Prepared in cooperation with the Iowa Department of Transportation and the
Iowa Highway Research Board (Project TR-678)

Comparisons of Estimates of Annual Exceedance-Probability Discharges for Small Drainage Basins in Iowa, Based on Data through Water Year 2013

Scientific Investigations Report 2015–5055

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: View looking northeast at West Branch at Parkside Drive bridge at Hoover Creek. Bridge is located about 0.25 miles downstream from streamgage Hoover Creek at Hoover National Historic Site at West Branch (05464942), Iowa. Photograph taken June 3, 2008; courtesy of National Park Service.

Comparisons of Estimates of Annual Exceedance-Probability Discharges for Small Drainage Basins in Iowa, Based on Data through Water Year 2013

By David A. Eash

Prepared in cooperation with the Iowa Department of Transportation and the
Iowa Highway Research Board (Project TR-678)

Scientific Investigations Report 2015–5055

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

Suggested citation:
Eash, D.A., 2015, Comparisons of estimates of annual exceedance-probability discharges for small drainage basins in Iowa, based on data through water year 2013: U.S. Geological Survey Scientific Investigations Report 2015–5055, 37 p., http://dx.doi.org/10.3133/sir20155055.

ISBN 978-1-4113-3917-0
ISSN 2328-031X (print)
ISSN 2328-0328 (online)

Acknowledgments

The author gratefully acknowledges Julie Kiang and Andrea Veilleux (U.S. Geological Survey) for their assistance in recommending the use of two evaluation metrics to compare estimates from annual exceedance-probability discharge methods and for their considerations of the evaluation results. The author also expresses gratitude to the many U.S. Geological Survey employees who assisted with the collection and analysis of flood data used in this report. The flood data often were collected during adverse conditions, and the efforts of these individuals made this report possible.

The information contained herein also is based on data collected by the U.S. Army Corps of Engineers, the National Weather Service, and several State and local agencies who were involved with the collection of flood data.

Contents

Figures

Tables

Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	4,047	square meter (m^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Supplemental Information

Water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year. Thus, the water year ending September 30, 2013, is the “2013 water year.”

Slope; to convert Inch/Pound units to International System of units, multiply feet per mile (ft/mi) by 0.1894 to get meters per kilometer (m/km).

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Map projections are Universal Transverse Mercator, Zone 15.

Abbreviations

1987 single-variable RREs	single-variable regional-regression equations from 1987 U.S. Geological Survey (USGS) report by Lara
2013 multivariable RREs	multivariable regional-regression equations from 2013 USGS report by Eash and others
2013 single-variable RREs	single-variable regional-regression equations from 2013 USGS report by Eash and others
AEP	annual exceedance probability
AEP1	AEP of 50 percent
AEP2	AEP of 0.5 and 0.2 percent
AEP5	AEPs of 20, 10, 4, 2, and 1 percent
AEP6	AEPs of 50, 20, 10, 4, 2, and 1 percent
AEPD	annual exceedance-probability discharge
BSLDEM10M	average basin slope calculated from 10-meter digital elevation model (DEM)
Bulletin 17B	Bulletin 17B annual exceedance-probability analysis with standard Grubbs-Beck low-outlier test
CCM	constant of channel maintenance
CN	curve number
CSG	crest-stage gage
CSL100	stream slope calculated as entire LENGTH
CSL1085LFP	stream slope calculated as the change in elevation between points located at 10 and 85 percent of the length along the longest flow path that was determined by geographic information system (GIS), then divided by the length between the points
DEM	digital elevation model
DRNAREA	GIS-determined drainage area
EMA/MGB	expected moments algorithm annual exceedance-probability analysis with multiple Grubbs-Beck low-outlier test
GIS	geographic information system
GLS	generalized-least-squares regression
Iowa DOT	Iowa Department of Transportation
Iowa Runoff Chart	method used in Iowa to estimate AEPDs for small basins
IRC	Iowa Runoff Chart
LENGTH	main-channel length as measured from basin outlet to basin divide
LF	land-use and slope-description factor for a watershed
Log	logarithm (base 10)
mean ratio	an evaluation metric that gives an indication of the degree of bias of an AEPD-estimation method
MGB	multiple Grubbs-Beck low-outlier test
MPRE	mean percent relative error, an evaluation metric that gives an indication of the overall accuracy of an AEPD-estimation method
n	number of streamgages in the comparison dataset

NWIS	National Water Information System
OLS	ordinary-least-squares regression
$Pseudo\text{-}R^2$	pseudo coefficient of determination
Q	discharge, in cubic feet per second
$Q_{50\%}$	annual exceedance-probability discharge of 50 percent (2-year recurrence-interval flood discharge)
$Q_{20\%}$	annual exceedance-probability discharge of 20 percent (5-year recurrence-interval flood discharge)
$Q_{10\%}$	annual exceedance-probability discharge of 10 percent (10-year recurrence-interval flood discharge)
$Q_{4\%}$	annual exceedance-probability discharge of 4 percent (25-year recurrence-interval flood discharge)
$Q_{2\%}$	annual exceedance-probability discharge of 2 percent (50-year recurrence-interval flood discharge)
$Q_{1\%}$	annual exceedance-probability discharge of 1 percent (100-year recurrence-interval flood discharge)
$Q_{0.5\%}$	annual exceedance-probability discharge of 0.5 percent (200-year recurrence-interval flood discharge)
$Q_{0.2\%}$	annual exceedance-probability discharge of 0.2 percent (500-year recurrence-interval flood discharge)
RI	recurrence interval
RMSE	root mean square error, also referred to as SEE
ROWCROP	percent of area of cultivated crops
RRE	regional-regression equation
SEE	average standard error of estimate, also referred to as RMSE
SEP	average standard error of prediction
SLOP30	percent of area with slopes greater than 30 percent
SOILASSURGO	percent area underlain by hydrologic soil type A
SOILBSSURGO	percent area underlain by hydrologic soil type B
SOILCSSURGO	percent area underlain by hydrologic soil type C
SOILDSSURGO	percent area underlain by hydrologic soil type D
StreamStats	USGS Web-based GIS tool (http://water.usgs.gov/osw/streamstats/index.html)
STRMTOT	total length of all mapped streams in basin
Tc	time of concentration
TR-55	a single-event rainfall runoff model for small watersheds from the Natural Resources Conservation Service
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WIE	weighted independent estimates

Comparisons of Estimates of Annual Exceedance-Probability Discharges for Small Drainage Basins in Iowa, Based on Data through Water Year 2013

By David A. Eash

Abstract

Traditionally, the Iowa Department of Transportation has used the Iowa Runoff Chart and single-variable regional-regression equations (RREs) from a U.S. Geological Survey report (published in 1987) as the primary methods to estimate annual exceedance-probability discharge (AEPD) for small (20 square miles or less) drainage basins in Iowa. With the publication of new multi- and single-variable RREs by the U.S. Geological Survey (published in 2013), the Iowa Department of Transportation needs to determine which methods of AEPD estimation provide the best accuracy and the least bias for small drainage basins in Iowa. In response to this need, the U.S. Geological Survey, in cooperation with the Iowa Department of Transportation and the Iowa Highway Research Board, initiated a statewide study in 2014 to compare and evaluate AEPD estimates from five different AEPD-estimation methods.

Twenty five streamgages with drainage areas less than 2 square miles (mi^2) and 55 streamgages with drainage areas between 2 and 20 mi^2 were selected for the comparisons that used two evaluation metrics. Estimates of AEPDs calculated for the streamgages using the expected moments algorithm/multiple Grubbs-Beck test analysis method were compared to estimates of AEPDs calculated from the 2013 multivariable RREs; the 2013 single-variable RREs; the 1987 single-variable RREs; the TR-55 rainfall-runoff model; and the Iowa Runoff Chart.

For the 25 streamgages with drainage areas less than 2 mi^2, results of the comparisons indicate that estimates of AEPDs calculated from the 2013 multi- and single-variable RREs, the 1987 single-variable RREs, and the TR-55 method tend to overestimate AEPDs and that estimates calculated from the Iowa Runoff Chart method tend to primarily underestimate AEPDs. The comparisons seem to indicate the best overall accuracy and the least bias may be achieved by using the TR-55 method for flood regions 1 and 3 (published in 2013) and by using the 1987 single-variable RREs for flood region 2 (published in 2013).

For drainage basins with areas between 2 and 20 mi^2, results of the comparisons indicate that estimates of AEPDs from the 2013 multi- and single-variable RREs and the TR-55 method tend to overestimate AEPDs, and that estimates calculated from the 1987 single-variable RREs tend to overestimate and underestimate AEPDs. The comparisons seem to indicate the best overall accuracy and the least bias may be achieved by using the 1987 single-variable RREs for the Southern Iowa Drift Plain landform region and for flood region 3 (published in 2013), by using the 2013 multivariable RREs for the Iowan Surface landform region, and by using the 2013 or 1987 single-variable RREs for flood region 2 (published in 2013). For all other landform or flood regions in Iowa, use of the 2013 single-variable RREs may provide the best overall accuracy and the least bias.

Comparison results seem to indicate that the best accuracy and the least bias may be achieved by the use of different estimation methods of AEPD for different annual exceedance probabilities. The use of different estimation methods of AEPD for different annual exceedance probabilities is not appropriate because this approach could lead to inconsistencies with predictions of AEPDs. The number of streamgages included in the dataset comparisons range from 10 to 55. Information in this report needs to be used with caution because comparisons for datasets with a small number of streamgages provide limited information on the accuracy of the AEPD estimates for different AEPD-estimation methods. Thus, larger datasets may provide different results from those presented in this study.

An examination was conducted to understand why the 1987 single-variable RREs seem to provide better accuracy and less bias than either of the 2013 multi- or single-variable RREs. The re-assignment of hydrologic regions for streamgages and the use of a mixed landform calculation for the 1987 single-variable RREs seem to have had no substantial effect regarding the relative accuracy and bias compared to the 2013 multi- or single-variable RREs for drainage basins with areas less than 20 mi^2. Re-assignments of hydrologic regions defined in the 1987 U.S. Geological Survey report may be subjective for ungaged sites if users do not use a quantitative method to guide the re-assignment. A comparison of expected moments algorithm/multiple Grubbs-Beck estimates calculated through the 2013 water year to those calculated through

the 2010 water year does not indicate a general increase or decrease in 2013 estimates when compared to 2010 estimates.

A comparison of 1-percent annual exceedance-probability regression lines for hydrologic regions 1–4 from the 1987 single-variable RREs and for flood regions 1–3 from the 2013 single-variable RREs indicates that the 1987 single-variable regional-regression lines generally have steeper slopes and lower discharges when compared to 2013 single-variable regional-regression lines for corresponding areas of Iowa. The combination of the definition of hydrologic regions, the lower discharges, and the steeper slopes of regression lines associated with the 1987 single-variable RREs seem to provide better accuracy and less bias when compared to the 2013 multi- or single-variable RREs; better accuracy and less bias was determined particularly for drainage areas less than 2 mi^2, and also for some drainage areas between 2 and 20 mi^2. The 2013 multi- and single-variable RREs are considered to provide better accuracy and less bias for larger drainage areas.

Results of this study indicate that additional research is needed to address the curvilinear relation between drainage area and AEPDs for areas of Iowa. The development of two sets of RREs for large and small drainage areas, and the development of a method to resolve the problem of transitioning estimates of AEPDs between the two sets of RREs, may need to be reconsidered in future research for flood-estimation studies in Iowa.

Introduction

With the publication of the U.S. Geological Survey (USGS) annual exceedance-probability discharge (AEPD) estimation report, “Methods for Estimating Annual Exceedance-Probability Discharges for Streams in Iowa, Based on Data through Water Year 2010” (Eash and others, 2013) and with the implementation of regional-regression equations (RREs) from the report in Iowa StreamStats (U.S. Geological Survey, 2015a) in 2013, the Iowa Department of Transportation (Iowa DOT) needs information on the relative accuracy and the amount of bias of AEPD-estimation methods that can be used for drainage basins with areas less than 2 square miles (mi^2) and for drainage basins with areas between 2 and 20 mi^2. The USGS StreamStats AEPD-estimation equations are applicable to drainage basins with areas as small as 0.05 to 0.08 mi^2 depending on where an ungaged site is located in the three flood regions of Iowa (Eash and others, 2013). Traditionally, Iowa DOT has used the Iowa Runoff Chart method (Bureau of Public Roads, 1950) for drainage basins with areas less than 2 mi^2. The RREs from the USGS report, “Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa” (Lara, 1987), have also been used by Iowa DOT as a primary AEPD-estimation method for small drainage basins in Iowa. In response to the need to determine which AEPD-estimation methods provide the best estimates for small drainage basins in Iowa, the USGS, in cooperation with the Iowa DOT and the Iowa Highway Research Board, initiated a statewide study in 2014.

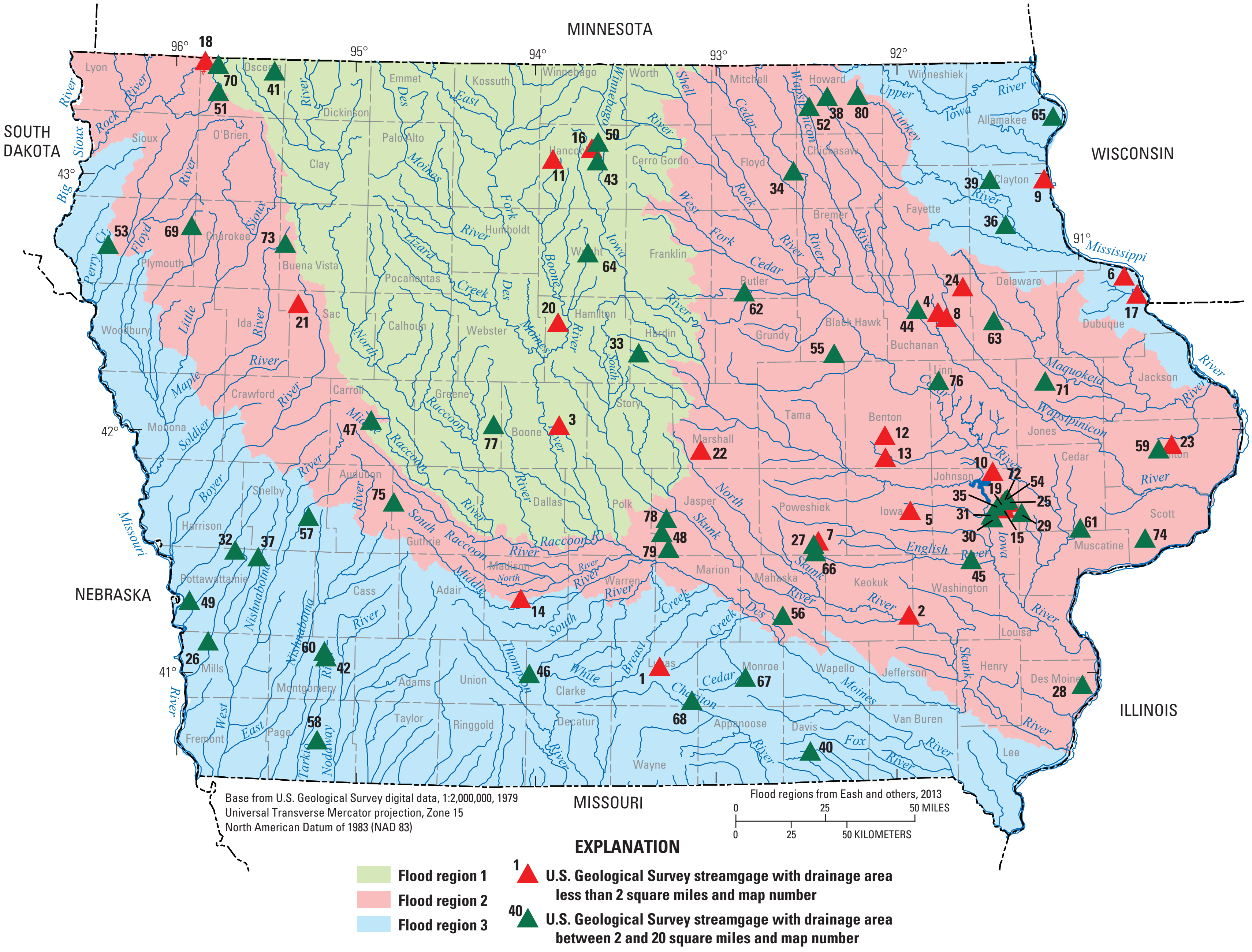
Purpose and Scope

This report presents two comparisons of estimates of AEPDs for small drainage basins in Iowa. First, AEPDs were estimated from five different AEPD-estimation methods for streamgages with drainage areas less than 2 mi^2 and were compared to AEPDs that were estimated from observed data from the same streamgages using a streamgage probability-analysis method named the expected moments algorithm/multiple Grubbs-Beck test, hereafter referred to as the EMA/MGB analysis method (Cohn and others, 1997, 2001, 2013; Eash and others, 2013). The five AEPD-estimation methods include (1) StreamStats multivariable RREs from a 2013 USGS AEPD-estimation report (tables 9–11 in Eash and others, 2013), hereafter referred to as the 2013 multivariable RRE method; (2) single-variable RREs also from the 2013 USGS AEPD-estimation report (table 15 in Eash and others, 2013), hereafter referred to as the 2013 single-variable RRE method; (3) single-variable RREs from a 1987 USGS AEPD-estimation report (table 2 in Lara, 1987), hereafter referred to as the 1987 single-variable RRE method; (4) the TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009), and (5) the Iowa Runoff Chart method (Bureau of Public Roads, 1950).

Second, AEPDs estimated from four different AEPD-estimation methods for streamgages in Iowa with drainage areas between about 2 and 20 mi^2 were compared to AEPDs that were estimated from observed data from the same streamgages using the EMA/MGB analysis method. With the exception of the Iowa Runoff Chart method, the four other AEPD-estimation methods included in the first set of comparisons also were included in the second set of comparisons for streamgages in Iowa with drainage areas between about 2 and 20 mi^2.

Streamgages listed in table 1 and shown in figure 1, that were used in this study, meet all USGS requirements for the EMA/MGB analysis method and data from these 80 streamgages were included in the development of the 2013 multi- and single-variable RREs. Of these 80 streamgages, 25 of them have drainage areas less than 2 mi^2 and 55 of them have drainage areas between about 2 and 20 mi^2.

Estimates of AEPDs were compared for eight selected flood-discharge estimates that have annual exceedance probabilities (AEPs) of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent, which are equivalent to annual flood-frequency recurrence intervals (RIs) of 2, 5, 10, 25, 50, 100, 200, and 500 years, respectively (table 2); hereafter, these eight selected AEP statistics are referred to as $Q_{50\text{-percent }(\%)}$, $Q_{20\%}$, $Q_{10\%}$, $Q_{4\%}$, $Q_{2\%}$, $Q_{1\%}$, $Q_{0.5\%}$, and $Q_{0.2\%}$, respectively. Estimates of AEPDs for $Q_{50\%}$, $Q_{0.5\%}$, and $Q_{0.2\%}$ are not applicable for the Iowa Runoff Chart method and estimates of AEPDs for $Q_{0.5\%}$, and $Q_{0.2\%}$ are not applicable for the 1987 single-variable RREs.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1979
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983 (NAD 83)

Figure 1. Location of 2013 flood regions and U.S. Geological Survey streamgages included in this study, Iowa.

Table 1. Data for streamgages in Iowa used for analysis in this study.

