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Improved Continuing Losses Estimation Using Initial Loss-Continuing Loss Model for Medium Sized Rural Catchments

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Abstract: Problem statement: The rainfall based design flood estimation techniques are commonly adopted in hydrological design and require a number of inputs including information on soil loss characteristics. **Approach:** A conceptual loss model known as the 'Initial Loss-Continuing Loss (IL-CL) model' is widely used in Australia. **Results:** The Initial Loss (IL) occurs at the beginning of the rainfall event, prior to the commencement of surface runoff and the Continuing Loss (CL) is the average rate of loss throughout the remainder of the storm. The currently recommended design loss values depicted in "Australian Rainfall and Runoff Vol. 1" for Queensland (Australia) has some basic limitations. This study investigated how more accurate CL values can be estimated and derived for medium sized tropical Queensland catchments using long term rainfall and streamflow data. Accuracy in CL estimation has got significant implications in the estimation of design floods. **Conclusion/Recommendations:** The results showed that CL value is not fixed and constant through out the duration of the storm but the CL value decays with the duration of the storm.

Key words: Initial loss, continuing loss, rural catchments, flood estimation, rainfall-runoff modeling

PROBLEM STATEMENT

Flood estimation is often required in hydrologic design and has important economic significance[2]. Flood estimation and risk analysis in Australia involves an annual spending of the order of $650 million[4]. Rainfall-based flood estimation techniques are most commonly adopted and often require several inputs/parameters to convert design rainfalls to design floods[6,8]. Of the many inputs/parameters, the concept "loss" is an important parameter. Loss is the amount of precipitation that does not appear as direct runoff. Factors pertaining to loss in effect reduce the runoff during a flood event[2,7].

In design flood estimation, simplified lumped conceptual loss models are commonly used because of their simplicity and ability to approximate catchment runoff behavior. Secondly, the detailed parameters needed for calculating individual loss components are generally not available. This is particularly true for design loss which is probabilistic in nature and for which complicated theoretical models may not be required. The common loss factors include rainfall intercepted by vegetation (interception loss), infiltration into the soil (infiltration), retention on the surface (depression storage), evaporation and loss through the streambed and banks. As these loss components are dependent on topography, soil characteristics, vegetation and climate; the components exhibit a high degree of temporal and spatial variability during high rainfall events. Many loss models do not account for the interception, depression storage and evaporation losses separately. Instead, such losses are considered as infiltration into the soil. In Australia, the most commonly adopted conceptual loss model is the initial loss-continuing loss model[1,4,6]. The initial loss occurs prior to the commencement of surface runoff and can be considered to be composed of the interception loss, depression storage and infiltration that occur before the soil surface is saturated. In design rainfall events, the continuing loss is computed as the average rate of loss that occurs up to the end of the rainfall event, after the initial loss is satisfied.

Selection of catchments: This study was aimed at deriving new improved design losses for Queensland catchments. A total of 48 unregulated rural catchments were selected from the entire state of Queensland. The selection of catchments was done based on the catchment size, regulation, record lengths of rainfall and streamflow data. However, from these primarily selected catchments, final selection of catchments was done based on location of the pluviograph station, daily rainfall station, streamflow gauging station and the catchment boundary.

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Catchment area: A primary selection parameter was size of the catchment; small or large. The loss (IL-CL) model which was used in this research is only suitable for small to medium size catchments and not suitable to compute the loss values for the larger catchments. The reason is that the process of computing loss values for larger catchments is different from the process of computing loss values for smaller catchments. It was observed that for larger catchments there is lack of uniformity in catchment characteristics than in smaller to medium sized catchments. Laurens on and Pilgrim[5] mentioned that catchment characteristic is a factor which affects the loss value. Australian Rainfall and Runoff[4] suggests the catchment area with an upper limit of 1000 km^2 can be considered as a small to medium sized catchments, which was taken as a guide to selecting the study catchments.

