PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS (24 HOUR, TYPE II STORM DISTRIBUTION)

Figure A-2.3



PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS (24-HOUR, TYPE II STORM DISTRIBUTION)

Figure A-2.4

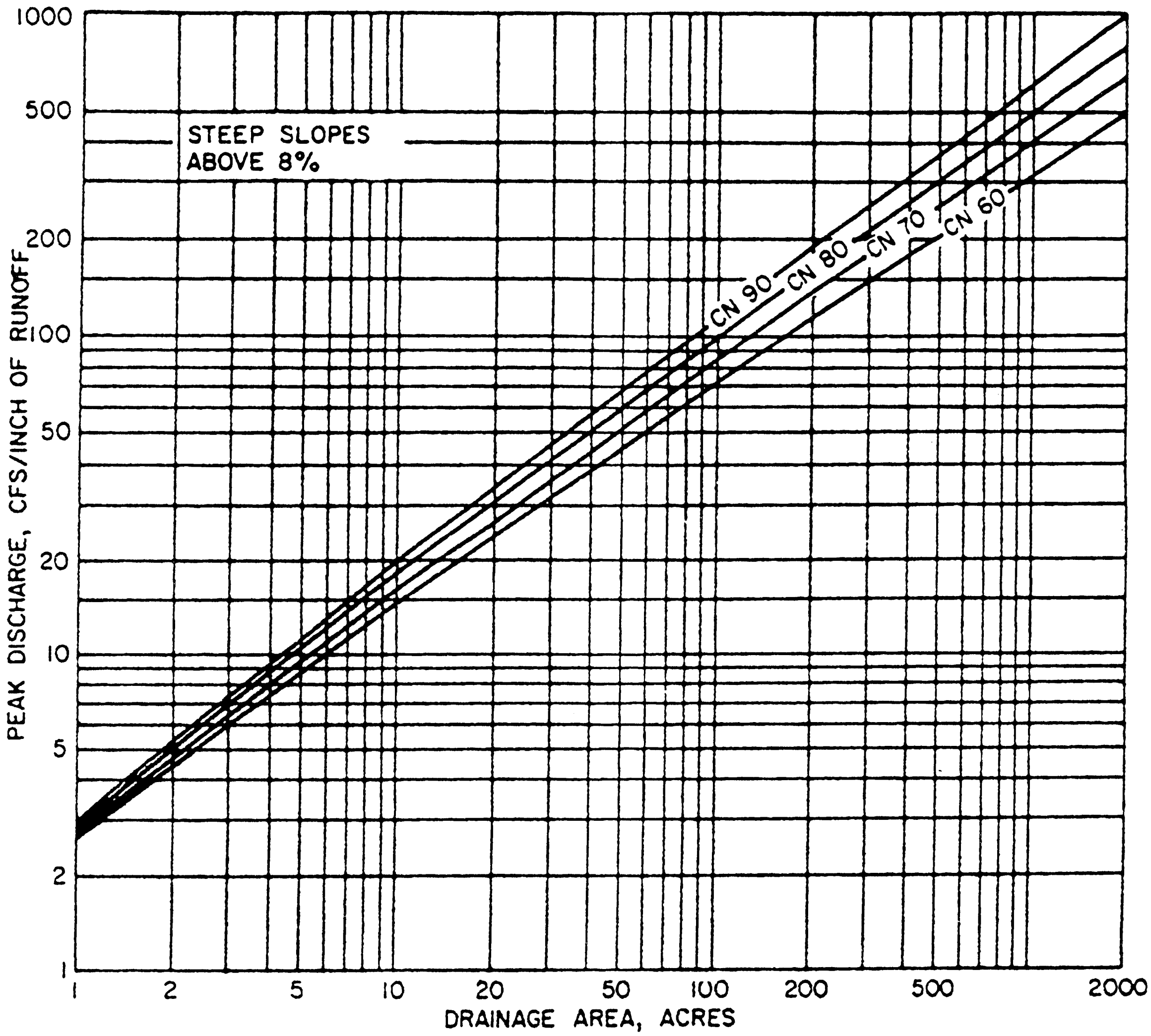


Figure A-2.5. – Peak rates of discharge for small watersheds (24-hour, type II storm distribution).

Table 2-1 (Appendix A-1) find 2.04 inches of runoff from 4 inches of rainfall and a CN of 80. The peak discharge is then 295 x 2.04 or 602 cfs.

2. Determine the interpolation factor. From Table A-2.1, find 7-percent slope under MODERATE heading and read an interpolation factor of 1.23 for a drainage area of 1,000 acres. (The peak from a 1,000-acre watershed with a watershed slope of 7 percent is 1.23 times greater than for an average watershed slope of 4 percent.)
3. Determine the peak discharge of 7-percent slope.

$$q = (602)(1.23) = 740 \text{ cfs}$$

Examples A-2.3

Compute the peak discharge for a 15-acre watershed with an average slope of 0.5 percent and a runoff curve number of 80 for 4 inches of rainfall.

1. Determine the peak discharge for a watershed with a flat slope (1 percent). From Figure A-2.3 read a peak discharge of 11.2 cfs per inch of runoff for 15 acres and a CN of 80. From Table A-2.1, find 2.04 inches of runoff for 4 inches of rainfall and a CN of 80. The peak discharge is then 11.2 x 2.04 or 23 cfs.
2. Determine the interpolation factor. From Table A-2.1 find 0.5-percent slope under FLAT heading. Read a slope interpolation factor of 0.81 interpolated between the values for 10 acres and 20 acres.
3. Determine the peak discharge for 0.5-percent slope.

$$q = (23)(.81) = 19 \text{ cfs}$$

Table A-2.1. – Slope adjustment factors by drainage areas.

