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Evaluation of Kovacs 1988 Regional Maximum Flood Method

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Estimation of design flood peaks is required for the design and evaluation of hydraulic structures. Methodologies developed between the 1960s and the late 1980s, such as the Regional Maximum Flood (RMF), are used to estimate extreme flood peaks in South Africa. The RMF method uses envelope curves to estimate the maximum flood that can be expected in a specific region in South Africa and neighbouring countries, and represents an indicative upper flood limit for other flood estimation methods. The method developed by Kovacs for South Africa was last updated in 1988. Using more than 30 years of additional data for analysis, this paper highlights the RMF's perceived shortcomings. In two RMF regions, updated observed flood peaks exceeded the existing envelope curves. In 78% of the catchment areas of the evaluated stations, the station RMF values were at least 50% more than the observed maximum flood peak. When the different parameters from the Kovacs 1988 and present DWS (Department of Water and Sanitation) datasets were compared, 98% of the evaluated stations had different flood peaks recorded/reported, while 33% of the stations logged different catchment area sizes. Kovacs 1988 ratios used to estimate flood peaks at different probabilities of occurrence, using the RMF, were found to generally over-estimate expected flood peaks. It is concluded that the 1988 RMF method needs to be updated to still provide relevant guidance.

INTRODUCTION

South Africa has experienced significant flooding since 1981, which include the cyclone Domonia floods in 1984, KwaZulu-Natal floods in 1987, Orange River Basin floods in 1988 and Limpopo floods in 2000 (Görgens *et al* 2006). Additionally, the Western Cape experienced flooding in 2005, while the Eastern Cape and Free State experienced flooding in 2011 (Smithers 2012). To design and evaluate hydraulic structures, a clear understanding of the magnitude and probability of occurrence of flood peaks is needed. According to SANCOLD (1990), the Safety Evaluation Discharge (SED) is used as a general criterion to evaluate the sufficiency of a spillway for a new or existing dam. The SED is based on an extreme flood, hence calculated using the Regional Maximum Flood (RMF) method (SANCOLD 1990). The SED is expressed as an unrouted discharge based on the calculated RMF. The RMF is also widely used by practitioners, particularly in the Department of Water and Sanitation (DWS), to assess the resulting flood peaks when using different estimation approaches. The RMF method is an empirical method that relates flood peaks to catchment size, and physiographic and meteorological characteristics (Smithers 2012). The RMF is an upper-limit extreme flood peak for a particular region, estimated using envelope curves (Kovacs 1988). The method has not been updated since 1988. The method was adopted from Francou and Rodier (1967) by Kovacs in 1980 for South Africa (Kovacs 1980). Pilon and Adamowski (1992), cited by Smithers (2012), credit the method for its ability to estimate an extreme flood without streamflow data. Several studies (Pegram & Parak 2004; Görgens *et al* 2007; Van Vuuren *et al* 2013; Smithers 2012; Nortje 2010) reviewed the method.

REVIEWS ON THE RMF

According to Pegram and Parak (2004), the RMF method is robust and simple to use in estimating maximum floods at

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any site using only the regional scale and catchment area. Alexander (1990) claimed that the RMF method is reliable in medium-sized catchments. However, other studies have found inconsistencies in the method. Görgens *et al* (2006) showed that post-1988 flood peaks may have exceeded the RMF envelopes. According to Parak (2007), the RMF does not give an exact design flood peak.

Görgens (2002) stated that "... statistically speaking, the method used to determine Kovacs (1988) RI ratios was too simplistic ...", and through a re-analysis it showed that the 1:200-, 1:100-, 1:50-year RI ratios needed to be reduced by 0.90, 0.80 and 0.70, respectively. According to Parak (2007), the recurrence interval (RI) ratios may need to be scaled down. Van Vuuren *et al* (2013) stated that the Kovacs procedure used in the 1988 RMF analysis should be revised to include all available data to reproduce the maximum envelope curves. According to Nortje (2010), the RMF method cannot confirm the Annual Exceedance Probability (AEP) of the RMF value for a given site. Nortje (2010) further stated that the RMF's AEP is not constant, but varies significantly between sites and regions. Smithers (2012) stated that the Kovacs (1988) RMF regions should be updated and refined. He added

Table 1 Evaluation of the 1988 RMF method

Comparative analysis of Kovacs 1988 RMF and Kovacs 1988 flood peaks (ANALYSIS 1)
■ The analysis compared the RMF (calculated the differences) against the maximum observed flood peak values of each station. ■ Maximum flood peaks from the Kovacs 1988 TR 137 dataset were used.
Comparative analysis of data parameters (ANALYSIS 2)
■ The parameters from the dataset used in the RMF approach, such as flood peaks, date of flood peaks and catchment areas were compared. Parameters from the Kovacs 1988 TR137 dataset and DWS dataset for the same gauging stations and storm events were compared. DWS data is from dam gauging stations or verified flood peaks, as calculated by DWS.
Evaluation of the 1988 RMF envelope curves (ANALYSIS 3)
■ Kovacs (1988) RMF envelope curves were juxtaposed against the 494 new flood peaks from the dataset obtained from the DWS. ■ Any flood peak exceeding the envelope curves was identified.
Comparative analysis of K_R and K_E values (ANALYSIS 4)
■ Kovacs (1988) RMF regional envelope (K_E) values were compared with the DWS gauging station's calculated K (K_R) values. ■ The K_R values were geographically plotted in each respective K_E region and the variation was observed to assess if all stations are still well represented by the regions.
Evaluation of Kovacs 1988 RMF: RI flood peak ratios (ANALYSIS 5)
■ The recent AMS (Annual Maximum Series) of the 93 gauging stations from Kovacs 1988 were plotted using Cunnane plotting positions, and cumulative probability distributions were fitted. ■ Probability distributions included the Normal distribution, Log-Pearson Type III and General Extreme Value distribution. RI (50, 100 and 200-year) flood peaks from the best-fitting distributions were determined. ■ RI flood peaks for the 93 gauging stations were calculated using the 1988 Kovacs ratios (Q_T/Q_{RMF}). The RMF was calculated using Kovacs (1988) K_E values. ■ The difference between the RI flood peaks (using the recent AMS and Kovacs (1988) K_E values) for each station was determined. ■ Percentage differences, expressed as a percentage of the flood peak determined from the probabilistic approach, were calculated for each station, and a regional difference was evaluated.