Regulation: To select the study catchments, consideration was given to whether the study catchments were regulated or unregulated, as major regulation affects the natural rainfall-runoff relationship significantly. Gauging stations subject to major regulation (such as dams, gates, diversions and back water effect) were not included in this study. Also urbanization affects the catchment hydrology, so no urban catchment was selected. Only unregulated rural catchments were selected for this study. Topographic Maps of Australia (1:100000) were consulted to investigate the nature of streamflow network and nature of regulation in the selected catchments. Also the gauging authority was consulted to know about any recent changes of regulation and land use in the selected catchments.

Record length: It was aimed to have significantly longer record lengths for the length of the rainfall and streamflow data of the catchments under study, as more number of rainfall and streamflow events will produce more reliable results. Among collected data, the highest record length of streamflow data is 48 years and the lowest record length of streamflow data is 11 years. The mean and median values of streamflow record length are 30 and 31 years. A total of 132 pluviograph stations and 338 daily rainfall stations were selected from and near the selected catchments. The rainfall data were obtained from the Bureau of Meteorology (BoM), Australia.

Catchment boundary: All the 48 catchment boundaries were collected from the Department of Natural Resources and Mines in electronic format. Mapinfo Professional 5.0 was used to delineate the catchment boundary for the selected catchments.

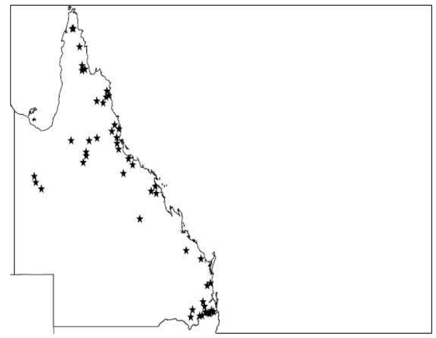


Fig. 1: Map of Queensland showing catchment locations

After mapping the catchment boundary, an electronic layer of stream gauging stations were laid over the catchment boundary. The catchments whose location of the stream gauging station in the map was found away from the catchment boundary, that catchment was not selected as study catchment. Catchments were selected, when there was one or more pluviograph station or daily rainfall stations within the catchment boundary. To select a rainfall streamflow event to estimate loss values the temporal pattern of the rainfall over the catchment is necessary. Catchments with only one pluviograph station but no daily rainfall station within the catchment boundary were selected as candidate catchments. As the catchments were small to medium in size, it was assumed that the temporal pattern of the pluviograph data was the representative temporal pattern of the whole catchment, provided the pluviograph station was located well inside the catchment boundary. But catchments with no pluviograph station inside or within 50 km of the catchment boundary were not selected as study catchments, though there was daily rainfall station within or near the catchment boundary. Again catchments having a pluviograph station close to the boundary and with daily rainfall stations within the catchment boundary were selected as study catchments. Because, it was assumed that when the pluviograph station and daily rainfall station are closely located, the temporal pattern of the daily rainfall station and the pluviograph station were same. Hence the pluviograph data can be used to proportion the daily rainfall data to obtain the representative temporal pattern of rainfall within the catchment.

The distribution of the candidate catchments selected from all over the Queensland is shown in Fig. 1. The locations of the study catchments were identified by the electronic layer of catchment boundaries with in the Queensland boundary using Mapinfo Professional.

Table 1: Stream gauge station number, location, catchment area and streamflow record length of the study catchments

