Determination of a Design Rainfall Pattern by Comparing with its Effect on Streamflow on Greater Colombo Watershed in Sri Lanka

W.H. Keerthirathne and N.T.S. Wijesekera

ABSTRACT

IDF curves provide the rainfall quantity corresponding to a particular critical duration and the design return period. In order to carryout infrastructure designs with the use of high resolution mathematical models it is necessary to select the most appropriate temporal distribution of design rain event. In cases of sufficient data availability, literature recommends the use of pattern based location specific design rainfalls for optimum designs.

Present study aimed to develop design rainfall patterns based on rainfall observations, and compare with the Alternating Block, Uniform Intensity, and Greater Colombo Flood Design Patterns by evaluating the runoff response from S CS HEC HMS model developed for a sub watershed of Greater Colombo Region.

A literature review was conducted to select the design rainfall pattern presently used for water infrastructure engineering.30 years of 15-minute resolution rainfall data of Colombo Meteorological station were used to separate events. Events separation were carried out by nominating Minimum Inter Event Time (MIT) of 6hrs. 220 observed events were separated into six groups considering event durations. Analysis were carried out by developing dimensionless mass curve and percentile curve for each category. Design patterns were developed from percentile curve for each event duration. Design hyetographs were developed for each duration corresponding to design rainfall depth calculated with IDF curves for Colombo and selected data for analysis. Average recurrence Interval (ARI). Runoff response for all patterns were evaluated using the nature of the outflow hydrographs with reference to flood peak and time to peak .

It was observed that highest runoff response was given by Enveloped curve developed with observed data. A high runoff variation was observed between rainfall patterns. ABM base pattern can be used with reliable confidence where there is no data for analysis. Criticality Index was developed to account for the pattern of design event with regards to flood peak and time of occurrence. Enveloped curve and 10% probability distribution pattern showed the highest criticality and ABM showed the most consistent criticality for all event categories.

KEYWORDS: IDF Curves, Design Rainfall, Flood management, HEC-HMS, Criticality Index

1. Introduction

1.1. General

Rainfall is the key input parameter when streamflow modelling is carried out for the design of hydraulic structures in associated watersheds. Magnitude of the design rainfall, design storm duration and storm pattern are major considerations that have to be taken care of when carrying out risk based water infrastructure designs. Design rainfall depth is usually calculated using the IDF curves for the concerned location and corresponding to the critical duration and for a predetermined design return period. After the determination of rainfall depth for the critical duration, a modeler has to identify the temporal distribution of the rainfall within that duration. This distribution has a very high impact on the streamflow peak both in terms of the magnitude and the time of occurrence. Therefore, the selection of most appropriate temporal distribution of a design rain event is vital for economically feasible and safe drainage infrastructures.

The simplest method of developing a design hyetograph is the Alternating Block Method (Chow, Maidment, & Mays, 1988 and Haan, Barfield, & Hayes, 1981). In cases of sufficient data availability, literature recommends the use of pattern based location specific design rainfall for optimum designs. A typical example is the use of results reported by Soil Conservation Service (SCS) where rainfall distributions Type I, IA, II, and III, are available for applications within specific locations in the United States of America (Chow at el., 1978).

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Though there had been occasions where pattern based design rainfall had been used for major infrastructure designs in Greater Colombo region of Sri Lanka, there are no reviewed publications, or detailed guidelines, or comparative evaluations.
Hence a study was undertaken to analyze 30 years of 15-minute resolution rainfall data of Colombo Meteorological station in order to identify the design rainfall patterns and then to compute the effect of each pattern on the streamflow response from the Greater Colombo watershed.

1.2. Study Area

Greater Colombo basin located in the Colombo District of Western province in Sri Lanka is in Figure 1.1. Project area Covers an approximate land extent of 100Km2. Consists of two main sub watershed namely Malambe basin (12.8Km2) and Greater Colombo basin (87.5km2). Study are consists of a well-defined canal network which was rehabilitated in 1982.