Slope (percent)	10 acres	20 acres	50 acres	100 acres	200 acres	500 acres	1,000 acres	2,000 acres
FLAT SLOPES								
0.1	0.49	0.47	0.44	0.43	0.42	0.41	0.41	0.40
0.2	.61	.59	.56	.55	.54	.53	.53	.52
0.3	.69	.67	.65	.64	.63	.62	.62	.61
0.4	.76	.74	.72	.71	.70	.69	.69	.69
0.5	.82	.80	.78	.77	.77	.76	.76	.76
0.7	.90	.89	.88	.87	.87	.87	.87	.87
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.13	1.14	1.14	1.15	1.16	1.17	1.17	1.17
2.0	1.21	1.24	1.26	1.28	1.29	1.30	1.31	1.31
MODERATE SLOPES								
3	.93	.92	.91	.90	.90	.90	.89	.89
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1.04	1.05	1.07	1.08	1.08	1.08	1.09	1.09
6	1.07	1.10	1.12	1.14	1.15	1.16	1.17	1.17
7	1.09	1.13	1.18	1.21	1.22	1.23	1.23	1.24
STEEP SLOPES								
8	.92	.88	.84	.81	.80	.78	.78	.77
9	.94	.90	.86	.84	.83	.82	.81	.81
10	.96	.92	.88	.87	.86	.85	.84	.84
11	.96	.94	.91	.90	.89	.88	.87	.87
12	.97	.95	.93	.92	.91	.90	.90	.90
13	.97	.97	.95	.94	.94	.93	.93	92
14	.98	.98	.97	.96	.96	.96	.95	.95
15	.99	.99	.99	.98	.98	.98	.98	.98
16	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10
25	1.06	1.08	1.12	1.14	1.15	1.16	1.17	1.19
30	1.09	1.11	1.14	1.17	1.20	1.22	1.23	1.24
40	1.12	1.16	1.20	1.24	1.29	1.31	1.33	1.35
50	1.17	1.21	1.25	1.29	1.34	1.37	1.40	1.43

ADJUSTMENT FACTORS FOR SWAMPY AND PONDING AREAS

Peak flows determined from Figure A-2.3 through A-2.5 assume that the topography is such that surface flow into ditches, drains, and streams is approximately uniform. On very flat areas and where ponding or swampy areas occur in the watershed, a considerable amount of the surface runoff may be retained in temporary storage. The peak rate of runoff should be reduced to reflect this condition. Tables A-2.2, A-2.3, and A-2.4 provide adjustment factors to determine this reduction based on the ratio of the ponding or swampy area to the total watershed area for a range of storm frequencies.

Table A-2.2 contains adjustment factors to be used when the ponding or swampy areas are located in the path of flow in the vicinity of the design point. Table A-2.3 contains adjustment factors to be used when a significant amount of the flow from the total watershed passes through ponding or swampy areas and these areas are spread throughout the watershed. Table A-2.4 contains adjustment factors to be used when a significant amount of the flow passes through ponding or swampy areas located in the upper reaches of the watershed.

These conditions may occur in a proposed or existing urban or suburban area and the adjustment factors from Tables A-2.2, A-2.3, or A-2.4 should be applied after the peaks have been adjusted for the effects of urbanization.

Table A-2.2. – Peak flow adjustment factors where ponding and swampy areas occur at the design point.

Ratio of drainage area to ponding and swampy area	Percentage of ponding and swampy area	Storm frequency (years)						
		1	2	5	10	25	50	100
500	0.2	0.91	0.92	0.94	0.95	0.96	0.97	0.98
200	.5	.85	.86	.87	.88	.90	.92	.93
100	1.0	.79	.80	.81	.83	.85	.87	.89
50	2.0	.73	.74	.75	.76	.79	.82	.86
40	2.5	.68	.69	.70	.72	.75	.78	.82
30	3.3	.63	.64	.65	.67	.71	.75	.78
20	5.0	.58	.59	.61	.63	.67	.71	.75
15	6.7	.56	.57	.58	.60	.64	.67	.71
10	10.0	.52	.53	.54	.56	.60	.63	.68
5	20.0	.47	.48	.49	.51	.55	.59	.64

Table A-2.3. – Peak flow adjustment factors where ponding and swampy areas are spread throughout the watershed or occur in central parts of the watershed.

Ratio of drainage area to ponding and swampy area	Percentage of ponding and swampy area	Storm frequency (years)						
		1	2	5	10	25	50	100
500	0.2	0.93	0.94	0.95	0.96	0.97	0.98	0.99
200	.5	.87	.88	.89	.90	.91	.92	.94
100	1.0	.83	.83	.84	.86	.87	.88	.90
50	2.0	.77	.78	.79	.81	.83	.85	.87
40	2.5	.72	.73	.74	.76	.78	.81	.84
30	3.3	.68	.69	.70	.71	.74	.77	.81
20	5.0	.64	.65	.66	.68	.72	.75	.78
15	6.7	.61	.62	.63	.65	.69	.72	.75
10	10.0	.57	.58	.59	.61	.65	.68	.71
5	20.0	.52	.53	.54	.56	.60	.63	.68
4	25.0	.49	.50	.51	.53	.57	.61	.66

Table A-2.4. – Peak flow adjustment factors where ponding and swampy areas are located only in upper reaches of the watershed.

Ratio of drainage area to ponding and swampy area	Percentage of ponding and swampy area	Storm frequency (years)						
		1	2	5	10	25	50	100
500	0.2	0.95	0.96	0.97	0.98	0.98	0.99	0.99
200	.5	.92	.93	.94	.94	.95	.96	.97
100	1.0	.89	.90	.91	.92	.93	.94	.95
50	2.0	.86	.87	.88	.88	.90	.91	.93
40	2.5	.84	.85	.85	.86	.88	.89	.91
30	3.3	.81	.82	.83	.84	.86	.88	.89
20	5.0	.79	.80	.81	.82	.84	.86	.88
15	6.7	.77	.78	.79	.80	.82	.84	.86
10	10.0	.76	.77	.77	.78	.80	.82	.84
5	20.0	.73	.74	.75	.76	.78	.80	.82

Example A-2.4

A 5-acre pond is located at the downstream end of a 100-acre watershed in which a housing development is proposed. The average watershed slope is 4 percent and the present-condition curve number is 75. After the installation of the housing development, 30 percent of the watershed will be impervious and 50 percent of the hydraulic length will be modified. The future-condition curve number is estimated to be 80. For a 100-year storm 24-hour duration in central Glascock County, determine the present-condition and future-condition peak discharges downstream of the pond.