Sr. No.	Basin ID	Streamflow name	Location of stream gauging station	Lat. of stream gauge	Long. of stream gauge	Catchment area (km^2)	Start date of streamflow	Finish date of streamflow
1	102101A	Pascoe river	Fall creek	12.87	142.97	635	1/10/1967	Continue
2	104001A	Stewart river	Telegraph road	14.17	143.38	480	18/01/1970	"
3	105105A	E. Norman by river	Development road	15.77	145.00	300	24/02/1969	"
4	107001B	Endeavour river	Flaggy	15.42	145.05	310	1/10/1967	"
5	107003A	Anna river	Beesbike	15.68	145.20	247	9/03/1990	"
6	112003A	N. Johnston river	Glen allyn	17.37	145.65	173	1/10/1958	"
7	112101B	S. Johnston river	Upstream central meal	17.60	145.97	400	1/10/1974	"
8	114001A	Murray river	Upper murray	18.10	145.80	155	26/05/1970	"
9	116008B	Gowrie creek	Abergowrie	18.43	145.83	124	1/10/1953	"
10	116015A	Blunder creek	Wooroora	17.73	145.43	127	20/10/1966	"
11	116017A	Stone river	Running creek	18.77	145.95	157	30/06/1970	"
12	118003A	Bohle river	Hervey range road	19.32	146.70	143	1/04/1985	"
13	119006A	Major creek	Damsite	19.67	147.02	468	4/05/1978	"
14	120014A	Broughton river	Oak meadows	20.17	146.32	182	5/11/1970	13/04/1999
15	120216A	Broken river	Old racecourse	21.18	148.43	78	1/06/1969	"
16	124002A	St. Helens creek	Calen	20.90	148.75	129	7/02/1973	"
17	125005A	Blacks creek	Whitefords	21.32	148.82	505	12/12/1973	"
18	130207A	Sande creek	Clermont	22.78	147.57	409	21/01/1965	"
19	136108A	Monal creek	Upper monal	24.60	151.10	92	15/07/1962	"
20	137101A	Gregory river	Burrum highway	25.08	152.23	454	10/02/1966	"
21	138110A	Mary river	Bellbird creek	26.62	152.70	486	1/10/1959	"
22	141009A	N. Maroochy river	Eumundi	26.48	152.95	38	15/02/1982	"
23	143110A	Bremer river	Adams bridge	27.82	152.50	125	30/09/1968	"
24	143212A	Tenhill creek	Tenhill	27.55	152.38	447	18/03/1968	"
25	145003B	Logan river	Forest home	28.20	152.77	175	1/10/1953	"
26	145010A	Running creek	5.8 km Deickmans bridge	28.23	152.88	128	26/11/1965	"
27	145011A	Teviot brook	Croftby	28.13	152.57	83	7/02/1966	"
28	146014A	Back creek	Beechmont	28.12	153.18	7	5/06/1971	"
29	145101D	Albert river	Lumeah number 2	28.05	153.03	169	1/10/1953	"
30	416410A	Macintyre brook	Barongarook	28.43	151.45	465	15/06/1967	"
31	422321B	Spring creek	Killarney	28.35	152.32	35	1/10/1972	"
32	422338A	Canal creek	Leyburn	28.02	151.58	395	27/03/1972	"
33	422394A	Cadamine river	Elbow vally	28.37	152.13	325	2/12/1972	"
34	913005A	Paroo creek	Damsite	20.33	139.52	305	20/11/1968	1/10/1988
35	913009A	Gorge creek	Flinders highway	20.68	139.63	248	13/11/1970	Continue
36	915205A	Malbon river	Black Gorge	21.05	140.06	425	1/10/1970	1/10/1988
37	916002A	Norman river	Strathpark	19.53	143.25	285	1/10/1969	30/09/1988
38	916003A	Moonlight creek	Alehvale	18.27	142.33	127	1/10/1969	10/04/1989
39	917005A	Agate creek	Cave creek junction	18.93	143.47	228	1/07/1969	30/09/1988
40	917007A	Percy river	Ortana	19.15	143.48	445	2/09/1969	30/09/1988
41	917107A	Elizabeth creek	Mount surprise	18.13	144.30	585	23/07/1968	Continue
42	917114A	Routh creek	Beef road	18.28	143.70	81	11/12/1972	30/09/1988
43	919201A	Palmer river	Goldfields	16.10	144.77	530	11/12/1967	Continue
44	919205A	North palmer river	4.8 km	16.00	144.28	430	16/10/1973	30/09/1988
45	921001A	Holroyd river	Ebagoola	14.23	143.15	365	19/01/1970	17/05/1988
46	922101B	Coen river	Racecourse	13.95	143.17	166	10/11/1967	Continue
47	926002A	Dulhunty river	Dougs pad	11.83	142.42	325	18/11/1970	"
48	926003A	Bertie creek	Swordgrass swamp	11.82	142.50	130	10/11/1972	"

Each study catchment is represented by a stream gauging station. A list of selected stream gauging stations numbers, streamflow names, location of stream gauging stations, latitude and longitude of stream gauging stations, catchment area and streamflow record length (start and finish date) is shown in Table 1.