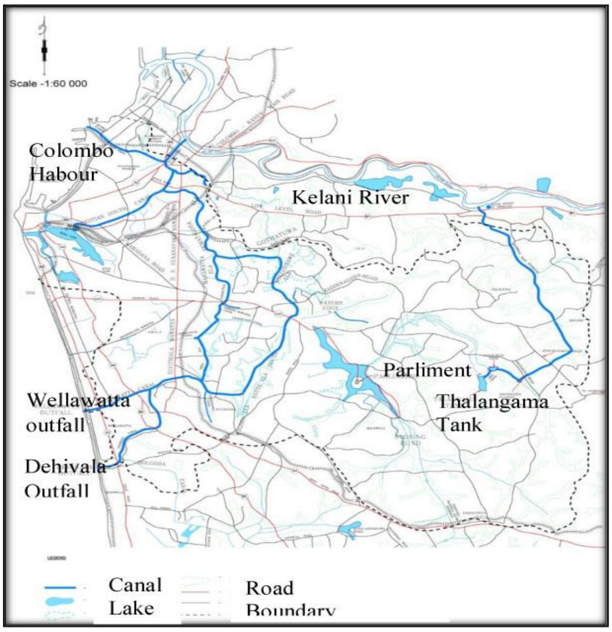

Figure 1.1: Project Area

2. Objectives

The objective of the present work was to develop design rainfall patterns based on the observed rainfall and then carry out a comparison with the Alternating Block, Uniform Intensity, and the presently used Greater Colombo Design Patterns through a comparative evaluation of computed streamflow from a SCS HEC HMS model developed for Greater Colombo Watershed.

3. Literature Review

3.1. Event Separation

For the purpose of event analysis, event separation from continuous data is required. Literature showed that there are two methods for event separation namely Window based and Minimum Inter Event Time (MIT) based (Ariff & Jeman, 2012). MIT is defined as the time between events, which are independent of each other (Dunkerley, 2008). Literature indicated that there is no established criteria for selecting MIT (Dunkerly, 2008) and many researchers defined their own criteria to fix MIT for event separation. Dunkerly (2008) indicated that irrespective of the location of work most researchers have used a MIT value between 6 hr to 8 hr when separating independent events from continuous data

3.2. Event Selection

Time of concentration (TC) and ARI are the main parameters considered when selecting events for drainage infrastructure design. ARI is directly related to the flood safety level and the Irrigation Department Guideline (Ponrajah, 1984) recommends either a 2-year or a 5-year return period for town drainage infrastructure design.

3.3. Design Rainfall Patterns

Many countries develop guideline for determination of rainfall magnitude estimated from IDF curve (ARR(1997). MSMA(2013),SCS(1973). Irrigation department guideline (Ponrajah, 1984) has recommended a uniform intensity rainfall for catchments up to 52km2. Studying the impact of design rainfall pattern on safety consideration in Engineering Infrastructure for Water Resource Development, Wijesekara & Wijesinghe (2013) concluded that that Alternating Block Method provides a better and reliable methodology ensuring safety of the structure. The study of Storm water drainage plan for Colombo Metropolitan Region(CMR),carried out by Nippon Koei Co Ltd for Sri Lanka Land Reclamation and Development Corporation (SLLR & DC),an Extreme event was used as pattern to distribute the design event magnitude.

4. Data And Data Checking

4.1. Rainfall Data

Continues rainfall with 15minutes resolution, for a period of 30 year commencing 1981 and up to 2010 were extracted from pluviograph charts recorded by automatic rain gauge located at Colombo Meteorological Station. Daily rainfall records for the same period separately recorded using a standard rain gauge located at the same place were also obtained for data verification. Data were checked with daily data of standard and the data which deviated more than 20% were excluded from the analysis. Monthly pattern of the data was also compared to capture disparities in the rainfall records.

5. Analysis and Results

Events separation, from the continuous data was carried out by defining Minimum Inter Event Time (MIT). A six hour MIT value guided by the literature was taken for the event separation. Considering the lack of watershed information such as initial storage the rainfall threshold value was taken as zero for the determination of MIT. Estimation of TC for all sub watersheds of the study basin revealed a variation between 0.23hrs to 9hrs. Rainfall value corresponding to minimum TC (0.23hr) and ARI (2year) was selected as rainfall threshold value for event selection. Two hundred twenty rain events identified from the entire dataset was selected for the analysis. These events were grouped into five classes of event durations as 6, 12, 18, 24 and 36hrs. Summary of the observed events are shown in table 5.1

Table 5.1: Summary of Observed Events

Selected Storm Category						
		1	2	3	4	5
Event Duration/Hrs	<6	6	12	18	24	36
Total number of Events	45	87	35	20	10	24
Duration Range	0-3	3-9	9-15	15-21	21-27	27-48
Max RF Intensity(15minute data resolution)	218.6	188.4	44.9	133.2	30.0	203.3
Max total Rainfall	123.0	207.0	440.2	269.8	496.7	459.6
Average Intensity/mm/Hrs	38.8	14.9	6.9	5.3	6.9	3.7