1. Determine the present-condition peak discharge assuming the pond is not in place: From Figure A-2.4, find the peak discharge to be 59 cfs per inch of runoff. From Figure A-2.13, the rainfall for central Glascock County is 8 inches. From TR-55, Table 2.1 (Appendix A-1) find the runoff to be 5.04 inches. The peak discharge is 59 x 5.04 or 297 cfs.
2. Determine the ponding adjustment factor: Since the pond is at the lower end of the watershed, use Table A-2.2. The ratio of the drainage area to pond area is 100/5 or 20. For a 100-year frequency event, the adjustment factor is 0.75.
3. Compute the present-condition peak discharge:

   Q = 0.75 (297) = 233 cfs

4. Compute the basic future-condition peak discharge: From Figure A-2.4, find the peak discharge to be 65 cfs per inch of runoff. From TR-55, Table 2-1, (Appendix A-1), Find the runoff to be 5.62 inches The peak discharge is then 65 x 5.62 or 365 cfs.
5. Determine the modification factors for proposed urbanization: Taken from Figures A-2.1 and A-2.2 for a curve number of 80: impervious factor = 1.16; hydraulic length factor = 1.31; urbanization factor = (1.16) (1.31) = 1.52.
6. Compute the future condition peak discharge:

   q = 1.52 (365) = 555 cfs

7. Compute the fugure-condition peak below the pond: From step 2 the ponding factor is 0.75.

   q = 0.75 (555) = 416 cfs

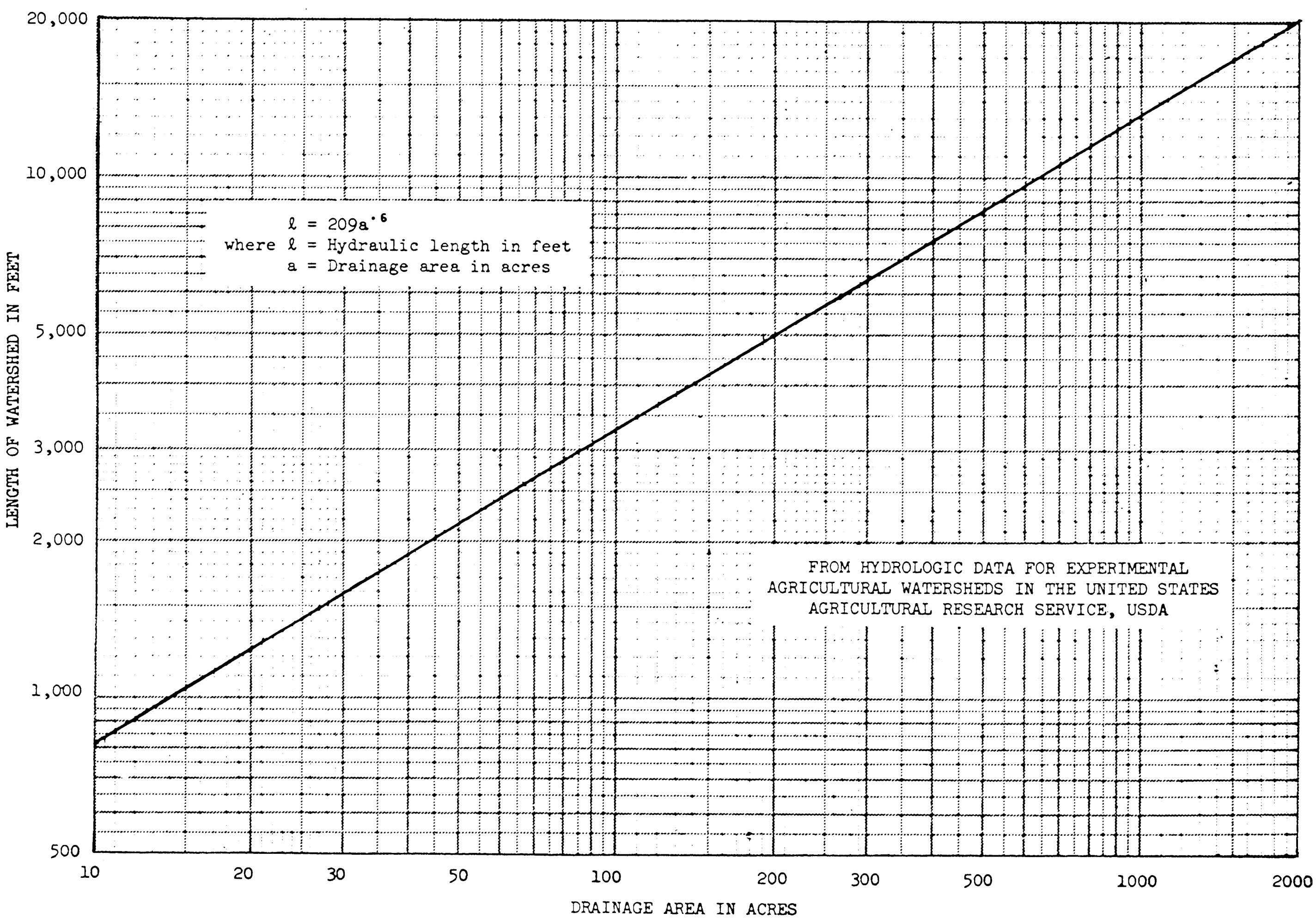


Figure A-2.6 – Hydraulic length and drainage area relationship.

ADJUSTMENT FOR WATERSHED SHAPE FACTOR

The equation used in computing peak discharges from Figures A-2.3 through A-2.5 was based in part on a relationship between the hydraulic length and the watershed area from Agricultural Research Services's studies on small experimental watersheds. Figure A-2.6 shows the best fit line relating length to drainage area. The equation of the line is $l = 209a^{0.6}$. A watershed shape factor, lw (where w is the average width of the watershed), is then fixed for any given drainage area. For example, for drainage areas of 10, 100, and 1,000 acres, the watershed shape factor is 1.58, 2.51, and 3.98, respectively.