[no. and No., number; EMA/MGB, expected moments algorithm/multiple Grubbs-Beck test; mi^2, square miles; GIS, geographic information system; DRNAREA, geographic-information-system drainage area; AEP, annual exceedance probability; LENGTH, main-channel length as measured from the basin outlet to the basin divide; mi, mile; BSLDEM10M, average basin slope computed from 10-meter digital elevation model (DEM); ROWCROP, percent area of cultivated crops; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; SOILDSSURGO, hydrologic soil type D; CSL1085LFP, stream slope computed as the change in elevation between points 10 and 85 percent of length along LENGTH divided by the length between the points; ft/mi, feet per mile; CSL100, stream slope computed as entire LENGTH; SLOP30, percent area with slopes greater than 30 percent; CSG, crest-stage gage; SIDP, Southern Iowa Drift Plain; DML, Des Moines Lobe; IS, Iowan Surface; PP, Paleozoic Plateau; NWIP, Northwest Iowa Plains; ECIDP, East-Central Iowa Drift Plain; CON, continuous-record streamgage; LH, Loess Hills]

Map no. (fig. 1)	Streamgage number	Streamgage name	Type of streamgage	Systematic peaks in EMA/MGB analysis (years)	Historical period of EMA/MGB analysis	Historical period length of EMA/MGB analysis (years)
1	05487825	Little White Breast Creek Tributary near Chariton	CSG	24	1990–2013	24
2	05472555	Skunk River Tributary near Richland	CSG	24	1990–2013	24
3	05481528	Peas Creek Tributary at Boone	CSG	13	1990–2003	14
4	05421100	Pine Creek Tributary near Winthrop	CSG	62	1952–2013	62
5	05454180	Clear Creek Tributary near Williamsburg	CSG	24	1990–2013	24
6	05414605	Bloody Run Tributary near Sherrill	CSG	23	1991–2013	23
7	05455350	South English River Tributary No. 2 near Montezuma	CSG	28	1953–80	28
8	05421300	Wapsipinicon Tributary at Winthrop	CSG	58	1953–2012	60
9	05389501	Mississippi River Tributary at McGregor	CSG	23	1990–2013	24
10	05453430	North Fork Tributary to Mill Creek near Solon	CSG	17	1997–2013	17
11	0548065350	Drainage Ditch 97 Tributary near Britt	CSG	19	1991–2013	23
12	05464535	Prairie Creek Tributary near Van Horne	CSG	24	1990–2013	24
13	05464562	Thunder Creek at Blairstown	CSG	21	1977–2013	37
14	05485940	Cedar Creek Tributary No. 2 near Winterset	CSG	15	1990–2004	15
15	05453900	Rapid Creek Tributary near Oasis	CSG	42	1951–92	42
16	05448600	East Branch Iowa River above Hayfield	CSG	58	1953–2013	61
17	05414600	Little Maquoketa River Tributary at Dubuque	CSG	49	1951–2002	52
18	06483420	Schutte Creek near Sibley	CSG	21	1952–73	22
19	05453850	Rapid Creek Tributary No. 3 near Oasis	CSG	39	1951–92	42
20	05480993	Brewers Creek Tributary near Webster City	CSG	24	1990–2013	24
21	0660683710	Halfway Creek at Schaller	CSG	24	1990–2013	24
22	0547209280	Snipe Creek Tributary at Melbourne	CSG	24	1977–2013	37
23	05418645	Williams Creek near Charlotte	CSG	19	1989–2013	25
24	05416200	Lamont Creek Tributary near Lamont	CSG	20	1991–2013	23
25	05453700	Rapid Creek Tributary No. 4 near Oasis	CSG	24	1951–74	24
26	06805849	Keg Creek Tributary near Mineola	CSG	23	1991–2013	23
27	05455280	South English River Tributary near Barnes City	CSG	23	1953–76	24
28	05469350	Haight Creek at Kingston	CSG	24	1990–2013	24
29	05464942	Hoover Creek at Hoover National Historic Site, West Branch	CON	12	1967–2013	47
30	05455010	South Branch Ralston Creek at Iowa City	CON	17	1964–80	17
31	05455000	Ralston Creek at Iowa City	CON	58	1925–82	58
32	06610581	Mosquito Creek Tributary near Neola	CSG	23	1979–2013	35
33	0545129280	Honey Creek Tributary near Radcliffe	CSG	22	1991–2013	23
34	545776680	Gizzard Creek Tributary near Bassett	CSG	24	1990–2013	24
35	05453950	Rapid Creek Tributary near Iowa City	CSG	39	1951–92	42
36	05412030	French Hollow Creek near Elkader	CSG	24	1990–2013	24
37	06807720	Middle Silver Creek near Avoca	CSG	32	1953–86	34

Iowa landform region	Published drainage area (mi^2)	GIS drainage area, DRNAREA (mi^2)	Drainage area used for calculating AEP estimates (mi^2)	LENGTH (mi)	BSLDEM10M (percent)	ROWCROP (percent area)	SOILASSURGO (percent area)	SOILBSSURGO (percent area)	SOILCSSURGO (percent area)	SOILDSSURGO (percent area)	CSL1085LFP (ft/mi)	CSL100 (ft/mi)	SLOP30 (percent area)
SIDP	0.05	0.05	0.05	0.255	4.200	0	0	0	92.952	7.105	137.097	125.433	0
SIDP	0.18	0.18	0.18	0.666	3.903	78.235	0	82.009	17.967	0	85.415	77.657	0
DML	0.30	0.27	0.27	0.950	2.704	73.967	0	100	0	0	61.840	59.817	0.014
IS	0.33	0.32	0.32	0.914	3.649	86.639	0	99.975	0	0	87.662	95.821	0
SIDP	0.37	0.37	0.37	1.033	4.008	95.902	0	87.661	11.623	0	69.561	60.527	0
PP	0.59	0.59	0.59	1.038	7.017	23.115	0	99.978	0	0	92.068	114.329	0
SIDP	0.52	0.64	0.64	1.311	1.549	94.961	0	64.526	35.462	0	32.554	31.656	0
IS	0.70	0.67	0.67	1.555	2.820	79.122	1.042	94.483	0	0	47.729	52.018	0
PP	0.72	0.69	0.69	1.714	17.768	0	0	99.839	0	0	215.155	202.343	17.606
IS	0.78	0.73	0.73	1.670	5.247	84.712	4.634	95.325	0	0	48.588	64.123	0
DML	0.94	0.92	0.92	2.436	1.764	93.583	0	99.996	0	0	32.570	33.370	0
IS	0.94	0.94	0.94	1.594	2.366	77.383	0	99.641	0	0	41.208	32.789	0
IS	0.96	0.96	0.96	1.507	3.981	69.131	2.287	97.609	0	0	53.777	62.335	0
SIDP	1.02	0.99	0.99	1.524	1.111	82.126	0	69.209	30.787	0	26.774	21.767	0
SIDP	0.97	1.01	1.01	2.004	5.879	89.657	0	99.051	0.303	0	52.111	45.002	0
DML	2.23	1.54	1.54	2.214	1.288	90.537	16.004	81.133	2.763	0	12.625	14.689	0
PP	1.54	1.54	1.54	2.749	14.128	7.089	0	99.413	0	0.472	102.236	124.949	4.773
NWIP	1.43	1.59	1.59	3.526	1.269	95.245	0	100	0	0	23.730	22.752	0
SIDP	1.62	1.63	1.63	2.267	7.707	41.298	0	97.350	2.477	0	41.023	49.899	0
DML	1.58	1.71	1.71	2.211	0.759	89.072	0	99.879	0	0	18.560	14.396	0
NWIP	1.74	1.74	1.74	2.403	2.462	91.396	0	89.545	10.317	0	39.330	38.476	0
SIDP	1.61	1.76	1.76	2.096	3.760	85.689	0	97.074	0.929	1.549	47.326	38.811	0
ECIDP	1.77	1.77	1.77	1.884	6.163	90.724	0	98.663	1.043	0	43.794	61.317	0
IS	1.78	1.78	1.78	2.307	2.216	93.143	0.513	84.533	13.735	1.086	33.068	44.693	0
SIDP	1.95	1.94	1.94	2.327	4.772	83.564	0	99.563	0.311	0	26.777	31.338	0
SIDP	2.01	2.07	2.07	2.208	11.378	68.268	0	99.512	0	0	91.775	117.899	0.011
SIDP	2.51	2.36	2.36	2.532	3.097	86.636	0	71.174	25.265	3.553	39.980	32.489	0
SIDP	2.67	2.57	2.57	2.780	8.817	33.588	0	52.466	46.880	0	72.270	71.203	0.631
SIDP	2.58	2.59	2.59	3.822	5.870	61.097	0	97.074	2.645	0	25.254	29.592	0
SIDP	2.94	2.94	2.94	4.100	5.873	18.833	0	99.835	0.082	0	22.218	34.050	0
SIDP	3.01	3.11	3.11	4.419	8.925	16.321	0	99.834	0.118	0	30.354	34.868	0.051
SIDP	3.22	3.24	3.24	3.617	8.371	89.417	0	99.446	0.269	0	43.665	64.487	0.048
DML	3.29	3.40	3.40	4.140	1.983	89.988	0.036	99.848	0	0	16.027	15.983	0
IS	3.42	3.47	3.47	4.694	1.564	72.352	1.151	98.593	0.246	0	16.981	17.014	0
SIDP	3.43	3.49	3.49	4.481	8.525	39.214	0	98.878	0.968	0	30.575	31.503	0.054
PP	3.56	3.50	3.50	3.887	12.457	14.355	0	92.406	7.457	0	73.433	112.079	1.316
SIDP	3.21	4.10	4.10	3.683	4.736	80.840	0	99.467	0	0	31.231	31.496	0

Table 1. Data for streamgages in Iowa used for analysis in this study.—Continued

Map no. (fig. 1)	Streamgage number	Streamgage name	Type of streamgage	Systematic peaks in EMA/MGB analysis (years)	Historical period of EMA/MGB analysis	Historical period length of EMA/MGB analysis (years)
38	05411650	Crane Creek Tributary near Saratoga	CSG	23	1953–75	23
39	05412060	Silver Creek near Luana, Iowa (L-23S)	CON	11	1980–2003	24
40	05495600	South Wyaconda River near West Grove	CSG	23	1953–75	23
41	06604584	Dry Run Creek near Harris	CSG	19	1990–2013	24
42	06811800	East Tarkio Creek near Stanton	CSG	55	1958–2013	56
43	05448900	East Branch Iowa River Tributary near Garner	CSG	34	1952–86	35
44	05420960	Harter Creek near Independence	CSG	12	1952–63	12
45	05455550	Bulgers Run near Riverside	CSG	48	1965–2013	49
46	06897858	Sevenmile Creek near Thayer	CSG	19	1991–2013	23
47	05483349	Middle Raccoon River Tributary at Carroll	CSG	47	1948–2013	66
48	05487540	Walnut Creek near Prairie City	CON	10	1996–2005	10
49	06610500	Indian Creek at Council Bluffs	CON	22	1942–2013	72
50	05448700	East Branch Iowa River near Hayfield	CSG	37	1952–91	40
51	06483450	Wagner Creek near Ashton	CSG	22	1952–73	22
52	05420620	Little Wapsipinicon River near Acme	CSG	41	1953–93	41
53	06599800	Perry Creek near Merrill	CSG	56	1953–2013	61
54	05453600	Rapid Creek below Morse	CSG	40	1951–92	42
55	05464025	Miller Creek near Eagle Center	CSG	23	1990–2013	24
56	05489150	Little Muchakinock Creek at Oskaloosa	CSG	23	1966–88	23
57	0680737930	Elm Creek near Jacksonville	CSG	23	1991–2013	23
58	06811875	Snake Creek near Yorktown	CSG	30	1966–2013	48
59	05421890	Silver Creek at Welton	CSG	47	1966–2013	48
60	06811760	Tarkio River near Elliott	CSG	59	1952–2013	62
61	05464880	Otter Creek at Wilton	CSG	27	1966–93	28
62	05462750	Beaver Creek Tributary near Aplington	CSG	26	1966–91	26
63	05416972	Sand Creek near Manchester	CSG	23	1991–2013	23
64	05480930	White Fox Creek at Clarion	CSG	47	1966–2013	48
65	05388400	Wexford Creek near Harpers Ferry	CSG	35	1953–89	37
66	05455300	South English River near Barnes City	CSG	35	1953–88	36
67	05488620	Coal Creek near Albia	CSG	26	1951–92	42
68	06903500	Honey Creek near Russell	CON	11	1952–62	11
69	06601480	Big Whiskey Slough near Remsen	CSG	28	1967–98	32
70	06483410	Otter Creek north of Sibley	CSG	36	1952–88	37
71	05417590	Kitty Creek near Langworthy	CSG	26	1966–92	27
72	05453750	Rapid Creek south west of Morse	CSG	40	1951–92	42
73	06606790	Maple Creek near Alta	CSG	24	1955–90	36
74	05422560	Duck Creek at 110th Avenue at Davenport	CON	20	1994–2013	20
75	06808880	Bluegrass Creek at Audubon	CSG	31	1967–2013	47
76	05464318	East Blue Creek at Center Point	CSG	28	1966–93	28
77	05481690	West Beaver Creek at Grand Junction	CSG	24	1966–89	24
78	05471040	Squaw Creek near Colfax	CON	10	1996–2005	10
79	05487550	Walnut Creek near Vandalia	CON	11	1995–2005	11
80	05411530	North Branch Turkey River near Cresco	CSG	28	1966–93	28

Iowa landform region	Published drainage area (mi^2)	GIS drainage area, DRNAREA (mi^2)	Drainage area used for calculating AEP estimates (mi^2)	LENGTH (mi)	BSLDEM10M (percent)	ROWCROP (percent area)	SOILASSURGO (percent area)	SOILBSSURGO (percent area)	SOILCSSURGO (percent area)	SOILDSSURGO (percent area)	CSL1085LFP (ft/mi)	CSL100 (ft/mi)	SLOP30 (percent area)
IS	4.06	4.13	4.13	3.638	1.850	89.282	0	46.901	53.037	0	18.232	22.863	0
PP	4.39	4.37	4.37	4.225	5.220	83.510	0.088	98.001	1.839	0	30.035	39.223	0
SIDP	4.69	4.57	4.57	4.436	3.176	44.932	0	7.913	43.409	46.984	24.532	20.776	0
DML	4.30	4.84	4.84	4.914	1.424	94.145	0.192	96.983	2.816	0	9.530	11.046	0
SIDP	4.66	5.02	5.02	4.973	5.024	88.668	0	81.948	3.204	14.682	18.155	22.217	0
DML	5.98	5.63	5.63	5.100	1.989	90.499	10.308	78.176	11.341	0	4.018	13.981	0
IS	6.17	6.16	6.16	5.931	2.690	85.865	1.458	98.443	0	0	20.416	23.706	0
SIDP	6.31	6.31	6.31	6.162	6.616	45.912	0	86.498	13.138	0.315	20.411	23.326	0
SIDP	6.61	6.60	6.60	4.778	6.657	26.103	0	24.495	67.060	7.723	28.100	32.316	0.050
SIDP	6.58	6.72	6.72	4.619	6.575	91.452	0.150	99.148	0.579	0	29.064	40.604	0
SIDP	6.78	6.77	6.77	3.925	4.379	83.793	0	92.020	7.582	0.230	31.781	33.070	0
LH	7.99	6.95	6.95	5.719	12.331	17.437	0	98.537	0	0	34.045	47.529	0.815
DML	7.94	7.34	7.34	6.278	1.404	91.397	6.056	87.170	6.747	0	6.706	8.555	0
NWIP	7.09	7.35	7.35	6.385	1.421	91.053	0	99.823	0.193	0	15.000	14.202	0
IS	7.76	8.02	8.02	7.989	2.726	78.833	0.051	93.296	6.578	0	16.218	22.525	0
NWIP	8.17	8.14	8.14	5.936	3.775	87.883	0	99.875	0	0	17.766	22.684	0
SIDP	8.12	8.21	8.21	5.152	5.797	73.396	0	99.450	0.346	0	17.034	23.824	0
IS	9.14	8.75	8.75	5.307	2.505	92.816	0	99.017	0.840	0	16.041	18.924	0
SIDP	9.12	9.30	9.30	6.833	3.755	62.695	0	60.370	33.624	3.452	17.530	20.303	0.005
SIDP	9.43	9.53	9.53	6.400	7.494	89.277	0	96.819	3.171	0	23.147	32.464	0
SIDP	9.10	9.59	9.59	6.648	6.549	68.126	0	76.498	21.179	1.810	20.290	27.532	0.002
ECIDP	9.03	9.97	9.97	4.327	5.812	76.251	0	99.139	0.630	0	21.289	39.943	0
SIDP	10.70	10.68	10.70	8.955	4.197	88.371	0	93.498	2.613	3.789	14.156	13.756	0
SIDP	10.70	10.76	10.80	7.997	4.055	83.416	0.137	99.151	0.684	0	11.487	13.736	0
IS	11.60	11.07	11.10	6.664	2.359	89.023	0.160	99.822	0	0	15.898	21.564	0
IS	11.00	11.07	11.10	6.939	2.924	92.332	1.537	92.661	1.714	4.044	16.675	24.884	0
DML	13.30	11.37	11.40	7.264	2.201	83.110	0.946	91.782	2.568	0	11.041	13.775	0
PP	11.90	11.42	11.40	7.223	14.777	18.171	0.346	79.272	19.771	0.558	69.071	77.884	12.219
SIDP	11.50	12.05	12.10	7.821	3.828	80.890	0.006	73.718	23.281	2.822	12.551	15.886	0
SIDP	13.50	13.27	13.30	7.065	8.800	19.521	0	16.019	65.509	17.532	19.034	27.889	0.039
SIDP	13.20	13.30	13.30	9.209	5.834	40.999	0	1.850	86.501	10.407	10.358	14.034	0
NWIP	12.90	13.45	13.50	9.862	1.838	91.373	0	98.982	0.520	0	10.401	10.730	0
NWIP	11.90	13.81	13.80	9.647	1.226	86.957	0.137	93.272	6.018	0	4.427	10.503	0
IS	14.40	14.03	14.00	6.709	4.840	79.563	2.183	96.540	1.057	0.003	20.903	34.852	0
SIDP	15.20	15.18	15.20	6.689	5.564	74.934	0	99.405	0.388	0	14.226	21.455	0.001
NWIP	15.50	15.46	15.50	10.326	1.943	91.265	0.138	96.509	3.301	0	10.250	15.541	0
SIDP	16.10	15.52	15.50	7.257	4.202	82.510	0	92.037	7.755	0	18.951	18.242	0.002
SIDP	15.40	15.69	15.70	9.856	6.533	82.457	0.464	89.583	9.084	0.191	15.682	24.240	0
IS	17.60	17.00	17.00	10.259	3.167	75.084	21.825	77.804	0.052	0	12.303	15.899	0.001
DML	12.60	18.22	18.20	13.430	1.295	89.914	0.245	97.793	0.977	0	10.333	9.537	0
SIDP	18.40	18.40	18.40	8.374	5.503	80.758	1.868	94.297	3.068	0.592	11.283	15.770	0.005
SIDP	20.30	20.25	20.20	10.206	5.533	63.555	0	86.138	13.088	0.551	12.112	16.833	0.010
IS	19.50	20.44	20.40	9.708	1.957	85.119	0.829	92.033	6.540	0.105	11.090	13.719	0

Table 2. Annual exceedance probability and equivalent flood-recurrence interval for selected probabilities.

Annual exceedance probability (percent)	Recurrence interval (years)
50	2
20	5
10	10
4	25
2	50
1	100
0.5	200
0.2	500

Comparisons for the two sizes of drainage area were evaluated two different ways to determine which of the four or five AEPD-estimation methods provides the best accuracy. First, the AEPD-estimation method that provides the best accuracy for AEPs, or RIs, selected by Iowa DOT was determined. The Iowa DOT selected AEPDs of 4, 2, and 1 percent, or flood RIs of 25, 50, and 100 years for this comparison because these AEPDs are used most frequently by Iowa DOT for flood estimation. Second, the AEPD-estimation method that provides the best accuracy for the greatest number of AEPs, or greatest number of RIs, also was determined.

Description of Study Area

The study area (fig. 1) includes the entire State of Iowa. There are 10 landform regions in Iowa, each having distinctive topography and geology (fig. 2). A brief description of the landform regions in Iowa is presented in Eash and Barnes (2012) and a detailed description is presented by Prior (1991). Prior and others (2009) describe updates to landform regions in Iowa.

Most precipitation in the study area results from storms moving inland primarily from the Gulf of Mexico and secondarily from the Pacific Ocean (Soenksen and Eash, 1991). Annual precipitation, which is mostly rain, ranges from 26 inches (in.) in the extreme northwest to as much as 38 in. in the southeast; the statewide average is around 34 in. (National Climatic Data Center, 2012). About 75 percent of the annual precipitation is received during April through September. Typically, during August through February, streamflow in most unregulated streams in the study area is base flow; during March through July, streamflow is substantially greater, primarily as a result of snowmelt during late February through early April and rainfall during May through July. Annual maximum streamflows are typically during April through July.

Methods of Estimation for Annual Exceedance-Probability Discharges

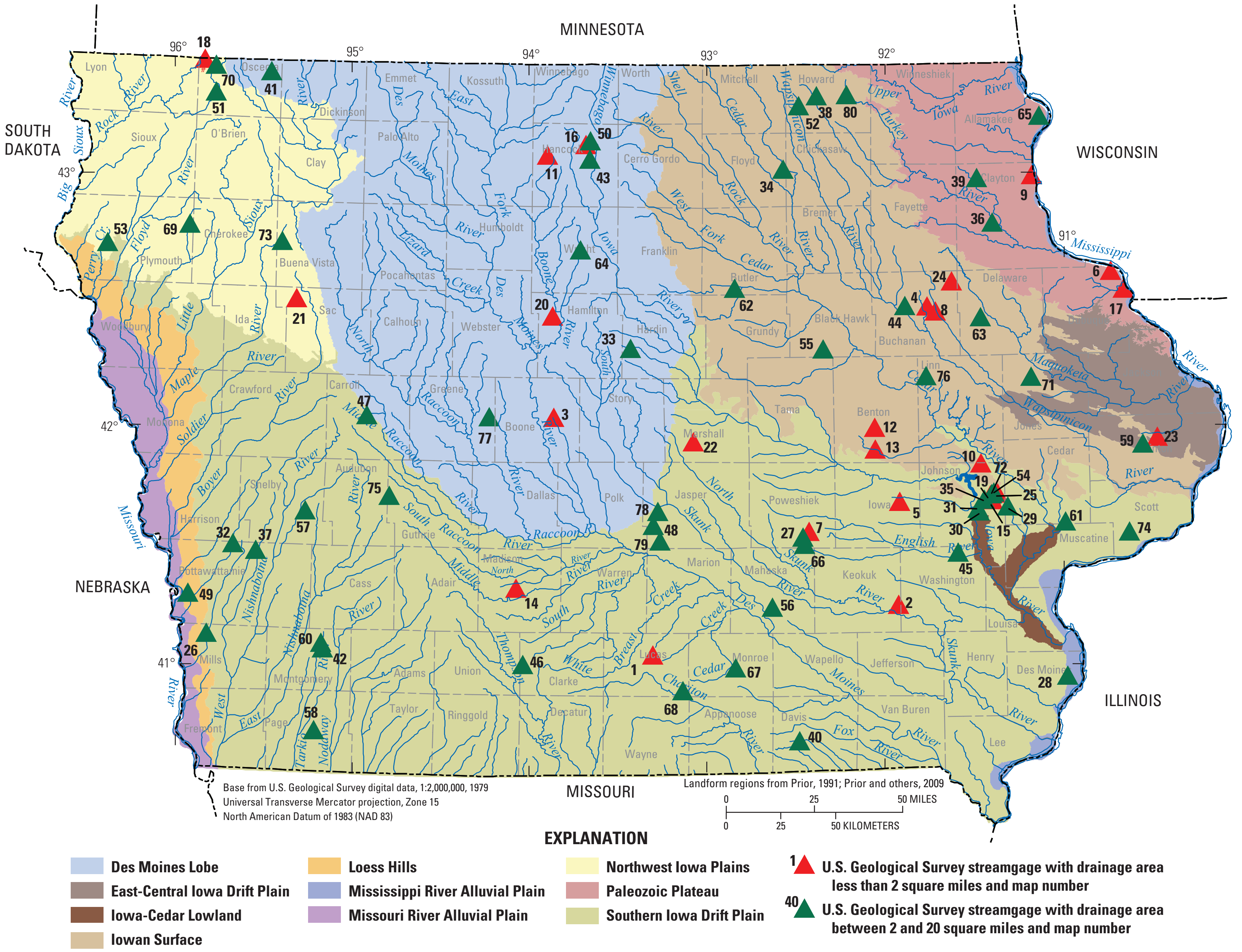
The AEPDs derived from the EMA/MGB analysis method are considered the best estimates for the 80 streamgages because they were calculated using observed annual peak-discharge data collected for at least 10 years and the USGS PeakFQ streamgage probability-analysis program (Veilleux and others, 2014). AEPDs estimated from the other four or five AEPD-estimation methods were evaluated for overall accuracy and bias relative to the AEPDs estimated by the EMA/MGB analysis method for the comparisons of the two sizes of drainage area.