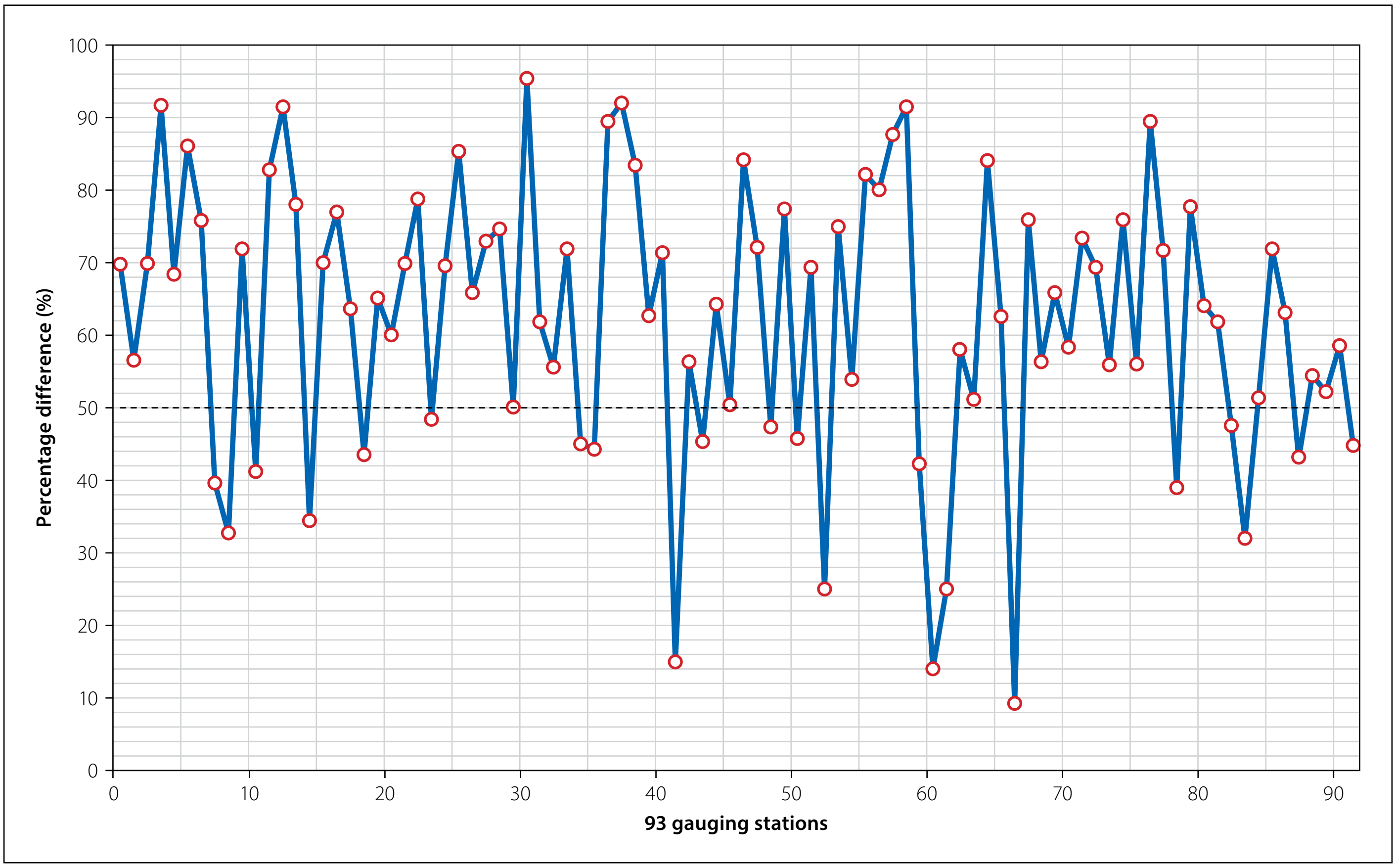


Figure 1 Difference (percentage) between the RMF and flood peak from 1988 TR 137 dataset

