Rainfall, Runoff and Peak Flows: Calibration of Hydrologic Design Methods for the Kansas City Area

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Research Sponsors

- Kansas City Metro Chapter, American Public Works Association
- Johnson County Stormwater Management Program
- Kansas Department of Transportation
- City of Overland Park

Hydrologic Methods in KC-APWA Section 5600

1. Rational Method: $Q = C\ i\ A$ (for watersheds ≤ 200 acres)

   Q = discharge with specified AEP
   C = runoff coefficient for specified AEP
   i = rainfall intensity for specified AEP and duration equal to watershed's time of concentration (T_C)
   A = drainage area

   <u>Needs</u>

   Best available rainfall frequency estimates
   Calibrated relationship for estimating T_C
   Calibrated C values for urban green space and undeveloped land

Hydrologic Methods in KC-APWA Section 5600

2. Flood hydrograph simulation by NRCS methods

Rainfall: 24-hour NRCS Type II storm

Runoff: NRCS curve-number method

Streamflow hydrograph: NRCS synthetic unit hydrograph method

<u>Inputs</u>

- 24-hour rainfall depth for specified AEP
- Runoff curve number (CN) for specified AEP
- Basin lag time (T_L)
- Drainage area

<u>Needs</u>

- Best available rainfall frequency estimates
- Calibrated relationship for estimating T_L
- Calibrated CN values for urban green space and undeveloped land

Rainfall Frequency

Rainfall frequency information in Section 5600 is derived from:

- NOAA Technical Memorandum NWS HYDRO-35 (1977) for durations ≤ 60 minutes
- U.S. Weather Bureau Technical Paper 40 (1961) for durations > 60 minutes

NOAA published new rainfall frequency estimates for Kansas and Missouri in 2014:

- in NOAA Atlas 14, Volume 8
- on NWS Precipitation Frequency Data Server

NOAA's National Weather Service

Hydrometeorological Design Studies Center

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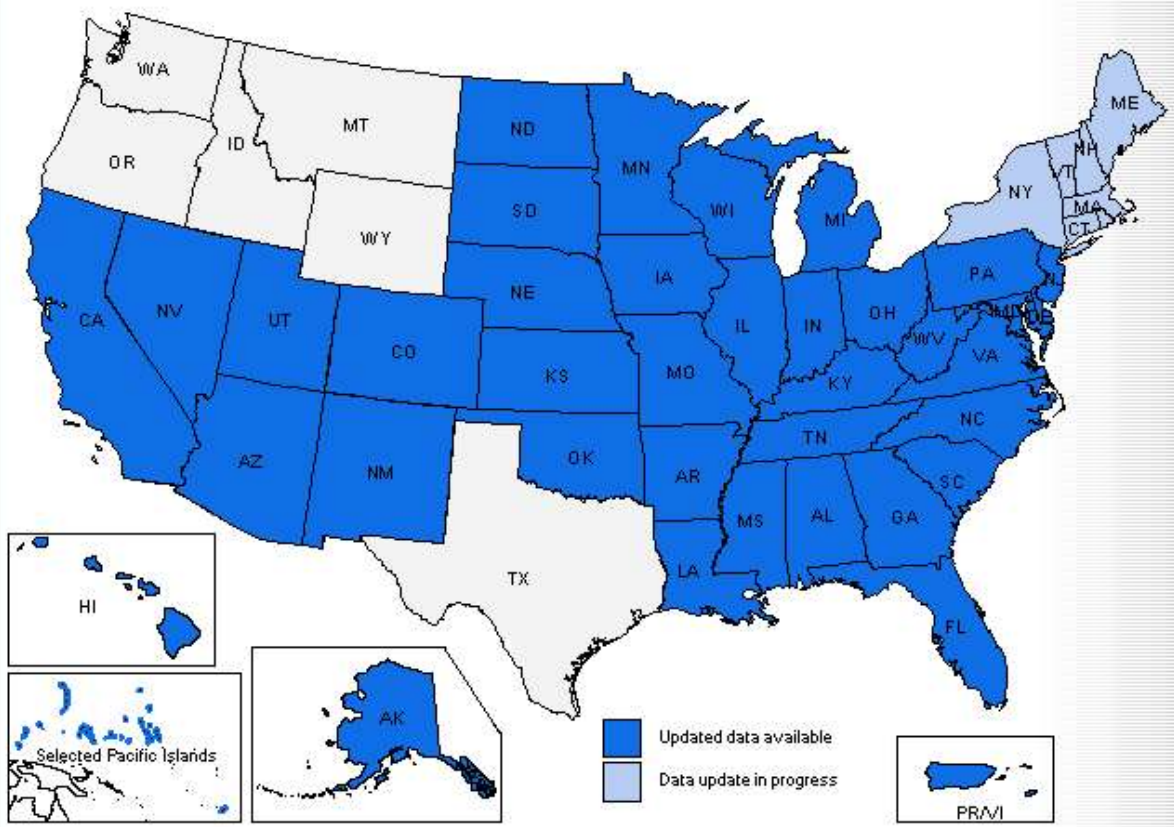