The streamgage datasets included in this study are not independent of those used in the development of the 2013 multivariable RREs and the 2013 single-variable RREs, except for the addition of three more years of annual peak-discharge data. The streamgage datasets included in this study also may not be independent of those used to develop the 1987 single-variable RREs, or possibly even the TR-55 rainfall-runoff model or the Iowa Runoff Chart method, because these methods may have used some of these same streamgage datasets in their development. Therefore, conclusions regarding the relative quality of the AEPD-estimation methods may or may not be extended to ungaged sites. The relative quality of the estimates of AEPDs calculated for streamgages from the AEPD-estimation methods compared in this study are assumed to extend to all conclusions referencing ungaged sites.

Drainage-area values for each streamgage included in this study are listed in table 1. Each streamgage has a drainage area that is listed in the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2015b), which is referred to as the “published” drainage area. Published drainage areas were determined primarily from 1:24,000-scale topographic maps by manual methods (planimeter) or digitizing methods (geographic information system [GIS]) at the time streamgage operation began. Drainage-area values listed in table 1 as “GIS” drainage areas (DRNAREA) were measured as part of the 2013 USGS AEPD-estimation study (Eash and others, 2013). Generally, GIS-delineated drainage-area values are believed to be more accurate than the published drainage-area values (Eash and others, 2013). The GIS measurements of drainage area (DRNAREA), rounded to the same number of significant figures as output from StreamStats, were used in this study to calculate estimates of AEPDs because users will likely use StreamStats to determine drainage-area values for ungaged stream sites in Iowa.

Expected Moments Algorithm/Multiple Grubbs-Beck Test Analysis Method

Crest-stage gages (CSGs) are the primary source of annual peak-discharge data for small drainage basins in Iowa (U.S. Geological Survey, Iowa Water Science Center, Flood



Base from U.S. Geological Survey digital data, 1:2,000,000, 1979
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983 (NAD 83)

Landform regions from Prior, 1991; Prior and others, 2009

Figure 2. Location of landform regions in Iowa and U.S. Geological Survey streamgages included in this study, Iowa.

Information at Selected Bridge and Culvert Sites; http://ia.water.usgs.gov/projects/ia006.html). Annual peak discharges are computed for continuous-record streamgages and CSGs by use of a stage-discharge relation (Rantz and others, 1982). The stage-discharge relation, or rating, is used to determine discharges for all recorded stages at streamgages with the exception for some types of flow conditions at CSG culverts (Bodhaine, 1968); peak discharges are determined independently of a stage-discharge rating using the USGS Culvert Analysis Program (Fulford, 1998). The largest discharge during a water year is the annual peak discharge, and the annual peak-discharge record is the compilation of all recorded annual peak discharges.

Water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and that includes 9 of the 12 months of that year. Thus, the water year ending September 30, 2013, is the “2013 water year.” Annual peak-discharge records collected through the 2013 water year were retrieved from the USGS NWIS database (U.S. Geological Survey, 2015b) for the 80 streamgages included in this study (table 1) to estimate the EMA/MGB AEPDs. The number of annual peak discharges, or systematic peaks, collected at the 25 streamgages with drainage areas less than 2 mi^2 that were used in the EMA/MGB analyses ranged from 13 to 62 years, with an average of 29 years and a median of 24 years (table 1). The number of systematic peaks collected at the 55 streamgages with drainage areas between 2 and 20 mi^2 that were used in the EMA/MGB analyses ranged from 10 to 59 years, with an average of 29 years and a median of 24 years (table 1).

AEPDs for a streamgage are calculated from an AEP analysis that relates observed annual peak discharges to AEPs. The EMA/MGB analysis method within the USGS PeakFQ, (version 7.1) program (Cohn and others, 1997, 2001, 2013; Eash and others, 2013; Veilleux and others, 2014) and the results of a new statewide regional skew study (Veilleux and others, 2012; Eash and others, 2013) were used to estimate AEPDs for data at the 80 streamgages (table 1). EMA/MGB AEP analyses provide a new alternative method to standard (hereafter referred to as Bulletin 17B) AEP analyses (Interagency Advisory Committee on Water Data, 1982; Veilleux and others, 2014). EMA/MGB estimates calculated through the 2013 water year at the 80 streamgages for AEPs of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent are listed in table 3 (link to Excel file). A minimum of 10 years of annual peak-discharge record is recommended by the Interagency Advisory Committee on Water Data (1982) to estimate AEPDs using the Bulletin 17B analysis method. The EMA/MGB estimates of AEPDs were not weighted with RRE estimates of AEPDs using the Weighted Independent Estimates (WIE) method (Cohn and others, 2012; Eash and others, 2013) to provide some measure of independence to this dataset.

AEPs formerly were reported as flood RIs expressed in years (Holmes and Dinicola, 2010). Estimates of AEPDs at streamgages change as additional annual peak discharges are measured; EMA/MGB estimates of AEPDs are updated and become more statistically reliable.

2013 Multivariable Regional-Regression Equations

Multivariable RREs from Eash and others (2013) were developed for three new flood regions defined for Iowa (fig. 1). Each set of regression equations for each flood region requires the measurement of three basin characteristics. The RREs were developed using GIS measurements of the basin characteristics as the independent variables and EMA/MGB estimates of AEPDs as the dependent variables in the regression analyses. The basin characteristics were measured from high-resolution (1:24,000 scale) elevation, stream, and watershed-boundary data (Eash and others, 2013). Information on the GIS measurements of basin characteristics, basin-characteristic values for the 80 streamgages, the definition of the three flood regions in Iowa, and the development of the multivariable RREs is presented in Eash and others (2013).

The GIS data layers used to measure the basin characteristics along with the 2013 multivariable RREs developed for Iowa (Eash and others, 2013) were included in the USGS National StreamStats Program (U.S. Geological Survey, 2015a). In June 2013, the Iowa StreamStats implementation was released, which allows users to interactively delineate drainage-basin boundaries, measure basin-characteristic values, and solve RREs for ungaged stream sites in Iowa. The multivariable RREs presented in tables 9–11 in Eash and others (2013) are applicable for drainage basins:

- With areas as small as 0.06 mi^2 for flood region 1,
- As small as 0.08 mi^2 for flood region 2, and
- As small as 0.05 mi^2 for flood region 3.

Average standard errors of prediction (SEP, in percent) for the multivariable RREs from Eash and others (2013) range from 31.8 to 45.2 percent for flood region 1, from 19.4 to 46.8 percent for flood region 2, and from 26.5 to 43.1 percent for flood region 3. The 2013 multivariable RRE estimates for AEPs of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent (table 4 in Eash and others, 2013) are listed in table 4 (link to Excel file) for the 80 streamgages.

2013 Single-Variable Regional-Regression Equations

Single-variable RREs also were developed for the three new flood regions defined for Iowa (fig. 1) by Eash and others (2013). The single-variable RREs, which only require drainage-area measurements (DRNAREA), were not formally published as equations by Eash and others (2013). Rather, the exponents and constants of the 2013 single-variable RREs were published (table 15 in Eash and others, 2013) so that the exponents from the single-variable RREs would be available

Table 5. Single-variable regression equations (2013) for estimating annual exceedance-probability discharges for unregulated streams in flood region 1, Iowa.[1]

[SEP, average standard error of prediction; *Pseudo-R^2*, pseudo coefficient of determination; SEM, average standard error of model; AVP, average variance of prediction; log, logarithm; $Q_{x\%}$, annual exceedance-probability discharge of x percent; %, percent; DRNAREA, geographic-information-system drainage area]

Annual exceedance-probability equation	SEP (percent)	*Pseudo-R^2* (percent)	SEM (percent)	AVP (log $ft^3/s)^2$
(91 streamgages used to develop equations)				
$Q_{50\%}$=45.5 DRNAREA$^{0.641}$	51.9	91.9	50.5	0.045
$Q_{20\%}$=116 DRNAREA$^{0.592}$	42.9	93.3	41.5	0.032
$Q_{10\%}$=181 DRNAREA$^{0.569}$	42.4	92.9	40.8	0.031
$Q_{4\%}$=282 DRNAREA$^{0.548}$	44.4	91.7	42.6	0.034
$Q_{2\%}$=369 DRNAREA$^{0.535}$	46.6	90.5	44.7	0.037
$Q_{1\%}$=462 DRNAREA$^{0.524}$	48.9	89.2	46.8	0.040
$Q_{0.5\%}$=564 DRNAREA$^{0.516}$	51.8	87.7	49.6	0.045
$Q_{0.2\%}$=708 DRNAREA$^{0.506}$	55.8	85.5	53.4	0.051

[1] From Eash and others (2013).

Table 6. Single-variable regression equations (2013) for estimating annual exceedance-probability discharges for unregulated streams in flood region 2, Iowa.[1]

[SEP, average standard error of prediction; *Pseudo-R^2*, pseudo coefficient of determination; SEM, average standard error of model; AVP, average variance of prediction; log, logarithm; $Q_{x\%}$, annual exceedance-probability discharge of x percent; %, percent; DRNAREA, geographic-information-system drainage area]

Annual exceedance-probability equation	SEP (percent)	Pseudo-R^2 (percent)	SEM (percent)	AVP (log $ft^3/s)^2$
(176 streamgages used to develop equations)				
$Q_{50\%}$=143 DRNAREA$^{0.579}$	47.4	91.3	46.4	0.038
$Q_{20\%}$=376 DRNAREA$^{0.525}$	28.2	95.9	27.1	0.014
$Q_{10\%}$=598 DRNAREA$^{0.499}$	23.6	96.9	22.4	0.010
$Q_{4\%}$=931 DRNAREA$^{0.476}$	24.0	96.5	22.6	0.011
$Q_{2\%}$=1,210 DRNAREA$^{0.463}$	25.4	95.9	24.0	0.012
$Q_{1\%}$=1,510 DRNAREA$^{0.453}$	26.9	95.2	25.4	0.013
$Q_{0.5\%}$=1,820 DRNAREA$^{0.445}$	29.1	94.3	27.5	0.015
$Q_{0.2\%}$=2,250 DRNAREA$^{0.436}$	32.6	92.6	30.9	0.019

[1] From Eash and others (2013).

for calculating area-weighted estimates of AEPDs for ungaged sites on gaged streams. Thus, estimates of AEPDs could be calculated at ungaged stream sites using drainage area only.

The 2013 single-variable RREs for flood region 1 were implemented in Iowa StreamStats for use when the basin-characteristic value for the total length of all streams (determined at the 1:24,000 scale) in a drainage basin (STRMTOT; table 2 in Eash and others, 2013) equals zero or when the constant of channel maintenance (CCM) basin-characteristic value is greater than 3.87. The STRMTOT basin-characteristic value is used to compute the CCM basin-characteristic value (CCM is equal to DRNAREA divided by STRMTOT). Because small drainage basins in flood region 1 may have STRMTOT values of zero or CCM values greater than 3.87, for which the 2013 multivariable RREs cannot be used, the single-variable RREs were implemented in Iowa StreamStats as an alternative set of RREs for flood region 1.

The 2013 single-variable RREs (table 15 in Eash and others, 2013) are presented in tables 5–7 (this report). The 2013 single-variable RREs were developed using generalized least-squares (GLS) regression. The constant values listed in table 15 in Eash and others (2013) are in logarithm (log) units and are rounded to three significant figures. The coefficients of the RREs listed in tables 5–7 are untransformed from the same constants (in log units as listed in table 15 of Eash and others, 2013), except the constants are rounded to four significant figures. Thus, untransforming a constant value (table 15 in Eash and others, 2013) will produce a slightly different coefficient value than that listed in tables 5–7. Because the same streamgages used to develop the 2013 multivariable RREs

Table 7. Single-variable regression equations (2013) for estimating annual exceedance-probability discharges for unregulated streams in flood region 3, Iowa.[1]

[SEP, average standard error of prediction; *Pseudo-R^2*, pseudo coefficient of determination; SEM, average standard error of model; AVP, average variance of prediction; log, logarithm; $Q_{x\%}$, annual exceedance-probability discharge of x percent; %, percent; DRNAREA, geographic-information-system drainage area]

Annual exceedance-probability equation	SEP (percent)	*Pseudo-R^2* (percent)	SEM (percent)	AVP (log ft³/s)²
(127 streamgages used to develop equations)				
$Q_{50\%}$=205 DRNAREA$^{0.579}$	44.0	91.9	43.1	0.033
$Q_{20\%}$=488 DRNAREA$^{0.528}$	34.4	93.8	33.5	0.021
$Q_{10\%}$=741 DRNAREA$^{0.503}$	33.2	93.7	32.2	0.020
$Q_{4\%}$=1,120 DRNAREA$^{0.479}$	33.6	93.0	32.5	0.020
$Q_{2\%}$=1,440 DRNAREA$^{0.466}$	35.6	91.9	34.5	0.023
$Q_{1\%}$=1,770 DRNAREA$^{0.455}$	37.6	90.7	36.4	0.025
$Q_{0.5\%}$=2,120 DRNAREA$^{0.447}$	39.7	89.5	38.4	0.028
$Q_{0.2\%}$=2,590 DRNAREA$^{0.438}$	43.2	87.3	41.9	0.032

[1] From Eash and others (2013).

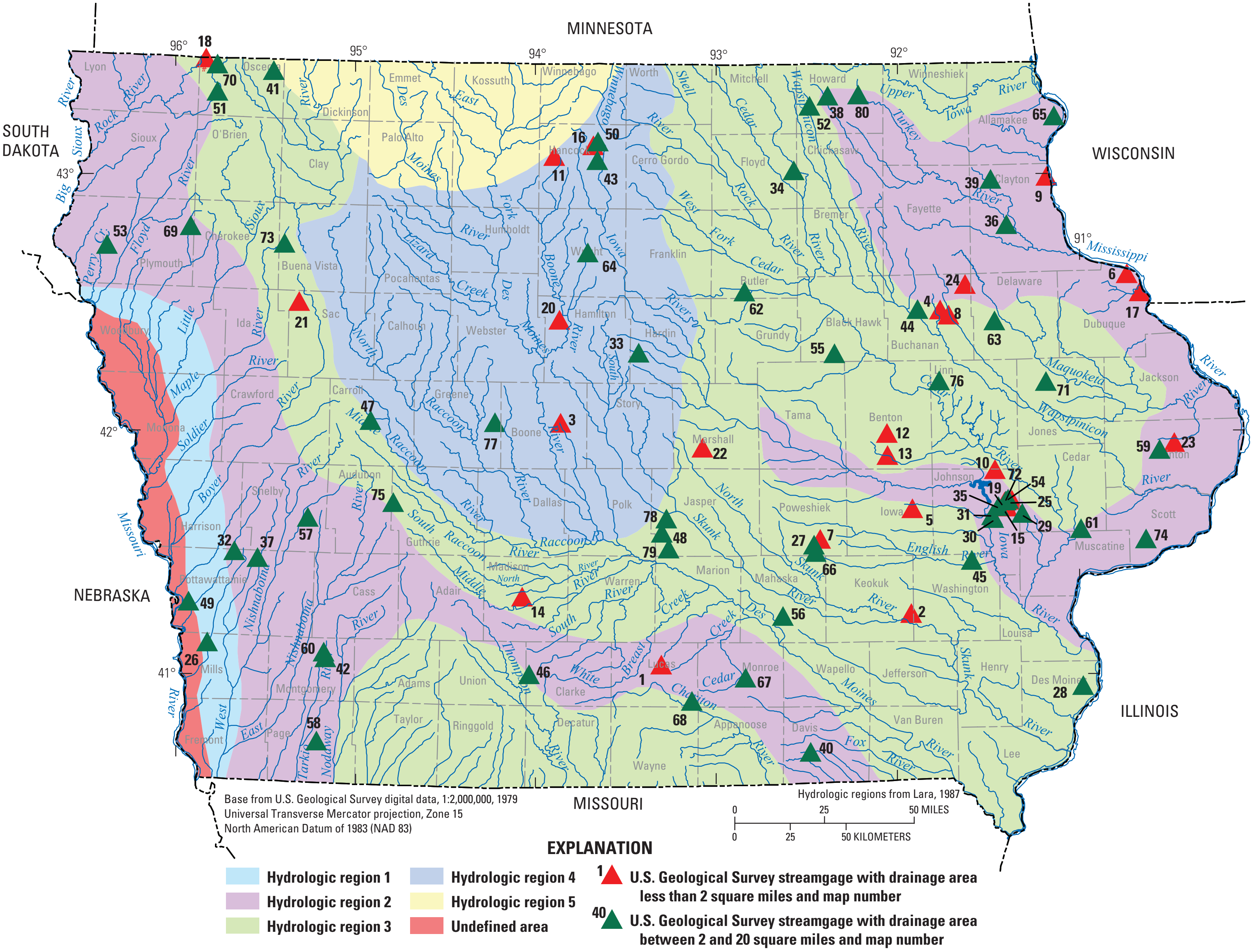
were used to develop the 2013 single-variable RREs, the same range of DRNAREA values are applicable for the 2013 single-variable RREs as for the 2013 multivariable RREs (table 12 in Eash and others, 2013). For the 24 single-variable RREs developed for estimating AEPDs for flood regions 1–3, an average standard error of prediction, a *pseudo-R^2* (in percent), an average error of model (in percent), and an average variance of prediction (in log units) are reported in tables 5–7 as performance metrics. A description of GLS regression and the performance metrics is presented in Eash and others (2013). The SEPs for the 2013 single-variable RREs range from 42.4 to 55.8 percent for flood region 1, from 23.6 to 47.4 percent for flood region 2, and from 33.2 to 44.0 percent for flood region 3 (tables 5–7). The 2013 single-variable RRE estimates for AEPs of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent at the 80 streamgages (tables 5–7; table 15 in Eash and others, 2013) are listed in table 8 (link to Excel file).

1987 Single-Variable Regional-Regression Equations

Single-variable RREs developed by Lara (1987) for five flood regions defined for Iowa (fig. 3) were used to estimate AEPDs for the 80 selected streamgages. The 1987 single-variable RREs only require the measurement of drainage area and these RREs are used by Iowa DOT to estimate AEPDs for small drainage basins in Iowa (Iowa Department of Transportation, 2014a; see section 3.2.2, "Stream and river crossings"). Lara (1987) assigned some streamgages to a different hydrologic region than the region where the streamgage is present [fig. 3 and table 9 (link to Excel file) streamgages with map numbers 8, 40, 68, and 73]; thus, for this study, streamgages that were included in the development of the 1987 single-variable RREs are assigned to the same hydrologic region as used by Lara (1987) (table 9).

In a two-page addendum to Lara (1987) (Oscar Lara, U.S. Geological Survey, written commun., 1987), Lara noted the importance of recognizing that within the hydrologic regions, small watersheds may have landform characteristics that produce peak discharges typical of other hydrologic regions; professional judgment may be needed when selecting and using the appropriate set of equations and ultimately selecting the AEPDs. An example of a calculation of AEPDs that encompass mixed landforms for drainage basins with areas of 20 mi² or less was presented in the addendum. After inspecting the location (using 1:24,000-scale topographic maps) of each of the 80 streamgages, the calculation of mixed landform presented in the addendum to Lara (1987) was used to estimate AEPDs for two streamgages that were representative of mixed landform regions (table 9, streamgages with map numbers 13 and 59 shown on fig. 3).

Forty-three of the 80 streamgages listed in table 9 were not included in the development of the 1987 single-variable RREs and were not assigned to a hydrologic region by Lara (1987). Thus, for this study, these 43 streamgage needed to be evaluated to determine if any of them should be assigned to a different hydrologic region than the region where the streamgage is present. The GIS-measured basin characteristics (table 1 in this report; table 2 in Eash and others, 2013) were evaluated for streamgages within each hydrologic region. The 80 streamgages were sorted into hydrologic regions 1 to 4 (none of the streamgages are located in hydrologic region 5, fig. 3) as previously assigned by Lara (1987) for 37 of the streamgages or to the region where the streamgage is present for the 43 streamgages that were not included in the development of the 1987 single-variable RREs (fig. 3). Mean, median, minimum, and maximum basin-characteristic values were then calculated for the streamgages within each hydrologic region:



Base from U.S. Geological Survey digital data, 1:2,000,000, 1979
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983 (NAD 83)

Hydrologic regions from Lara, 1987

Figure 3. Location of 1987 hydrologic regions and U.S. Geological Survey streamgages included in this study, Iowa.

1. For average basin slope (BSLDEM10M).
2. For stream slope calculated as the change in elevation between points located at 10 and 85 percent of the length along the longest flow path that was determined by GIS, then divided by the length between the points (CSL1085LFP).
3. For stream slope calculated from the entire main-channel length from basin outlet to basin divide (CSL100).
4. For percent of area with slopes greater than 30 percent (SLOP30).

CSL1085LFP (listed as “10–85 stream slope method” in Iowa StreamStats) is a basin characteristic that is currently (2015) available in Iowa StreamStats. Six of the 43 streamgages that were not included in the development of the 1987 single-variable RREs were identified with basin-characteristic values that seem to be more representative of a different hydrologic region than the region where the streamgage is present and they were assigned to a different hydrologic region (table 9 and fig. 3, streamgages with map numbers 3, 9, 10, 28, 36, and 69). Thus, AEPDs for 12 of 80, or 15 percent, of the streamgages were calculated using RREs for a different hydrologic region than the region where the streamgage is present.