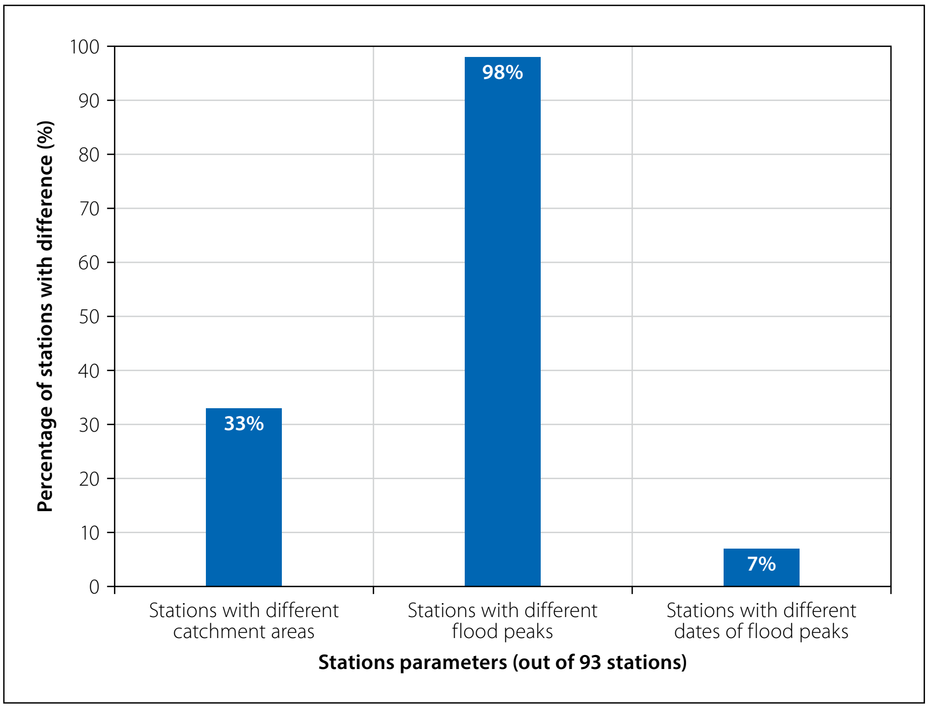


Figure 2 DWS and Kovacs database parameters comparison

that it would be prudent to investigate the use of probability of exceedance associated with the RMF. Verwey (2015) stated that Kovacs's method of regionalising K_R values (calculated Francou and Rodier K-value) into K_E values (Kovacs Envelope Curve K-value) is inconsistent. Several deficiencies were further investigated in this review. This paper aims to evaluate the performance of the Kovacs RMF method through comparative analyses to determine the method's current applicability.

METHODOLOGY

This paper used flood peak data obtained from the DWS of 93 flow-gauging stations still operational from the Kovacs 1988 TR 137 dataset, as well as 494 new flow-gauging stations from the DWS dataset. The methodology used in the review study is summarised in Table 1.

ANALYSIS AND RESULTS

Analysis 1: Comparative analysis of Kovacs 1988 RMF and Kovacs 1988 flood peaks

The analysis was performed to compare the RMF and observed flood peak values reported in the Kovacs 1988 TR 137 report and to highlight the differences accepted at the time of the original research. Figure 1 shows the comparison, using Equation 1, of the RMF and the observed flood peaks, for the 93 gauging stations, using only the 1988 data.

$$\% \text{ diff} = \frac{Q_{RMF} - Q_{Obs}}{Q_{RMF}} \times 100 \qquad (1)$$

Figure 1 shows that 73 out of 93 (78%) gauging stations had a 50% or greater difference between RMF and the observed flood peak. This means that the regional maximum flood peak is 50% or more greater than the sites' observed maximum flood peak.

Analysis 2: Comparative analysis of data parameters

Kovacs (1988) determined some of his flood peaks (when the capacity of the gauging stations was exceeded) from hand-drawn log-log curves of annual maximum observed flood peaks fitted on a regression line against the gauging station weir flow depth. Kovacs, using the DWS records, discovered that some of those maximum flood peaks did not fall on the regression line, and he then adjusted these peak flow values when the gauging stations' capacity was exceeded (Verwey 2015). This analysis compares such data values, including the date of flood peak and catchment area, between the two datasets (TR137 and DWS).

Figure 2 summarises the differences between Kovacs's 1988 dataset and the DWS dataset. Only those stations that are present in both the Kovacs and DWS datasets are presented.

Figure 2 shows that 98% of the gauging stations reflected differences between flood peaks between the two datasets. On average Kovacs flood peaks were 27% (expressed as a percentage of Kovacs flood peaks) larger than the DWS flood peaks. It was observed that 16 stations (17% of the stations) had flood peak differences of less than 10%, 12 stations (13%) had differences in the range of 40% to 60%, and 18 stations (19%) in the range of 80% – 100%. The adjustment made by Kovacs to the observed annual maximum flood peaks to fit a regression line is sensitive to small changes, and it resulted in a consistent trend in which Kovacs-adjusted values were frequently higher than those in the DWS dataset. The comparison revealed that in 33% of the gauging stations a difference in catchment area between the two datasets was observed.