Precipitation Frequency Data Server (PFDS)

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NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: MO

DATA DESCRIPTION

Data type: precipitation depth | Units: english | Time series type: partial duration

SELECT LOCATION

1. Manually:

a) Enter location (decimal degrees, use "-" for S and W): latitude: longitude: submit

b) Select station (click here for a list of stations used in frequency analysis for MO): select station

2. Use map:

Rainfall estimates for certain durations and AEPs

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AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	0.436 (0.346-0.559)	0.571 (0.451-0.734)	0.678 (0.533-0.873)	0.825 (0.627-1.09)	0.941 (0.699-1.25)	1.06 (0.761-1.43)	1.19 (0.815-1.62)	1.35 (0.895-1.88)	1.49 (0.956-2.08)
10-min	0.638 (0.506-0.819)	0.836 (0.661-1.07)	0.993 (0.780-1.28)	1.21 (0.919-1.59)	1.38 (1.02-1.83)	1.55 (1.11-2.09)	1.74 (1.19-2.38)	1.98 (1.31-2.76)	2.18 (1.40-3.05)
15-min	0.779 (0.617-0.999)	1.02 (0.806-1.31)	1.21 (0.951-1.56)	1.47 (1.12-1.94)	1.68 (1.25-2.23)	1.90 (1.36-2.55)	2.12 (1.46-2.90)	2.42 (1.60-3.37)	2.66 (1.71-3.72)
30-min	1.09 (0.868-1.40)	1.44 (1.14-1.85)	1.71 (1.35-2.21)	2.09 (1.59-2.75)	2.38 (1.77-3.17)	2.69 (1.93-3.62)	3.00 (2.07-4.11)	3.44 (2.27-4.78)	3.78 (2.43-5.29)
60-min	1.44 (1.14-1.84)	1.91 (1.51-2.45)	2.29 (1.80-2.94)	2.81 (2.14-3.70)	3.22 (2.39-4.28)	3.65 (2.62-4.91)	4.09 (2.81-5.60)	4.70 (3.11-6.54)	5.18 (3.33-7.25)
2-hr	1.78 (1.43-2.26)	2.38 (1.90-3.02)	2.86 (2.27-3.64)	3.53 (2.71-4.61)	4.05 (3.04-5.33)	4.60 (3.33-6.14)	5.17 (3.60-7.02)	5.96 (3.98-8.22)	6.58 (4.28-9.13)
3-hr	2.01 (1.62-2.54)	2.71 (2.18-3.42)	3.27 (2.61-4.14)	4.05 (3.13-5.26)	4.67 (3.53-6.11)	5.32 (3.88-7.06)	5.99 (4.19-8.09)	6.92 (4.65-9.50)	7.66 (5.00-10.6)
6-hr	2.43 (1.98-3.03)	3.31 (2.68-4.13)	4.01 (3.23-5.01)	4.99 (3.90-6.41)	5.77 (4.40-7.47)	6.59 (4.85-8.65)	7.44 (5.25-9.95)	8.62 (5.85-11.7)	9.56 (6.30-13.1)
12-hr	2.88 (2.37-3.55)	3.92 (3.21-4.84)	4.76 (3.88-5.89)	5.93 (4.68-7.54)	6.86 (5.29-8.79)	7.84 (5.83-10.2)	8.85 (6.31-11.7)	10.3 (7.03-13.8)	11.4 (7.57-15.4)
24-hr	3.36 (2.79-4.09)	4.53 (3.75-5.52)	5.46 (4.50-6.68)	6.77 (5.40-8.51)	7.82 (6.08-9.90)	8.91 (6.69-11.5)	10.0 (7.23-13.1)	11.6 (8.04-15.5)	12.9 (8.65-17.2)