APPROACH

Methodology (CL estimation): In ARR[4] the continuing loss is defined as the loss that occurs at a constant rate after the commencement of the surface runoff. The procedure which was adopted in this analysis to compute the continuing losses was the same as the procedure adopted in ARR[4] i.e., the continuing loss is the rate of loss that occurred during the remainder of the storm.

The rates of continuing loss are constant as recommended in ARR[4], however in reality the value could be decreasing with the time depending upon the soil cover and duration of the storm. In this study, it was investigated whether continuing loss rate is constant in nature or decays with the duration of the storm.

In this analysis Initial Loss and Continuing Loss (IL-CL) model was used to compute the initial loss and continuing loss values from the rainfall and streamflow events. ARR[4] recommended design median initial losses ranging from 15.0-35.0 mm and design median continuing loss 2.5 mm h^{-1} for eastern catchments of Queensland. Similarly for western Queensland catchments, the recommended median continuing loss is 1.4 mm h^{-1}. As per ARR recommendations, the design initial loss varies with the duration; however the design continuing loss does not vary with time but remain constant throughout the duration of the storm.

The water balance equation from the start of a rainfall event till the end of a runoff event may be expressed as:

$$R = IL+CL*t+QF \quad (1)$$

Where:

- R = Total rainfall of the event expressed in average depth of rainfall in mm over the catchment
- QF = Quickflow, assumed to be resulted from the rainfall event, expressed in mm
- t = Time elapsed between the start of the surface runoff till the end of the rainfall event (h)

Since, QF is the total Streamflow (SFT) minus Baseflow (BF), Eq. 1 may be written as:

$$R = IL+CL*t+SFT-BF \quad (2)$$

where, both SFT and BF are expressed in mm.

As IL-CL model does not consider the temporal variability of losses. From Eq. 1 CL may be expressed as:

$$CL = (R-IL-QF)/t \quad (3)$$

To estimate QF in Eq. 3, separation of base flow from total streamflow was required. A lower limit of 0.0 mm h^{-1} and an upper limit of 20.0 mm h^{-1} were imposed for the continuing loss computation and events outside of this range were excluded from this analysis. As continuing loss value more than 20.0 mm h^{-1}, needs more detailed investigation.

RESULTS

The descriptive statistics of all the selected 969 rainfall streamflow events of IL and CL values are shown in Table 2. A total of 48 catchments were considered as for this analysis. The IL values range was 0.0-189.37 mm and the CL values range was 0.01-18.31 mm h^{-1} and the median IL values range was from 0.7- 71.77 mm and the median CL values range was from 0.71-5.8 mm h^{-1} respectively.

Table 2 shows that the derived continuing loss values for all the 48 selected catchments are from 0.01-18.31 mm h^{-1} and median continuing loss values for all the 48 selected catchments are from 0.71-5.8 mm h^{-1}. Hence it is observed that the continuing loss varies with the duration of the storm rather than it remains constant throughout the storm. Similar characteristics are expected from other catchments around the world.

To examine the effect of duration on continuing loss an analysis was performed with all the selected 969 rainfall events using a threshold value of 0.01 mm h^{-1}. To examine how continuing loss varies with the duration, the continuing losses of all the selected 969 rainfall events were plotted against their duration (duration between the end of initial loss and the end of the rainfall event) of all the events as shown in Fig. 2. The continuing loss for each catchment was examined against their durations of the remainder of the storm. It was observed that the continuing loss decays with duration i.e., it is not a single fixed value as recommended in ARR[4].

In Queensland, the loss value varies with the location of the catchments. To examine the effect of duration in loss values for different regions of Queensland, the Queensland catchments were divided into two categories to compute storm losses such as eastern catchments and western catchments. The initial losses in western catchments are sometimes higher because the catchments are dryer than the eastern catchments. An investigation was performed to examine the effect of duration on continuing losses for different locations of Queensland catchments. Out of all selected 48 Queensland catchments 11 eastern catchments, 5 western catchments and 12 northern Queensland catchments were selected to examine the effect of duration on continuing loss values.