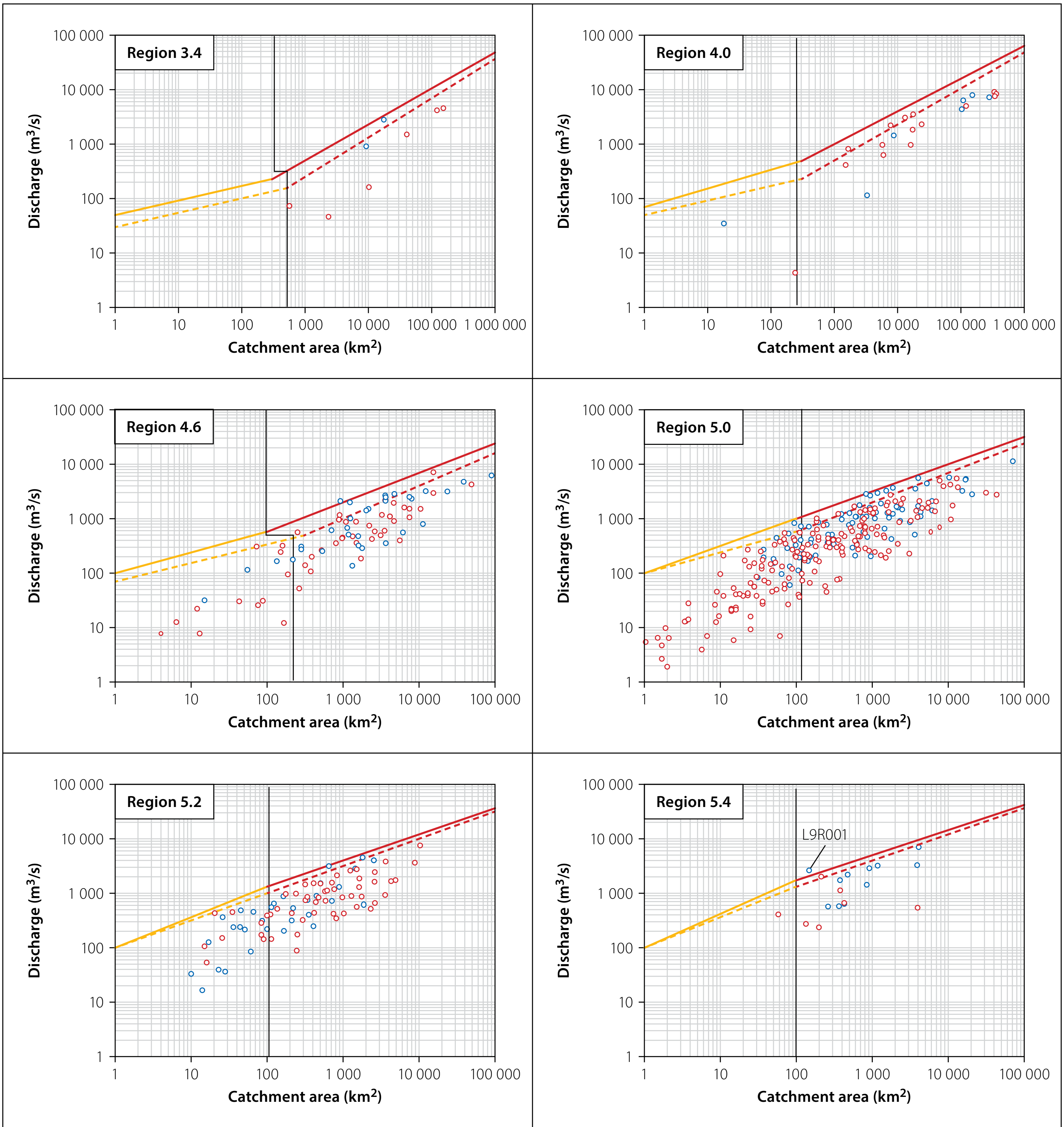
Analysis 3: Evaluation of the 1988 RMF envelope curves

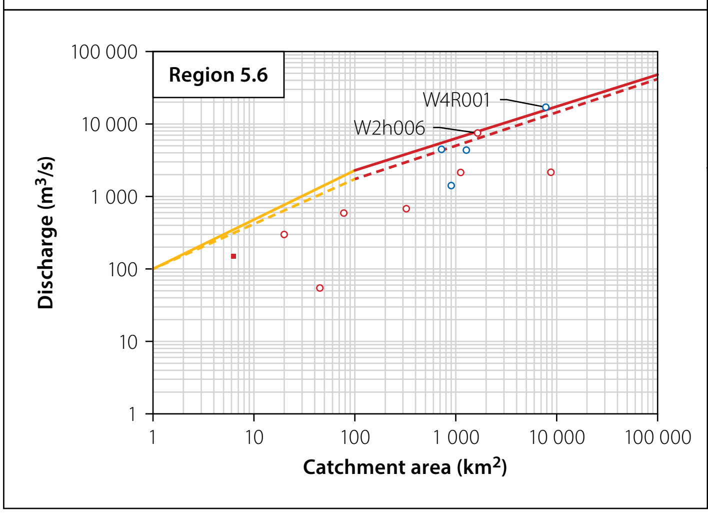
Görgens *et al* (2006) reported that post-1988 flood peaks may have exceeded Kovacs (1988) RMF envelope curves. To verify this, recent flood peaks (from dam and river stations) were plotted against Kovacs (1988) RMF envelope curves for each K_E region. The dam station data presents calibrated dam inflow data, which includes the maximum flood peaks for South Africa's major dams. The river station data reflects the data collected at river gauges as reported by DWS. Figure 3 presents the results.

From Figure 3, as summarised in Table 2, it is clear that flood events in regions 5.4 and 5.6 exceeded Kovacs's (1988) RMF envelope curves. It is also evident that some observed flood peaks plotted very close to or on the envelope curve.

Table 2 Gauging stations where RMF was exceeded

Gauging station	Observed flood peak (m^3/s)	K region (K_E)	Catchment area (km^2)	RMF (m^3/s)	Percentage above RMF (%)
L9R001	2 514	5.4	138	2 016	25
W4R001	16 761	5.6	7 814	15 591	8





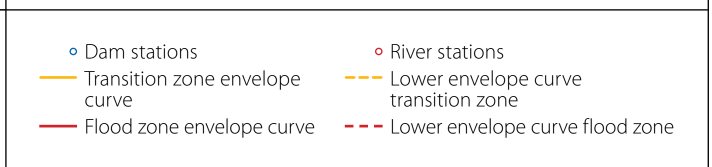


Figure 3 Analysis of Kovacs 1988 envelope curves

Analysis 4: Comparative analysis of K_R and K_E values

This analysis used the Kovacs 1988 TR 137 regions to evaluate the variation between K_R (station calculated K value, using the DWS dataset) and K_E (regional envelope K value). Kovacs's K_R values for each station were used and regionalised to reflect a K_M value (regional maximum K_R value). A safety factor of ΔK was then added to the highest K_M to obtain K_E values. Figure 4 shows K_R values within region $K_E = 5.0$.