Rainfall estimates for certain durations and ARIs

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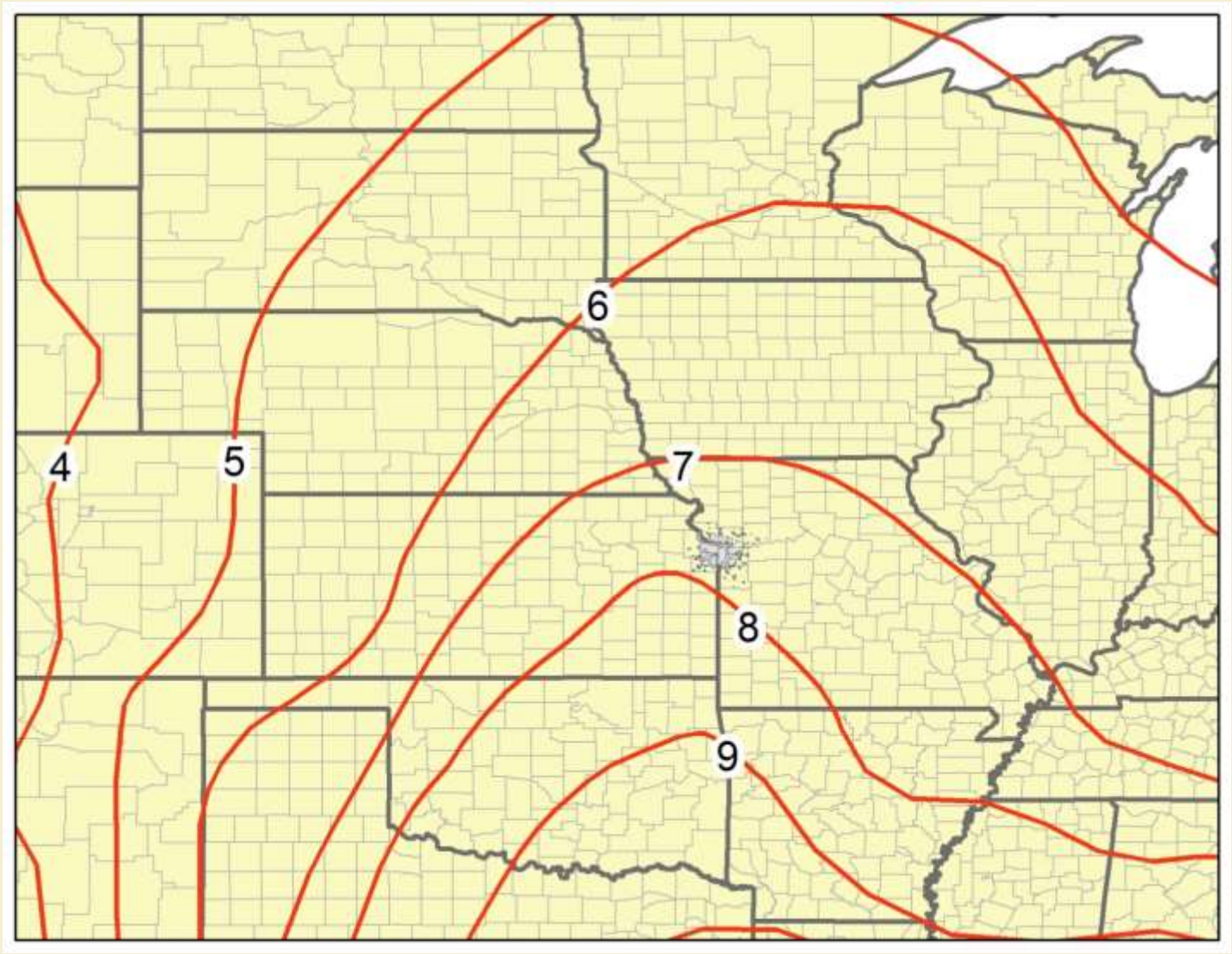
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.402 (0.319-0.516)	0.471 (0.373-0.604)	0.586 (0.463-0.753)	0.686 (0.539-0.883)	0.828 (0.631-1.09)	0.943 (0.700-1.25)	1.06 (0.761-1.43)	1.19 (0.815-1.62)	1.35 (0.895-1.88)	1.49 (0.956-2.08)
10-min	0.589 (0.467-0.755)	0.689 (0.546-0.884)	0.858 (0.678-1.10)	1.00 (0.789-1.29)	1.21 (0.924-1.60)	1.38 (1.03-1.83)	1.55 (1.11-2.09)	1.74 (1.19-2.38)	1.98 (1.31-2.76)	2.18 (1.40-3.05)
15-min	0.718 (0.570-0.921)	0.840 (0.666-1.08)	1.05 (0.827-1.34)	1.23 (0.962-1.58)	1.48 (1.13-1.95)	1.68 (1.25-2.24)	1.90 (1.36-2.55)	2.12 (1.46-2.90)	2.42 (1.60-3.37)	2.66 (1.71-3.72)
30-min	1.01 (0.800-1.29)	1.18 (0.937-1.52)	1.48 (1.17-1.90)	1.73 (1.36-2.23)	2.10 (1.60-2.77)	2.39 (1.77-3.17)	2.69 (1.93-3.62)	3.00 (2.07-4.11)	3.44 (2.27-4.78)	3.78 (2.43-5.29)
60-min	1.32 (1.05-1.69)	1.56 (1.24-2.00)	1.96 (1.55-2.52)	2.31 (1.82-2.98)	2.82 (2.15-3.73)	3.23 (2.40-4.29)	3.65 (2.62-4.92)	4.09 (2.81-5.60)	4.70 (3.11-6.54)	5.18 (3.33-7.25)
2-hr	1.63 (1.31-2.07)	1.93 (1.55-2.45)	2.45 (1.95-3.11)	2.90 (2.30-3.69)	3.54 (2.73-4.63)	4.06 (3.05-5.35)	4.60 (3.34-6.15)	5.17 (3.60-7.02)	5.96 (3.98-8.22)	6.58 (4.28-9.13)
3-hr	1.84 (1.48-2.32)	2.19 (1.76-2.76)	2.79 (2.24-3.52)	3.31 (2.64-4.19)	4.07 (3.15-5.29)	4.68 (3.53-6.13)	5.32 (3.88-7.06)	5.99 (4.19-8.09)	6.92 (4.65-9.50)	7.66 (5.00-10.6)
6-hr	2.22 (1.81-2.76)	2.65 (2.16-3.31)	3.40 (2.76-4.25)	4.06 (3.27-5.08)	5.01 (3.92-6.45)	5.78 (4.41-7.49)	6.59 (4.85-8.66)	7.44 (5.25-9.95)	8.62 (5.85-11.7)	9.56 (6.30-13.1)
12-hr	2.62 (2.16-3.23)	3.15 (2.58-3.87)	4.04 (3.31-4.99)	4.82 (3.93-5.97)	5.96 (4.71-7.59)	6.88 (5.30-8.81)	7.84 (5.83-10.2)	8.85 (6.31-11.7)	10.3 (7.03-13.8)	11.4 (7.57-15.4)
24-hr	3.07 (2.55-3.74)	3.65 (3.03-4.45)	4.66 (3.85-5.68)	5.53 (4.55-6.76)	6.80 (5.43-8.56)	7.83 (6.09-9.92)	8.91 (6.69-11.5)	10.0 (7.23-13.1)	11.6 (8.04-15.5)	12.9 (8.65-17.2)