Time distribution curves were plotted for events groups under the five selected categories. Figure 5.1 showed the pattern under category -3

Rain events of each group were analysis of probability of occurrence (10%-90%).P percentage probability of occurrence illustrate the storm pattern that was occurred in p percentage observed events. Six design events were developed from above probability curve namely Envelope curve, Median curve,25% probability curve, 75% probability curve upper cord and Lower cord. These patterns were compare with "Uniform" and "Alternating Block" rainfall pattern.

Design pattern corresponding to event duration of 24hrs is showed in Figure 5.2.

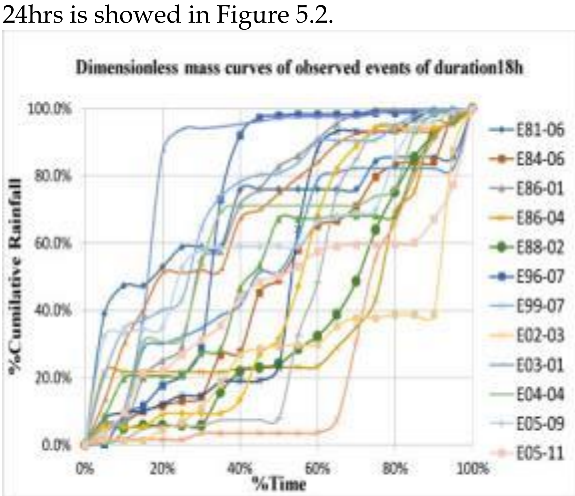

Figure 5.1: Time distribution of Observed Event duration 18hrs

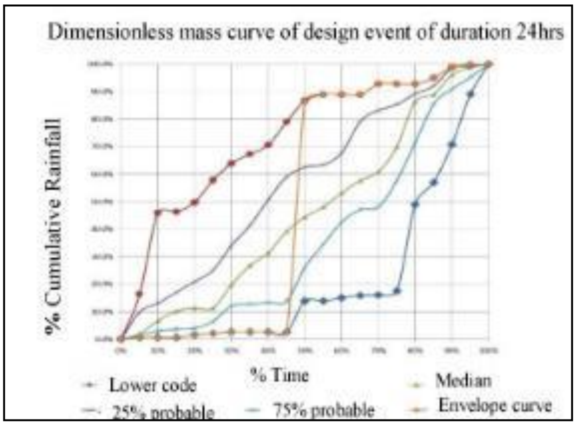

Figure 5.2: Design Rainfall pattern for duration 12h

Forty design hyetographs were developed for the entire set of event durations by distributing design rainfall depth calculated from IDF curve of the study area corresponding to 10 year ARI. igure 5.3 shows the design rainfall patterns for the rainfall category 2 of Table 5.1

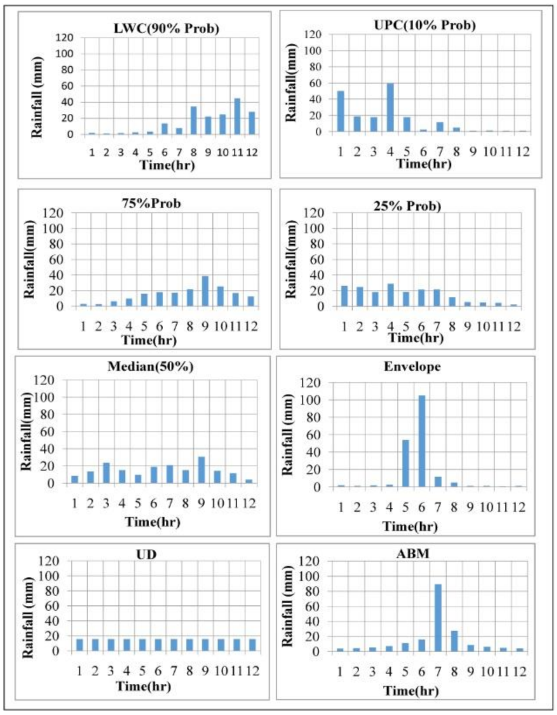

Figure 5.3: Design rainfall hyetograph for duration 12h

In order to compare the runoff response for different design rainfall patterns, a HEC- HMS (USACE, 2000) rainfall run off model was developed for the selected sub watershed of Greater Colombo Main Basin (Figure5.4)

Outflow hydrographs for all design events of 12hrs are shown in figure 5.5.

