ORIGINAL ARTICLE

A Comparative Evaluation of Empirical Methods for Estimating Instantaneous Peak Flow (Case Study: Zafarqand Basin)

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ABSTRACT

Regarding the significance of estimating instantaneous peak flow discharge in catchment basin for watershed management studies, the present study is aimed to select the most appropriate method via making a comparison between empirical relationships. Here, Fuller's method, empirical rational relationships and curve number are used. Resulted data was calculated in return periods 10-, 2-, 50-, and 200-year in each sub-basin. Also, the water flow passing the bridge existing in each sub-basin was calculated as probable flow. This study was conducted for 32 sub-basins in Ardistan Province, Isfahan. Finally, to compare the empirical methods of estimating flow discharge in each sub-basin, SPSS Software was used for each return period at a time. Results demonstrated that no significant difference was observed between Fuller's method and rational technique yet a significant difference was observed between the rational method and curve number and between Fuller's method and curve number (p<0.05). In most cases, the estimation of curve number method was higher than Fuller's and Fuller's is higher than the rational method. Hence, it can be concluded that the greater the area of basin is, the greater the differences between rational and Fuller's method results will be.
Key words*: Ardestan, Empirical method, Instantaneous peak flow discharge*

INTRODUCTION

With the critical role water plays in environmental and economic issues in our country and the application of the science of hydrology across the land, annually severe floods happen in different parts of Iran. In hydrology, it is always required that the size of incidences is estimated in the places where no data is observed. For instance, the design of a watercourse in a highway and/or the design of overflow for a modified dam in a watercourse need the estimation of peak flow discharge in a certain period which there may not exist in respective statistical area.

In this regard, domestic and foreign studies have been conducted some of which are implied here. In Greece, Mi Mi Ko (1990) showed that, in addition to average precipitation and area of the watershed, three major factors play a great role in the incidence of flood discharges: main watershed slope, the frequency of watercourses, and the index related to soil. Chive conducted researches on the simultaneous use of eye and gap. [2] Doing so, he gained considerable results regarding the control of scour. He observed that an eye with a diameter twice times the basis diameter can reduce scour depth as about %20, whereas if a gap with a width of 0.25b (or one fourth of the basis width) is also added then the scour depth will reach 0.

Studying the data of flood in the South basins of Central Africa, Rodir concluded that the variables of runoff coefficient have been the most important effect regarding the basin's physiographic factors. Telvari has evaluated the efficiency of some empirical methods such as Kriger, Horton, and Fuller methods to estimate maximum flood flow discharge in Karkheh watershed, and concluded that Fuller's method is a suitable technique in estimating maximum flood discharge due to considering quantitative geomorphologic characteristics, vegetation and climate. [18] In a study on 10 watersheds in Azerbaijan zone and Northern Alborz, Yazdani examined maximum flood flow discharge using 7 methods. [17] Results indicated that among Kriger, Mayer, Horton, Brid and Mc Ilirt, SCS, graphic SCS, and FHWA for all basins under study, the graphic method and FHWA respectively have minimum and maximum error.

MATERIALS AND METHODS

The Geographical Status of the Area under Study
Ardistan Province ($A=11591 Km^2$) is located 118km from the Northeast of Isfahan Province's center. Ardistan Province is located N33'23° and E52'22°. Zafarqnad has 32 sub-basins.

Methods
To design the water structures in the areas where there is no hydrologic data to determine flood, many empirical formulae are offered by hydrologists corresponding to special areas. In this study, three methods are used: rational, Fuller, and curve number.

First Method: Rational Relationship
This method is applied for small basins and in particular in urban hydrology to commercially design drainage (Equation 1).

(1)

Q: maximum flood M^3/Sec

$$Q = 0/278 C.I.A$$

A: the area of basin taking part in flow Km^2
I: shower intensity m.m/h

C: ground flow coefficient, from the table related to the American Association of Civil Engineering (ASCE) and Water Pollution Committee (WPCE) resulted from single showers

Second Method: Fuller's Relationship
This method is proposed for calculating maximum flood flow discharge with different return periods (Eq. 2 & 3).