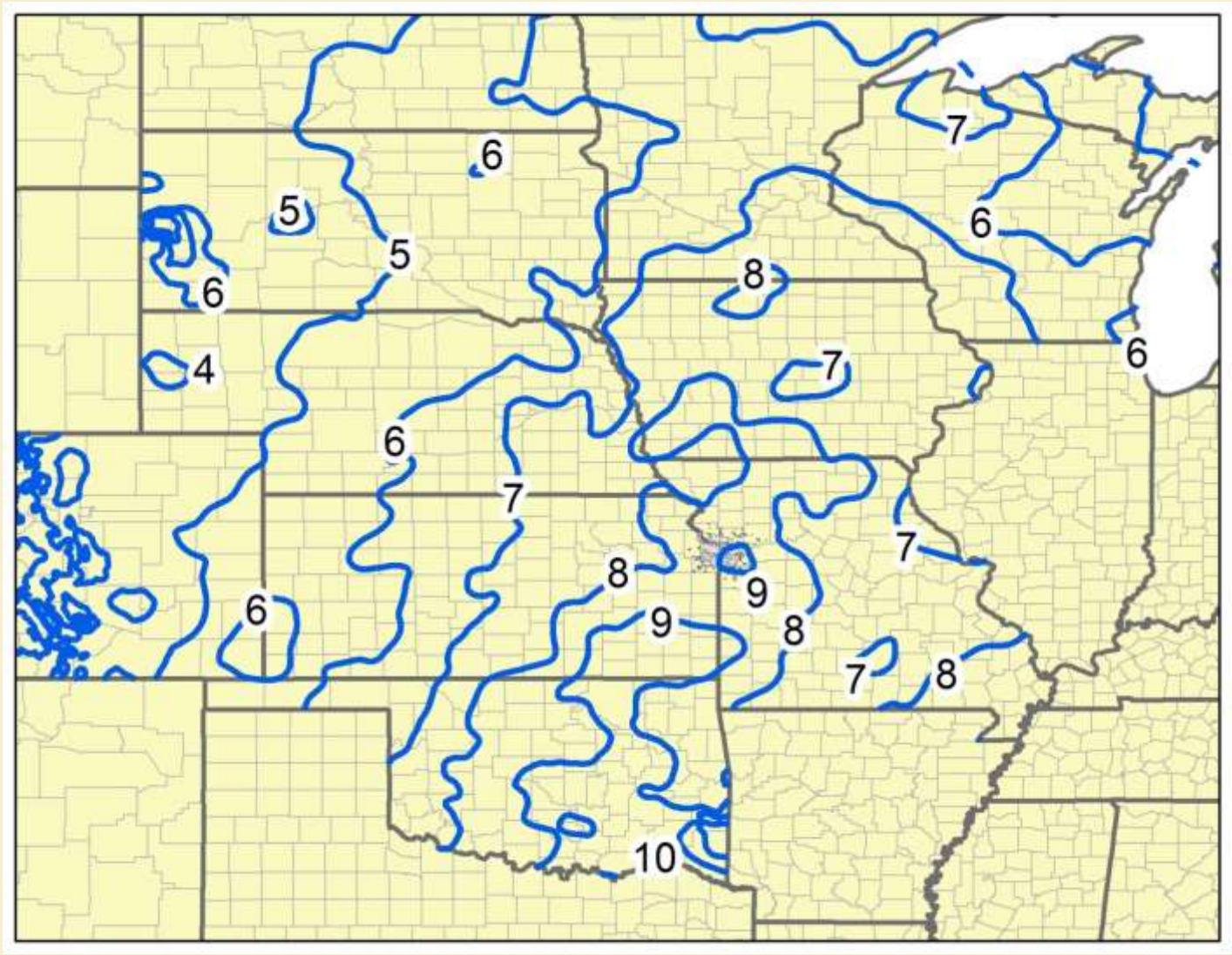
100-year, 24-hour rainfall

OLD: TP-40



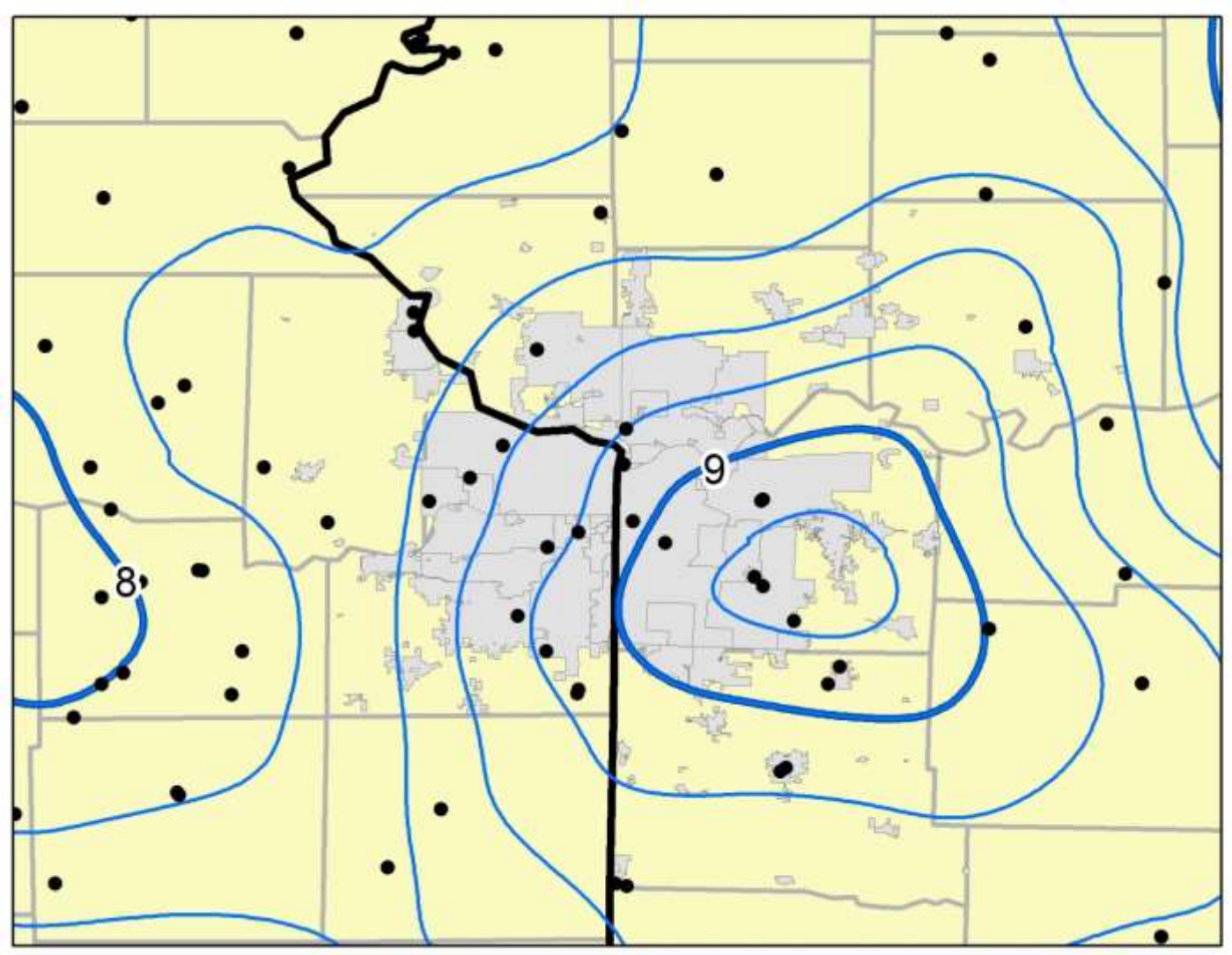
100-year, 24-hour rainfall

NEW: Atlas 14



100-year, 24-hour rainfall for Kansas City area

NEW: Atlas 14



Comparison of Old and New Estimates of 100-Year Rainfall Depths Lee's Summit (NE Scruggs Road & Blackwell Road)