There are watersheds that deviate considerably from these relationships. The peaks can be modified for other shape factors. The procedure is as follows:

1. Determine the hydraulic length of the watershed and compute "equivalent" drainage area using $l = 209a^{0.6}$ or Figure A-2.6.
2. Determine the "equivalent" peak flow from the charts for the "equivalent" drainage area.
3. Compute the "actual" peak discharge for the watershed by multiplying the equivalent peak discharge by the ratio of actual drainage area to the equivalent drainage area.

   The factors for modifying the peak for urbanization can then be applied to the revised peak discharge.

Example A-2.5

From a topographic map the hydraulic length of a 100-acre watershed with moderate slopes and a CN of 75 was measured to be 2,200 feet. Determine the peak discharge for a 6-inch, 24-hour rainfall.

1. Determine the "equivalent" drainage area for a watershed with a hydraulic length of 2,200 feet. From Figure A-2.6, read 51 acres. (Note that in a 100-acre watershed, the hydraulic length would be 3,300 feet from Figure A-2.6).
2. Determine the "equivalent" peak flow from Figure A-2.4 for a drainage area of 51 acres and a CN of 75. Read 37 cfs per inch of runoff. From TR-55 Table 2-1 (Appendix A-1), find the runoff to be 3.28 or 121 cfs.
3. Compute the actual peak discharge for 100 acres.

$$\text{actual discharge} = \text{equivalent discharge} \left(\frac{\text{actual drainage area}}{\text{equivalent drainage area}} \right)$$

$$q = 121 \left(\frac{100}{51} \right) = 237 \text{ cfs}$$

The peak discharge for the 100-acre watershed with a hydraulic length of 2,200 feet is 237 cfs (versus 194 cfs for a "normal" 100-acre watershed). Adjustments to this peak discharge for urbanization can be made using factors discussed on page A-2-1.

4. The procedure in steps 1, 2, and 3 can be used to determine peak discharges when the actual hydraulic length is longer than that shown on Figure A-2.6. For example, if the actual length were 4,500 feet instead of 3,300 feet, the equivalent area would be 170 acres, as shown in Figure A-2.6.

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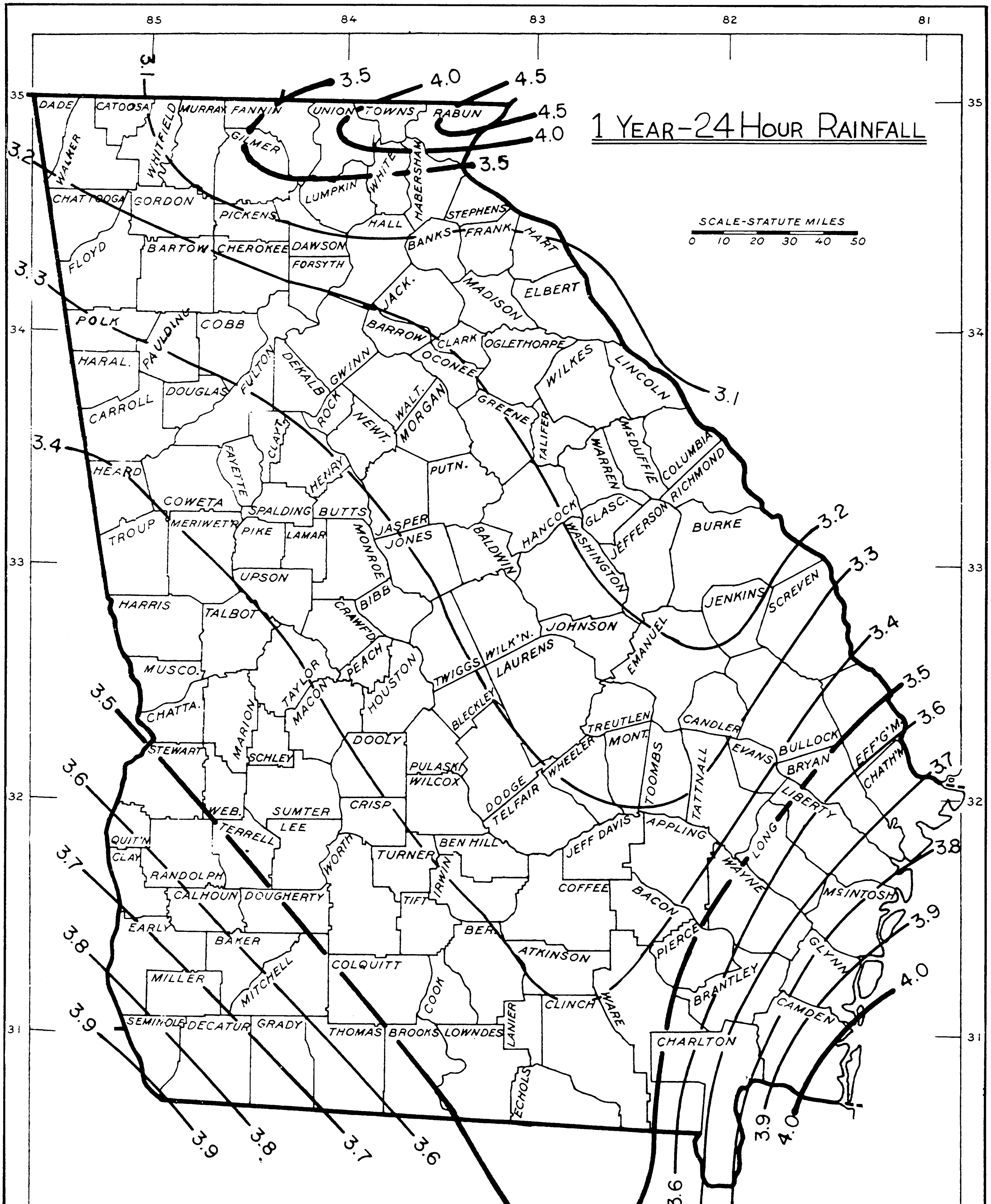

Figure A-2.7 – Total rainfall (P) for 1-year/24-hour storm.