Main characteristic of a hydrograph is Time to Peak (Tp) and the peak flow rate (Qp). These two parameters were compared for all patterns within the group and among the group. Figure 5.6 and Figure 5.7 are showed Variation of Qp with event duration.

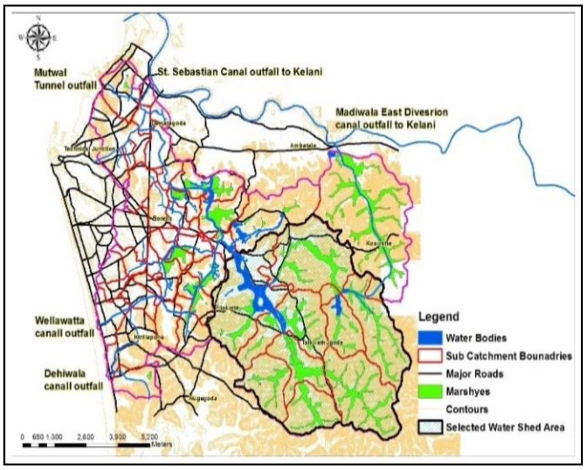

Figure 5.4: Selected sub Watershed in Greater Colombo basin for run off model

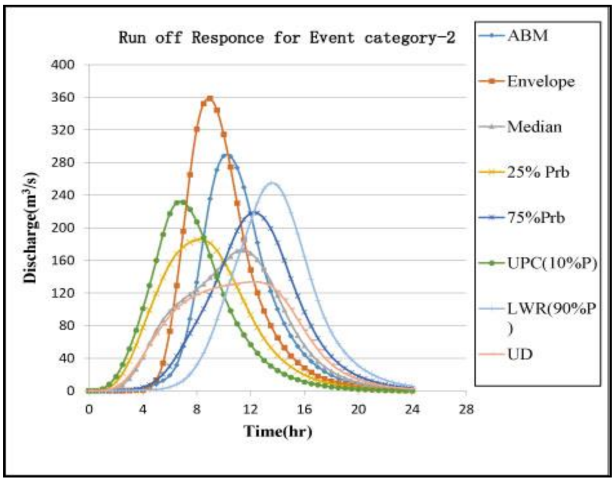

Figure 5.5 Estimated Streamflow Hydrographs for Design Event Category-2(12hr)

Criticality index was developed to account for the pattern of design events with regards to flood peak and time of occurrence. Figure 5.8 showed the variation of criticality with all event categories Enveloped and 10% probability curve pattern showed highest criticality while ABM showed consistent criticality for all event categories.

$$\textbf{Event Criticality Index (Cr)} = \frac{Q\ (m^3/S)}{Tp(S)}$$

$$\textbf{\% Criticality} = \frac{\textbf{Cr of Event}}{\textbf{Max: Cr of Distributions}}$$

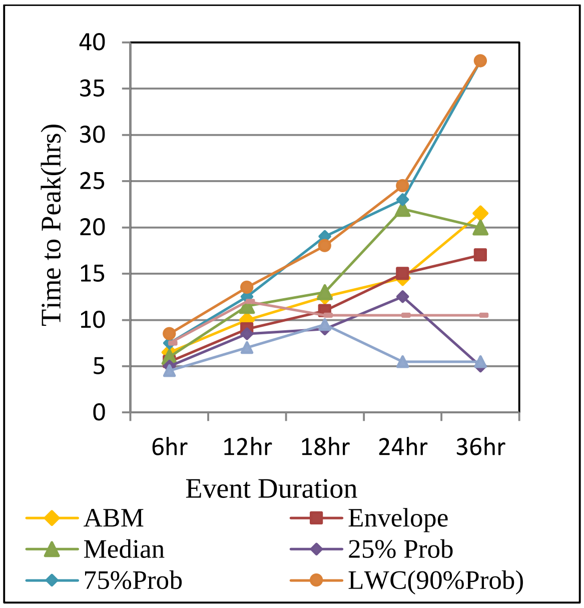

Figure 5.6. Variation of Tp with Event duration

Q(m3/S)