Duration	100-yr depth (in.)		Percent change
	5600	New	
5 min	0.85	1.05	23.5%
10 min	1.42	1.53	7.6%
15 min	1.82	1.87	2.7%
30 min	2.68	2.63	-1.8%
60 min	3.57	3.52	-1.4%
2 hr	4.34	4.41	1.6%
3 hr	4.79	5.10	6.5%
6 hr	5.73	6.41	11.9%
12 hr	6.80	7.86	15.6%
24 hr	7.72	9.28	20.2%

Problems

Rainfall frequency information in Section 5600 is outdated.

Atlas 14 estimates: few durations; excessive spatial variation

Solution

New Atlas 14-based rainfall depth and intensity tables and equations by county:

Buchanan, Cass, Clay, Jackson, Johnson, Leavenworth, Miami, Platte, Ray & Wyandotte

RAINFALL DEPTH TABLE
JACKSON COUNTY, MISSOURI

This table contains average rainfall depths in inches.

DURATION	ANNUAL EXCEEDANCE PROBABILITY					
(H:M)	50%	20%	10%	4%	2%	1%
0:05	0.44	0.58	0.68	0.83	0.94	1.05
0:06	0.49	0.64	0.76	0.92	1.04	1.17
0:07	0.54	0.70	0.83	1.00	1.13	1.27
0:08	0.58	0.75	0.89	1.07	1.22	1.37
0:09	0.61	0.80	0.95	1.14	1.30	1.46
0:10	0.65	0.85	1.00	1.21	1.37	1.54
0:11	0.68	0.89	1.05	1.27	1.44	1.61
0:12	0.71	0.93	1.09	1.32	1.50	1.69
0:13	0.74	0.96	1.14	1.38	1.56	1.75
0:14	0.77	1.00	1.18	1.43	1.62	1.82
0:15	0.79	1.03	1.22	1.47	1.67	1.88
0:16	0.82	1.07	1.26	1.52	1.73	1.94
0:17	0.84	1.10	1.30	1.57	1.78	2.00
0:18	0.87	1.13	1.34	1.62	1.84	2.06
0:19	0.89	1.16	1.38	1.66	1.89	2.12
0:20	0.92	1.20	1.41	1.71	1.94	2.17

Lag Time and Time of Concentration

Objective

- Reliable T_L and T_C relationships for KC-area urban watersheds
- Must account for channel condition (enclosed/paved vs. natural)

Approach

- Determine lag times for KC-area urban watersheds from ALERT data
- Develop equation for T_L the accounts for relevant watershed characteristics
- Calibrate T_L equation with KC-area data
- $T_C = 5/3\ T_L$