The presence of low K_R values (1.9, 2.25, 2.4, 2.5 and 2.7), circled within K_E region 5.0, suggests that its boundaries could

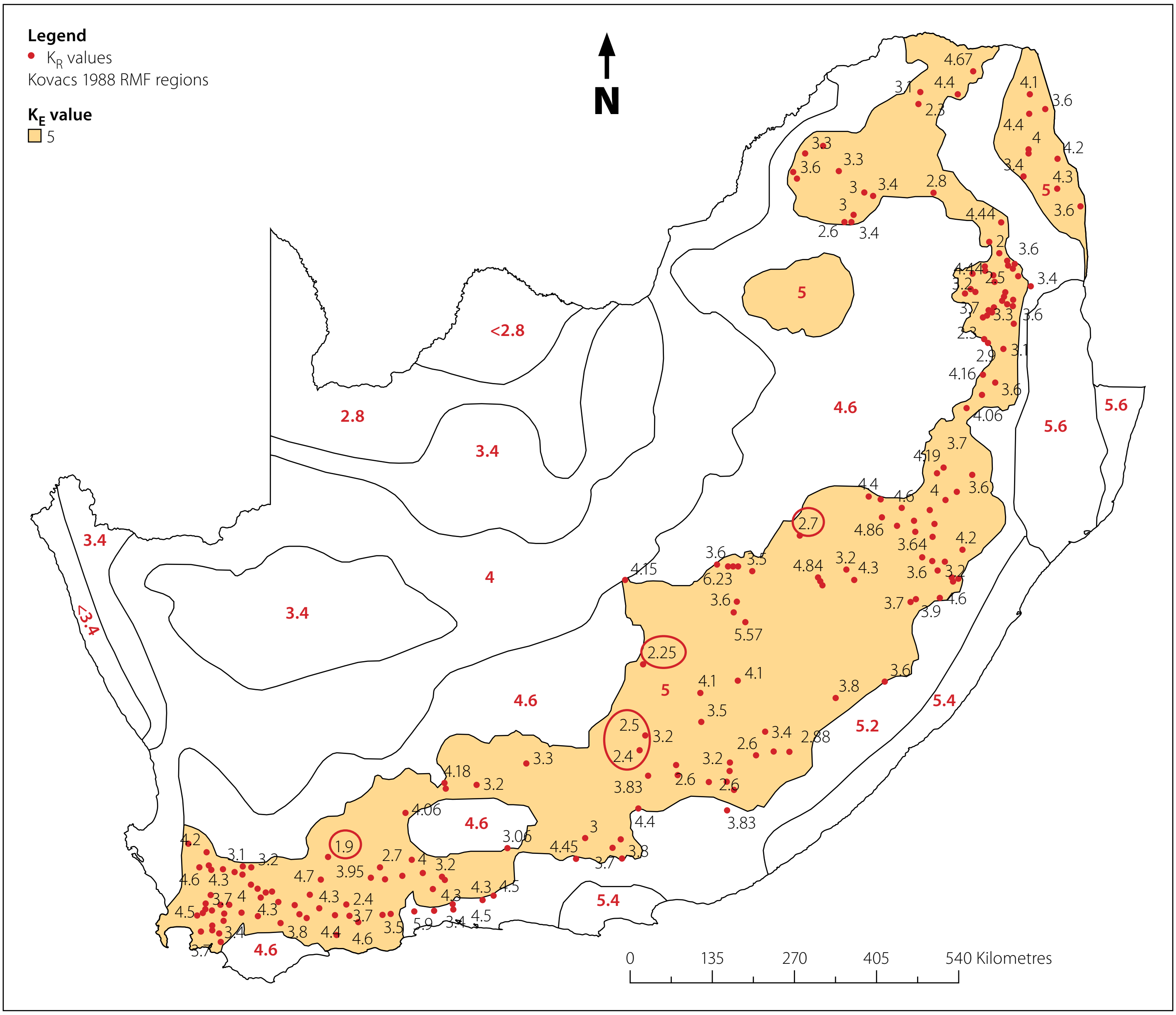


Figure 4 K_R values within K_E = 5.0 region (Kovacs 1988)

be revised to include intermediate regions with K_E values less than 5.0. Similar trends were observed in K_E regions 3.4 to 5.6. This implies that smaller, more localised regions with K_E values close to gauging station K_R values could be defined.

Analysis 5: Analysis of the 1988 Kovacs Q_T/Q_{RMF} ratios

Kovacs (1988) provided ratios (Q_T/Q_{RMF}) that can be used to calculate RI flood peaks (Q_T) (greater or equal to 1:50-year) using the RMF. According to Van der Spuy and Rademeyer (2010), the ratios estimate exceedance probability flood peaks which are too high. Parak (2007) also stated that the ratios may need to be scaled down. To examine these research findings, flood peak estimates from the updated DWS dataset using probabilistic approaches were compared to those calculated using Kovacs ratios, for various RIs (1:50, 1:100 and 1:200). The differences between these flood peaks are expressed as a percentage difference (% diff) of the probabilistic flood peak. Table 3 provides an explanation of the different variables used in the analysis.

The $Q_{(prob)}$ and $Q_{(Kovacs\ ratios)}$ RI flood peaks were determined, and the percentage differences were calculated using Equation 2.

$$\%\ diff = \frac{Q_{(Kovacs\ ratio)} - Q_{(prob)}}{Q_{(prob)}} \times 100 \qquad (2)$$

The percentage difference was calculated to evaluate the magnitude at which the ratios underestimated or overestimated the $Q_{(prob)}$ RI flood peaks. Table 4 shows the 50-year RI flood peaks and their percentage differences for gauging stations in region K_E = 5.0.