(2)

$$q(T) = q_1 + 0/8 \log 10T)$$

$$q_m = q(t)\left(1 + \frac{2/66}{A}\right)$$

(3)

q_1: average maximum flow discharges in each year (annual overflow) based on statistical data

q(t): maximum flood flow discharge with different return periods

q_m: maximum instantaneous flow discharge

Third Method: Estimating the Height of Runoff in Curve Number Method and NRCS
In this method developed based on several observations in different well-known basins and in various American climates, the height of rain runoff is gained from the following equation which cannot be used for precipitations like snow and does not include basic water, as well [15, 16, 17, 18]. (Eq. 4).

$$Q = \frac{(P - 0/2S)^2}{P + 0/8S}$$

(4)

Q: the height of runoff
P: the height of precipitation in 24h
S: maximum strength related to intercession and permeation into soil and ground reserve
Recent studies show that a notation of 0.2 for S might be good for great showers in nonurban areas but it is too much for small and medium showers as well as urban areas. Sum of permeation amount for a rain incident can be as follow (Eq. 5 & 6):

$$F = \frac{\left(P - \frac{0}{2S}\right)S}{P + \frac{0}{2S}}$$

(5)

For P>0.2S, the permeation intensity (f) is:

$$f = \frac{dF}{dt} = \frac{s^2 i}{(P + 0/8S)^2}$$

(6)

Where i is the rain intensity (i=dP/dt).
Total loss or S is gained with a dimensionless factor called Curve Number (CN).
Formula

Field Studies

Estimating Flow Discharge
To estimate maximum by Maning's method, the watercourse intersection was required. To do so, in addition to rotation area, the field visit of the intersections of all respective watercourses was done. After surveying the height of points from the bottom of the watercourse up to the balance line (a line connecting the past floods hot waters) and the interval distances of the points, the data was entered into Auto CAD Software and the intersection of the intercourse was drawn. Using respective options, the area

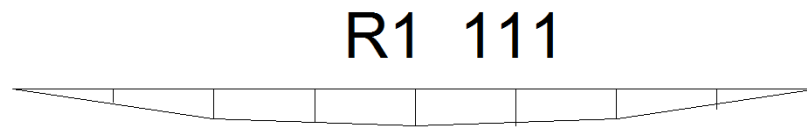of watercourse was estimated. In Figure (2) illustrates an example of the intersections drawn by the software.

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Fig (2): drawing the watercourses' intersections by the aid of Auto CAD Software

Estimating the Dimensions of Bridge Span

For the sake of comparison regarding the existence of a rational relationship between maximum flow discharge and bridges' span, the dimensions of all bridges were collected.

Estimating Concrete Compressive Strength

To estimate the compressive strength of concrete used in bridges, three points of the bridge section was randomly beaten by Schmidt's hammer and average numbers gained was chosen as the compressive strength.

Estimating the Presence and Absence of Scour

To do so, during the field visit of respective area, most foundations were not exposed to scour and/or if they were the extent of scour was insignificant (except seven cases). The amount of their scour is presented in Table (1).

Table (1): The amount of their scour in the foundations of bridges in the area under study

Number	Code	) cm (**amount of scour**
1	100	5
2	103	5
3	105	10
4	107	10
5	108	4
6	109	6
7	126	5

It must be noted that all topographic maps (scale=1:25000) were prepared from their respective offices in digital form and the surveyed points including bridges and respective watercourses were specified on them using Arc GIS and Arc View softwares.

Since the empirical formulae are mainly based on the physiographic characteristics of basins, hence these characteristics were calculated for the area under study using GIS.

Data Analysis

In the present study, to compare the methods, data normalization was examined using Shapiro-Wilk. Since data was not normal, to make a total comparison, nonparametric Kruskal-wallis test was used and, in case of any differences ($p<0.05$), Mann-withney U test was used for two-by-two comparison.

RESULTS

After data collection, the probable floods in return periods 10-, 2-, 50-, and 200-year was calculated using Fuller, rational, curve number and Manning's methods. The methods were compared and the best one was chosen regarding the rational estimation of flood. Results of the above methods are presented in Tables (2-3-4-5).