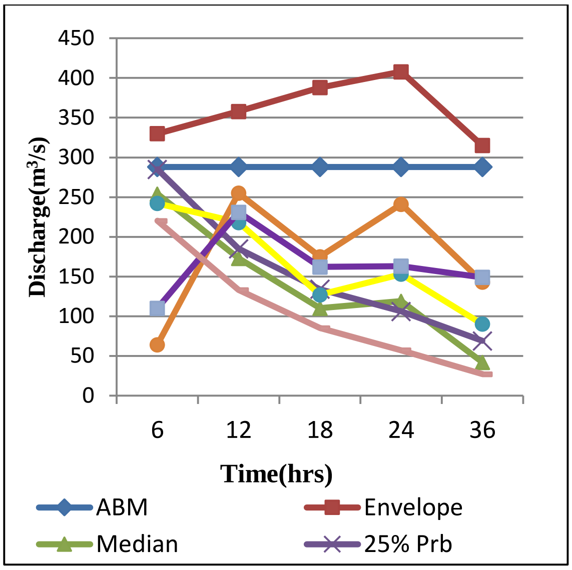

Figure 5.7. Variation of Peak Streamflow rate with Event Duration

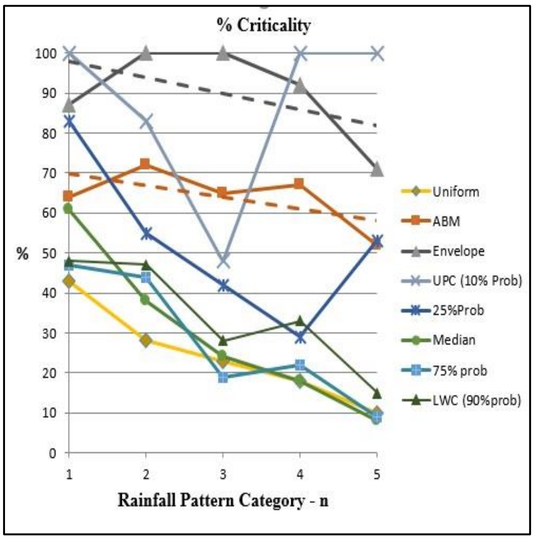

Figure.5. 8.Variation of % criticality with Event Category

6. Discussions

Rainfall records, by Automatic rain gauge and standard rain gauge were found differ each other for some days in several year in the span of the data period. Hence, selection of data records were done by identifying missing data and data with ambiguous.

Literature survey revealed that no Specific method of selecting MIT for event separation. Different researchers selected MIT on criteria developed by themselves. MIT directly affected to number of event to be selected from continuous data

Not all events, separated from the continuous data were selected for event analysis. Hence, Event threshold value had to define after having extensive analysis on Tc of each sub watershed in the main study basin and design return period of rain events used in the past. All events with rainfall depth corresponding to minimum TC and return period and above were selected for analysis.

Events were grouped into five categories after having considered TC of sub watershed of the main basin.

An infinite number of time distributions can be incorporated for a rain magnitude which is determined by the use of IDF curves. Usually these patterns are generated either by selecting a single probability of occurrence or by combining two probabilities. The envelope curve the pattern developed by combining 10% and 90% probability curved produced most highest run off for the study area. Hence it would be more useful designing hydraulic structures with higher safely level. for Six different rainfall pattern were developed with probability curved. Storm pattern with higher frequency of occurrence(90%) can be used for economical hydraulic structure design.

An observed pattern of critical rain event was used by Nippon Koei Consultant for Greater Colombo basin in 2000.this was compared with pattern developed with probability curve and found that highest run off generation was produce by the event developed with enveloped curved.

For all event category, Pattern developed with ABM showed consistency behavior compared to the rest of event pattern. Run off response for UD and 50% probable rainfall pattern showed almost similar behavior. UD rainfall pattern was very useful for identifying the Tc of the basin.

An indicator to reflect the "criticality" of an event on the watershed would require to have a combination of direct runoff magnitude and the time to peak, thereby reflecting how quickly a flood with a certain magnitude would reach the gauge point. In this study, an "Event Criticality Index" was defined to capture both these factors.

7. Conclusion

1. An event criticality indicator identified in this study, enabled capturing of critical events reflecting the severity of peak runoff rate and time to the occurrence of peak runoff
2. Design Rainfall pattern developed by Envelope curve and ABM generate higher intensity rainfalls.
3. Catchment response for uniform rainfall events showed that Tc for a catchment is not consistent with rainfall duration.
4. ABM based pattern can be used with reliable confidence when there is no sufficient number of observed patterns available.

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