The 1987 single-variable RREs are applicable for drainage basins:

- With areas as small as 0.7 mi^2 for hydrologic region 1,
- As small as 0.08 mi^2 for hydrologic region 2,
- As small as 0.04 mi^2 for hydrologic region 3,
- As small as 7.9 mi^2 for hydrologic region 4, and
- As small as 45 mi^2 for hydrologic region 5.

For this study, 1987 single-variable RREs were applied to data from streamgages with drainage areas smaller than the applicable limits of the equations for comparison purposes. Standard errors of estimates (SEE, in percent) are unknown for the equations when drainage-area values are used in the equations that are outside of the range of values used to develop the equations. Standard errors of estimate for the 1987 single-variable RREs range from 21 to 61 percent for hydrologic region 1, from 32 to 55 percent for hydrologic region 2, from 35 to 44 percent for hydrologic region 3, from 29 to 40 percent for hydrologic region 4, and from 20 to 27 percent for hydrologic region 5 (table 2 in Lara, 1987). The 1987 single-variable RRE estimates for AEPs of 50, 20, 10, 4, 2, and 1 percent at the 80 streamgages are listed in table 9.

TR-55 Rainfall-Runoff Model

The WinTR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009) was used in this study to estimate AEPDs. The WinTR-55 model is a single-event rainfall-runoff model for small watersheds. The model can be used to analyze watersheds with drainage areas as large as 25 mi^2 and with time of concentration (*Tc*) values from 0.1 to 10 hours. Bradley and others (2009) determined that use of the TR-55 method tends to underestimate AEPDs when compared to those calculated using the Bulletin 17B AEP analysis (Interagency Advisory Committee on Water Data, 1982) for 46 streamgage watersheds in the Midwest with drainage areas less than 200 acres (0.31 mi^2).

The *Tc* is the time required for runoff to travel from the most distant point in the watershed to its outlet. The watershed-lag method (Natural Resources Conservation Service, 2010) was used to calculate *Tc* values for input to the WinTR-55 model. The watershed-lag method requires values for the longest flow-path length, the average land slope of the watershed, and a curve number (*CN*). The *CN* is defined as a dimensionless number of 98 or less that relates runoff to the soil-cover complex of a watershed; the *CN* indicates the runoff potential of a soil-cover complex during periods when the soil is not frozen; higher values of *CN* indicate greater runoff (Natural Resources Conservation Service, 2012). The main-channel length was measured by using a GIS (table 2 in Eash and others, 2013); the main-channel length (LENGTH) was measured from the basin outlet to the basin divide and was used for the longest flow-path length. The average land slope of the watershed (BSLDEM10M) was calculated by using a GIS and a 10-meter digital elevation model (DEM). Measurements of LENGTH and BSLDEM10M were used for each of the 80 selected streamgages to calculate *Tc* (tables 1 and 10, link to Excel file). The WinTR-55 model was used to calculate *CN* in the land-use details module of the model after areas, in square miles, for each land-use type for each hydrologic soil group (table 1) were entered in the module. The GIS measurements of the percent area of cultivated crops (ROWCROP), proportioned by the percent area of hydrologic soils groups (SOILASSURGO, SOILBSSURGO, SOILCSSURGO, and SOILDSSURGO) (Eash and others, 2013), provided most of the information needed for calculating *CN* values (tables 1 and 10). SOILASSURGO, SOILBSSURGO, SOILCSSURGO, AND SOILDSSURGO are basin characteristics that will be available in version 3 of Iowa StreamStats (U.S. Geological Survey, 2015a), which is anticipated to be released in 2015. The percent area of pasture and woods, proportioned by hydrologic soil-group areas, were estimated from topographic maps (1:24,000 scale) and aerial photography to account for the remaining non-row crop areas within each of the 80 streamgage watersheds. For this study, *CN* values (table 10) were calculated by the WinTR-55 model on the basis of three land-use types for each watershed: row crop (straight row, good condition), pasture (fair condition), and woods (fair condition). A residential land-use type of one-quarter acre was used for small areas within a few watersheds to account for urban areas. The *CN* values calculated by the WinTR-55 model ranged from 68 to 83 with an average value of 76 (table 10). Because *Tc* values calculated for 4 streamgages (table 10, streamgages with map numbers 69, 70, 73, and 77) exceeded 10 hours, AEPDs could not be estimated for these four streamgages using the WinTR-55 model; thus, data for 76 streamgages were included in the comparisons for the TR-55 method.

Values for the 24-hour rainfall frequency (table 10) were input to the WinTR-55 model as user-provided, custom storm data in the storm data module of the model after the values were calculated for each watershed by using “Atlas 14” (Perica and others, 2013). Statewide GIS data layers of precipitation frequency grids were downloaded from “Atlas 14” for 24-hour rainfalls that have AEPs of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent using the Precipitation Frequency Data Server (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Weather Service, 2014). The zonal statistics tool within ArcGIS (version 10.0; Esri, 2012) was used to calculate eight rainfall-frequency values for each streamgage (table 10); WinTR-55 rainfall-runoff model estimates for AEPs of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent at 76 streamgages are listed in table 10.

Iowa Runoff Chart

The Iowa Runoff Chart method of calculating AEPDs was adapted in the 1950s by the Iowa State Highway Commission (now the Iowa DOT) from the Bureau of Public Roads’ Chart 1021.1 (Bureau of Public Roads, 1950). A document presenting the Iowa Runoff Chart is provided by the Iowa Department of Transportation (2014b). The Iowa Runoff Chart method has been widely used by Iowa DOT for small drainage basins with areas of 2 mi^2 or less (Iowa Department of Transportation, 2014a; see section 3.2.2, “Stream and river crossings”). Bradley and others (2009) determined that use of the Iowa Runoff Chart method tends to underestimate AEPDs when compared to those calculated using the Bulletin 17B AEP analysis (Interagency Advisory Committee on Water Data, 1982) for 46 streamgage watersheds in the Midwest with drainage areas less than 200 acres. In this study, the Iowa Runoff Chart method was used for streamgages with drainage areas as large as 1.94 mi^2 or 1,242 acres (table 1). The Iowa Runoff Chart method calculation for estimating AEPDs is shown in the following equation:

$$Q_{design} = LF \times FF \times Q, \qquad (1)$$

where

Q_{design} is the estimated peak discharge, in cubic feet per second;

LF is a land-use and slope-description factor for the watershed;

FF is a frequency factor applied for specific AEPs or flood RIs; and

Q is discharge, in cubic feet per second, and is calculated as $Q = 8.124\,A^{0.739}$;

where

A is the drainage area in acres.

For this study, LF values were determined for the drainage basins of 25 streamgages with drainage areas less than 2 mi^2 (tables 1 and 11) on the basis of GIS measurements (table 2 in Eash and others, 2013) of DRNAREA, BSLDEM10M, CSL1085LFP, CSL100, SLOP30, and ROWCROP. DRNAREA and CSL1085LFP (“10–85 stream slope method” in Iowa StreamStats) are the only basin characteristics that are currently (2015) available in Iowa StreamStats. Slight adjustments were applied to the LF values initially determined by the USGS for 12 of the 25 streamgage watersheds following a review of the LF values by Iowa DOT (David Claman, Iowa Department of Transportation, written commun., 2014) to ensure that LF values used in this study are consistent with Iowa DOT values. Iowa Runoff Chart estimates for AEPs of 20, 10, 4, 2, and 1 percent at the 25 streamgages are listed in table 11.

Comparisons of Estimates of Annual Exceedance-Probability Discharges

AEPDs estimated by using the EMA/MGB analysis method were compared to estimates calculated using the different AEPD-estimation methods on the basis of two evaluation metrics as recommended by the USGS Office of Surface Water (A.G. Veilleux and J.E. Kiang, U.S. Geological Survey, written commun., 2014). The mean percent relative error (MPRE) provides an indication of the overall accuracy of an AEPD-estimation method and the mean ratio of the AEPD-estimation method (AEPD estimate to the EMA/MGB AEPD estimate) gives an indication of the degree of bias of an AEPD-estimation method (Haddad and others, 2012). MPRE is calculated using the following equation:

$$MPRE = \frac{100}{n} \sum_{i=1}^{n} abs\left(\frac{Q_{AEPD\text{-}estimation\ method} - Q_{EMA/MGB}}{Q_{EMA/MGB}}\right) \qquad (2)$$

where

$MPRE$ is the mean percent relative error, which indicates the overall accuracy between the values estimated by using the EMA/MGB AEPD and the AEPD-estimation method;

n is the number of streamgages in the comparison dataset;

abs is the absolute value of the term that follows;

$Q_{AEPD\text{-}estimation\ method}$ is the AEPD estimate determined by using the AEPD-estimation method, in cubic feet per second, for the 2013 multivariable RREs, the 2013 single-variable RREs, the 1987 single-variable RREs, the TR-55 rainfall-runoff model, or the Iowa Runoff Chart; and

$Q_{EMA/MGB}$ is the EMA/MGB AEPD estimate, in cubic feet per second.

The AEPD-estimation method with the lowest MPRE value is considered to provide the most accurate estimates of AEPDs in comparison to the EMA/MGB estimates of AEPDs. The mean ratio is calculated using the following equation:

Table 11. Estimates of annual exceedance-probability discharges for selected streamgages in Iowa, using the Iowa Runoff Chart method.

[no. and No., number; *LF*, land factor representing land use and slope of the watershed (Iowa Department of Transportation, 2014b)]

Map no. (fig. 1)	Streamgage number	Streamgage name	*LF*	Estimates of annual exceedance-probability discharges, in cubic feet per second				
				20 percent	10 percent	4 percent	2 percent	1 percent
1	05487825	Little White Breast Creek Tributary near Chariton	0.6	31.6	44.2	50.5	63.1	75.8
2	05472555	Skunk River Tributary near Richland	0.5	67.8	94.9	108	136	163
3	05481528	Peas Creek Tributary at Boone	0.4	73.2	102	117	146	176
4	05421100	Pine Creek Tributary near Winthrop	0.6	124	174	199	249	299
5	05454180	Clear Creek Tributary near Williamsburg	0.6	139	194	222	277	332
6	05414605	Bloody Run Tributary near Sherrill	0.8	261	365	417	522	626
7	05455350	South English River Tributary No. 2 near Montezuma	0.5	173	242	277	346	415
8	05421300	Wapsipinicon Tributary at Winthrop	0.5	179	251	286	358	430
9	05389501	Mississippi River Tributary at McGregor	1.0	366	512	586	732	878
10	05453430	North Fork Tributary to Mill Creek near Solon	0.8	305	427	488	610	732
11	0548065350	Drainage Ditch 97 Tributary near Britt	0.4	181	253	290	362	435
12	05464535	Prairie Creek Tributary near Van Horne	0.6	276	386	441	552	662
13	05464562	Thunder Creek at Blairstown	0.5	234	327	374	467	561
14	05485940	Cedar Creek Tributary No. 2 near Winterset	0.4	191	268	306	382	459
15	05453900	Rapid Creek Tributary near Oasis	0.7	339	475	543	679	815
16	05448600	East Branch Iowa River above Hayfield	0.2	132	185	212	265	318
17	05414600	Little Maquoketa River Tributary at Dubuque	1.0	662	927	1,060	1,320	1,590
18	06483420	Schutte Creek near Sibley	0.4	271	380	434	543	651
19	05453850	Rapid Creek Tributary No. 3 near Oasis	0.6	414	580	663	829	995
20	05480993	Brewers Creek Tributary near Webster City	0.2	143	200	229	286	344
21	0660683710	Halfway Creek at Schaller	0.6	435	609	696	870	1,040
22	0547209280	Snipe Creek Tributary at Melbourne	0.6	439	614	702	877	1,050
23	05418645	Williams Creek near Charlotte	0.8	587	822	940	1,170	1,410
24	05416200	Lamont Creek Tributary near Lamont	0.6	442	619	708	885	1,060
25	05453700	Rapid Creek Tributary No. 4 near Oasis	0.6	471	660	754	943	1,130

$$Mean\ Ratio = \frac{1}{n}\sum_{i=1}^{n}\frac{Q_{AEPD\text{-}estimation\ method}}{Q_{EMA/MGB}} \qquad (3)$$

where

Mean Ratio gives an indication of the degree of bias between the EMA/MGB AEPD estimate and the AEPD estimate determined by using the AEPD-estimation method;

n is described in equation 2;

$Q_{AEPD\text{-}estimation\ method}$ is described in equation 2; and

$Q_{EMA/MGB}$ is described in equation 2.

The mean ratio provides an indication of systematic overestimation or underestimation of an AEPD-estimation method, where a value of 1 indicates a good average agreement between the $Q_{AEPD\text{-}estimation\ method}$ and $Q_{EMA/MGB.}$ A mean ratio value in the range of 0.5 to 2 may be regarded as an acceptable estimate, a value less than 0.5 may be regarded as a large underestimation and a value greater than 2.0 may be regarded as a large overestimation. The values are only arbitrary limits and would provide a reasonable guide about the relative accuracy of the AEPD-estimation methods regarding their practical use (Haddad and others, 2012). In applying these evaluation metrics to compare AEPD-estimation methods, factors such as data error (measurement error and error because of rating-curve extrapolation) and error because of EMA/MGB analysis were not considered.

Different datasets were compared and evaluated for this study for streamgages within the two sizes of drainage areas (1) 5 datasets were compared and evaluated for streamgages with drainage areas less than 2 mi^2 (tables 12 and 13), and (2) 8 datasets were compared and evaluated for streamgages with drainage areas between 2 and 20 mi^2 (tables 14 and 15). Datasets were compiled for 6 general types of comparisons for each size of drainage areas if at least 10 streamgages were available to form a dataset:

1. For all streamgages statewide.
2. For all streamgages statewide with more than 22 years of systematic annual peaks that were included in the EMA/MGB analysis.
3. For all streamgages statewide with annual peak-discharge records through the 2012 or 2013 water year.
4. For all streamgages statewide with more than 22 years of systematic annual peaks that were included in the EMA/MGB analysis and with annual peak-discharge records through the 2012 or 2013 water year.
5. For streamgages within the flood region areas (fig. 1) defined for Iowa (Eash and others, 2013).
6. For streamgages within the landform regions (fig. 2) defined for Iowa (Prior, 1991; Prior and others, 2009).

The number of streamgages evaluated for each dataset comparison (tables 12–15) is noted with "*n*." Values of *n* in the dataset comparisons range from 10 to 55. Information in these tables needs to be used with caution because comparisons for datasets with small values of "*n*" provide limited information on the accuracy of the AEPD estimates for different AEPD-estimation methods.

The AEPD-estimation methods that provide results for the best overall accuracy (tables 12 and 14) and the least overall bias (tables 13 and 15) are highlighted to compare the 13 datasets:

1. Tables 12 and 14 show the lowest MPRE values (highlighted in gold) and show MPRE values that are within a magnitude of 5 percent of the lowest MPRE value (highlighted in yellow) for each AEP to indicate the AEPD-estimation method with the best overall accuracy when compared to the EMA/MGB AEPD.
2. Tables 13 and 15 show mean ratio values that are the closest value to 1.0 (highlighted in gold) and show mean ratio values with an absolute value difference from 1.0 that is determined by adding 0.05 to the absolute value difference between the closest value and 1.0 (highlighted in yellow) for each AEP to indicate the AEPD-estimation method with the least overall bias when compared to the EMA/MGB AEPD. For example, if the closest value to 1.0 is 1.12 (value highlighted in gold), which has an absolute value difference from 1.0 of 0.12, then adding 0.05 to 0.12 equals 0.17; thus mean ratio values within a range from 0.83 to 1.17 are highlighted in yellow.

The 5-percent threshold for MPRE, and the 0.05 threshold for mean ratio, are arbitrary and are used to indicate other AEPD-estimation methods that also are considered to provide reasonable accuracy or less bias. Three AEPDs (4, 2, and 1 percent) were specifically selected by the Iowa DOT for comparison because these AEPDs are used most frequently by Iowa DOT for flood estimation (bold red text in tables 12–15).

Drainage Basins with Areas less than 2 Square Miles

Comparisons of estimates of AEPDs for drainage basins with areas less than 2 mi^2 are listed in tables 12 and 13 for 25 streamgages in Iowa (figs. 1–3). All 25 of these streamgages are CSGs (table 1).

Evaluation of Comparisons of Estimates for Selected Annual Exceedance-Probability Discharges of 4, 2, and 1 percent

Three AEPDs of 4, 2, and 1 percent were specifically selected because these AEPDs are used most frequently by Iowa DOT for flood estimation (as noted with bold red text in tables 12 and 13).

On the basis of the mean ratio results for all 25 streamgages for AEPs of 4, 2, and 1 percent (first comparison in table 13):

1. The 2013 multi- and single-variable RREs tend to overestimate AEPDs with mean ratios of 1.34 to 1.36, and 1.45 to 1.56, respectively.
2. The 1987 single-variable RREs tend to overestimate AEPDs with mean ratios of 1.11 to 1.12.
3. The TR-55 method tends to overestimate AEPDs with mean ratios of 1.09 to 1.11.
4. The Iowa Runoff Chart method tends to underestimate AEPDs with mean ratios of 0.73 to 0.74.

Results of the four statewide comparisons for MPRE and mean ratio (first four comparisons in tables 12 and 13) indicate that the TR-55 method provides the best overall accuracy and that the TR-55 method and the 1987 single-variable RREs provide the least bias of the five AEPD-estimation methods evaluated.

Flood region 2 (last comparison in tables 12 and 13) is the only flood region or landform region dataset with at least 10 streamgages in which data could be compiled for comparisons. Results for flood region 2 for MPRE and mean ratio indicate that the 1987 single-variable RREs and the TR-55 method seem to provide the best overall accuracy and the least bias.

The best overall accuracy and the least overall bias for AEPD estimation for ungaged drainage basins in Iowa with areas less than 2 mi^2 may be achieved for AEPDs of 4, 2, and 1 percent:

1. Use of the TR-55 method for sites in flood regions 1 and 3 (fig. 1).
2. Use of the 1987 single-variable RREs for sites in flood region 2 (fig. 1).

In the Des Moines Lobe landform region (fig. 2), the 1987 single-variable RREs are not applicable for drainage

Table 12. Comparisons of mean percent relative errors for estimates of annual exceedance-probability discharge for drainage basins with areas less than 2 square miles, Iowa.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; MPRE–EMA/MGB[5]; IRC[6]. Cells highlighted in gold indicate the lowest MPRE value for each AEP and cells highlighted in yellow indicate a value that is within a magnitude of 5 percent of the lowest MPRE value]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
MPRE-EMA/MGB for all streamgages statewide (%)									
MRRE2013	66.0	42.9	41.0	46.5	49.8	53.5	65.5	62.5	25
SRRE2013	61.7	50.4	53.2	62.8	70.6	79.1	86.4	94.6	25
SRRE1987	75.0	45.7	41.3	41.8	44.0	46.7	ND	ND	25
TR-55	100.9	40.5	31.6	31.4	34.5	38.9	42.2	47.4	25
IRC	ND	36.8	33.1	40.1	42.8	45.3	ND	ND	25
MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis (%)									
MRRE2013	77.3	46.5	43.1	45.4	46.9	49.5	59.9	56.1	17
SRRE2013	72.2	55.6	57.1	65.1	72.1	80.3	87.5	95.2	17
SRRE1987	81.2	45.5	40.6	40.3	42.1	44.5	ND	ND	17
TR-55	111.6	44.0	32.8	31.1	31.9	34.8	36.6	40.0	17
IRC	ND	34.9	31.8	39.6	40.6	41.4	ND	ND	17
MPRE-EMA/MGB for all streamgages statewide with annual peak-discharge records through the 2012 or 2013 water year (%)									
MRRE2013	69.5	41.3	39.0	46.3	51.9	58.1	72.5	72.0	17
SRRE2013	62.3	50.4	55.2	69.0	79.9	92.0	102.8	115.2	17
SRRE1987	73.1	47.5	46.0	49.8	54.4	59.4	ND	ND	17
TR-55	103.0	38.8	31.7	35.3	40.9	48.0	53.5	61.4	17
IRC	ND	38.6	35.5	43.9	47.3	50.6	ND	ND	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year (%)									
MRRE2013	82.8	44.0	40.7	44.4	47.8	52.5	63.9	62.8	12
SRRE2013	76.7	56.8	60.9	72.5	81.5	92.7	103.0	114.1	12
SRRE1987	92.4	50.5	46.0	46.7	49.1	52.7	ND	ND	12
TR-55	120.9	40.2	29.6	31.1	34.3	39.8	43.6	49.3	12
IRC	ND	36.8	34.1	43.1	44.9	46.5	ND	ND	12
MPRE-EMA/MGB for streamgages within flood region 2 (fig. 1) (%)									
MRRE2013	80.2	52.7	49.8	57.6	60.9	64.9	82.5	76.4	16
SRRE2013	71.1	55.6	55.4	63.7	71.2	80.3	88.3	97.5	16
SRRE1987	81.7	41.2	32.1	29.7	30.9	33.6	ND	ND	16
TR-55	98.6	41.3	31.6	32.8	35.6	40.3	43.6	49.5	16
IRC	ND	33.6	30.7	37.0	38.7	40.7	ND	ND	16

[1] StreamStats 2013 multivariable RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean percent relative error (MPRE) between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

[6] Iowa Runoff Chart (IRC) method (Iowa Department of Transportation, 2014b).