Table (2) Estimation of Peak flow with rational method for different return periods

Sub Basin	A(km²)	Tc(hr)	2	10	50	200
201	0.29	1.01	0.28	0.50	0.71	0.89
202	0.66	1.55	0.65	1.13	1.62	2.03
203	0.71	2.48	0.49	0.86	1.23	1.55
204	0.097	2.30	0.07	0.12	0.17	0.21
100	0.47	0.84	0.46	0.81	1.15	1.45
101	0.18	1.95	0.13	0.22	0.31	0.39
102	0.58	1.56	0.40	0.71	1.01	1.27
103	0.025	2.53	0.02	0.03	0.04	0.05
104	0.86	0.28	1.22	2.13	3.04	3.83
105	0.0675	2.89	0.04	0.07	0.10	0.12
106	0.74	0.65	0.84	1.47	2.10	2.65

107	0.125	2.36	0.60	1.05	1.49	1.88
108	0.157	1.38	0.15	0.27	0.38	0.48
109	11.51	1.25	11.27	19.72	28.17	35.45
110	0.63	4.46	0.62	1.08	1.54	1.94
111	0.27	1.71	0.19	0.33	0.47	0.59
112	10.5	1.49	10.28	17.99	25.70	32.34
113	5.89	2.81	3.55	6.15	8.57	10.63
114	1.42	2.34	0.99	1.73	2.47	3.11
115	0.12	0.87	0.12	0.21	0.29	0.37
116	2.29	0.66	2.24	3.92	5.61	7.05
117	0.1	2.03	0.07	0.12	0.17	0.22
118	0.055	0.86	0.05	0.09	0.13	0.17
119	5.61	0.49	7.94	13.9	19.85	24.98
120	1.07	2.49	0.74	1.3	1.86	2.34
121	0.72	0.95	0.71	1.23	1.76	2.22
122	0.41	1.42	0.4	0.7	1	1.26
123						
124	0.035	0.37	0.02	0.03	0.04	0.05
125	0.05	0.37	0.58	1.02	1.45	1.83
126	0.03	0.6	0.04	0.07	0.11	0.13

Table(3)Estimation of Peak flow with Fulerl method for different return periods

number	code	2	10	50	200
1	201	0.60	0.88	1.15	1.38
2	202	0.96	1.40	1.83	2.21
3	203	1.00	1.46	1.91	2.30
4	204	0.33	0.48	0.63	0.75
5	100	0.79	1.15	1.51	1.82
6	101	0.46	0.67	0.88	1.06
7	102	0.89	1.30	1.70	2.05
8	103	0.16	0.23	0.30	0.36
9	104	1.12	1.63	2.14	2.57
10	105	0.27	0.39	0.51	0.62
11	106	1.03	1.49	1.96	2.36
12	107	0.38	0.55	0.72	0.87
13	108	0.43	0.62	0.82	0.98
14	109	5.39	7.82	10.25	12.33
15	110	0.94	1.36	1.79	2.15
16	111	0.58	0.84	1.10	1.33
17	112	5.08	7.38	9.67	11.64
18	113	3.54	5.15	6.75	8.12
19	114	1.50	2.18	2.86	3.45
20	115	0.37	0.54	0.70	0.85
21	116	2.00	2.90	3.80	4.57
22	117	0.33	0.49	0.64	0.77
23	118	0.24	0.35	0.46	0.55
24	119	3.44	4.99	6.55	7.88
25	120	1.27	1.85	2.43	2.92
26	121	1.01	1.47	1.93	2.32
27	122	0.73	1.07	1.40	1.68
28	123				
29	124	0.19	0.28	0.36	0.43
30	125	0.23	0.33	0.44	0.53
31	126	0.17	0.25	0.33	0.40
32	127				