Table 3 Variables used for calculating percentage difference

RI flood peak	Approach	Description
$Q_{(prob)}$	Probabilistic approach (Normal distribution, Log-Pearson Type III and General Extreme Values)	RI flood peak from probabilistic approach
$Q_{(Kovacs\ ratio)}$	Q = Kovacs ratio (Q_T/Q_{RMF}) × Q_{RMF}	RI flood peak from Kovacs ratios Q_{RMF} calculated using K_E region

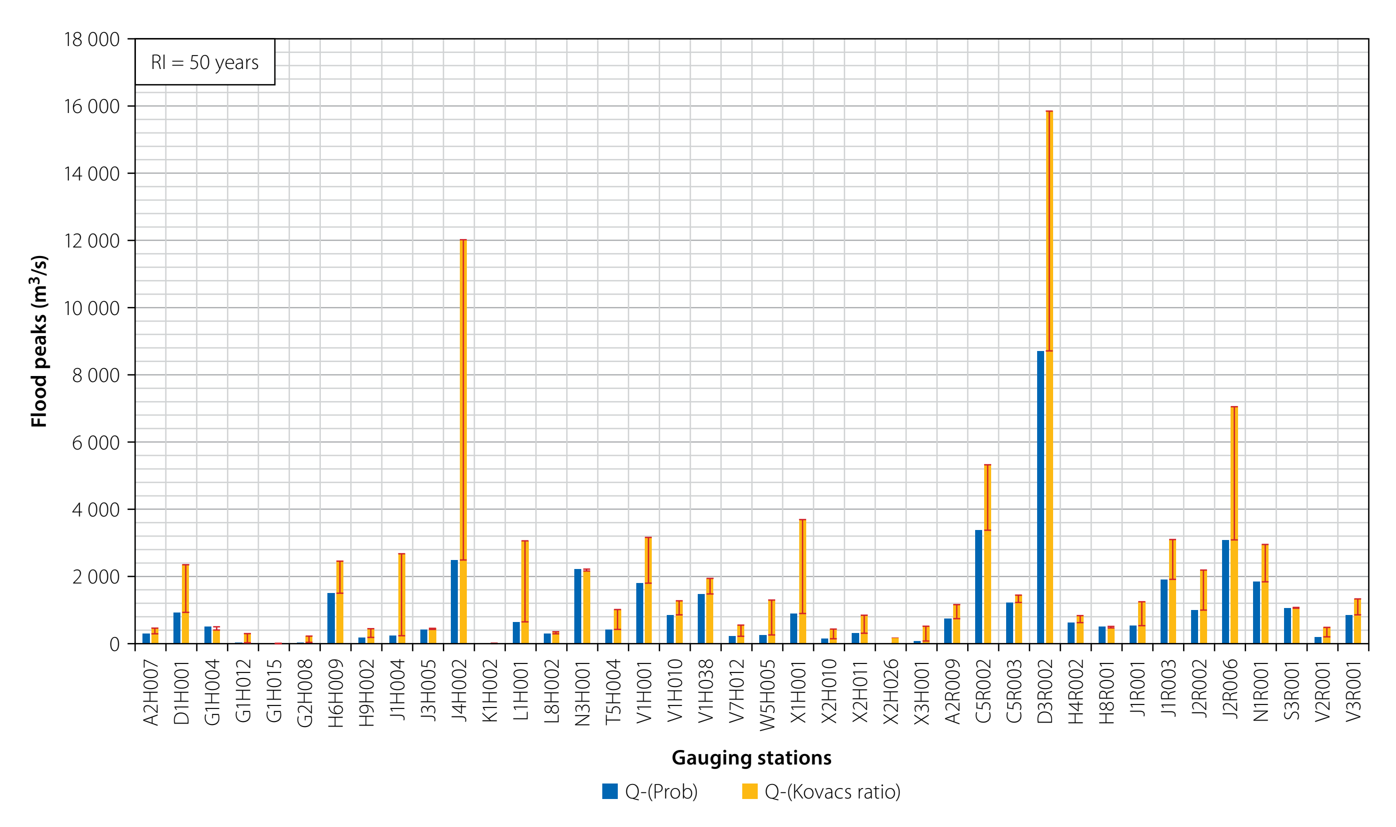


Figure 5 Comparison of RI flood peaks for a 50-year RI

Figure 5 shows the percentage difference calculated at each station. The bars are shown relative to the $Q_{(prob)}$ RI flood peak.

Data as presented in Table 4 was used to calculate the mean, smallest and largest difference percentages (assuming the probabilistic peak to be the correct peak) for K_E regions 3.4 to 5.6, and for RI 1:50- to 1:200-year. The results are presented in Table 5.

Figure 6 shows a graphical summary of percentage differences for each region.

According to Kovacs (1988), the average $Q_{T\ (Kovacs\ ratio)}$/RMF (ratio) for the 1:50, 1:100 and 1:200 year is 0.50, 0.575 and