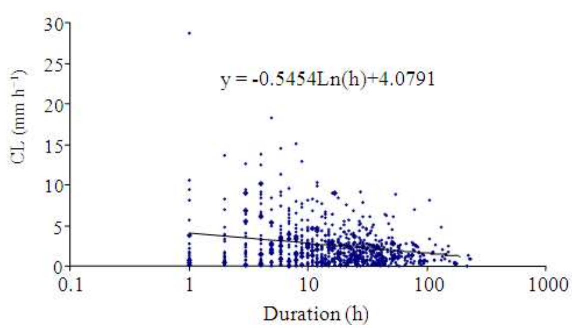


Fig. 2: Variation of continuing loss values with duration in all 48 selected Queensland catchments

Table 2: Descriptive statistics of the computed IL and CL values

Catchment ID	Name	Area (km^2)	N	Storm Initial Losses (IL), mm Range	Median	Storm Continuing Losses (CL) mm h^{-1} Range	Median
102101	Pascoe river	635	93	0.2-174.88	37.61	0.05-13.67	1.910
104001	Stewart river	480	7	3.89-78.3	42.17	0.9-6.59	1.420
105105	E. Norman river	300	3	10.92-18.39	11.92	0.92-1.43	1.300
107001	Endeavour river	310	3	16.35-114.03	71.77	0.57-3.07	0.710
107003	Anna river	247	3	12.24-36.46	14.00	0.94-2.63	1.490
112003	N. Johnston river	173	15	3.3-108.55	34.04	0.3-7.79	2.690
112101	S. Johnston river	400	3	31.52-112.72	41.66	2.68-4.48	3.340
114001	Murray river	155	23	1.6-159.22	65.75	0.05-8.44	4.740
116008	Gowrie river	124	61	0.29-155.01	21.74	0.01-10.29	2.630
116015	Blunder creek	127	48	1.92-189.37	70.53	0.07-11.3	1.460
116017	Stone river	157	55	0.26-161.71	33.23	0.09-14.52	2.540
118003	Bohle river	143	24	0.11-93.2	28.80	0.66-7.63	2.260
119006	Major creek	468	4	10.27-79.87	35.25	0.33-1.20	1.150
120014	Broughton river	182	19	2.0-71.0	18.42	0.16-8.39	2.060
120216	Broken river	78	11	29.35-123.37	64.26	0.56-9.11	1.700
124002	St. Helens creek	129	11	11.56-154.62	53.71	0.33-6.04	1.620
125005	Blacks creek	505	35	0.8-144.39	57.63	0.22-15.39	3.450
130207	Sande creek	409	14	3.84-97.04	27.74	0.18-8.99	2.680
136108	Monal creek	92	12	2.71-48.2	13.08	0.18-9.12	1.210
137101	Gregory river	454	8	3.57-123.05	29.81	0.12-5.74	2.035
138110	Mary river	486	23	0.6-126.09	29.95	0.1-4.01	1.020
141009	N. Maroochy river	38	22	1.52-113.26	42.27	0.16-3.71	0.890
143110	Bremer river	125	37	0.24-116.98	39.04	0.02-12.55	1.170
143212	Tenhill creek	447	24	6.86-125.46	43.48	0.01-7.58	1.160
145003	Logan river	175	42	0.2-99.01	30.82	0.07-18.31	1.460
145010	Running creek	128	20	0.0-80.57	31.86	0.01-10.17	1.180
145011	Teviot brook	83	37	1.5-91.9	29.70	0.01-6.99	1.000
145101	Albert river	169	35	0.59-165.84	43.46	0.01-6.95	1.520
146014	Back creek	7	10	0.0-49.55	4.84	0.52-2.92	1.870
416410	Macintyre brook	465	28	0.05-93.34	28.73	0.15-15.06	1.770
422321	Spring creek	35	6	0.24-40.41	4.29	0.05-1.76	0.730
422338	Canal creek	395	27	0.07-116.41	24.24	0.13-6.84	1.580
422394	Cadamine river	325	21	8.99-89.35	40.51	0.08-3.2	0.920
913005	Paroo creek	305	6	1.06-25.64	9.31	0.64-5.58	2.380
913009	Gorge creek	248	9	0.03-46.23	6.20	0.17-5.39	1.060
915205	Malbon river	425	5	9.17 59.79	34.21	0.56-14.61	3.950
916002	Norman river	285	9	0.66 -102.63	16.61	0.54-5.63	3.200
916003	Moonlight creek	127	7	0.51-60.58	28.93	0.45-10.4	2.400
917005	Agate creek	228	19	0.14-34.67	13.90	0.23-7.12	2.830
917007	Percy river	445	8	0.11-24.85	24.49	0.04-5.02	1.920
917107	Elizabeth creek	585	8	2.74-42.09	27.25	0.25-4.03	2.040
917114	Routh creek	81	7	6.57-61.03	29.55	0.67-4.06	1.440
919201	Palmer river	530	5	1.82-55.86	38.31	0.08-8.62	2.200
919205	N. Palmer river	430	7	0.8-46.19	14.51	0.3-10.95	5.800
921001	Holroyd river	365	16	1.91-90.31	39.29	0.26-16.04	1.190
922101	Coen river	166	59	0.26-81.89	24.52	0.08-9.45	2.160
926002	Dulhunty river	325	12	0.0-6.29	3.39	0.03-5.91	1.600
926003	Bertie creek	130	8	0.0-5.03	0.70	0.18-6.85	1.640
Average			20	0.0-189.37	0.7-71.77	0.01-18.31	0.71-5.8