30 gaged watersheds

Sizes: 113 ac to 11 mi^2

Lag times: 6 min to 2 hr

Relevant watershed characteristics

A = drainage area

L = length of longest flow path

S = average slope of longest flow path

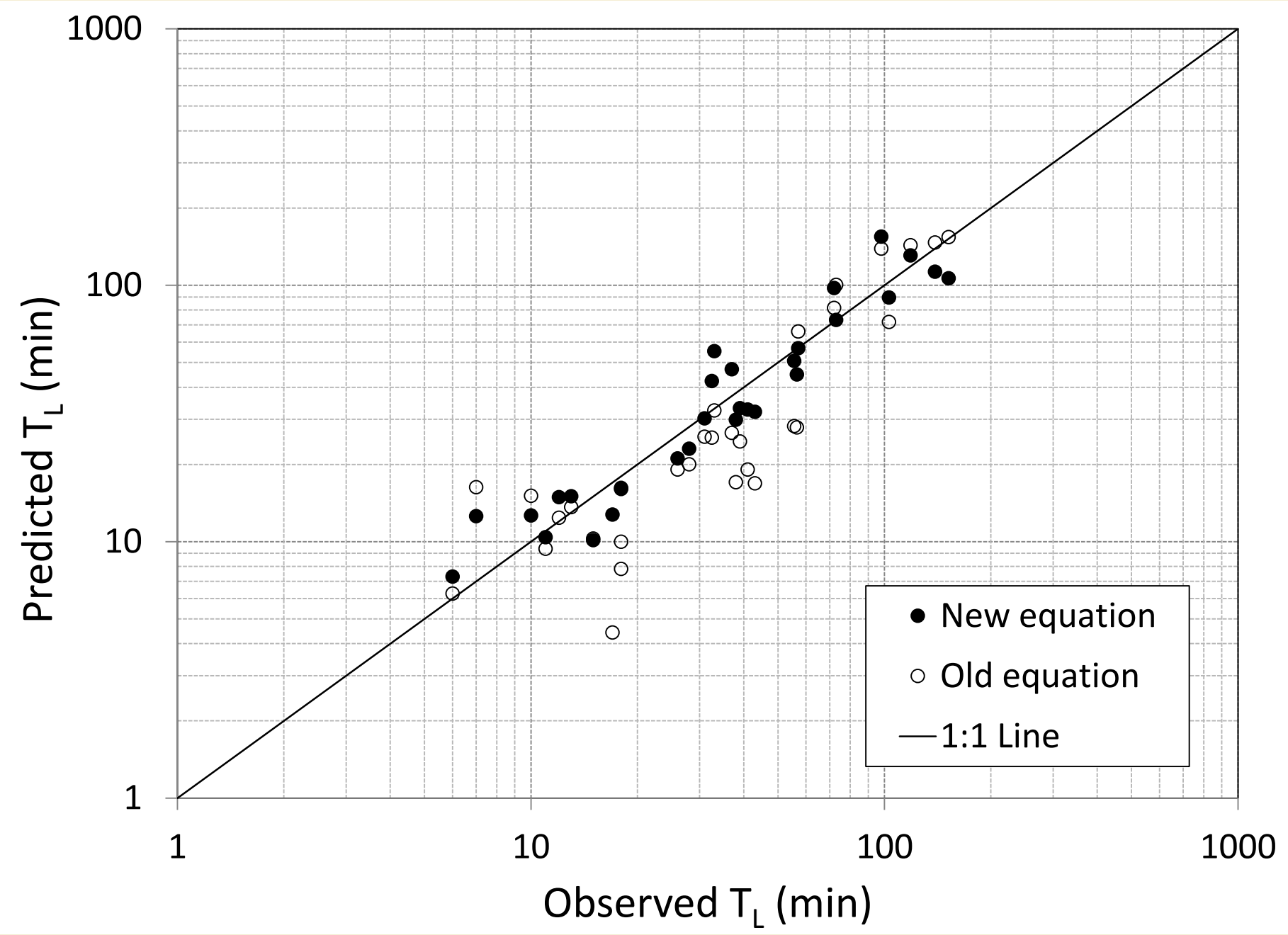
R_c = channel development ratio (% enclosed or paved)

R_i = impervious area ratio (impervious area / total area)

W = A/L = average width of watershed

Calibrated lag-time equation for urban watersheds in KC area

$$T_L = 0.0112 \left[\frac{L\,(1 - 0.75\,R_c)}{\sqrt{S}} \right]^{0.87} [W\,(1 + 2.0\,R_i)]^{-0.26}$$


1000
100
10
1
Predicted T_L (min)
1
10
100
1000
Observed T_L (min)
New equation
Old equation
1:1 Line

Rational Method in Section 5600

$Q = K\ C\ i\ A$

where

$C = 0.3 + 0.6 \cdot R_i$

R_i = impervious fraction

AEP	K
≤ 10%	1.0
4%	1.1
2%	1.2
1%	1.25

C = area-weighted average of 0.3 for pervious surfaces and 0.9 for impervious surfaces.

K factor effectively increases composite C for AEP < 10%

Objective

Calibrate frequency-dependent C value (K·C in Section 5600) for KC-area pervious surfaces (urban green space and undeveloped land)