Table(4)Estimation of Peak flow with maning method for different return periods

Number	code	A(cm2)	A(m2)	P+T	T	P	p(m)	R	s(m/m)	n	Qmax	Qmax
1	201	27550	2.755	3911	2700	1211	12.11	0.23	0.041	0.16	1.31	1.31
2	202	7551	0.7551	847	420	427	4.27	0.18	0.04	0.16	0.30	0.30
3	203	31400	3.14	3556	1775	1781	17.81	0.18	0.039	0.16	1.23	1.23
4	204	6845	0.6845	1249	620	629	6.29	0.11	0.037	0.16	0.19	0.19
5	100	16376	1.6376	1398	696	702	7.02	0.23	0.039	0.16	0.77	1.14
		12156	1.2156	2033	1014	1019	10.19	0.12	0.039	0.16	0.37	
6	101	3100	0.31	602	300	302	3.02	0.10	0.038	0.16	0.08	0.22
		3760	0.376	468	230	238	2.38	0.16	0.038	0.16	0.14	
7	102	6917	0.6917	1193	595	598	5.98	0.12	0.038	0.16	0.20	0.20
8	103	24424	2.4424	1450	714	736	7.36	0.33	0.039	0.16	1.46	1.46
9	104	5630	0.563	671	330	341	3.41	0.17	0.037	0.16	0.21	0.53
		6339	0.6339	676	333	343	3.43	0.18	0.037	0.16	0.25	
		2590	0.259	429	210	219	2.19	0.12	0.037	0.16	0.08	
10	105	13140	1.314	1883	940	943	9.43	0.14	0.036	0.16	0.42	0.42
11	106	_		_	_	_	_	_	_	0.16	_	_
12	107	2108	0.2108	609	254	355	3.55	0.06	0.033	0.16	0.04	0.19
		848	0.0848	212	104	108	1.08	0.08	0.033	0.16	0.02	
		4025	0.4025	872	435	437	4.37	0.09	0.033	0.16	0.09	
		2600	0.26	1204	600	604	6.04	0.04	0.033	0.16	0.04	
13	108	500	0.05	281	140	141	1.41	0.04	0.029	0.16	0.01	0.09
		3737	0.3737	753	375	378	3.78	0.10	0.029	0.16	0.09	
14	109	5592	0.5592	1119	557	562	5.62	0.10	0.049	0.16	0.17	0.68
		8720	0.872	1192	594	598	5.98	0.15	0.049	0.16	0.34	
		3810	0.381	1262	630	632	6.32	0.06	0.049	0.16	0.08	
		4510	0.451	1642	820	822	8.22	0.05	0.049	0.16	0.09	
15	110	7550	0.755	1625	810	815	8.15	0.09	0.035	0.16	0.18	0.21
		2025	0.2025	1082	540	542	5.42	0.04	0.035	0.16	0.03	
16	111	1800	0.18	482	240	242	2.42	0.07	0.029	0.16	0.03	1.03
		35825	3.5825	5420	2700	2720	27.2	0.13	0.029	0.16	1.00	
17	112	11390	1.139	2532	1260	1272	12.72	0.09	0.091	0.16	0.44	0.69
		6495	0.6495	1436	715	721	7.21	0.09	0.091	0.16	0.25	
18	113	_		_	_	_	_	_	_	0.16	_	_
19	114	_		_	_	_	_	_	_	0.16	_	_
20	115	2576	0.2576	728	363	365	3.65	0.07	0.048	0.16	0.06	0.06
21	116	_		_	_	_	_	_	_	0.16	_	_
22	117	_		_	_	_	_	_	_	0.16	_	_
23	118	_		_	_	_	_	_	_	0.16	_	_
24	119	_		_	_	_	_	_	_	0.16	_	_
25	120	_		_	_	_	_	_	_	0.16	_	_
26	121	2160	0.216	443	220	223	2.23	0.1	0.053	0.16	0.07	0.07
27	122	14610	1.461	1676	930	746	7.46	0.2	0.044	0.16	0.65	0.65
28	123	_		_	_	_	_	_	_	0.16	_	_
29	124	2901	0.2901	590	293	297	2.97	0.1	0.052	0.16	0.09	0.15
		2290	0.229	622	310	312	3.12	0.07	0.052	0.16	0.06	
30	125	4020	0.402	585	290	295	2.95	0.14	0.047	0.16	0.15	0.15
31	126	4545	0.4545	572	282	290	2.9	0.16	0.048	0.16	0.18	0.18
32	127	_		_	_	_	_	_	_	0.16	_	_