To examine how continuing loss varies with duration, the continuing loss and the duration of 270 rainfall events of 11 eastern Queensland catchments were plotted as shown in Fig. 3. It shows that, the continuing loss is not constant with storm duration but rather it decays with the duration. The equation of the decaying curve is shown in Fig. 3.

In Fig. 4 the continuing losses of 96 rainfall events of 5 western catchments in Queensland are plotted against their respective durations to examine the effect of duration on continuing losses. Figure 4 shows that the continuing loss is not constant in respect of duration, but it decays with respect to duration of the rainfall event. The equation of the decaying curve is also shown in Fig. 4.

In Fig. 5 the continuing losses of 340 rainfall events of 12 northern catchments of Queensland are plotted against their respective durations to examine the effect of duration on continuing losses. Figure 5 shows that the continuing loss is not constant in respect of duration, but that it decays with respect to duration of the rainfall event. The equation of the decaying curve is shown in Fig. 5. Also the results of the continuing losses against their durations for few individual catchments are shown in Fig. 6.

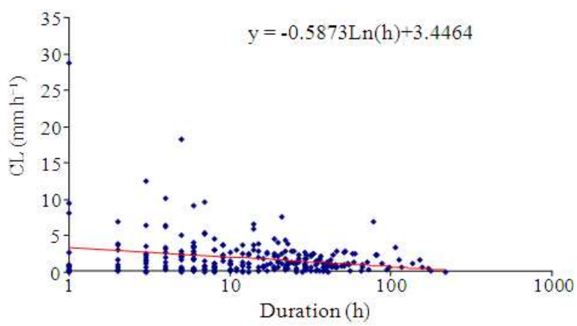


Fig. 3: Variation of continuing loss values with duration in 11 eastern Queensland catchments

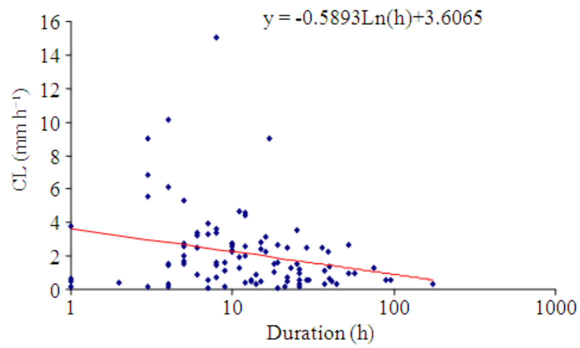


Fig. 4: Variation of continuing loss values with duration in 5 western Queensland catchments