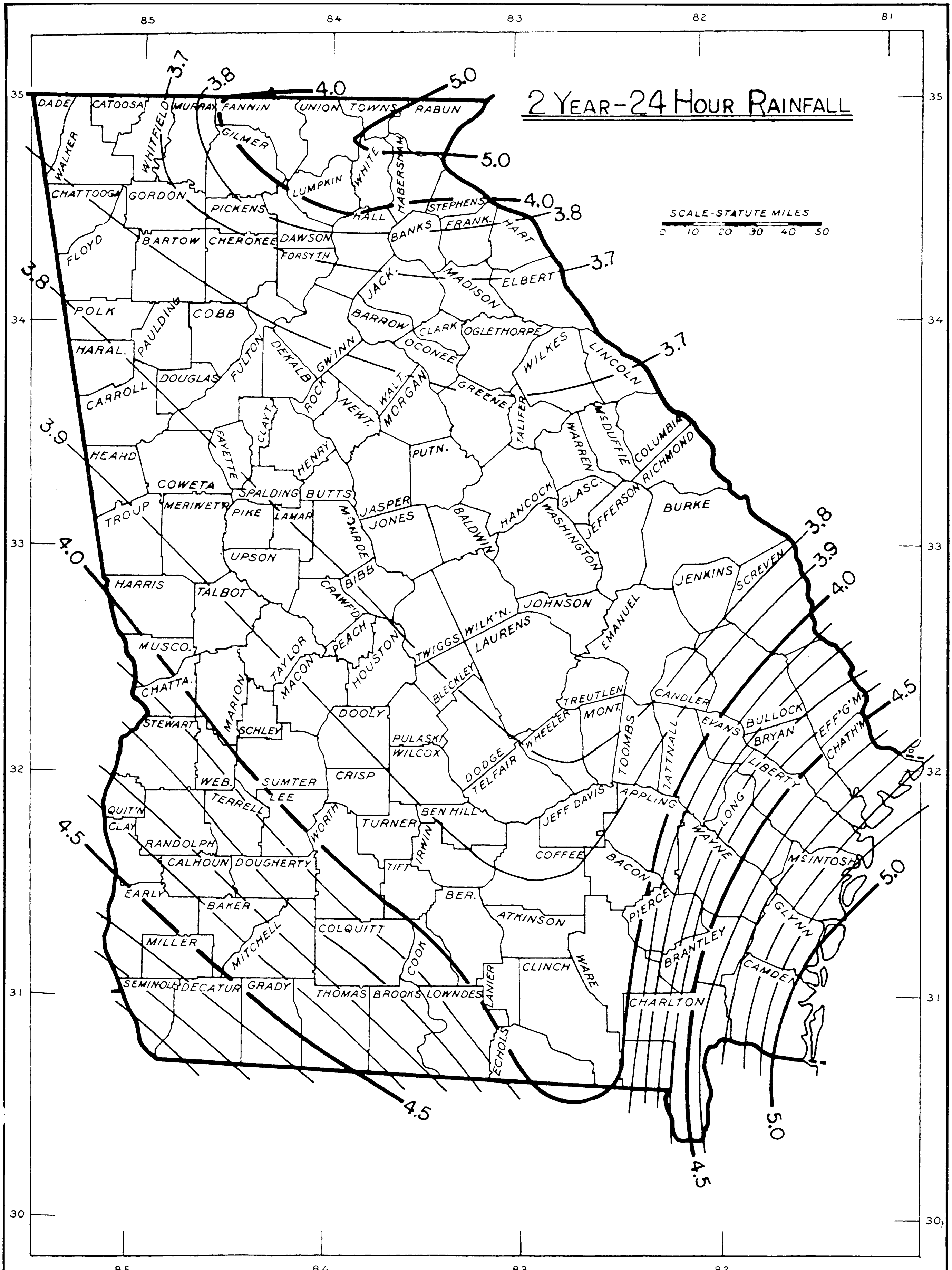

Figure A-2.8 – Total rainfall (P) for 2-year/24-hour storm.