Table 13. Comparisons of mean ratios for estimates of annual exceedance-probability discharge for drainage basins with areas less than 2 square miles, Iowa.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; mean-ratio EMA/MGB[5]; IRC[6]. Cells highlighted in gold indicate the mean ratio value closest to 1.0 for each AEP and cells highlighted in yellow indicate values within an absolute value difference from 1.0 that is determined by adding 0.05 to the absolute value difference between the closest value (cell highlighted in gold) and 1.0. For example, if the closest value to 1.0 is 1.12 (cell highlighted in gold), which has an absolute value difference from 1.0 of 0.12, then adding 0.05 to 0.12 equals 0.17; thus mean ratio values within a range from 0.83 to 1.17 are highlighted in yellow]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
	Mean-ratio EMA/MGB for all streamgages statewide								
MRRE2013	1.47	1.30	1.31	1.36	1.35	1.34	1.45	1.36	25
SRRE2013	1.33	1.31	1.37	1.45	1.51	1.56	1.61	1.66	25
SRRE1987	1.54	1.20	1.13	1.11	1.11	1.12	ND	ND	25
TR-55	1.89	1.23	1.12	1.09	1.09	1.11	1.13	1.17	25
IRC	ND	1.04	0.95	0.74	0.73	0.73	ND	ND	25
	Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis								
MRRE2013	1.61	1.37	1.35	1.37	1.33	1.31	1.40	1.30	17
SRRE2013	1.51	1.45	1.50	1.56	1.61	1.66	1.70	1.74	17
SRRE1987	1.60	1.21	1.12	1.09	1.08	1.09	ND	ND	17
TR-55	1.99	1.25	1.13	1.08	1.08	1.09	1.11	1.14	17
IRC	ND	1.02	0.93	0.71	0.70	0.69	ND	ND	17
	Mean-ratio EMA/MGB for all streamgages statewide with annual peak-discharge records through the 2012 or 2013 water year								
MRRE2013	1.48	1.28	1.29	1.35	1.35	1.36	1.49	1.42	17
SRRE2013	1.35	1.32	1.40	1.51	1.60	1.68	1.75	1.84	17
SRRE1987	1.45	1.13	1.09	1.10	1.12	1.15	ND	ND	17
TR-55	1.90	1.22	1.12	1.11	1.13	1.17	1.21	1.27	17
IRC	ND	1.00	0.94	0.74	0.75	0.76	ND	ND	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
	Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year								
MRRE2013	1.69	1.37	1.34	1.36	1.33	1.31	1.41	1.32	12
SRRE2013	1.58	1.46	1.52	1.60	1.67	1.74	1.80	1.86	12
SRRE1987	1.66	1.20	1.11	1.09	1.10	1.11	ND	ND	12
TR-55	2.10	1.27	1.14	1.09	1.10	1.12	1.14	1.18	12
IRC	ND	1.00	0.90	0.69	0.69	0.68	ND	ND	12
	Mean-ratio EMA/MGB for streamgages within flood region 2 (fig. 1)								
MRRE2013	1.54	1.37	1.43	1.53	1.53	1.52	1.70	1.59	16
SRRE2013	1.39	1.40	1.49	1.59	1.66	1.72	1.78	1.85	16
SRRE1987	1.59	1.23	1.16	1.14	1.14	1.16	ND	ND	16
TR-55	1.84	1.24	1.15	1.12	1.13	1.16	1.19	1.23	16
IRC	ND	1.00	0.95	0.75	0.76	0.77	ND	ND	16

[1] StreamStats 2013 multivariable RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean ratio between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

[6] Iowa Runoff Chart (IRC) method (Iowa Department of Transportation, 2014b).

Table 14. Comparisons of mean percent relative errors for estimates of annual exceedance-probability discharge for drainage basins with areas between 2 and 20 square miles, Iowa.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; MPRE–EMA/MGB[5]. Cells highlighted in gold indicate the lowest MPRE value for each AEP and cells highlighted in yellow indicate a value that is within a magnitude of 5 percent of the lowest MPRE value]

Flood-estimation method	Annual exceedance probability								
	50%	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**	***n***
MPRE-EMA/MGB for all streamgages statewide (%)									
MRRE2013	73.1	41.0	35.9	37.2	39.6	42.8	48.7	51.3	55
SRRE2013	69.1	39.4	33.7	35.7	39.0	42.8	46.9	51.8	55
SRRE1987	82.2	41.6	35.4	35.0	37.2	40.8	ND	ND	55
TR-55	110.0	55.8	50.2	52.0	55.7	60.7	65.9	73.0	51
MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis (%)									
MRRE2013	80.4	42.0	34.3	33.1	35.3	37.8	41.3	44.0	41
SRRE2013	78.0	42.6	34.2	34.1	36.4	38.8	42.0	45.6	41
SRRE1987	94.8	45.7	36.1	32.7	33.5	35.9	ND	ND	41
TR-55	121.4	57.8	50.4	50.1	52.0	55.5	59.4	64.7	37
MPRE-EMA/MGB for all streamgages statewide with annual peak-discharge record through the 2012 or 2013 water year (%)									
MRRE2013	62.9	39.4	32.0	30.1	31.1	33.3	36.6	40.0	23
SRRE2013	61.9	36.2	28.7	29.0	31.3	33.7	36.8	40.8	23
SRRE1987	61.5	41.1	38.1	39.5	42.3	45.4	ND	ND	23
TR-55	105.3	46.7	39.8	38.5	40.7	44.8	49.6	55.6	23
MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year (%)									
MRRE2013	70.1	44.6	33.9	30.0	31.0	32.6	33.8	37.4	17
SRRE2013	71.8	42.2	32.3	29.5	30.2	31.3	33.5	36.5	17
SRRE1987	66.8	43.5	36.9	35.2	37.4	39.3	ND	ND	17
TR-55	116.7	45.9	36.7	33.0	33.4	36.3	39.8	44.0	17

Flood-estimation method	Annual exceedance probability								
	50%	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**	***n***
MPRE-EMA/MGB for streamgages within flood region 2 (fig. 1) (%)									
MRRE2013	70.8	34.3	30.6	34.6	39.0	43.7	52.2	55.1	32
SRRE2013	64.9	33.8	29.2	33.8	38.9	44.0	48.8	54.5	32
SRRE1987	79.5	36.7	31.7	32.0	34.4	38.3	ND	ND	32
TR-55	60.4	35.1	35.0	40.9	46.8	53.0	59.0	67.2	30
MPRE-EMA/MGB for streamgages within flood region 3 (fig.1) (%)									
MRRE2013	76.4	50.4	42.8	41.5	42.5	44.2	46.7	48.8	16
SRRE2013	70.4	42.1	36.1	35.5	36.9	38.6	41.2	44.5	16
SRRE1987	66.8	34.0	28.5	29.3	32.2	36.7	ND	ND	16
TR-55	131.1	52.3	41.9	38.5	38.4	41.0	44.2	48.4	16
MPRE-EMA/MGB for streamgages within the Southern Iowa Drift Plain landform region (fig. 2) (%)									
MRRE2013	51.2	37.5	37.1	44.0	48.7	53.4	63.5	65.8	29
SRRE2013	49.4	33.8	32.6	38.9	44.9	50.5	56.0	62.4	29
SRRE1987	45.5	29.3	29.7	33.5	37.2	41.3	ND	ND	29
TR-55	98.1	46.3	42.7	45.1	50.0	56.8	63.9	73.3	29
MPRE-EMA/MGB for streamgages within the Iowan Surface landform region (fig. 2) (%)									
MRRE2013	49.1	24.5	19.3	19.2	22.3	25.7	27.1	31.2	10
SRRE2013	45.6	24.8	20.4	23.3	25.4	26.9	29.1	32.0	10
SRRE1987	54.4	33.2	31.6	34.6	38.0	39.8	ND	ND	10
TR-55	62.2	32.1	31.2	35.4	37.9	39.3	40.3	42.0	10

[1] StreamStats 2013 multivariable RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean percent relative error (MPRE) between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

Table 15. Comparisons of mean ratios for estimates of annual exceedance-probability discharge for drainage basins with areas between 2 and 20 square miles, Iowa.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; mean-ratio EMA/MGB[5]. Cells highlighted in gold indicate the mean ratio value closest to 1.0 for each AEP and cells highlighted in yellow indicate values within an absolute value difference from 1.0 that is determined by adding 0.05 to the absolute value difference between the closest value (cell highlighted in gold) and 1.0. For example, if the closest value to 1.0 is 1.12 (cell highlighted in gold), which has an absolute value difference from 1.0 of 0.12, then adding 0.05 to 0.12 equals 0.17; thus mean ratio values within a range from 0.83 to 1.17 are highlighted in yellow]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
Mean-ratio EMA/MGB for all streamgages statewide									
MRRE2013	1.50	1.21	1.15	1.15	1.12	1.10	1.17	1.10	55
SRRE2013	1.39	1.14	1.09	1.06	1.06	1.05	1.05	1.05	55
SRRE1987	1.60	1.12	1.00	0.93	0.90	0.88	ND	ND	55
TR-55	1.99	1.36	1.26	1.24	1.26	1.29	1.32	1.37	51
Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis									
MRRE2013	1.58	1.19	1.10	1.07	1.03	1.00	1.04	0.97	41
SRRE2013	1.48	1.14	1.06	1.01	0.99	0.97	0.96	0.95	41
SRRE1987	1.72	1.12	0.97	0.87	0.82	0.80	ND	ND	41
TR-55	2.10	1.35	1.23	1.19	1.19	1.20	1.22	1.26	37
Mean-ratio EMA/MGB for all streamgages statewide with annual peak-discharge record through the 2012 or 2013 water year									
MRRE2013	1.30	1.13	1.06	1.05	1.02	1.00	1.04	0.98	23
SRRE2013	1.22	1.03	0.98	0.94	0.93	0.92	0.91	0.90	23
SRRE1987	1.29	1.00	0.93	0.87	0.85	0.84	ND	ND	23
TR-55	1.93	1.26	1.15	1.12	1.13	1.14	1.17	1.21	23
Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year									
MRRE2013	1.36	1.13	1.03	0.99	0.95	0.92	0.94	0.87	17
SRRE2013	1.31	1.05	0.98	0.92	0.88	0.86	0.84	0.81	17
SRRE1987	1.30	0.95	0.85	0.77	0.73	0.71	ND	ND	17
TR-55	2.00	1.22	1.09	1.02	1.01	1.01	1.02	1.04	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
Mean-ratio EMA/MGB for streamgages within flood region 2 (fig. 1)									
MRRE2013	1.39	1.07	1.08	1.13	1.12	1.11	1.23	1.14	32
SRRE2013	1.21	1.03	1.02	1.04	1.05	1.07	1.09	1.11	32
SRRE1987	1.49	1.00	0.91	0.86	0.84	0.84	ND	ND	32
TR-55	1.44	1.09	1.06	1.08	1.12	1.16	1.21	1.27	30
Mean-ratio EMA/MGB for streamgages within flood region 3 (fig. 1)									
MRRE2013	1.69	1.43	1.26	1.19	1.13	1.10	1.08	1.03	16
SRRE2013	1.63	1.27	1.15	1.05	1.00	0.95	0.92	0.88	16
SRRE1987	1.59	1.17	1.05	0.93	0.89	0.85	ND	ND	16
TR-55	2.27	1.38	1.20	1.11	1.08	1.07	1.07	1.08	16
Mean-ratio EMA/MGB for streamgages within the Southern Iowa Drift Plain landform region (fig. 2)									
MRRE2013	1.25	1.18	1.18	1.24	1.25	1.26	1.37	1.30	29
SRRE2013	1.15	1.08	1.10	1.12	1.15	1.17	1.20	1.22	29
SRRE1987	1.21	1.01	0.97	0.95	0.95	0.96	ND	ND	29
TR-55	1.87	1.33	1.26	1.26	1.29	1.34	1.38	1.45	29
Mean-ratio EMA/MGB for streamgages within the Iowan Surface landform region (fig. 2)									
MRRE2013	1.22	0.96	0.94	0.94	0.90	0.87	0.94	0.84	10
SRRE2013	1.07	0.91	0.88	0.86	0.85	0.84	0.83	0.81	10
SRRE1987	1.18	0.81	0.72	0.65	0.62	0.60	ND	ND	10
TR-55	1.45	0.93	0.85	0.81	0.80	0.81	0.81	0.82	10

---

[1] StreamStats 2013 multivariable RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean ratio between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

basins with areas less than 7.9 mi^2 in hydrologic region 4 and for areas less than 45 mi^2 in hydrologic region 5 (fig. 3).

Evaluation of Comparisons of Estimates for All Annual Exceedance-Probability Discharges

Although eight AEPs were estimated for three AEPD-estimation methods (tables 4, 8, and 10), comparisons of estimates of AEPDs are limited to six AEPs for the 1987 single-variable RREs (table 9) and to five AEPs for the Iowa Runoff Chart method (table 11). Thus, comparisons were evaluated for the different AEPD-estimation methods according to the available AEPs. First, comparisons were evaluted for five AEPs (20, 10, 4, 2, and 1 percent) for all five AEPD-estimation methods, (hereafter, these five comparisons are referred to as “AEP5”). Second, comparisons were evaluated for one AEP (50 percent) for four AEPD-estimation methods that did not include the Iowa Runoff Chart method (hereafter, these comparisons are referred to as “AEP1”). Third, comparisons were evaluated for two AEPs (0.5 and 0.2 percent) for three AEPD-estimation methods that did not include the Iowa Runoff Chart method or the 1987 single-variable RREs (hereafter, these comparisons are referred to as “AEP2”).

On the basis of the mean ratio results for all 25 streamgages for all estimates of AEPDs (first comparison in table 13):

1. The 2013 multi- and single-variable RREs tend to overestimate AEPDs with mean ratios of 1.47 and 1.33, respectively, for an AEP of 50 percent and with mean ratios of 1.36 and 1.66, respectively, for an AEP of 0.2 percent.
2. The 1987 single-variable RREs tend to overestimate AEPDs with mean ratios of 1.54 for an AEP of 50 percent and 1.12 for an AEP of 1 percent.
3. The TR-55 method tends to overestimate AEPDs with mean ratios of 1.89 for an AEP of 50 percent and 1.17 for an AEP of 0.2 percent.
4. The Iowa Runoff Chart Method tends to primarily underestimate AEPDs with mean ratios of 1.04 for an AEP of 20 percent and 0.73 for an AEP of 1 percent.

Results of the four statewide comparisons for MPRE and mean ratio (first four comparisons in tables 12 and 13), indicate that the TR-55 method provides the best overall accuracy and that the 1987 single-variable RREs and the TR-55 method provide the least bias of the five AEPD-estimation methods evaluated for the AEP5 comparisons. The Iowa Runoff Chart method seems to provide the best overall accuracy and the least bias for an AEP of 20 percent and reasonable accuracy and the least bias for an AEP of 10 percent.

For flood region 2 (fig. 1; last comparison in tables 12 and 13), which is the only flood region or landform region dataset with at least 10 streamgages in which data could be compiled for comparisons:

1. The 1987 single-variable RREs seem to provide the best overall accuracy and the third overall least bias for the AEP5 comparisons.
2. The TR-55 method seems to provide the third overall best accuracy and the second overall least bias for the AEP5 comparisons.
3. The Iowa Runoff Chart method seems to provide the second best overall accuracy and the least overall bias for the AEP5 comparisons.
4. Results for AEPs of 20 and 10 percent indicate that the Iowa Runoff Chart method provides the best accuracy and the least bias.

For the AEP1 comparisons, the 2013 single-variable RREs seem to provide the best overall accuracy and the least bias for the statewide and flood region 2 (fig.1) comparisons (tables 12 and 13). For the AEP2 comparisons, the TR-55 method seems to provide the best overall accuracy and the least bias for the statewide and flood region 2 comparisons (tables 12 and 13).

Comparison of results for AEP5, AEP1, and AEP2 seem to indicate that the best accuracy and the least bias may be achieved by the use of different AEPD-estimation methods for different AEPs. The use of different AEPD-estimation methods for different AEPs is not appropriate because this approach could lead to predictive inconsistencies. For example, a 10-percent AEPD estimate could be greater than a 4-percent AEPD estimate.

The best overall accuracy and the least overall bias for AEPD estimation for ungaged drainage basins in Iowa with areas less than 2 mi^2 may be achieved for all AEPDs:

1. Use of the TR-55 method for sites in flood regions 1 and 3 (fig. 1).
2. Use of the 1987 single-variable RREs for sites in flood region 2 (fig. 1).

In the Des Moines Lobe landform region (fig. 2), the 1987 single-variable RREs are not applicable for drainage basins with areas less than 7.9 mi^2 in hydrologic region 4 and for areas less than 45 mi^2 in hydrologic region 5 (fig. 3).

Drainage Basins with Areas Between 2 and 20 Square Miles

Comparisons of estimates of AEPDs for drainage basins with areas between 2 and 20 mi^2 are listed in tables 14 and 15 for 55 streamgages in Iowa (figs. 1–3). Forty-five of these streamgages are CSGs and 10 are continuous-record streamgages (table 1). Because *Tc* values calculated for 4 streamgages exceeded 10 hours (table 10, streamgages with map numbers 69, 70, 73, and 77), estimates of AEPDs were not calculated using the WinTR-55 model for these four streamgages; thus, data for 51 streamgages were included in the comparisons for the TR-55 method (tables 14 and 15).

Four AEPD-estimation methods were compared for drainage basins with areas between 2 and 20 mi^2. The Iowa Runoff Chart method is not applicable for drainage areas greater that 2 mi^2.

Evaluation of Comparisons of Estimates for Selected Annual Exceedance-Probability Discharges of 4, 2, and 1 percent

Three AEPDs of 4, 2, and 1 percent were specifically selected because these AEPDs are used most frequently by Iowa DOT for flood estimation (as noted with bold red text in tables 14 and 15). On the basis of the mean ratio results for all 55 streamgages for AEPs of 4, 2, and 1 percent (51 streamgages for the TR-55 method, first comparison in table 15):

1. The 2013 multi- and single-variable RREs tend to overestimate AEPDs with mean ratios of 1.10 to 1.15, and 1.05 to 1.06, respectively.
2. The 1987 single-variable RREs tend to underestimate AEPDs with mean ratios of 0.88 to 0.93.
3. The TR-55 method tends to overestimate AEPDs with mean ratios of 1.24 to 1.29.

Results of the four statewide comparisons for MPRE and mean ratio (first four comparisons in tables 14 and 15) indicate that each of the four AEPD-estimation methods may provide the best (or reasonable) accuracy, and that each of the four AEPD-estimation methods may provide the least (or reasonably low) bias dependent on the statewide dataset evaluated for AEPDs of 4, 2, and 1 percent.

For the four regional comparisons (last four comparisons in tables 14 and 15), which are the only flood region or landform region (Prior, 1991; Prior and others, 2009) datasets with at least 10 streamgages in which data could be compiled for comparions:

1. The 1987 single-variable RREs seem to provide the best overall accuracy and the least bias for the Southern Iowa Drift Plain landform region (fig. 2).
2. The 2013 multivariable RREs seem to provide the best overall accuracy and the least bias for the Iowan Surface landform region (fig. 2).
3. For flood regions 2 and 3 (fig. 1), the 1987 single-variable RREs seem to provide the best overall accuracy; the 2013 single-variable RREs seem to provide the second best accuracy and the least overall bias.

The best overall accuracy and the least overall bias for AEPD estimation for ungaged drainage basins in Iowa with areas between 2 and 20 mi^2 may be achieved for AEPDs of 4, 2, and 1 percent:

1. Use of the 1987 single-variable RREs for sites in the Southern Iowa Drift Plain landform region (fig. 2).
2. Use of the 2013 multivariable RREs for sites in the Iowan Surface landform region (fig. 2).
3. Use of the 1987 single-variable RREs may provide the best overall accuracy and use of the 2013 single-variable RREs may provide the second best overall accuracy and the least overall bias for sites in all other landform regions in Iowa.

In the Des Moines Lobe landform region, the 1987 single-variable RREs are not applicable for drainage basins with areas less than 7.9 mi^2 in hydrologic region 4 and for areas less than 45 mi^2 in hydrologic region 5 (fig. 3).

Evaluation of Comparisons of Estimates for All Annual Exceedance-Probability Discharges

Although eight AEPs were estimated for three AEPD-estimation methods (tables 4, 8, and 10), comparisons of estimates of AEPDs are limited to six AEPs for the 1987 single-variable RREs (table 9). Thus, comparisons were evaluated for the different AEPD-estimation methods according to the available AEPs. First, comparisons were evaluted for six AEPs (50, 20, 10, 4, 2, and 1 percent) for all four AEPD-estimation methods (hereafter, these four comparisons are referred to as “AEP6”). Second, comparisons were evaluated for two AEPs (0.5 and 0.2 percent) for three AEPD-estimation methods that did not include the 1987 single-variable RREs; as noted previously in this report, these comparisons are referred to as “AEP2.”

On the basis of the mean ratio results for all 55 streamgages for all estimates of AEPDs (51 streamgages for the TR-55 method, first comparison in table 15):

1. The 2013 multi- and single-variable RREs tend to overestimate AEPDs with mean ratios of 1.50 and 1.39, respectively, for an AEP of 50 percent and with mean ratios of 1.10 and 1.05, respectively, for an AEP of 0.2 percent.
2. The 1987 single-variable RREs tend to overestimate and underestimate AEPDs with mean ratios of 1.60 for an AEP of 50 percent and 0.88 for an AEP of 1 percent.
3. The TR-55 method tends to overestimate AEPDs with mean ratios of 1.99 for an AEP of 50 percent and 1.37 for an AEP of 0.2 percent.

Results of the four statewide comparisons for MPRE and mean ratio (51 streamgages for the TR-55 method, first four comparisons in tables 14 and 15), seem to indicate that each of the four AEPD-estimation methods may provide the best (or reasonable) accuracy, and that each of the four AEPD-estimation methods may provide the least (or a reasonably low) bias dependent on the statewide dataset evaluated for the AEP6 comparisons, with the exception of the TR-55 method for an AEP of 50 percent.

For the estimation of AEP6 for the four regional comparisons (last four comparisons in tables 14 and 15), which are the only flood region or landform region datasets with at least 10 streamgages in which data could be compiled for comparisons:

1. The 1987 single-variable RREs seem to provide the best overall accuracy and the least overall bias for the Southern Iowa Drift Plain landform region (fig. 2) and for flood region 3 (fig. 1).
2. The 2013 single-variable RREs also seem to provide the least overall bias for flood region 3 (fig. 1).
3. The 2013 multivariable RREs seem to provide the best overall accuracy and the least overall bias for the Iowan Surface landform region.
4. The 2013 and 1987 single-variable RREs, for flood region 2 (fig. 1), seem to provide the best accuracy; the 2013 single-variable RREs seem to provide the least overall bias.