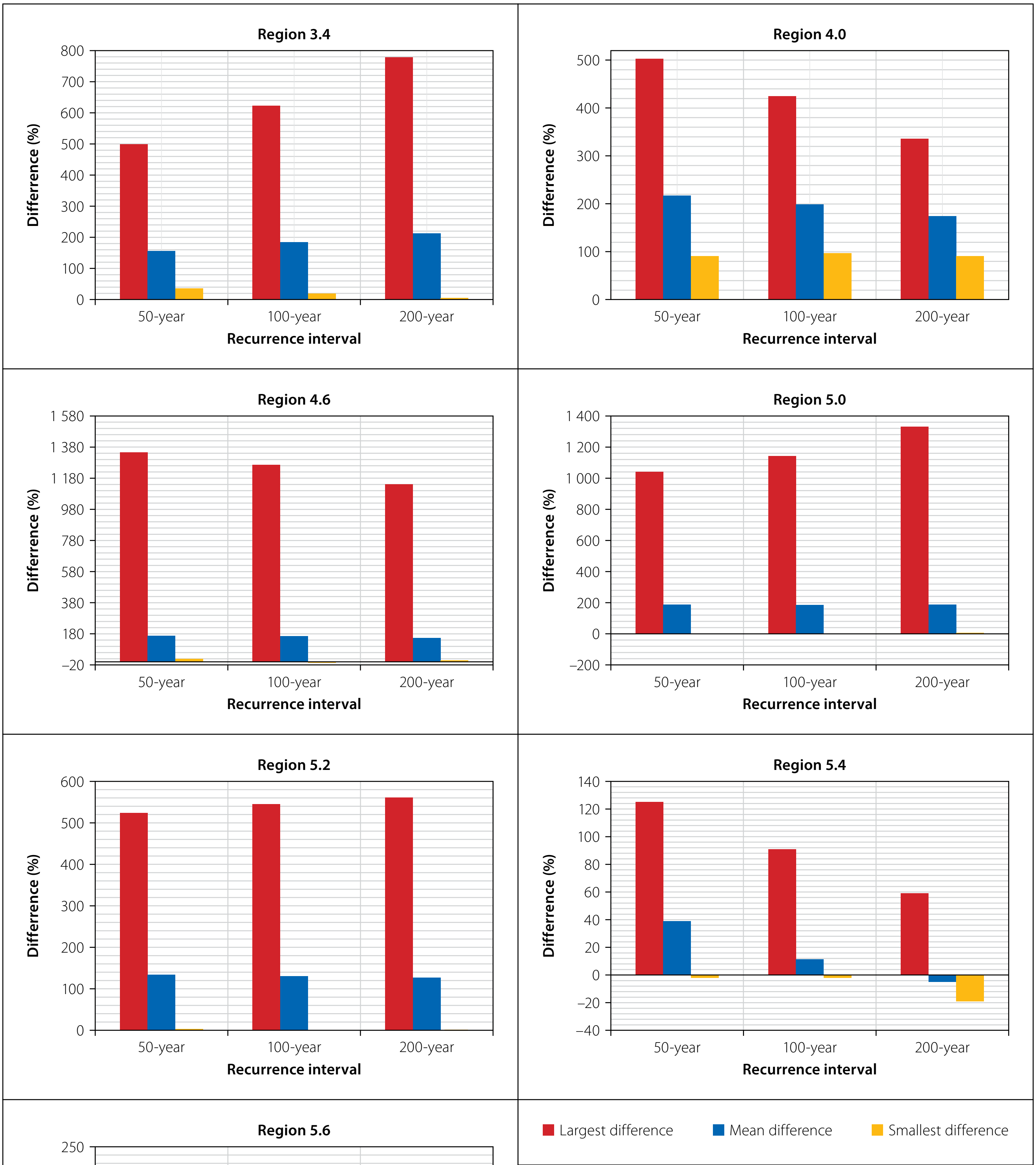
Table 4 Calculated differences between flood peaks for the 50-year RI

Station number	Catchment area (km²)	Historical maximum discharge (m³/s)	Kovacs K_E region		RI = 50-year			
			Kovacs K_E region	RMF (m³/s)	Q_T – (Prob) (m³/s)	Kovacs ratio	Q_T – (Kovacs ratio) (m³/s)	% diff
A2H007	142	65	5	1 192	291	0.39	461	58
D1H001	2 388	92	5	4 887	931	0.48	2 348	152
G1H004	70	227	5	837	503	0.48	403	–20
G1H012	36	13	5	600	28	0.50	298	966
G1H015	1.9	2	5	138	9	0.01	1	–86
G2H008	20	28	5	447	37	0.50	225	504
H6H009	2 008	133	5	4 481	1 503	0.55	2 454	63
H9H002	89	23	5	943	186	0.47	446	140
J1H004	3079	57	5	5 549	235	0.48	2 677	1 041
J3H005	95	31	5	975	421	0.47	458	9
J4H002	43 451	375	5	20 845	2 490	0.58	12 019	383
K1H002	3.8	4	5	195	13	0.02	3.47	–73
L1H001	3 938	141	5	6 275	650	0.49	3 061	371
L8H002	52	23	5	721	294	0.49	353	20
N3H001	1 597	181	5	3 996	2 218	0.54	2161	–3

Station number	Catchment area (km^2)	Historical maximum discharge (m^3/s)	Kovacs K_E region		RI = 50-year			
			Kovacs K_E region	RMF (m^3/s)	Q_T – (Prob) (m^3/s)	Kovacs ratio	Q_T – (Kovacs ratio) (m^3/s)	% diff
T5H004	545	88	5	2 335	423	0.43	1 013	140
V1H001	4 176	514	5	6 462	1 800	0.49	3 161	76
V1H010	782	243	5	2 796	855	0.46	1 276	49
V1H038	1 644	337	5	4 055	1 476	0.48	1 941	31
V7H012	196	45	5	1 400	221	0.39	553	150
W5H005	804	39	5	2 835	258	0.46	1 300	404
X1H001	5 503	165	5	7 418	896	0.50	3 690	312
X2H010	126	24	5	1 122	144	0.38	431	199
X2H011	402	93	5	2 005	309	0.42	843	173
X2H026	14	3	5	374	16	0.44	165	932
X3H001	174	15	5	1 319	81	0.39	516	539
A2R009	679	101	5	2 606	747	0.45	1 164	56
C5R002	10 268	219	5	10 133	3 376	0.53	5 326	58
C5R003	937	84	5	3 061	1 224	0.47	1 442	18
D3R002	70 665	2134	5	26 583	8 714	0.60	15 845	82
H4R002	396	12	5	1 990	625	0.42	834	34
H8R001	146	56	5	1 208	516	0.39	468	–9
J1R001	757	73	5	2 751	537	0.45	1 249	133
J1R003	4 030	120	5	6 348	1 916	0.49	3 100	62
J2R002	2 088	115	5	4 569	996	0.48	2 192	120
J2R006	17 055	226	5	13 059	3 086	0.54	7 050	128
N1R001	3 680	97	5	6 066	1 842	0.49	2 949	60
S3R001	602	38	5	2 454	1 057	0.44	1 078	2
V2R001	154	24	5	1 241	205	0.39	482	135
V3R001	834	223	5	2 888	855	0.46	1 332	56
							Average	186.6