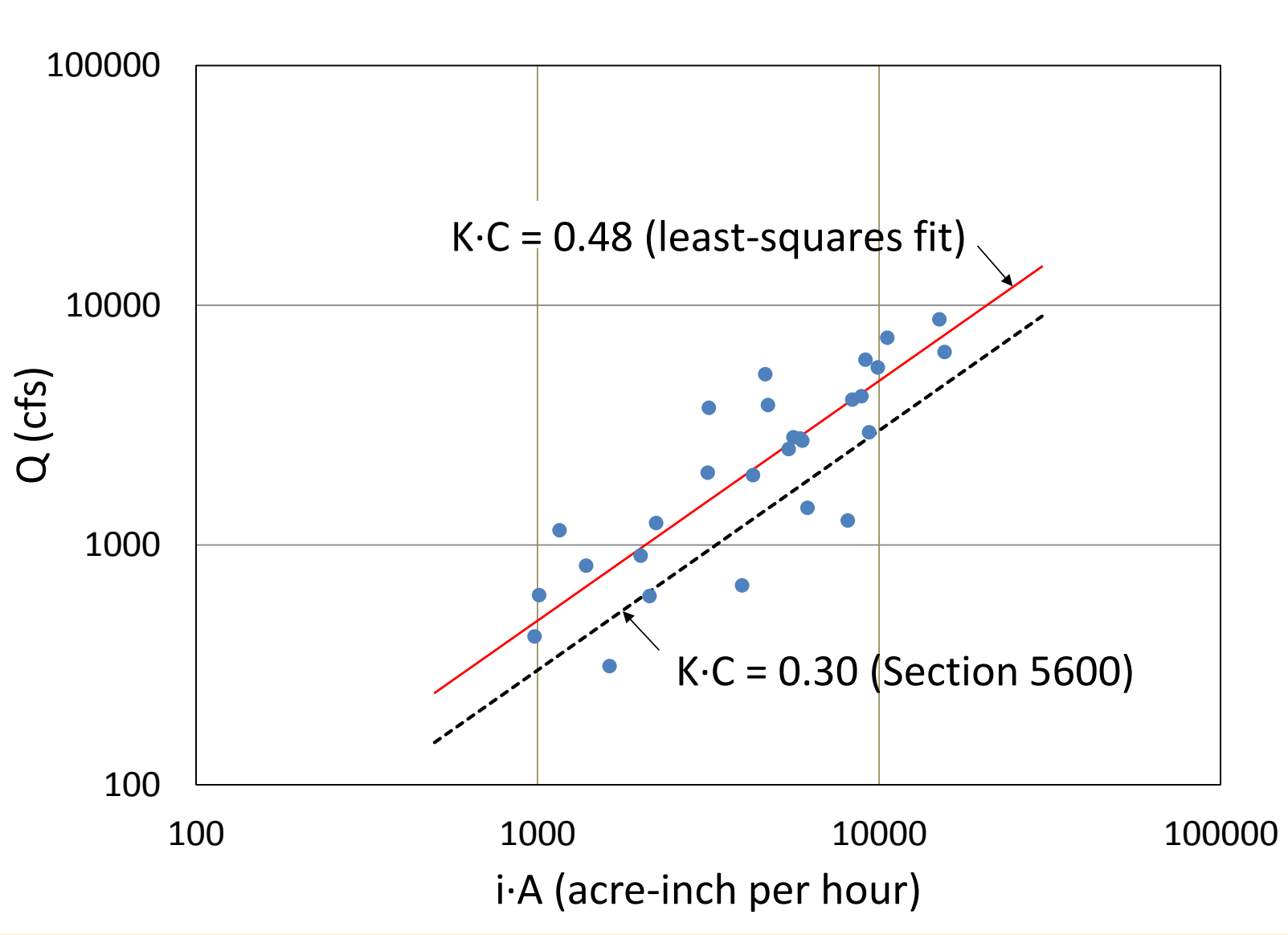
Approach

- Regional flood-frequency analysis of 28 USGS-gaged watersheds in KC area
- Calibrated C to match discharge estimates from regional regression equations
- Used NOAA Atlas 14 rainfall estimates

K·C for undeveloped land in the KC area

AEP	K·C	
	Calibrated with study-area data	Section 5600
50%	0.30	0.30
20%	0.42	0.30
10%	0.48	0.30
4%	0.55	0.33
2%	0.59	0.36
1%	0.63	0.375

Calibration of K·C for AEP = 10%



Recommended changes to rational method in Section 5600

- Omit K factor from rational equation
- For impervious surfaces, retain C = 0.9
- For pervious surfaces, use these frequency-dependent C values:

AEP	50%	20%	10%	4%	2%	1%
C	0.30	0.42	0.48	0.55	0.59	0.63

Runoff Curve Numbers in Section 5600

Section 5600 specifies a CN value of 74 for all pervious surfaces in KC area.

Objective

Calibrate frequency-dependent CN values for pervious surfaces in KC area

Approach

- Regional flood-frequency analysis of 28 USGS-gaged watersheds in KC area
- Calibrated CN to match discharge estimates from regional regression equations
- Used NOAA Atlas 14 rainfall estimates of 24-hour rainfall in NRCS Type II storm

Average CN values for undeveloped land in KC area, calibrated for peak flow:

AEP	50%	20%	10%	4%	2%	1%
CN	71	72	71	69	68	67

These values are lower than expected.

Why?

Recommended changes to CN values in Section 5600

None. The specified CN value of 74 for pervious surfaces appears to be appropriately conservative for all frequencies.

Summary of Recommendations

- Adopt new county rainfall tables based on NOAA Atlas 14
- Adopt new calibrated equations for lag time and time of concentration
- Adopt calibrated frequency-dependent rational C values for pervious surfaces
- No change to specified CN values