For the AEP2 comparisons, the 2013 multi- and single-variable RREs seem to provide the best overall accuracy and the least overall bias for the statewide and regional comparisons. The TR-55 method seems to provide reasonable accuracy and a reasonably low bias for flood region 3 (fig. 1) for the AEP2 comparisons, and the least bias for streamgages statewide with more than 22 years of systematic peaks that were included in the EMA/MGB analysis and with annual peak-discharge records through the 2012 or 2013 water year.

Comparison of results for AEP6 and AEP2 seem to indicate that the best accuracy and the least bias may be achieved by the use of different AEPD-estimation methods for different AEPs. The use of different AEPD-estimation methods for different AEPs is not appropriate because this approach could lead to predictive inconsistencies. For example, a 10-percent AEPD estimate could be greater than a 4-percent AEPD estimate.

The best overall accuracy and the least overall bias for AEPD estimation for ungaged drainage basins in Iowa with areas between 2 and 20 mi^2 may be achieved for all AEPDs:

1. Use of the 1987 single-variable RREs for sites in the Southern Iowa Drift Plain landform region and in flood region 3 (figs. 1 and 2).
2. Use of the 2013 multivariable RREs for sites in the Iowan Surface landform region (fig. 2).
3. Use of the 2013 or 1987 single-variable RREs for sites in flood region 2 (fig. 1).
4. Use of the 2013 single-variable RREs may provide the best overall accuracy and the least overall bias for sites in all other landform or flood regions in Iowa.

In the Des Moines Lobe landform region, the 1987 single-variable RREs are not applicable for drainage basins with areas less than 7.9 mi^2 in hydrologic region 4 and for areas less than 45 mi^2 in hydrologic region 5 (fig. 3).

Examination of the 1987 Single-Variable Regional-Regression Equations

An in-depth examination was conducted to better understand why AEPDs estimated by the 1987 single-variable RREs seem to provide better accuracy and less bias than AEPDs estimated by the 2013 multi- or single-variable RREs for most of the comparisons for drainage areas less than 2 mi^2 (tables 12–13) and for some of the comparisons for drainage areas between 2 and 20 mi^2 (tables 14–15). The 1987 single-variable RREs were developed using annual peak-flow data collected through the 1984 water year and the 2013 multi- and single-variable RREs were developed using annual peak-flow data collected through the 2010 water year.

Use of Hydrologic Regions for the 1987 Single-Variable Regional-Regression Equations

As previously mentioned in the section, “1987 Single-Variable Regional-Regression Equations,” 12 of the 80 streamgages (15 percent) included in this study (fig. 2 and table 9; Lara, 1987) had AEPDs estimated by (1) using RREs from a different hydrologic region than the region where the streamgage is present or, (2) using a mixed landform calculation. To determine the effect on MPRE and mean ratio results from the re-assignment of 1987 single variable RREs and from the use of the mixed landform calculation, these two evaluation metrics were recalculated for data from the 12 streamgages without the re-assignments or the mixed landform calculation using only the RREs for the hydrologic region in which the streamgage is present. Tables 16–19 list the MPRE and mean ratio results for the same 13 datasets as presented in tables 12–15; the difference between datasets in the tables is that the 1987 single-variable RREs were recalculated for data from the 12 streamgages (fig. 2 and table 9):

- By using hydrologic region 2 (fig. 3) RREs for data from streamgages with map numbers 9, 36, 40, 59, and 69;
- By using hydrologic region 3 RREs for data from streamgages with map numbers 8, 10, 13, 28, 68, and 73; and
- By using hydrologic region 4 RREs for data from one streamgage with map number 3.

For drainage basins with areas less than 2 mi^2, MPRE values compared (tables 16 and 12) for the 1987 single-variable RREs show that all recalculated MPRE values for all

Table 16. Comparisons of mean percent relative errors for estimates of annual exceedance-probability discharge for drainage basins with areas less than 2 square miles that do not include the re-assignment of hydrologic regions or the use of a mixed landform calculation for the 1987 single-variable regional-regression equations.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; MPRE–EMA/MGB[5]; IRC[6]. Cells highlighted in gold indicate the lowest MPRE value for each AEP and cells highlighted in yellow indicate a value that is within a magnitude of 5 percent of the lowest MPRE value]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
	MPRE-EMA/MGB for all streamgages statewide (%)								
MRRE2013	66.0	42.9	41.0	46.5	49.8	53.5	65.5	62.5	25
SRRE2013	61.7	50.4	53.2	62.8	70.6	79.1	86.4	94.6	25
SRRE1987	64.6	39.0	35.4	38.1	41.4	44.6	ND	ND	25
TR-55	100.9	40.5	31.6	31.4	34.5	38.9	42.2	47.4	25
IRC	ND	36.8	33.1	40.1	42.8	45.3	ND	ND	25
	MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis (%)								
MRRE2013	77.3	46.5	43.1	45.4	46.9	49.5	59.9	56.1	17
SRRE2013	72.2	55.6	57.1	65.1	72.1	80.3	87.5	95.2	17
SRRE1987	62.8	34.1	31.0	34.6	38.2	41.5	ND	ND	17
TR-55	111.6	44.0	32.8	31.1	31.9	34.8	36.6	40.0	17
IRC	ND	34.9	31.8	39.6	40.6	41.4	ND	ND	17
	MPRE-EMA/MGB for all streamgages statewide with annual peak-discharge records through the 2012 or 2013 water year (%)								
MRRE2013	69.5	41.3	39.0	46.3	51.9	58.1	72.5	72.0	17
SRRE2013	62.3	50.4	55.2	69.0	79.9	92.0	102.8	115.2	17
SRRE1987	54.4	33.7	33.4	40.5	46.4	52.1	ND	ND	17
TR-55	103.0	38.8	31.7	35.3	40.9	48.0	53.5	61.4	17
IRC	ND	38.6	35.5	43.9	47.3	50.6	ND	ND	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
	MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year (%)								
MRRE2013	82.8	44.0	40.7	44.4	47.8	52.5	63.9	62.8	12
SRRE2013	76.7	56.8	60.9	72.5	81.5	92.7	103.0	114.1	12
SRRE1987	66.3	34.4	32.5	38.7	43.6	48.4	ND	ND	12
TR-55	120.9	40.2	29.6	31.1	34.3	39.8	43.6	49.3	12
IRC	ND	36.8	34.1	43.1	44.9	46.5	ND	ND	12
	MPRE-EMA/MGB for streamgages within flood region 2 (fig. 1) (%)								
MRRE2013	80.2	52.7	49.8	57.6	60.9	64.9	82.5	76.4	16
SRRE2013	71.1	55.6	55.4	63.7	71.2	80.3	88.3	97.5	16
SRRE1987	62.4	29.1	22.3	24.5	28.0	32.3	ND	ND	16
TR-55	98.6	41.3	31.6	32.8	35.6	40.3	43.6	49.5	16
IRC	ND	33.6	30.7	37.0	38.7	40.7	ND	ND	16

[1] StreamStats 2013 multivariate RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean percent relative error (MPRE) between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

[6] Iowa Runoff Chart (IRC) method (Iowa Department of Transportation, 2014b).

Table 17. Comparisons of mean ratios for estimates of annual exceedance-probability discharge for drainage basins with areas less than 2 square miles that do not include the re-assignment of hydrologic regions or the use of a mixed landform calculation for the 1987 single-variable regional-regression equations.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; mean-ratio EMA/MGB[5]; IRC[6]. Cells highlighted in gold indicate the mean ratio value closest to 1.0 for each AEP and cells highlighted in yellow indicate values within an absolute value difference from 1.0 that is determined by adding 0.05 to the absolute value difference between the closest value (cell highlighted in gold) and 1.0. For example, if the closest value to 1.0 is 1.12 (cell highlighted in gold), which has an absolute value difference from 1.0 of 0.12, then adding 0.05 to 0.12 equals 0.17; thus mean ratio values within a range from 0.83 to 1.17 are highlighted in yellow]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
Mean-ratio EMA/MGB for all streamgages statewide									
MRRE2013	1.47	1.30	1.31	1.36	1.35	1.34	1.45	1.36	25
SRRE2013	1.33	1.31	1.37	1.45	1.51	1.56	1.61	1.66	25
SRRE1987	1.58	1.14	1.04	0.99	0.96	0.96	ND	ND	25
TR-55	1.89	1.23	1.12	1.09	1.09	1.11	1.13	1.17	25
IRC	ND	1.04	0.95	0.74	0.73	0.73	ND	ND	25
Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis									
MRRE2013	1.61	1.37	1.35	1.37	1.33	1.31	1.40	1.30	17
SRRE2013	1.51	1.45	1.50	1.56	1.61	1.66	1.70	1.74	17
SRRE1987	1.41	1.09	1.03	1.00	0.99	1.00	ND	ND	17
TR-55	1.99	1.25	1.13	1.08	1.08	1.09	1.11	1.14	17
IRC	ND	1.02	0.93	0.71	0.70	0.69	ND	ND	17
Mean-ratio EMA/MGB for all streamgages statewide with annual peak-discharge records through the 2012 or 2013 water year									
MRRE2013	1.48	1.28	1.29	1.35	1.35	1.36	1.49	1.42	17
SRRE2013	1.35	1.32	1.40	1.51	1.60	1.68	1.75	1.84	17
SRRE1987	1.21	0.97	0.93	0.95	0.96	0.99	ND	ND	17
TR-55	1.90	1.22	1.12	1.11	1.13	1.17	1.21	1.27	17
IRC	ND	1.00	0.94	0.74	0.75	0.76	ND	ND	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year									
MRRE2013	1.69	1.37	1.34	1.36	1.33	1.31	1.41	1.32	12
SRRE2013	1.58	1.46	1.52	1.60	1.67	1.74	1.80	1.86	12
SRRE1987	1.40	1.04	0.98	0.97	0.97	0.98	ND	ND	12
TR-55	2.10	1.27	1.14	1.09	1.10	1.12	1.14	1.18	12
IRC	ND	1.00	0.90	0.69	0.69	0.68	ND	ND	12
Mean-ratio EMA/MGB for streamgages within flood region 2 (fig. 1)									
MRRE2013	1.54	1.37	1.43	1.53	1.53	1.52	1.70	1.59	16
SRRE2013	1.39	1.40	1.49	1.59	1.66	1.72	1.78	1.85	16
SRRE1987	1.35	1.07	1.03	1.03	1.04	1.06	ND	ND	16
TR-55	1.84	1.24	1.15	1.12	1.13	1.16	1.19	1.23	16
IRC	ND	1.00	0.95	0.75	0.76	0.77	ND	ND	16

[1] StreamStats 2013 multivariate RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean ratio between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

[6] Iowa Runoff Chart (IRC) method (Iowa Department of Transportation, 2014b).

Table 18. Comparisons of mean percent relative errors for estimates of annual exceedance-probability discharge for drainage basins with areas between 2 and 20 square miles that do not include the re-assignment of hydrologic regions or the use of a mixed landform calculation for the 1987 single-variable regional-regression equations.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; MPRE–EMA/MGB[5]. Cells highlighted in gold indicate the lowest MPRE value for each AEP and cells highlighted in yellow indicate a value that is within a magnitude of 5 percent of the lowest MPRE value]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
	MPRE-EMA/MGB for all streamgages statewide (%)								
MRRE2013	73.1	41.0	35.9	37.2	39.6	42.8	48.7	51.3	55
SRRE2013	69.1	39.4	33.7	35.7	39.0	42.8	46.9	51.8	55
SRRE1987	74.5	40.2	35.4	37.7	40.9	44.2	ND	ND	55
TR-55	110.0	55.8	50.2	52.0	55.7	60.7	65.9	73.0	51
	MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis (%)								
MRRE2013	80.4	42.0	34.3	33.1	35.3	37.8	41.3	44.0	41
SRRE2013	78.0	42.6	34.2	34.1	36.4	38.8	42.0	45.6	41
SRRE1987	85.2	44.1	36.2	36.0	37.8	39.7	ND	ND	41
TR-55	121.4	57.8	50.4	50.1	52.0	55.5	59.4	64.7	37
	MPRE-EMA/MGB for all streamgages statewide with annual peak-discharge record through the 2012 or 2013 water year (%)								
MRRE2013	62.9	39.4	32.0	30.1	31.1	33.3	36.6	40.0	23
SRRE2013	61.9	36.2	28.7	29.0	31.3	33.7	36.8	40.8	23
SRRE1987	63.2	43.2	40.3	41.5	44.6	47.7	ND	ND	23
TR-55	105.3	46.7	39.8	38.5	40.7	44.8	49.6	55.6	23
	MPRE-EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year (%)								
MRRE2013	70.1	44.6	33.9	30.0	31.0	32.6	33.8	37.4	17
SRRE2013	71.8	42.2	32.3	29.5	30.2	31.3	33.5	36.5	17
SRRE1987	69.1	46.2	39.8	38.0	40.4	42.4	ND	ND	17
TR-55	116.7	45.9	36.7	33.0	33.4	36.3	39.8	44.0	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
	MPRE-EMA/MGB for streamgages within flood region 2 (fig. 1) (%)								
MRRE2013	70.8	34.3	30.6	34.6	39.0	43.7	52.2	55.1	32
SRRE2013	64.9	33.8	29.2	33.8	38.9	44.0	48.8	54.5	32
SRRE1987	67.5	33.3	30.3	34.7	38.2	41.4	ND	ND	32
TR-55	60.4	35.1	35.0	40.9	46.8	53.0	59.0	67.2	30
	MPRE-EMA/MGB for streamgages within flood region 3 (fig. 1) (%)								
MRRE2013	76.4	50.4	42.8	41.5	42.5	44.2	46.7	48.8	16
SRRE2013	70.4	42.1	36.1	35.5	36.9	38.6	41.2	44.5	16
SRRE1987	64.1	35.9	31.5	33.0	37.4	42.0	ND	ND	16
TR-55	131.1	52.3	41.9	38.5	38.4	41.0	44.2	48.4	16
	MPRE-EMA/MGB for streamgages within the Southern Iowa Drift Plain landform region (fig. 2) (%)								
MRRE2013	51.2	37.5	37.1	44.0	48.7	53.4	63.5	65.8	29
SRRE2013	49.4	33.8	32.6	38.9	44.9	50.5	56.0	62.4	29
SRRE1987	44.2	30.2	31.1	35.3	39.6	43.8	ND	ND	29
TR-55	98.1	46.3	42.7	45.1	50.0	56.8	63.9	73.3	29
	MPRE-EMA/MGB for streamgages within the Iowan Surface landform region (fig. 2) (%)								
MRRE2013	49.1	24.5	19.3	19.2	22.3	25.7	27.1	31.2	10
SRRE2013	45.6	24.8	20.4	23.3	25.4	26.9	29.1	32.0	10
SRRE1987	54.4	33.2	31.6	34.6	38.0	39.8	ND	ND	10
TR-55	62.2	32.1	31.2	35.4	37.9	39.3	40.3	42.0	10

[1] StreamStats 2013 multivariable RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean percent relative error (MPRE) between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

Table 19. Comparisons of mean ratios for estimates of annual exceedance-probability discharge for drainage basins with areas between 2 and 20 square miles that do not include the re-assignment of hydrologic regions or the use of a mixed landform calculation for the 1987 single-variable regional-regression equations.

[Annual exceedance probabilities (AEPs) of 4, 2, and 1 percent specifically selected by the Iowa Department of Transportation for comparison are noted with bold red text; water year, is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which the water year ends and includes 9 of the 12 months of that year; %, percent; *n*, number of streamgages included in comparison mean; MRRE2013[1]; SRRE2013[2]; SRRE1987[3]; ND, not determined; TR-55[4]; mean-ratio EMA/MGB[5]. Cells highlighted in gold indicate the mean ratio value closest to 1.0 for each AEP and cells highlighted in yellow indicate values within an absolute value difference from 1.0 that is determined by adding 0.05 to the absolute value difference between the closest value (cell highlighted in gold) and 1.0. For example, if the closest value to 1.0 is 1.12 (cell highlighted in gold), which has an absolute value difference from 1.0 of 0.12, then adding 0.05 to 0.12 equals 0.17; thus mean ratio values within a range from 0.83 to 1.17 are highlighted in yellow]

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
Mean-ratio EMA/MGB for all streamgages statewide									
MRRE2013	1.50	1.21	1.15	1.15	1.12	1.10	1.17	1.10	55
SRRE2013	1.39	1.14	1.09	1.06	1.06	1.05	1.05	1.05	55
SRRE1987	1.51	1.07	0.97	0.91	0.87	0.86	ND	ND	55
TR-55	1.99	1.36	1.26	1.24	1.26	1.29	1.32	1.37	51
Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis									
MRRE2013	1.58	1.19	1.10	1.07	1.03	1.00	1.04	0.97	41
SRRE2013	1.48	1.14	1.06	1.01	0.99	0.97	0.96	0.95	41
SRRE1987	1.61	1.07	0.94	0.85	0.80	0.77	ND	ND	41
TR-55	2.10	1.35	1.23	1.19	1.19	1.20	1.22	1.26	37
Mean-ratio EMA/MGB for all streamgages statewide with annual peak-discharge record through the 2012 or 2013 water year									
MRRE2013	1.30	1.13	1.06	1.05	1.02	1.00	1.04	0.98	23
SRRE2013	1.22	1.03	0.98	0.94	0.93	0.92	0.91	0.90	23
SRRE1987	1.27	0.98	0.91	0.85	0.83	0.82	ND	ND	23
TR-55	1.93	1.26	1.15	1.12	1.13	1.14	1.17	1.21	23
Mean-ratio EMA/MGB for all streamgages statewide with more than 22 years of systematic peaks included in the EMA/MGB analysis and with annual peak-discharge record through the 2012 or 2013 water year									
MRRE2013	1.36	1.13	1.03	0.99	0.95	0.92	0.94	0.87	17
SRRE2013	1.31	1.05	0.98	0.92	0.88	0.86	0.84	0.81	17
SRRE1987	1.28	0.93	0.82	0.74	0.70	0.68	ND	ND	17
TR-55	2.00	1.22	1.09	1.02	1.01	1.01	1.02	1.04	17

Flood-estimation method	Annual exceedance probability								
	50%	20%	10%	**4%**	**2%**	**1%**	0.5%	0.2%	*n*
Mean-ratio EMA/MGB for streamgages within flood region 2 (fig. 1)									
MRRE2013	1.39	1.07	1.08	1.13	1.12	1.11	1.23	1.14	32
SRRE2013	1.21	1.03	1.02	1.04	1.05	1.07	1.09	1.11	32
SRRE1987	1.35	0.95	0.88	0.84	0.83	0.83	ND	ND	32
TR-55	1.44	1.09	1.06	1.08	1.12	1.16	1.21	1.27	30
Mean-ratio EMA/MGB for streamgages within flood region 3 (fig. 1)									
MRRE2013	1.69	1.43	1.26	1.19	1.13	1.10	1.08	1.03	16
SRRE2013	1.63	1.27	1.15	1.05	1.00	0.95	0.92	0.88	16
SRRE1987	1.55	1.12	1.00	0.89	0.83	0.80	ND	ND	16
TR-55	2.27	1.38	1.20	1.11	1.08	1.07	1.07	1.08	16
Mean-ratio EMA/MGB for streamgages within the Southern Iowa Drift Plain landform region (fig. 2)									
MRRE2013	1.25	1.18	1.18	1.24	1.25	1.26	1.37	1.30	29
SRRE2013	1.15	1.08	1.10	1.12	1.15	1.17	1.20	1.22	29
SRRE1987	1.19	0.99	0.95	0.93	0.92	0.93	ND	ND	29
TR-55	1.87	1.33	1.26	1.26	1.29	1.34	1.38	1.45	29
Mean-ratio EMA/MGB for streamgages within the Iowan Surface landform region (fig. 2)									
MRRE2013	1.22	0.96	0.94	0.94	0.90	0.87	0.94	0.84	10
SRRE2013	1.07	0.91	0.88	0.86	0.85	0.84	0.83	0.81	10
SRRE1987	1.18	0.81	0.72	0.65	0.62	0.60	ND	ND	10
TR-55	1.45	0.93	0.85	0.81	0.80	0.81	0.81	0.82	10

[1] StreamStats 2013 multivariable RREs method (tables 9–11 in Eash and others, 2013).

[2] 2013 single-variable RREs method (table 15 in Eash and others, 2013).

[3] 1987 single-variable RREs (table 2 in Lara, 1987).

[4] TR-55 rainfall-runoff model (Natural Resources Conservation Service, 2009).

[5] Mean ratio between flood-estimation method estimates and expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB) estimates (Cohn and others, 1997, 2001, 2013; Eash and others, 2013).

AEPs for all five comparisons are lower. These comparisons indicate better overall accuracy without the re-assignments of 1987 single-variable RREs and the use of the mixed landform calculation for the 12 streamgages. Lower MPRE values for most AEPs of 50, 20, and 10 percent (table 16) indicate that the 1987 single-variable RREs provide better accuracy when compared to the MPRE values listed in table 12 from the 2013 single-variable RREs or from the Iowa Runoff Chart method, except for the first statewide dataset of all 25 streamgages. Mean ratio values compared (tables 17 and 13) for the 1987 single-variable RREs show that mean ratio values are closer to 1.0 for all AEPs for all five comparisons listed in table 17 indicating less overall bias, except for AEPs of 50 percent in the first statewide dataset of 25 streamgages. Mean ratio values listed in table 17 indicate the 1987 single-variable RREs have less bias when compared to the TR-55 method for AEPs of 4, 2, and 1 percent. For drainage basins with areas less than 2 mi^2, overall results (tables 16 and 17) seem to indicate better accuracy and less bias for the 1987 single-variable RREs when the 12 streamgages are not re-assigned to different hydrologic regions and when the mixed landform calculation is not applied.