Table 5 Percentage differences between ratio flood peaks and Q_{prob}

RI (years)	50			100			200		
RMF K_E regions	Mean difference (%)	Smallest difference (%)	Largest difference (%)	Mean difference (%)	Smallest difference (%)	Largest difference (%)	Mean difference (%)	Smallest difference (%)	Largest difference (%)
3.4	157	36	499	185	16	623	499	623	779
4.0	217	91	503	199	97	425	174	91	336
4.6	168	19	1 347	164	–6	1 267	153	10	1 141
5.0	187	2	1 041	184	–1	1 143	187	6	1 331
5.2	134	3	524	130	0.3	545	127	1	561
5.4	39	–2	125	11	–2	91	–4.8	–19	59
5.6	63	–21	220	40	–2	180	10	29	137



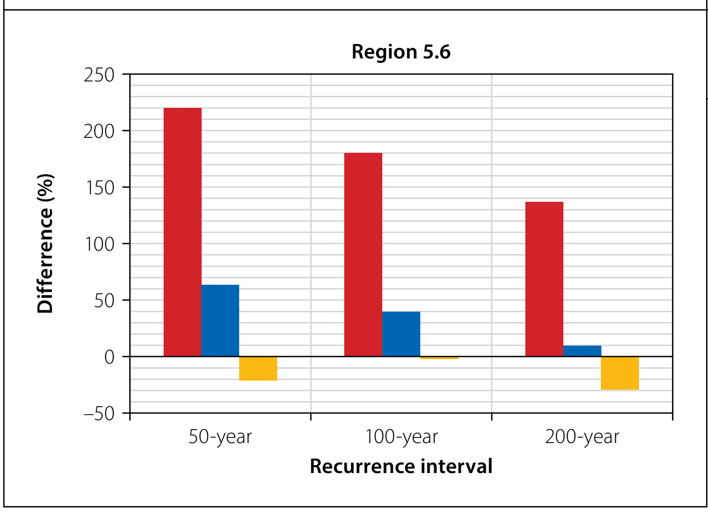


Figure 6 RMF K regional ratio differences

0.65 (Kovacs 1988), respectively. In this evaluation the average $Q_{T\text{-(Kovacs ratio)}}$/RMF and the $Q_{T\text{-(prob)}}$/RMF were determined as presented in Table 6.

DISCUSSION

From Analysis 1 it was clear that for 78% of the evaluated gauging stations in the Kovacs (1988) RMF approach, the RMF was 50% or more above the maximum observed flood peak, resulting in conservative RMF estimates.

Analysis 2 indicated the discrepancies between the DWS and Kovacs (1988) TR137 datasets. It was observed that 98% of

Table 6 Regional Q_T/RMF ratios for different RI

Region	RI = 50 year		RI = 100 year		RI = 200 year	
	$Q_{T\text{-(prob)}}$/RMF	$Q_{T\text{-(Kovacs ratio)}}$/RMF	$Q_{T\text{-(prob)}}$/RMF	$Q_{T\text{-(Kovacs ratio)}}$/RMF	$Q_{T\text{-(prob)}}$/RMF	$Q_{T\text{-(Kovacs ratio)}}$/RMF
3.4	0.23	0.40	0.31	0.5	0.40	0.60
4.0	0.23	0.85	0.28	0.93	0.32	0.98
4.6	0.29	0.45	0.38	0.55	0.36	0.65
5.0	0.20	0.33	0.21	0.39	0.27	0.45
5.2	0.10	0.35	0.25	0.42	0.34	0.52
5.4	0.35	0.43	0.51	0.51	0.7	0.64
5.6	0.47	0.56	0.68	0.69	0.96	0.70
Average	**0.27**	**0.48**	**0.37**	**0.57**	**0.48**	**0.65**

gauging stations had different observed/reported flood peaks for the same storm events. The average difference was 27%, with most of the Kovacs flood peaks exceeding those from the DWS dataset. While the analysis assumed that the published DWS dataset is correct and the best available data, some differences in the dataset cannot be excluded. It is, however, known that some of the flood peaks (probably those exceeding the flow-gauge capacity) used by Kovacs have been subjected to modification to enable the flood peak to fall on a regression line. A total of 33% of the gauging stations reflected different catchment areas between the two datasets, implying that these stations' RMF values, used by the DWS, are different from those used by Kovacs. The inconsistency was possibly due to the Kovacs computational and measurements methods available at the time.

Analysis 3 indicated that at two dam sites, the Kovacs (1988) RMF envelope curves were exceeded, and in some other cases the observed flood peaks were close to the 1988 RMFs.

The K_E regional boundaries might need to be adjusted to accommodate the observed larger flood peaks that exceeded the envelope curves.

Analysis 4 highlighted that many flood peaks also plotted significantly below the envelope curves.

Analysis 5 investigated the validity of the ratios suggested by Kovacs to convert RMF values to RI flood peaks. RI flood peaks calculated using the Kovacs ratios were greater than the RI flood peaks using a probabilistic approach, with significant differences, as presented in Table 5. It was found that Kovacs ratios produce too conservative RI flood peak estimates. Results presented on the review of the Kovacs Q_T/Q_{RMF} ratios indicate that these ratios are typically on average 0.20 more conservative for all RIs.

CONCLUSIONS

The uncertainties resulting from this research confirm the findings of various previous researchers, and indicate clearly that an update of the 1988 RMF approach is justified. It was clear from this research that the existing RMF ratios estimate too high RI flood peaks (ratios need to be reduced with 0.2 on average for all RIs). Therefore it is proposed that, until an update of the RMF approach provides different results, alternative methods should be used to estimate RI flood peaks.

In two regions (5.4 and 5.6) the existing envelope curves were already exceeded, and it can be concluded that these regions need to be re-assessed. Further inconsistencies indicated that more intermediate K_E RMF regions might be justified. However new intermediate K regions need to be justified based on, among other factors, the inclusion of hydroclimatic and geospatial characteristics. The 1988 RMF database parameter values need updating, and thereafter it is recommended that Kovacs's 1988 RMF method be updated and new RI ratios established.

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