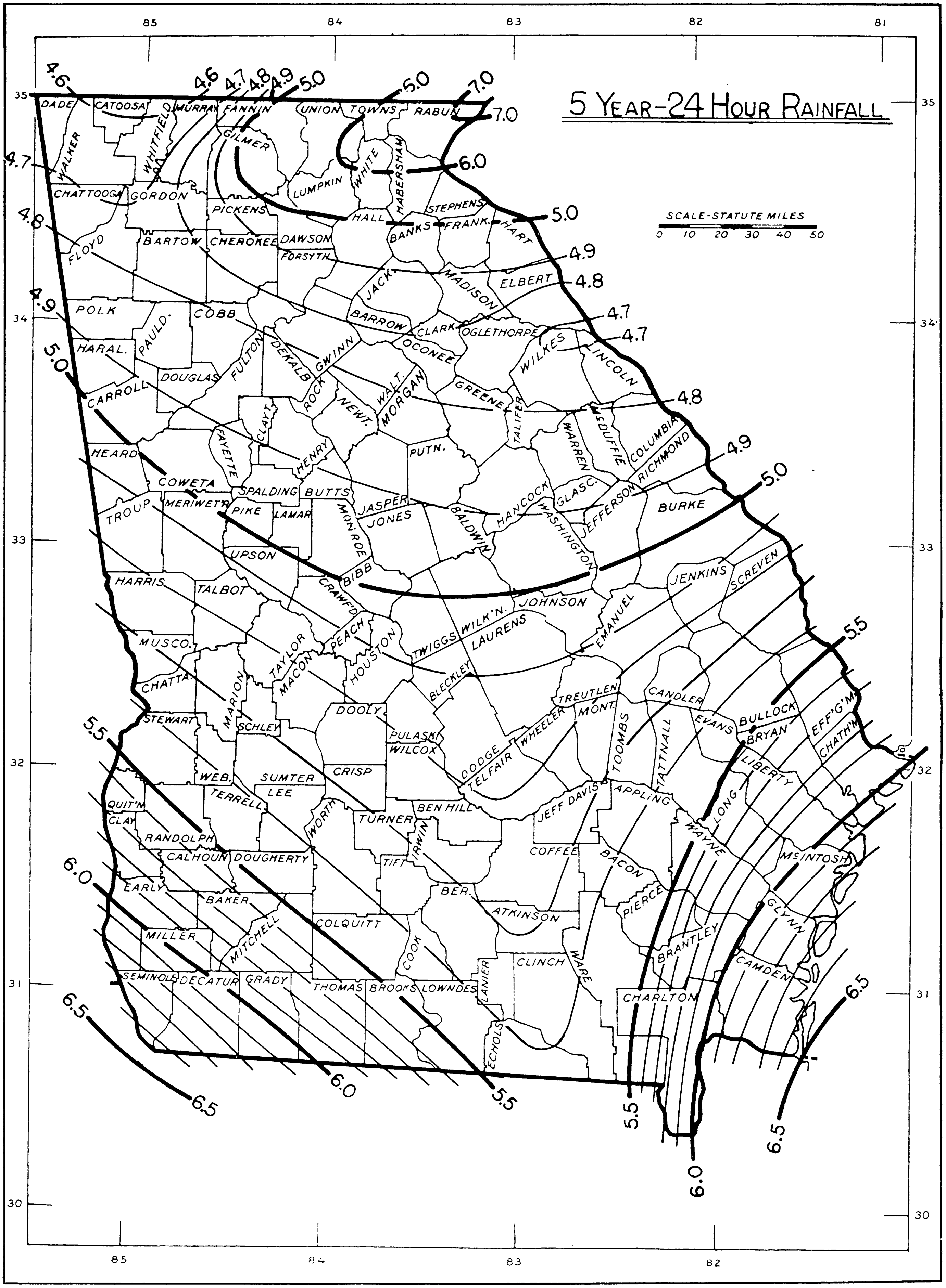

Figure A-2.9 – Total rainfall (P) for 5-year/24-hour storm.

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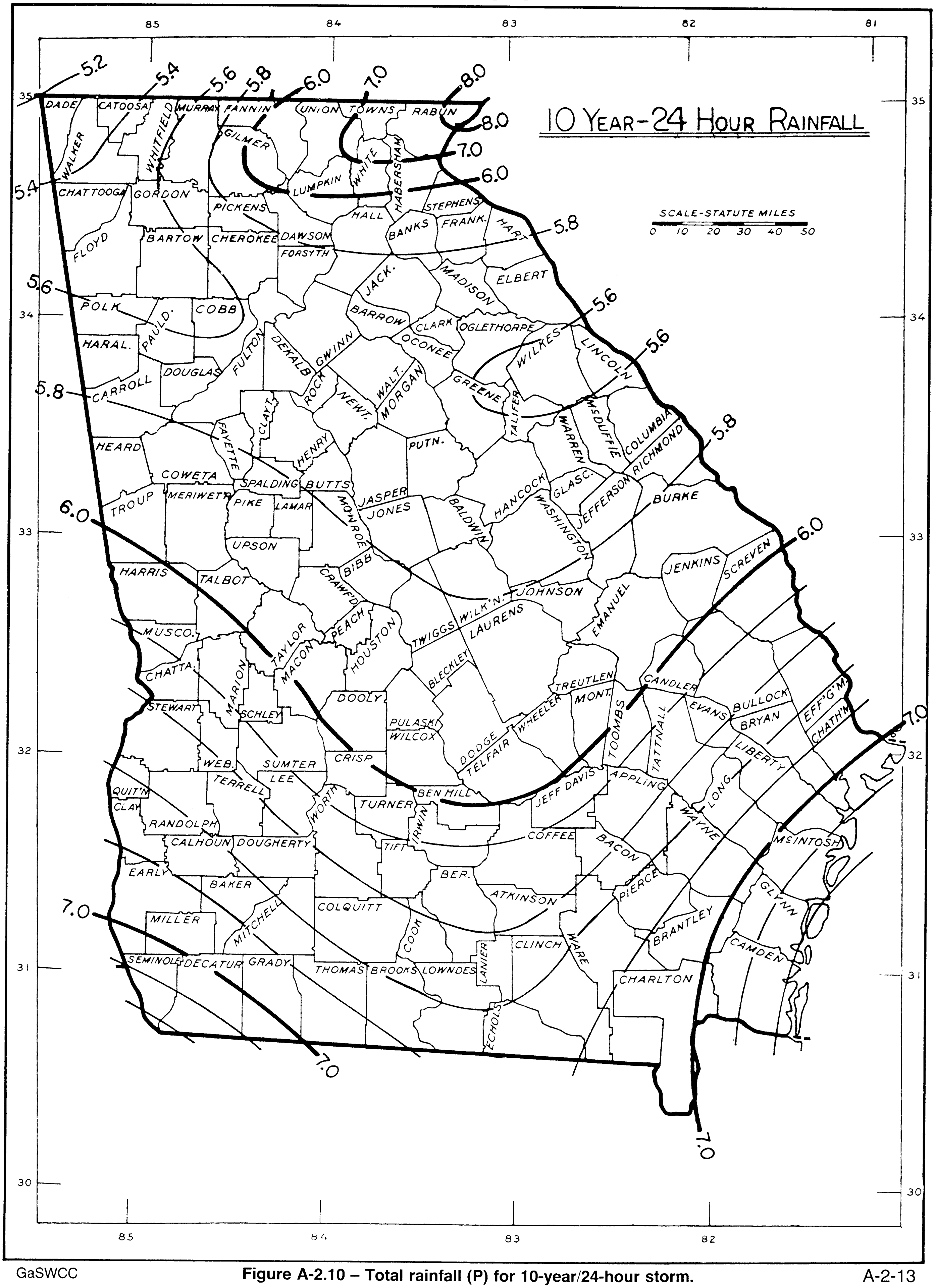

Figure A-2.10 – Total rainfall (P) for 10-year/24-hour storm.