For drainage basins with areas between 2 and 20 mi^2, MPRE values compared (tables 18 and 14) for the 1987 single-variable RREs show that most of the recalculated MPRE values increased for the eight comparisons, except for some AEPs of 50, 20, and 10 percent for which MPRE values decreased for some of the comparisons. In general, MPRE values in table 18 seem to indicate the 1987 single-variable RREs have less accuracy without the re-assignment of the 12 streamgages and without the use of the mixed landform calculation. Because none of the 12 streamgages with re-assigned 1987 single-variable RREs and with drainage areas between 2 and 20 mi^2 are located in the Iowan Surface landform region (fig. 2), MPRE and mean ratio values (tables 18 and 19) for the Iowan Surface landform region are the same as those listed in tables 14 and 15. Overall MPRE results in table 18 are similar to those in table 14, except that estimates from the 2013 multi- and single-variable RREs indicated better accuracy for AEPs of 4, 2, and 1 percent for the first two statewide datasets when compared to estimates from the 1987 single-variable RREs. Mean ratio values compared (tables 19 and 15) for the 1987 single-variable RREs show that most of the mean ratio values are numerically farther from 1.0 for the eight comparisons, except for some AEPs of 50, 20, and 10 percent for which mean ratio values are closer to 1.0 for some of the comparisons. In general, mean ratio values in table 19 seem to indicate the 1987 single-variable RREs have more bias without the re-assignment of the 12 streamgages and without the use of the mixed landform calculation. Overall mean ratio results in table 19 are similar to those in table 15. For drainage basins with areas between 2 and 20 mi^2, overall results (tables 18 and 19) seem to indicate less accuracy and more bias for the 1987 single-variable RREs when the 12 streamgages are not re-assigned to different hydrologic regions and when the mixed landform calculation is not used.

This examination of the re-assignment of the 1987 single-variable RREs and the use of the mixed landform calculation for 12 streamgages indicates different results for the two sizes of drainage areas that were evaluated. The re-assignment of the 1987 single-variable RREs and use of the mixed landform calculation seem to have had no substantial effect regarding the relative accuracy and bias of estimates of AEPDs when comparing the 2013 multi- and single-variable RREs to the 1987 single-variable RREs for drainage basins with areas less than 2 mi^2, except for AEPs of 50 percent. For drainage basins with areas between 2 and 20 mi^2, the re-assignment of the 1987 single-variable RREs and use of the mixed landform calculation also seem to have had no substantial effect regarding the relative accuracy and bias of estimates of AEPDs when comparing the 2013 multi- and single-variable RREs to the 1987 single-variable RREs. The MPRE results from the first two statewide datasets (table 18) indicate better accuracy for estimates from the 2013 multi- and single-variable RREs for AEPs of 4, 2, and 1 percent, when compared to estimates from the 1987 single-variable RREs that do not include re-assignment and or the use of the mixed landform calculation.

The re-assignment of 1987 single-variable RREs to a different hydrologic region than the region where the streamgage is present may be a subjective re-assignment for ungaged sites if users do not use a quantitative method similar to the one used in this study. In this study, mean, median, minimum, and maximum basin-characteristic values were calculated for data from streamgages within each hydrologic region for four selected basin characteristics (BSLDEM10M, CSL1085LFP, CSL100, and SLOP30). Basin-characteristic values measured for streamgages, that represent ungaged sites, were then compared to the mean, median, minimum, and maximum regional values to quantitatively re-assign 1987 single-variable RREs.

Comparison of Annual Exceedance-Probability Discharges Estimated by Using the Expected Moments Algorithm/Multiple Grubbs-Beck Test Analysis Method, Based on Data through Water Years 2013 and 2010

A comparison of estimates from the EMA/MGB AEP method calculated through the 2013 water year (table 3) to those calculated through the 2010 water year (table 4 in Eash and others, 2013) was performed to determine if 2013 estimates have generally increased or decreased when compared to 2010 estimates. Because estimates from the 2013 multi- and single-variable RREs are generally greater than estimates from the 1987 single-variable RREs (tables 13 and 15), an overall decrease in 2013 EMA/MGB estimates when compared to 2010 EMA/MGB estimates could indicate why the estimates from the 1987 single-variable RREs seem to provide better accuracy and less bias for some comparisons (tables 12–15). For an AEP of 1 percent, 2013 estimates have increased for 41 streamgages, have decreased for 33 streamgages, and have remained the same for 6 streamgages (table 3). For an AEP of 10 percent, 2013 estimates have increased for 36 streamgages, have decreased for 37 streamgages, and have remained the same for 7 streamgages. Overall, increases and decreases (from 2013 EMA/MGB estimates) seem to be about the same when compared to 2010 EMA/MGB estimates.

Comparisons of Regional-Regression Lines for 1-Percent Annual Exceedance-Probability Discharges

The 1-percent AEPD regression lines for hydrologic regions 1–4 (fig. 3) from the 1987 single-variable RREs and for flood regions 1–3 (fig. 1) from the 2013 single-variable RREs (tables 5–7 in this report; Eash and others, 2013) are shown in figure 4. The regression lines are displayed from the minimum drainage area size applicable for each RRE to 20 mi^2. A regression line is not displayed for hydrologic region 5 because the minimum drainage area size applicable for this RRE is 45 mi^2 (Lara, 1987). Hydrologic regions 4 and 5 (fig. 3) and flood region 1 (fig. 1) are nearly identical areas corresponding to the Des Moines Lobe landform region (fig. 2). Because a dataset with at least 10 streamgages could not be compiled for comparisons of AEPDs representing the Des Moines Lobe landform region for either size of drainage areas, direct comparisons of the two evaluation metrics for the Des Moines Lobe landform region are not available for this study. The four statewide comparison datasets listed in tables 12–19 may provide an indication of comparison results as noted in the previous sections. The 1-percent AEPD regression lines shown in figure 4 for hydrologic region 4 (fig. 3) (light brown line) and for flood region 1 (fig. 1) (dark green line) are comparable because they were developed for about the same area in the Des Moines Lobe landform region. These two regression lines show that estimates of 1-percent AEPDs for flood region 1 (fig. 1) are larger when compared to those for hydrologic region 4 (fig. 3) for drainage areas between 7.9 and 20 mi^2. The slope of the regression line for hydrologic region 4 (light brown line in fig. 4) is slightly steeper than the slope for the regression line for flood region 1 (dark green line in fig. 4). Regression lines with steeper slopes produce a greater “vertical change,” or a greater change in discharge for a given “horizontal change,” or change in drainage area, when compared to regression lines with flatter slopes.

Tables 12–13 and 16–17 list the results of a comparison for 16 streamgages located in flood region 2 (fig. 1) and tables 14–15 and 18–19 list the results of a comparison for 32 streamgages located in flood region 2 (fig. 1). The area of flood region 2 corresponds most closely statewide to hydrologic region 3 (fig. 3), and also includes some areas of hydrologic region 2 (fig. 3). A comparison of the regression lines (fig. 4) for flood region 2 (fig. 1) (black line) and for hydrologic region 3 (fig. 3) (blue line) shows that estimates of 1-percent AEPDs for flood region 2 are larger and the slope of the regression line is flatter when compared to hydrologic region 3 for drainage areas less than 20 mi^2. Thus, there is a greater difference in estimates of 1-percent AEPDs between these two RREs for smaller drainage areas, such as those less than 2 mi^2.

Tables 14–15 and 18–19 list the results of a comparison for 16 streamgages located in flood region 3 (fig. 1). The area of flood region 3 corresponds most closely statewide to hydrologic regions 1 and 2 (fig. 3), and also includes some areas of hydrologic region 3 (fig. 3). A comparison of the regression lines (fig. 4) for flood region 3 (fig. 1) (orange line) and for hydrologic region 2 (fig. 3) (red line) shows that estimates of 1-percent AEPDs for flood region 3 are larger and the slope of the regression line is flatter when compared to hydrologic region 2 for drainage areas less than 20 mi^2. Thus, there is a greater difference in estimates of 1-percent AEPDs between these two RREs for smaller drainage areas, such as those less than 2 mi^2. A comparison of the regression lines (fig. 4) for flood region 3 (fig. 1) (orange line) and for hydrologic region 1 (fig. 3) (light green line) shows that estimates of 1-percent AEPDs for flood region 3 are smaller and the slope of the regression line is flatter when compared to hydrologic region 1 for drainage areas less than 20 mi^2. Thus, there is less difference in estimates of 1-percent AEPDs between these two RREs for smaller drainage areas, such as those less than 2 mi^2.

The regression lines shown in figure 4 indicate that the 1987 single-variable RREs have steeper slopes when compared to the 2013 single-variable RREs for flood regions 2 (black line) and 3 (orange line). The 2013 single-variable RRE for flood region 1 (dark green line) has about the same slope as the 1987 single-variable RREs for hydrologic regions 2 (red line) and 3 (blue line). The magnitude of the 1-percent AEPDs are larger for the 2013 single-variable RREs when compared to those for the 1987 single-variable RREs for corresponding areas of Iowa, except for the 1987 single-variable RRE for hydrologic region 1 (light green line) for which the magnitude of 1-percent AEPDs exceeds all of those for 2013 single-variable RREs.

The 1987 single-variable RREs were developed using annual peak-flow data through the 1984 water year (Lara, 1987) and the 2013 multi- and single-variable RREs were developed using annual peak-flow data through the 2010 water year (Eash and others, 2013). Both sets of RREs were fit to all sizes of drainage areas for all streamgages included in each of these flood-estimation studies. Maximum drainage areas included in the development of the 1987 single-variable RREs range from 1,670 to 5,146 mi^2 for hydrologic regions 2–5 (maximum drainage area for hydrologic region 1 RREs is 374 mi^2) and for the 2013 single-variable RREs range from 2,809 to 7,783 mi^2. Because there were many more streamgages with drainage areas greater than 20 mi^2, than streamgages with drainage areas less than 20 mi^2, used in the development of 1987 and 2013 single-variable RREs, the fit of the regional-regression lines for both methods were predominately caused by the relation of AEPDs and drainage areas for streamgages with drainage areas greater than 20 mi^2. Thus, the magnitude of AEPDs and slope of the regional-regression

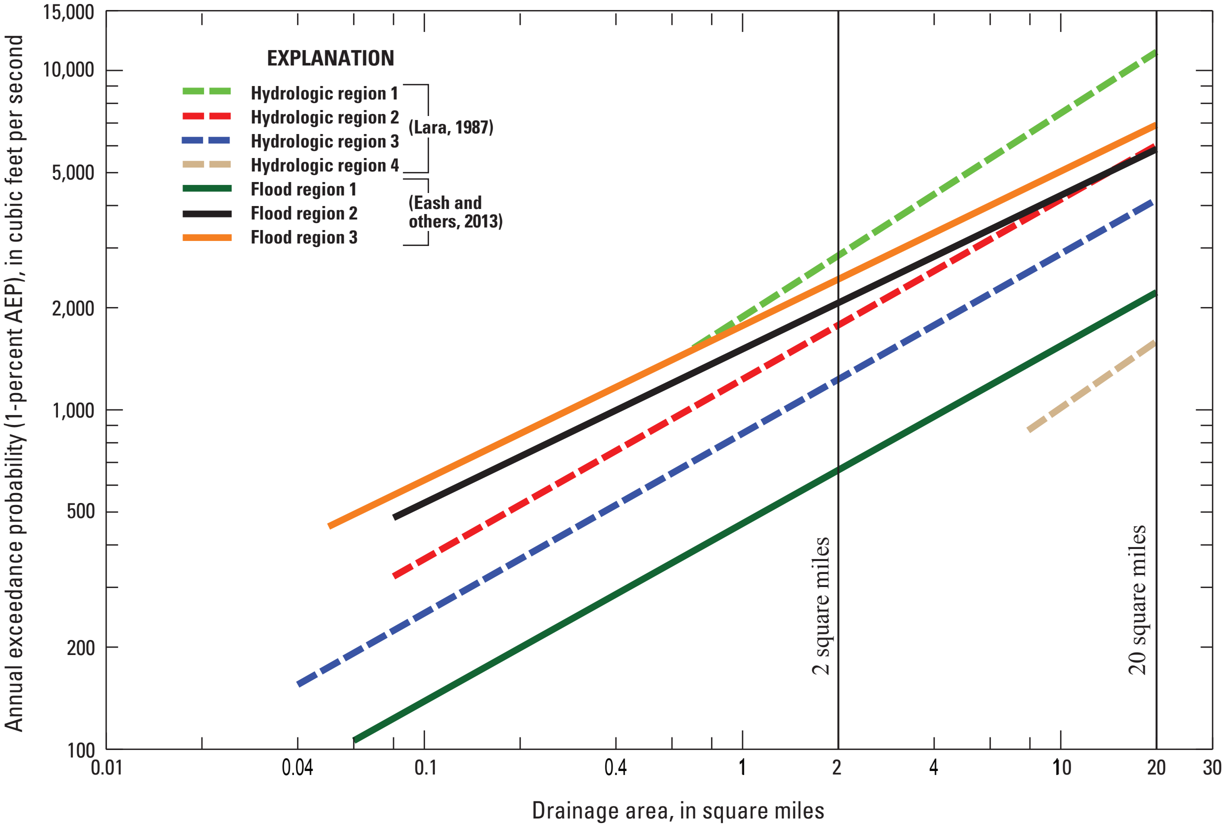


Figure 4. Relation between 1-percent annual exceedance-probability discharges and drainage area less than or equal to 20 square miles for 1987 and 2013 single-variable regional-regression equations.

lines (fig.4) were developed predominately using streamgages with drainage areas greater than 20 mi^2. Of the 251 streamgages used to develop the 1987 single-variable RREs, 68 of 251 streamgages, or 27 percent, had drainage areas less than 20 mi^2 (Lara, 1987). Likewise, of the 394 streamgages included in the development of the 2013 multi- and single-variable RREs, 137 of 394 streamgages, or 35 percent, had drainage areas less than 20 mi^2 (Eash and others, 2013).

For AEPs of 4, 2, and 1 percent for drainage areas less than 2 mi^2, MPRE and mean ratio results of this study seem to indicate that the definition of hydrologic regions, the magnitude of AEPDs, and the slope of the regression lines of the 1987 single-variable RREs provide better accuracy when compared to either the 2013 multi- or single-variable RREs for three of the five comparisons (table 12) and provide less bias for all five comparisons (table 13). For AEPs of 4, 2, and 1 percent for drainage areas between 2 and 20 mi^2, MPRE and mean ratio results of this study seem to indicate that the definition of hydrologic regions, the magnitude of AEPDs, and the slope of the regression lines of the 1987 single-variable RREs provide better accuracy when compared to either the 2013 multi- or single-variable RREs for five of the eight comparisons (table 14) and provide less bias for one of the eight comparisons (table 15). The combination of the definition of hydrologic regions, the lower discharges, and the steeper slopes of the regression lines of the 1987 single-variable RREs seem to provide better accuracy and less bias when compared to the 2013 multi- or single-variable RREs, particularly for drainage areas less than 2 mi^2, and also for some drainage areas between 2 and 20 mi^2. For most of the 1-percent AEPD datasets (tables 12–15) for flood regions 2 and 3 (fig. 1), better accuracy and less bias are indicated for the 1987 single-variable RREs. The 1987 single-variable RREs were developed with steeper slopes and lower magnitude discharges for 1-percent AEPs, when compared to either the 2013 multi- or single-variable RREs that were developed with flatter slopes and higher magnitude AEPDs. This comparison of 2013 and 1987 single-variable RREs indicates a curvilinear relation for 1-percent AEPDs for drainage areas less than 2 mi^2, and also for some drainage areas between 2 and 20 mi^2 (fig. 4). A curvilinear relation indicates that linear regression lines, such as those developed for 1-percent AEPs for flood regions 2 and 3 (fig. 1), may overestimate 1-percent AEPDs for small drainage areas.

Although AEPDs estimated by the 1987 single-variable RREs seem to provide better accuracy and less bias than AEPDs estimated by the 2013 multi- or single-variable RREs for most of the comparisons for drainage areas less than 2 mi^2 (tables 12–13) and for some of the comparisons for drainage areas between 2 and 20 mi^2 (tables 14–15), the 2013 multi- and single-variable RREs are considered to provide better accuracy and less bias for larger drainage areas. Comparisons of estimates of AEPDs to determine the size of drainage areas at which the 2013 multi- and single-variable RREs provide better accuracy and less bias, when compared to the 1987 single-variable RREs, are beyond the scope of this study. Differences between the 1987 single-variable RREs (Lara, 1987) and the 2013 multi- and single-variable RREs (Eash and others, 2013) are summarized:

1. Twenty-seven additional years of annual-peak discharge data were used to develop the 2013 multi- and single-variable RREs.
2. Three hundred and ninety-four streamgages were used to develop the 2013 multi- and single-variable RREs and 251 streamgages were used to develop the 1987 single-variable RREs.
3. A new regional skew study was used to calculate EMA/MGB AEP analyses for the 2013 flood-estimation study.
4. EMA/MGB AEP analyses were used to develop the 2013 multi- and single-variable RREs and Bulletin 17B AEP analyses were used to develop the 1987 single-variable RREs.
5. An analysis-of-covariance regression was used to test each of the 2013 flood regions for statistically significant differences.
6. Streamgages used in the 2013 regression analyses were not re-assigned to a different flood region than the region where the streamgage is present.
7. GLS regression was used to develop the 2013 multi- and single-variable RREs and ordinary least-squares (OLS) regression was used to develop the 1987 RREs.

The 1-percent AEPD regression lines, from the minimum to the maximum drainage area size applicable for each RRE, are shown in figure 5 for hydrologic regions 1–5 (fig. 3) from the 1987 single-variable RREs and for flood regions 1–3 (fig. 1) from the 2013 single-variable RREs (tables 5–7 in this report; Eash and others, 2013). The steeper slopes of the regression lines of the 1987 single-variable RREs for hydrologic regions 2, 3, and 4 (fig. 3) cause these 1-percent AEPD regression lines to cross the regression lines for the 2013 single-variable RREs for flood regions 1, 2, and 3 (figs. 1 and 5). Hydrologic regions 2, 3, and 4 consist of about 94 percent of Iowa (fig. 3). The 1-percent AEPD regression line for hydrologic region 2 (red line) crosses the regression line for flood region 2 (black line) where the drainage area is about 15 mi^2 and crosses the regression line for flood region 3 (orange line) where the drainage area is about 150 mi^2 (fig. 5). The 1-percent AEPD regression line for hydrologic region 3 (blue line) crosses the regression line for flood region 2 (black line) where the drainage area is about 1,700 mi^2 (fig. 5). The 1-percent AEPD regression line for hydrologic region 4 (light brown line) crosses the regression line for flood region 1 (dark green line) where the drainage area is about 280 mi^2 (fig. 5). Larger magnitude discharges are estimated for the 1987 single-variable RREs, than for the 2013 single-variable RREs, for drainage areas greater than those from where the regression lines cross.

Performance metrics for the 1987 single-variable RREs (Lara, 1987) were reported as standard errors of estimates (SEE) and for the 2013 multi- and single-variable RREs (Eash and others, 2013; tables 5–7 in this report) were reported as average standard errors of prediction (SEP). Although SEE, also referred to as root mean square error (RMSE), and SEP performance metrics are not directly comparable, overall, SEEs for hydrologic regions 2 and 3 (Lara, 1987) indicate less accuracy when compared to SEPs for flood regions 2 and 3 (multi- and single-variable RREs; Eash and others, 2013; tables 5–7 in this report) (table 20). SEEs for hydrologic region 4 (Lara, 1987) are better than SEPs for flood region 1 (multi- and single-variable RREs; Eash and others, 2013) (table 20). RMSE (SEE) is not appropriate for evaluating GLS regressions because of the unequal weighting given to the streamgages in GLS regression (Risley and others, 2008; Eash and others, 2013). The resulting unequally weighted GLS residuals from the 2013 multi- and single-variable RREs produce inflated RMSE values that are not comparable to RMSE (SEE) values from the 1987 single-variable RREs.

Considerations for Flood-Estimation Studies

As noted previously, values of *n* in the dataset comparisons range from 10 to 55 (tables 12–15). Information in these tables needs to be used with caution because comparisons for datasets with small values of *n* provide limited information on the accuracy of the AEPD estimates for different AEPD-estimation methods. Thus, larger datasets may provide different results from those presented in this study.

The use of a power transformation for drainage area for flood regions 2 and 3 (Eash and others, 2013) was considered to linearize the curvilinear relation, which resulted from a log transformation of drainage area, for each of these two flood regions and to provide better predictive accuracy for estimates of AEPDs. Results of this study indicate that additional research is needed to address the curvilinear relation between drainage area and AEPDs for areas of Iowa. Initial plans to develop two sets of RREs for large and small drainage areas, and to develop a method to resolve the problem of transitioning estimates of AEPDs between the two sets of RREs, was no longer investigated in the last flood-estimation study (Eash and others, 2013) when the use of the power transformations seemed to address the problem of curvilinear relations for areas of Iowa. The development of two sets of RREs for large and small drainage areas, and the devlopment of a method to resolve the problem of transitioning estimates of AEPDs between the two sets of RREs, may need to be reconsidered in future research for flood-estimation studies in Iowa.