Table (5) Estimating the maximum of discharge in Curve Number Method for different return periods

number	code	Tc(min)	Tp (min)	Tp (h)	CN	S (mm)	P (mm)	Q(mm)	Q(cm)	Qmax (m3/s)
1	201	92.99	15.22	0.25	66.00	130.85	52.00	10.68	1.07	2.54
2	202	148.60	21.11	0.35	66.00	130.85	52.00	10.68	1.07	4.17
3	203	138.27	20.06	0.33	66.00	130.85	52.00	10.68	1.07	4.73
4	204	50.24	10.10	0.17	66.00	130.85	52.00	10.68	1.07	1.28
5	100	117.09	17.85	0.30	66.00	130.85	52.00	10.68	1.07	3.52
6	101	93.60	15.29	0.25	66.00	130.85	52.00	10.68	1.07	1.57
7	102	151.85	21.43	0.36	66.00	130.85	52.00	10.68	1.07	3.61
8	103	16.98	5.14	0.09	66.00	130.85	52.00	10.68	1.07	0.65
9	104	173.35	23.57	0.39	66.00	130.85	52.00	10.68	1.07	4.87
10	105	39.11	8.60	0.14	66.00	130.85	52.00	10.68	1.07	1.05
11	106	141.64	20.40	0.34	66.00	130.85	52.00	10.68	1.07	4.84
12	107	82.95	14.08	0.23	66.00	130.85	52.00	10.68	1.07	1.18
13	108	74.99	13.16	0.22	66.00	130.85	52.00	10.68	1.07	1.59
14	109	267.67	32.42	0.54	66.00	130.85	52.00	10.68	1.07	47.39
15	110	102.36	16.26	0.27	66.00	130.85	52.00	10.68	1.07	5.17
16	111	89.62	14.84	0.25	66.00	130.85	52.00	10.68	1.07	2.43
17	112	168.61	23.10	0.39	66.00	130.85	52.00	10.68	1.07	60.67
18	113	140.48	20.28	0.34	66.00	130.85	52.00	10.68	1.07	38.77
19	114	52.10	10.34	0.17	66.00	130.85	52.00	10.68	1.07	18.32
20	115	39.78	8.69	0.14	66.00	130.85	52.00	10.68	1.07	1.84
21	116	121.51	18.31	0.31	66.00	130.85	52.00	10.68	1.07	16.69
22	117	51.48	10.26	0.17	66.00	130.85	52.00	10.68	1.07	1.30
23	118	29.54	7.21	0.12	66.00	130.85	52.00	10.68	1.07	1.02
24	119	149.50	21.20	0.35	66.00	130.85	52.00	10.68	1.07	35.33
25	120	56.99	10.97	0.18	66.00	130.85	52.00	10.68	1.07	13.02
26	121	85.18	14.34	0.24	66.00	130.85	52.00	10.68	1.07	6.70
27	122	52.62	10.41	0.17	66.00	130.85	52.00	10.68	1.07	5.26
28	123	_	_	_	_	_	_	_	_	_
29	124	22.19	6.04	0.10	66.00	130.85	52.00	10.68	1.07	0.77
30	125	36.00	8.16	0.14	66.00	130.85	52.00	10.68	1.07	0.82
31	126	19.99	5.67	0.09	66.00	130.85	52.00	10.68	1.07	0.71
32	127	_	_	_	_	_	_	_	_	_

Finally, to calculate maximum probable flow discharge based on the dimensions of the bridges' spans, the intersection required was calculated for the passage of maxim probable flood and maximum probable water velocity. The examination of suitable intersection of bridges for maximum flood flow discharge is presented in Table (6).

Table (6): the number of bridges with suitable span dimensions in different return periods

return periods	the number of bridges with suitable span
2	18
10	13
50	12
200	8

In studying the intersections of the bridges, 10 out of 32 basins in the area under study (codes: 106, 113, 114, 116, 117, 118, 119, 120, 123, 127) were omitted because of not having any specific basin and the 22