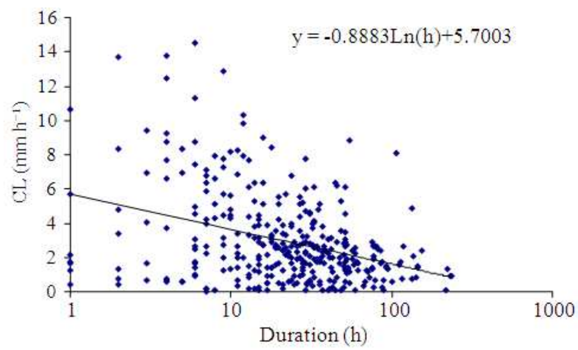
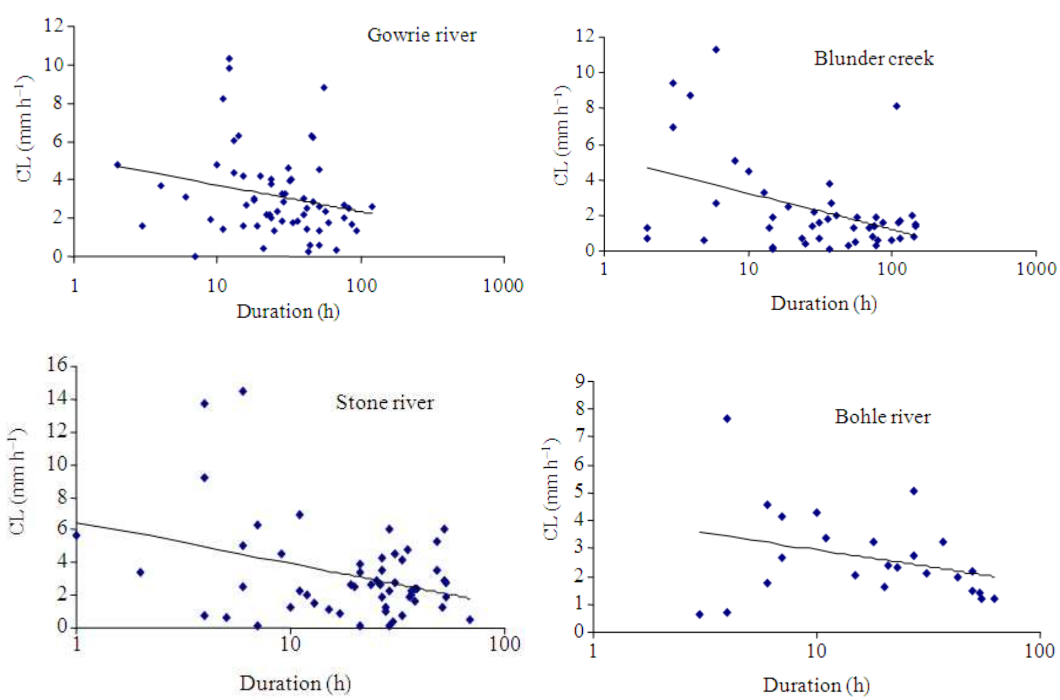


Fig. 5: Variation of continuing loss values with duration in 12 northern Queensland catchments