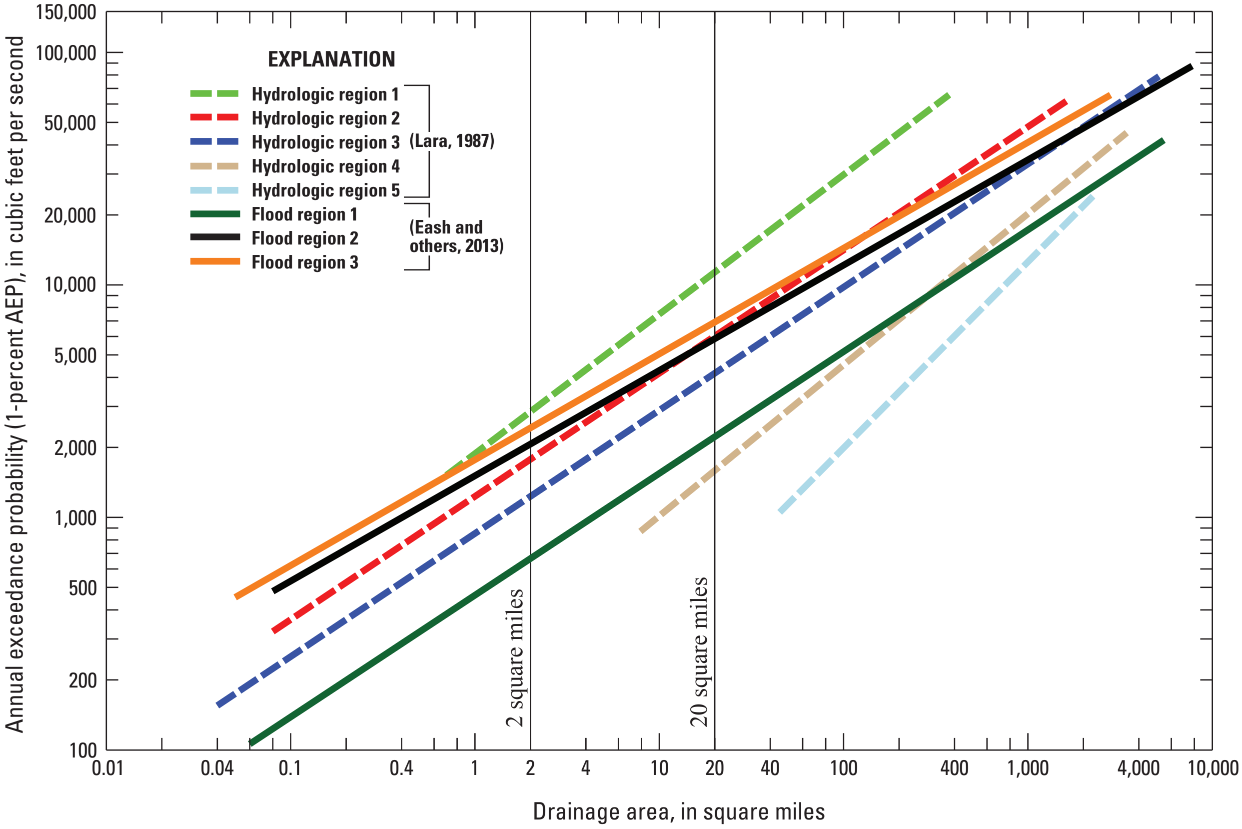


Figure 5. Relation between 1-percent annual exceedance-probability discharges and all sizes of drainage area for 1987 and 2013 single-variable regional-regression equations.

Table 20. Standard errors of estimate and average standard errors of prediction from 1987 and 2013 U.S. Geological Survey flood-estimation reports.[1]

[RRE, regional-regression equation; 1987 single, 1987 single-variable RREs (Lara, 1987); SEE, standard error of estimate; NA, not applicable; 2013 multi, 2013 multivariable RREs (Eash and others, 2013); 2013 single, 2013 single-variable RREs (Eash and others, 2013); SEP average standard error of prediction]

RRE	Region (figs. 3 and 1)	Performance metric	Number of streamgages used to develop equations	Performance metrics for annual exceedance probabilities							
				50 percent	20 percent	10 percent	4 percent	2 percent	1 percent	0.5 percent	0.2 percent
1987 single	Hydrologic region 1	SEE	19	61	37	28	24	21	24	NA	NA
1987 single	Hydrologic region 2	SEE	81	55	39	34	32	33	36	NA	NA
1987 single	Hydrologic region 3	SEE	119	44	36	35	37	39	41	NA	NA
1987 single	Hydrologic region 4	SEE	24	40	33	31	29	30	30	NA	NA
1987 single	Hydrologic region 5	SEE	8	27	21	20	24	24	26	NA	NA
2013 multi	Flood region 1	SEP	91	41.6	32.6	31.8	33.2	35.6	38.0	41.0	45.2
2013 multi	Flood region 2	SEP	176	46.8	25.7	20.8	19.4	20.4	22.3	24.9	28.2
2013 multi	Flood region 3	SEP	127	43.1	30.4	27.0	26.5	27.8	29.1	30.5	33.7
2013 single	Flood region 1	SEP	91	51.9	42.9	42.4	44.4	46.6	48.9	51.8	55.8
2013 single	Flood region 2	SEP	176	47.4	28.2	23.6	24.0	25.4	26.9	29.1	32.6
2013 single	Flood region 3	SEP	127	44.0	34.4	33.2	33.6	35.6	37.6	39.7	43.2

[1] Lara, 1987; Eash and others, 2013.

Summary

With the publication of a U.S. Geological Survey (USGS) annual exceedance-probability discharge (AEPD) estimation report in 2013 and with the implementation of regional-regression equations (RREs) from the report in Iowa StreamStats in 2013, the USGS, in cooperation with the Iowa Department of Transportation (Iowa DOT) and the Iowa Highway Research Board, initiated a statewide study in 2014. This report provides information on the relative accuracy and the amount of bias of AEPD estimation methods that can be used for drainage basins with areas less than 2 square miles (mi^2) and for drainage basins with areas between 2 and 20 mi^2. Traditionally, Iowa DOT has used the Iowa Runoff Chart method for drainage basins with areas less than 2 mi^2. RREs from a USGS AEPD-estimation report published in 1987 have also been used by Iowa DOT as a primary AEPD-estimation method for small drainage basins in Iowa. Eighty streamgages that were included in the development of the RREs implemented in Iowa StreamStats were selected for inclusion in this comparison study. Of these 80 streamgages, 25 of them have drainage areas less than 2 mi^2 and 55 of them have drainage areas between about 2 and 20 mi^2.

This report presents two comparisons of estimates of AEPDs. First, AEPDs were estimated from five different AEPD-estimation methods for streamgages with drainage areas less than 2 mi^2 and were compared to AEPDs that were estimated from observed data from the same streamgages using a streamgage probability-analysis method named the expected moments algorithm/multiple Grubbs-Beck test (EMA/MGB analysis method). The five AEPD-estimation methods include (1) multivariable RREs from the 2013 report (2013 multivariable RRE method); (2) single-variable RREs from the 2013 report (2013 single-variable RRE method); (3) single-variable RREs from the 1987 report (1987 single-variable RRE method); (4) the TR-55 rainfall-runoff model, and (5) the Iowa Runoff Chart method. Second, AEPDs estimated from four different AEPD-estimation methods for streamgages in Iowa with drainage areas between about 2 and 20 mi^2 were compared to AEPDs that were estimated from observed data from the same streamgages using the EMA/MGB analysis method. With the exception of the Iowa Runoff Chart method, the four other AEPD-estimation methods included in the first set of comparisons also were included in the second set of comparisons for streamgages in Iowa with drainage areas between about 2 and 20 mi^2.

The AEPD-estimation comparisons were performed using two evaluation metrics for annual exceedance probabilities (AEPs) of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent. Estimates of AEPDs for $Q_{50\%}$, $Q_{0.5\%}$, and $Q_{0.2\%}$ are not applicable for the Iowa Runoff Chart method and estimates of AEPDs for $Q_{0.5\%}$ and $Q_{0.2\%}$ are not applicable for the 1987 single-variable RREs. Comparisons for the two sizes of drainage area were evaluated first for AEPD-estimation methods that provide the best accuracy for Iowa DOT selected AEPs of 4, 2, and 1 percent and second for AEPD-estimation methods that provide the best accuracy for the greatest number of AEPs.

The streamgage datasets included in this study are not independent of those used in the development of the 2013 multivariable RREs and the 2013 single-variable RREs, except for the addition of three more years of annual peak-discharge data. The streamgage datasets included in this study also may not be independent of those used to develop the 1987 single-variable RREs, or possibly even the TR-55 rainfall-runoff model or the Iowa Runoff Chart method, because these methods may have used some of these same streamgage datasets in their development. Therefore, conclusions regarding the relative quality of the AEPD-estimation methods may or may not be extended to ungaged sites. The relative quality of the estimates of AEPDs calculated for streamgages from the AEPD-estimation methods compared in this study can be assumed to extend to all conclusions referencing ungaged sites.

For ungaged drainage basins in Iowa with areas less than 2 square miles, results of the comparisons indicate that estimates of AEPDs calculated from the 2013 multi- and single-variable regional-regression equations, the 1987 single-variable RREs, and the TR-55 method tend to overestimate AEPDs, and that estimates of AEPDs calculated from the Iowa Runoff Chart method tend to primarily underestimate AEPDs. Results of the comparisons seem to indicate the best overall AEPD-estimation accuracy and the least overall bias may be achieved with the use of the TR-55 method for sites in flood regions 1 and 3 and with the use of the 1987 single-variable RREs for sites in flood region 2. In the Des Moines Lobe landform region, the 1987 single-variable RREs are not applicable for drainage basins with areas less than 7.9 mi^2 in hydrologic region 4 and for areas less than 45 mi^2 in hydrologic region 5.

For ungaged drainage basins in Iowa with areas between 2 and 20 square miles, results of the comparisons indicate that estimates of AEPDs from the 2013 multi- and single-variable regional-regression equations and the TR-55 method tend to overestimate AEPDs, and that estimates of AEPDs calculated from the 1987 single-variable RREs tend to overestimate and underestimate AEPDs. Results of the AEPD comparisons seem to indicate the best overall AEPD-estimation accuracy and the least overall bias may be achieved with the use of the 1987 single-variable RREs for sites in the Southern Iowa Drift Plain landform region and in flood region 3, with the use of the 2013 multivariable RREs for sites in the Iowan Surface landform region, and with the use of the 2013 or 1987 single-variable RREs for sites in flood region 2. For sites in all other landform and flood regions in Iowa, use of the 2013 single-variable RREs may provide the best overall accuracy and the least bias. In the Des Moines Lobe landform region, the 1987 single-variable RREs are not applicable for drainage basins with areas less than 7.9 mi^2 in hydrologic region 4 and for areas less than 45 mi^2 in hydrologic region 5.

Comparison results seem to indicate that the best accuracy and the least bias may be achieved by the use of different estimation methods of AEPD for different AEPs. The

use of different estimation methods of AEPD for different AEPs is not appropriate because this approach could lead to inconsistencies with predictions of AEPDs. The number of streamgages included in the dataset comparisons range from 10 to 55. Information in this report needs to be used with caution because comparisons for datasets with small values of "*n*" provide limited information on the accuracy of the AEPD estimates for different AEPD-estimation methods. Thus, larger datasets may provide different results from those presented in this study.

An in-depth examination was conducted to better understand why the 1987 single-variable RRE estimates seem to provide better accuracy and less bias than the 2013 multi- or single-variable RRE estimates for most of the comparisons for drainage areas less than 2 mi^2 and for some of the comparisons for drainage areas between 2 and 20 mi^2. The re-assignment of the 1987 single-variable RREs and use of the mixed landform calculation seem to have had no substantial effect regarding the relative accuracy and bias of estimates of AEPDs when comparing the 2013 multi- and single-variable RREs to the 1987 single-variable RREs for drainage basins with areas less than 2 mi^2 or with areas between 2 and 20 mi^2. The re-assignment of 1987 single-variable RREs to a different hydrologic region than the region where the streamgage is present may be a subjective re-assignment for ungaged sites if users do not use a quantitative method similar to the one used in this study.

A comparison of EMA/MGB estimates calculated through the 2013 water year to those calculated through the 2010 water year was performed to determine if 2013 estimates have generally increased or decreased when compared to 2010 estimates. An overall decrease in 2013 EMA/MGB estimates when compared to 2010 EMA/MGB estimates could indicate why the 1987 single-variable RRE estimates seem to provide better accuracy and less bias for some comparisons. Overall, increases and decreases (from 2013 EMA/MGB estimates) seem to be about the same when compared to 2010 EMA/MGB estimates.

The 1-percent AEPD regression lines for hydrologic regions 1–4 from the 1987 single-variable RREs and for flood regions 1–3 from the 2013 single-variable RREs indicate that the 1987 single-variable RREs have steeper slopes when compared to the 2013 single-variable RREs for flood regions 2 and 3. Regression lines with steeper slopes produce a greater change in discharge for a given change in drainage area, when compared to regression lines with flatter slopes. The 2013 single-variable RRE for flood region 1 has about the same slope as the 1987 single-variable RREs for hydrologic regions 2 and 3. The magnitude of the 1-percent AEPDs are larger for the 2013 single-variable RREs when compared to those for the 1987 single-variable RREs for corresponding areas of Iowa, except for the 1987 single-variable RRE for hydrologic region 1 for which the magnitude of 1-percent AEPDs exceeds all of those for the 2013 single-variable RREs. The combination of the definition of hydrologic regions, the lower discharges, and the steeper slopes of the regression lines for the 1987 single-variable RREs seem to provide better accuracy and less bias when compared to either the 2013 multi- or single-variable RREs, particularly for drainage areas less than 2 mi^2, and also for some drainage areas between 2 and 20 mi^2. The 2013 multi- and single-variable RREs are considered to provide better accuracy and less bias for larger drainage areas.

Results of this study indicate that additional research is needed to address the curvilinear relation between drainage area and AEPDs for areas in Iowa. The development of two sets of RREs for large and small drainage areas, and the development of a method to resolve the problem of transitioning estimates of AEPDs between the two sets of RREs, may need to be reconsidered in future research for flood-estimation studies in Iowa.

References Cited

Bodhaine, G.L., 1968, Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A3, 60 p. [Also available at http://pubs.usgs.gov/twri/twri3-a3/pdf/TWRI_3-A3.pdf.]

Bradley, A.A., Wehmeyer, L.L., and Chen, L.C., 2009, Evaluation of design flood frequency methods for Iowa Streams: Iowa Institute of Hydraulic Engineering, Hydroscience and Engineering, IIHR Report No. 473. 94 p., accessed March 9, 2015, at http://www.iihr.uiowa.edu/wp-content/uploads/2013/06/IIHR473.pdf.

Bureau of Public Roads, 1950, Highway drainage manual: Washington, D.C., Bureau of Public Roads. [pagination unknown].

Cohn, T.A., Berenbrock, Charles, Kiang, J.E., and Mason, R.R., Jr., 2012, Calculating weighted estimates of peak streamflow statistics: U.S. Geological Survey Fact Sheet 2012–3038, 4 p. [Also available at http://pubs.usgs.gov/fs/2012/3038/pdf/fs2012-3038.pdf.); also see http://water.usgs.gov/usgs/osw/swstats/freq.html.]

Cohn, T.A., England, J.F., Berenbrock, C.E., Mason, R.R., Stedinger, J.R., and Lamontagne, J.R., 2013, A generalized Grubbs-Beck test statistic for detecting multiple potentially influential low outliers in a flood series: Water Resources Research, v. 49, no. 8, p. 5047–5058, accessed March 9, 2015, at http://onlinelibrary.wiley.com/doi/10.1002/wrcr.20392/pdf.

Cohn, T.A., Lane, W.L., and Baier, W.G., 1997, An algorithm for computing moments-based flood quantile estimates when historical flood information is available: Water Resources Research, v. 33, no. 9, p. 2089–2096, accessed March 9, 2015, at http://onlinelibrary.wiley.com/doi/10.1029/97WR01640/pdf.

Cohn, T.A., Lane, W.L., and Stedinger, J.R., 2001, Confidence intervals for expected moments algorithm flood quantile estimates: Water Resources Research, v. 37, no. 6, p. 1695–1706, accessed March 9, 2015, at http://timcohn.com/Publications/CohnLaneSted2001WR900016.pdf.

Eash, D.A., and Barnes, K.K., 2012, Methods for estimating low-flow frequency statistics and harmonic mean flows for streams in Iowa: U.S. Geological Survey Scientific Investigations Report 2012–5171, 94 p. [Also available at http://pubs.usgs.gov/sir/2012/5171/.]

Eash, D.A., Barnes, K.K., and Veilleux, A.G., 2013, Methods for estimating annual exceedance-probability discharges for streams in Iowa, based on data through water year 2010: U.S. Geological Survey Scientific Investigations Report 2013–5086, 63 p. with appendix. [Also available at http://pubs.usgs.gov/sir/2013/5086/.]

Esri, 2012, ArcGIS Resource Center, Desktop 10, accessed March 9, 2015, at http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html.

Fulford, J.M., 1998, User's guide to the U.S. Geological Survey Culvert Analysis Program, Version 97–08: U.S. Geological Survey Water-Resources Investigations Report 98–4166, 70 p. [Also available at http://pubs.usgs.gov/wri/1998/4166/report.pdf.]

Haddad, Khaled, Rahman, Ataur, and Stedinger, J.R., 2012, Regional flood frequency analysis using Bayesian generalized least squares—A comparison between quantile and parameter regression techniques: Hydrological Processes, v. 26, p. 1008–1021, accessed March 9, 2015, at http://onlinelibrary.wiley.com/doi/10.1002/hyp.8189/pdf.

Holmes, R.R., Jr., Dinicola, Karen, 2010, 100-year flood—It's all about chance: U.S. Geological Survey General Information Product 106, 4 p. [Also available at http://pubs.usgs.gov/gip/106/pdf/100-year-flood-handout-042610.pdf.]

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: U.S. Geological Survey, Office of Water Data Coordination, Bulletin 17B of the Hydrology Subcommittee, 28 p., plus appendixes. [Also available at http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html.]

Iowa Department of Transportation, 2014a, LRFD design manual: Iowa Department of Transportation, accessed April 13, 2015, at http://www.iowadot.gov/bridge/manuallrfd.htm.

Iowa Department of Transportation, 2014b, Guidelines for preliminary design of culverts, appendix A, Iowa Runoff Chart: Iowa Department of Transportation, accessed March 9, 2015, at http://www.iowadot.gov/bridge/policy/03-PDG_App_A_Jan13.pdf.

Lara, O.G., 1987, Methods for estimating the magnitude and frequency of floods at ungaged sites on unregulated rural streams in Iowa: U.S. Geological Survey Water-Resources Investigation Report 87–4132, 34 p. [Also available at http://pubs.usgs.gov/wri/1987/4132/report.pdf; for two-page addendum, see http://publications.iowa.gov/16015/1/IADOT_hr268_Method_Estimating_Magnitude_Frequency_Floods_Rural_Streams_1987.pdf.]

National Climatic Data Center, Climate of Iowa, 2012, accessed March 9, 2015, at http://www.crh.noaa.gov/images/dvn/downloads/Clim_IA_01.pdf.

Natural Resources Conservation Service, 2009, Small watershed hydrology—Win TR-55 user guide: U. S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, 139 p., with appendixes, accessed March 9, 2015, at ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/WinTR55/WinTR55UserGuide.pdf.

Natural Resources Conservation Service, 2010, Time of concentration: U. S. Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook, Part 630, chap. 15, 22 p., accessed March 9, 2015, at ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/NEHhydrology/ch15.pdf.

Natural Resources Conservation Service, 2012, Glossary: U.S. Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook, Part 630, chap. 22, 15 p., accessed March 9, 2015, at ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/NEHhydrology/ch22.pdf.

Perica, Sanja, Martin, Deborah, Pavlovic, Sandra, Roy, Ishani, St. Laurent, Michael, Trypaluk, Carl, Unruh, Dale, Yekta, Michael, Bonnin, Geoffrey, 2013, Precipitation-Frequency Atlas of the United States: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, v. 8, version 2.0—Midwestern States, Silver Springs, Md, 292 p., accessed March 9, 2015, at http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume8.pdf.

Prior, J.C., 1991, Landforms of Iowa: Iowa City, Iowa, University of Iowa Press, 154 p.

Prior, J.C., Kohrt, C.J., and Quade, D.J., 2009, The landform regions of Iowa, vector digital data: Iowa City, Iowa, Iowa Geological Survey, Iowa Department of Natural Resources, accessed March 9, 2015, at ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/geologic/landform/landform_regions.zip.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow— Measurement of stage and discharge, volume 1, and Computation of discharge volume 2: U.S. Geological Survey Water-Supply Paper 2175, 631 p. [Also available at http://pubs.usgs.gov/wsp/wsp2175/.]

Risley, John, Stonewall, Adam, and Haluska, Tana, 2008, Estimating flow-duration and low-flow frequency statistics for unregulated streams in Oregon: U.S. Geological Survey Scientific Investigations Report 2008–5126, 22 p. [Also available at http://pubs.usgs.gov/sir/2008/5126/.]

Soenksen, P.J., and Eash, D.A., 1991, Iowa floods and droughts, *in* Paulson, R.W., ed., National Water Summary 1988–89—Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2375, 591 p. [Also available at http://pubs.er.usgs.gov/publication/wsp2375.]

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Weather Service, 2014, Precipitation frequency data server: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Weather Service, accessed March 9, 2015, at http://hdsc.nws.noaa.gov/hdsc/pfds/.

U.S. Geological Survey, 2015a, Welcome to StreamStats—The Streamstats Program: U.S. Geological Survey, accessed April 30, 2015, at http://water.usgs.gov/osw/streamstats/index.html.

U.S. Geological Survey, 2015b, National Water Information System (NWISWeb): U.S. Geological Survey database, accessed April 30, 2015, at http://waterdata.usgs.gov/nwis/sw.

Veilleux, A.G., Cohn, T.A., Flynn, K.M., Mason, R.R., Jr., and Hummel, P.R., 2014, Estimating magnitude and frequency of floods using the PeakFQ 7.0 program: U.S. Geological Survey Fact Sheet 2013–3108, 2 p. [Also available at: http://dx.doi.org/10.3133/fs20133108.]

Veilleux, A.G., Stedinger, J.R., and Eash, D.A., 2012, Bayesian WLS/GLS regression for regional skewness analysis for crest stage gage networks, *in* Loucks, E.D., ed., Proceedings of the World Environmental and Water Resources Congress—Crossing boundaries, May 20–24, 2012 [abs.]: Albuquerque, N. Mex., American Society of Civil Engineering, paper 227, p. 2253–2263, accessed March 9, 2015. [Also available at http://ia.water.usgs.gov/media/pdf/report/Veilleux-Stedinger-Eash-EWRI-2012-227R.pdf.]

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Iowa Water Science Center
P.O. Box 1230
Iowa City, IA 52244
(319) 337–4191

Or visit the Iowa Water Science Center Web site at:
http://ia.water.usgs.gov/

David A. Eash—**Comparisons of Estimates of Annual Exceedance-Probability Discharges for Small Drainage Basins in Iowa**—Scientific Investigations Report 2015–5055

ISSN 2328-031X (print)
ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20155055

ISBN 978-1-4113-3917-0