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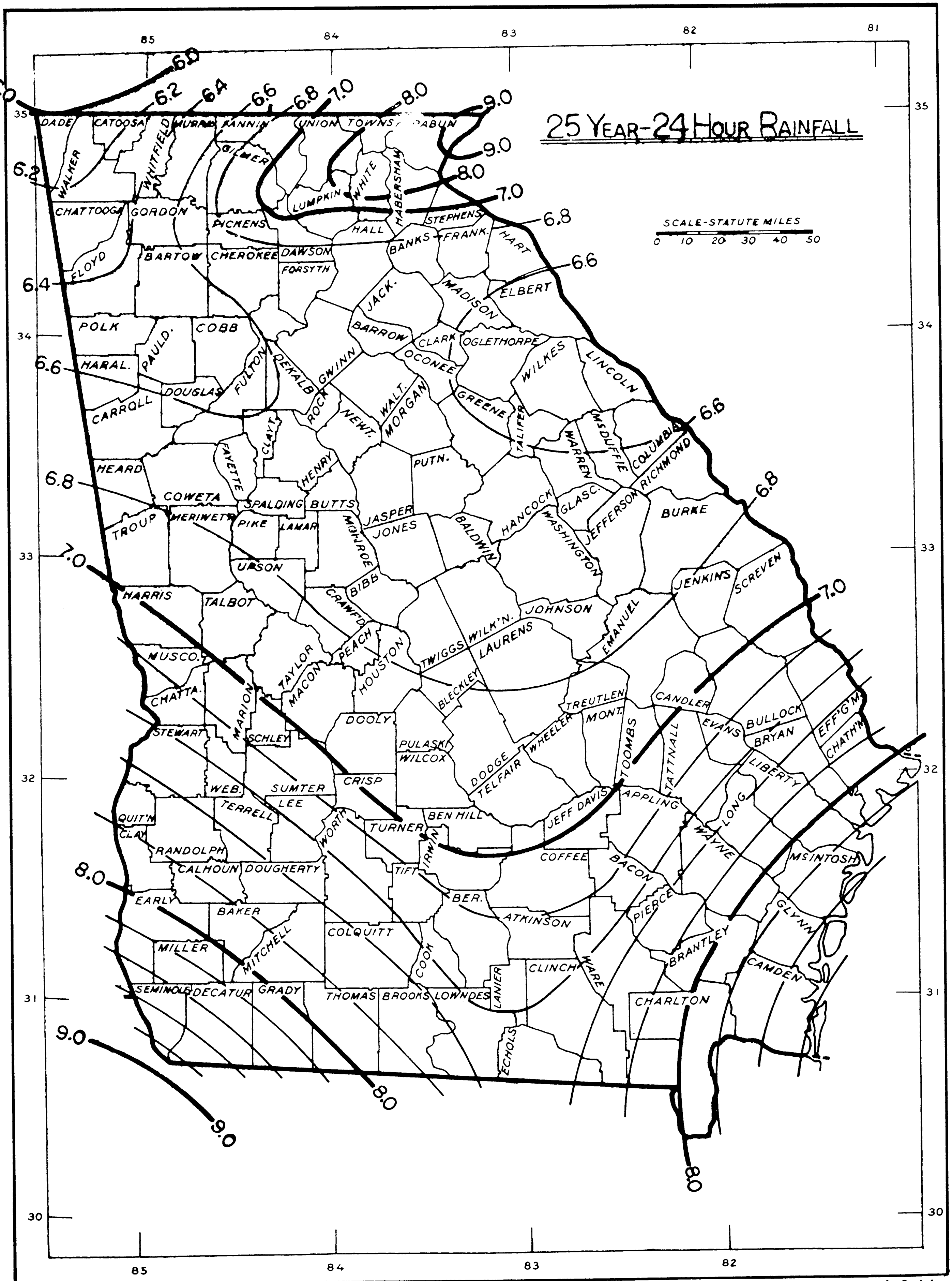

Figure A-2.11 – Total rainfall (P) for 25-year/24-hour storm.