others were compared using Fuller, rational, curve number and Manning's methods with maximum flow discharge through bridges intersections and the results are presented in Diagrams (1), (2), (3), and (4).
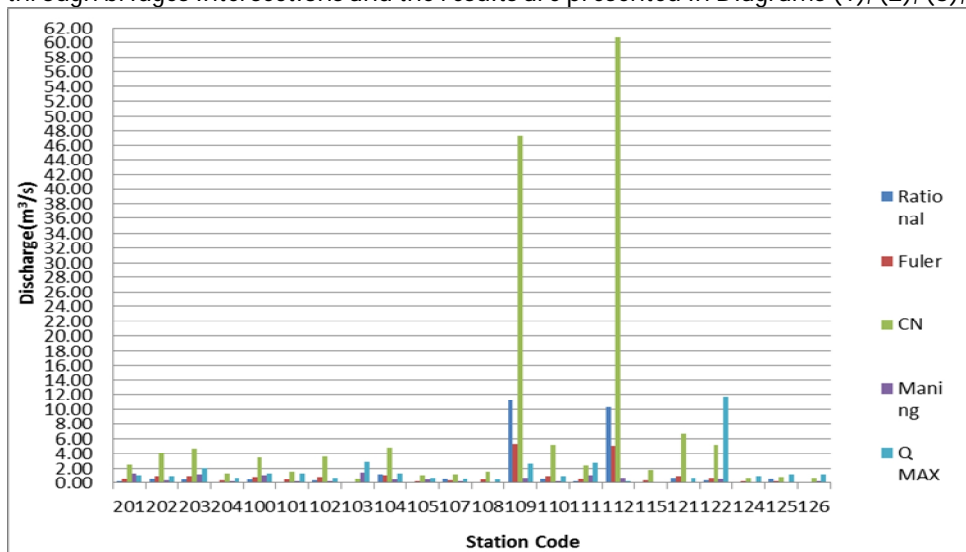

Diagram (1): comparing maximum flow discharges in 2-year return period with maximum probable flow discharge
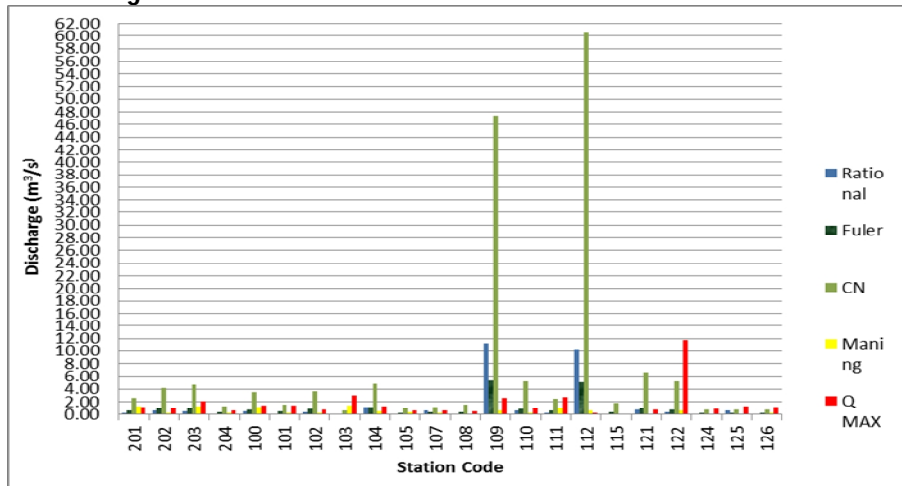