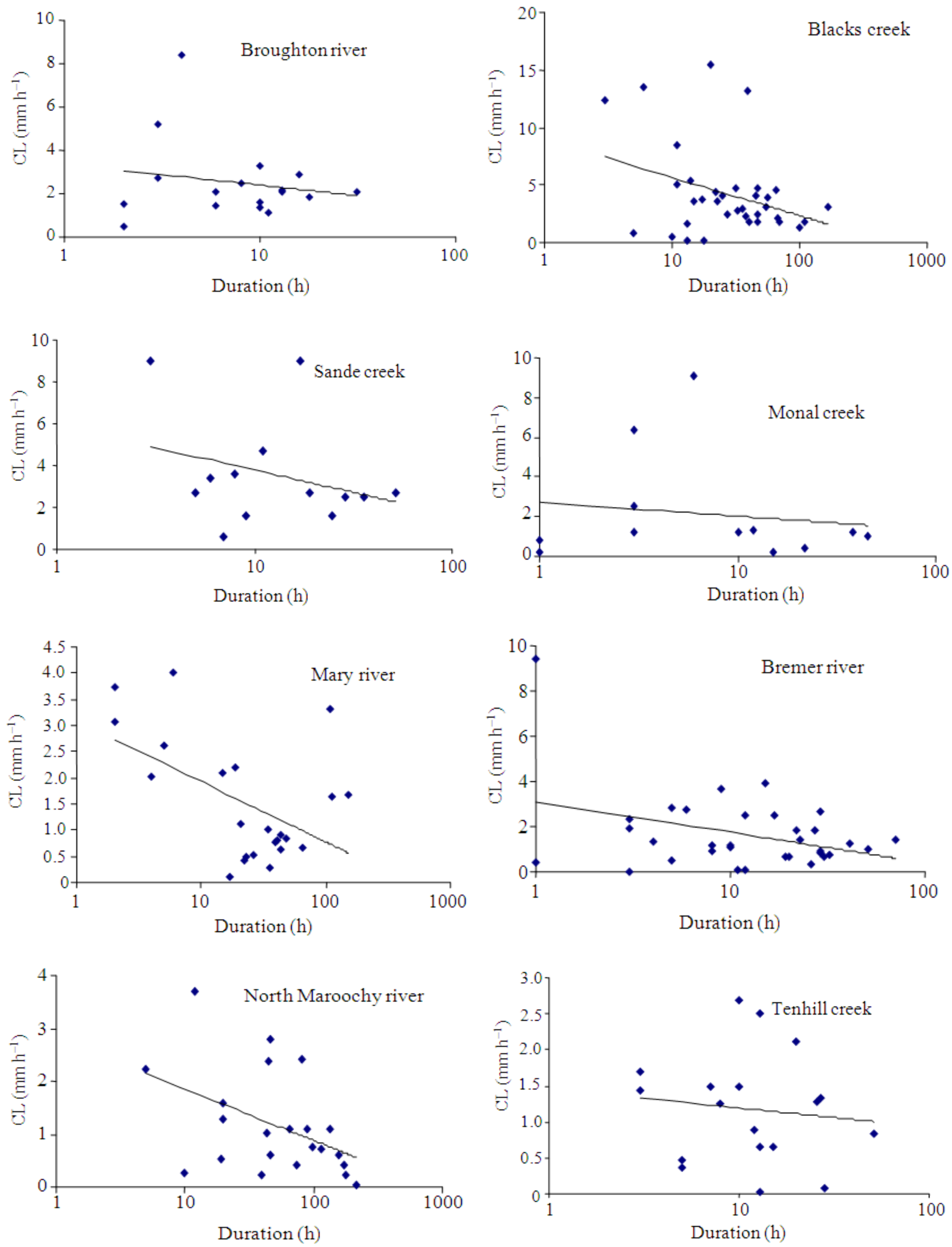


Fig. 6: Plots of continuing losses against their durations for few individual catchments

DISCUSSION

IL-CL model and associated parameters are widely used in Australia for design flood estimations. Current design practice is to use ARR[4] recommended region specific values. ARR[4] recommended that continuing loss rate is constant throughout the duration of the storm. However, using many years of data, derived continuing losses values found in this study are not constant. Rather, it is found that continuing loss value decreases with the increase of the duration of the rainfall event i.e., CL value is not a fixed single value for a catchment as recommended in ARR[4] but it decays with the increase in the duration of the storm. Hence, it was observed that the continuing loss of the Queensland catchments can be described as probability distributed losses.

CONCLUSION

This research analyzed how to improve the design continuing loss estimate for flood estimation in Queensland. The finding has important significance for design flood estimation. The following conclusions can be drawn from the analysis:

- It was observed that the computed median CL value for western Queensland catchments was 12.86% higher than that of ARR recommended median continuing loss value
- It is recommended in ARR that the continuing loss that occurs for a rainfall event is at a constant rate during the remainder of the storm. But this recommendation is not correct as per Fig. 2-6, which proved that the continuing loss decreases with the time i.e., it is not a single fixed value during the remainder of the storm. Hence, the continuing losses for the Queensland catchments are in reality probability distributed losses
- This finding (probability distributed losses) is required to be confirmed with a larger data set. A larger data set is required to derive stochastic continuing losses for application with Joint Probability Approach as described by Ilahee *et al.*[3]

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