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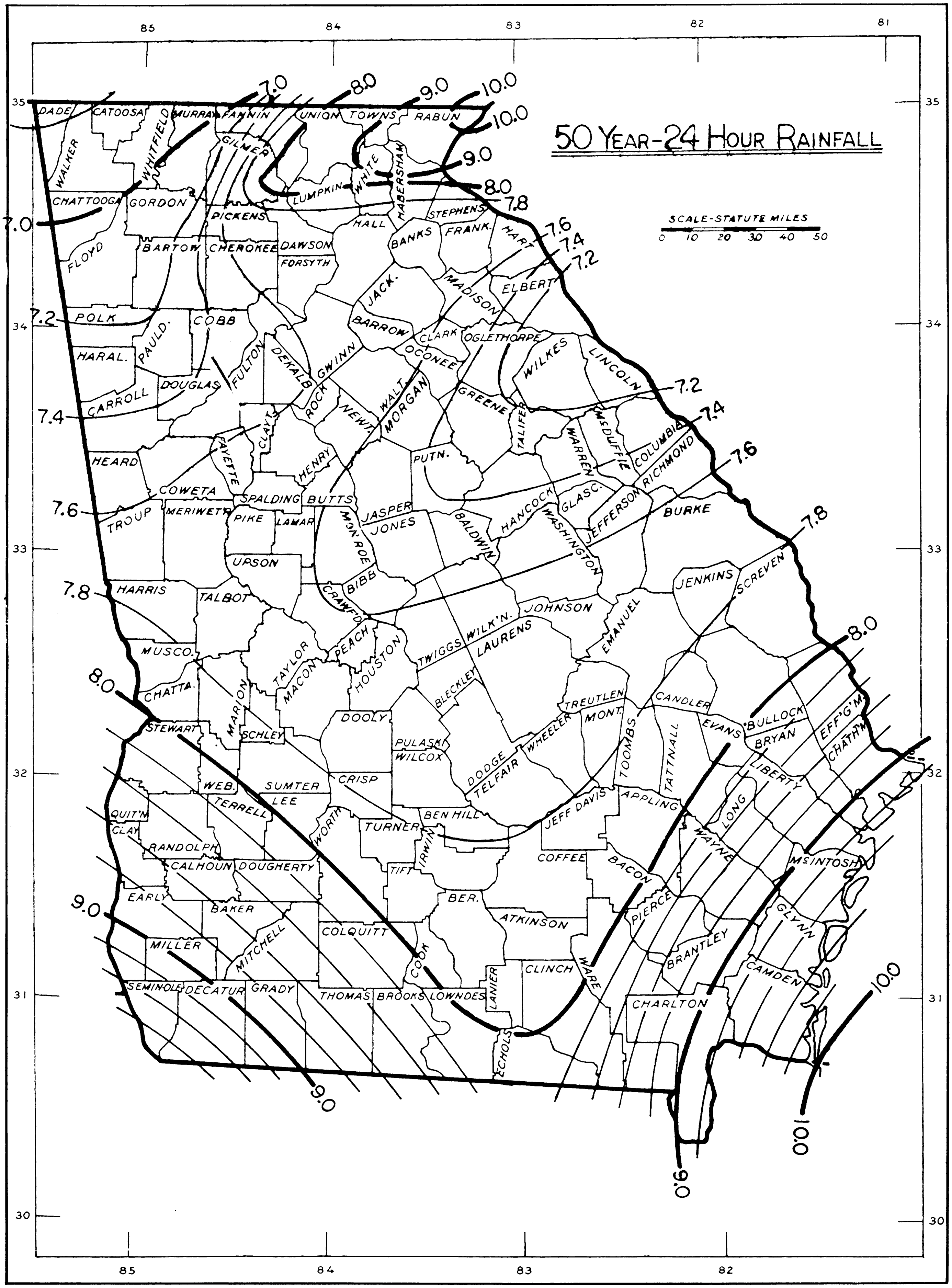

Figure A-2.12 – Total rainfall (P) for 50-year/24-hour storm.

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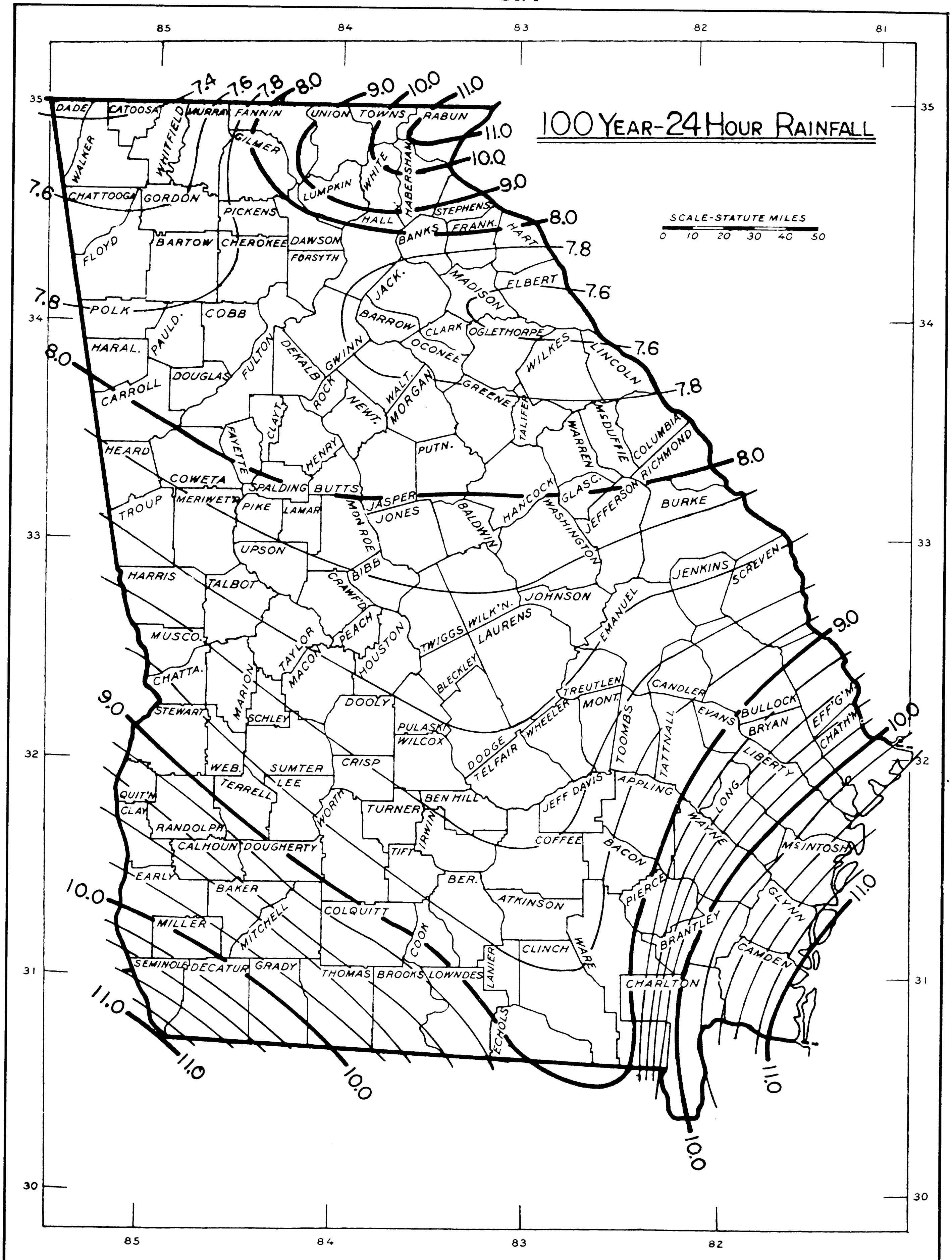

Figure A-2.13 – Total rainfall (P) for 100-year/24-hour storm.

APPENDIX A-3
Rational Method