Diagram (2): comparing maximum flow discharges in 10-year return period with maximum probable flow discharge
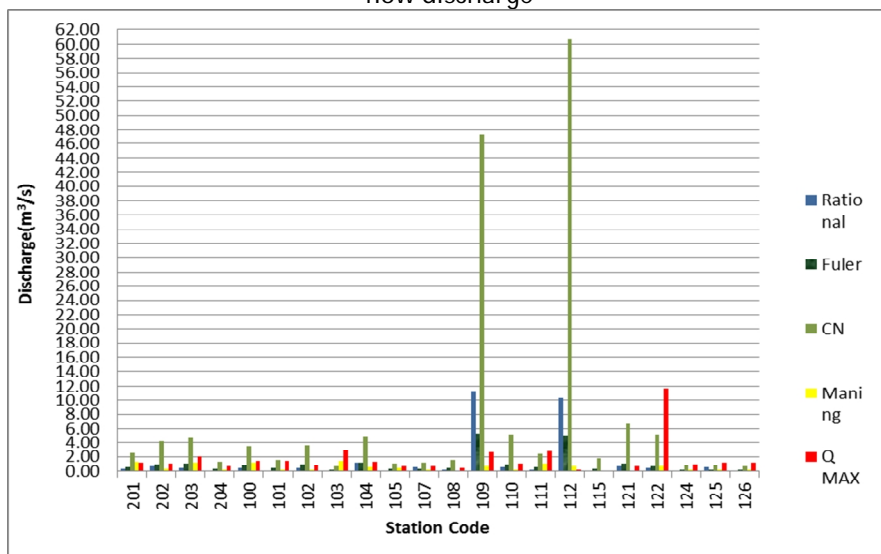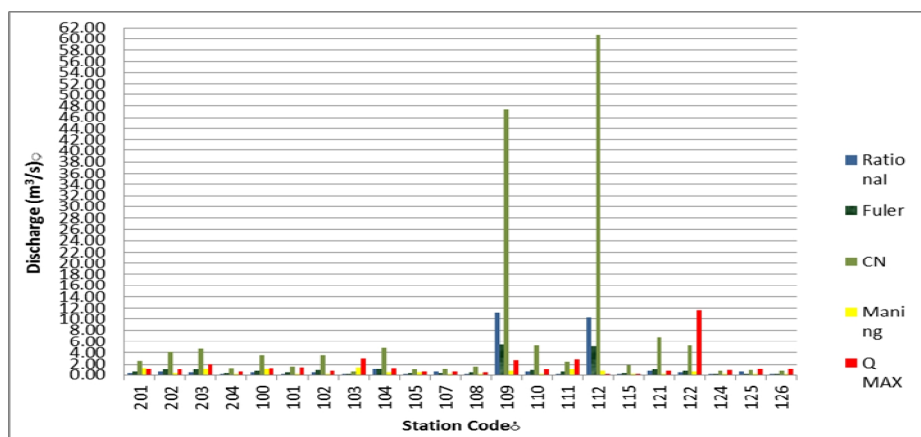

Diagram (3): comparing maximum flow discharges in 50-year return period with maximum probable flow discharge

Diagram (4): comparing maximum flow discharges in 200-year return period with maximum probable flow discharge

DISCUSSION AND CONCLUSION

Regarding the above diagrams, it can be concluded that the significant differences between estimations in basins 108 and 111 is due to very low concentration time. The simultaneous increase of watercourse length and reduction of height difference and the reduction of slope lead to the reduction of concentration time using Makcus method. Based on the abovementioned, following results can be implied: curve number method is highly sensitive to area factor so that, in basins with over 50 acre area, the estimation is too large and most of the time illogical. In most cases, curve number's estimation is more than Fuller's and the Fuller's one is more than the rational method estimation. Results of Fuller and rational method are close in most cases. The larger the area of basin is, the further the differences of results from the two methods will be. Based on the results of the number of bridges with suitable span dimensions in different return periods, it seems that in most cases the span dimensions were calculated based on Maning' method and determined as suitable. Whereas results of rational method, curve number and Fuller are higher estimations. There was no significant difference between rational and Fuller method yet the difference was significant between rational and curve number methods as well as Fuller and curve number methods ($p < 0.05$). The results of estimating the concrete compressive strength of the bridges using Schmidt's hammer demonstrate that the existing concrete has adequate strength against the compressive forces from live and dead loads. Also, using the hammer for estimation was in a non-destructive form the results of which are not reliable and definite. Yet, they are considered as criterion for estimating strength. Another important issue is concrete durability in melt-freeze cycles and minerals like sulfates. In most cases, concrete surface cracks and armature corrosion is observed. About %22 of bridges are exposed to mild scour which, with respect to the deep foundations of bridges, it does not seem that such scours lead to any problems by posing sub-pressure forces. Frequently, the estimation by curve number method is more than Fuller's and Fuller's is more than the rational method, so it can be concluded that the greater the area of basin is, the greater the difference between the results of rational and Fuller's methods will be. [12] Also concluded that Fuller's method is the best for estimating maximum flood flow discharge in most sub-basins of the area under study with respect to quantitative geomorphologic qualities, vegetation, and climate.

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