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Extension of the Stochastic Flow Duration Curve to the Upper Reaches of Streams

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Abstract

In this paper a new procedure for the construction of a flow duration curve is presented. The probability of each streamflow calculated by the Weibull plotting formula is used to draw the stochastic flow duration curve. We show, comparing the shape of the lower half of the curve, that the flow duration curve drawn in this way offers a stochastic estimation of drought condition in the upper reaches of streams. The effectiveness of this technique for drought evaluation is illustrated through its application to four dam basin areas located in Thailand and Japan. Detailed discussion on the relationship between the master recession curve constant and the shape of the later half of the flow duration curve may be a future hot topic.

Keywords: stochastic flow duration curve, drought evaluation, master recession curve, geology, plotting formula, geomorphology

1. INTRODUCTION

The flow duration curve of daily flows is a cumulative frequency curve that shows the percent of time a specified discharge has been equaled or exceeded during a given period, and has been used as a useful tool for various water resources problems since the end of the 19th century. However as the flow duration curve is not appropriate for extracting stochastic hydrologic information, that curve has rarely been applied to the evaluation of drought situations in the upper reaches of streams. And then the research study on relations between the shape of the flow duration curve and watershed characteristics has been carried out rather than that on the evaluation of drought situations so far. Many hydrologists and/or engineers have been interested in the construction of the flow duration curve at ungaged sites , namely, the synthesis of flow duration curves (for example, Dingman,1978: Quimpo at al.,1983: Mimikou at al.,1985). It is particularly important that a synthesis is carried out based on the relation between the lower half of the curve and basin area, basin relief, and soil characteristics and/or groundwater geology (Singh, 1971: Fennessey, 1990)

The flow duration curve shows the statistical distribution of daily mean stream flows for a period of years, and the lower end of that curve is a useful expression of the low flow characteristics of the stream. If the flow duration curve can be drawn by using probability values, it is possible to extract stochastic hydrologic information from that curve. The aim of this work is to show a new technique for constructing a flow duration curve , and to apply this to the upper reaches of several streams in Japan and Thailand, and further to examine what influence on the lower end of curve could be made.

2. CONSTRUCTION OF THE STOCHASTIC FLOW DURATION CURVE

In order to draw statistical hydrologic information in the flow duration curve, the curve is drawn by plotting discharge magnitude in determining the probability at each time interval. A new technique is shown as follows.

I . The steps in reading values at each time interval from the flow duration curve of observed daily discharge are:

① Construct a flow duration curve of one water year period by arranging the discharge values in descending order.

② Read the values of daily discharge parallel to the ordinate and cross to the flow duration curve at suitable intervals from 0 to 100 percent on the time axis (Figure 1).

At least 8-15 ploints are needed in order to successfully draw a new flow duration curve. In this paper, an 8 percent interval is used.

Continue above-mentioned ①→② for each of the given water years.

II. The steps in plotting the magnitude versus the probability are:

③ Order the discharge values read from the flow duration curve from the smallest to the largest value.

④ Calculate the plotting position from the following Weibull plotting relationship and plot on a sheet of logarithmic probability paper.

$$P=m/(n+1)\times 100\ \% \qquad (1)$$

where P: the percentage of all events less than or equal to each discharge value, m: the rank of the event, n: the number of events on record.

⑤ Fit a straight line through the estimated values by eye (Figure 2).

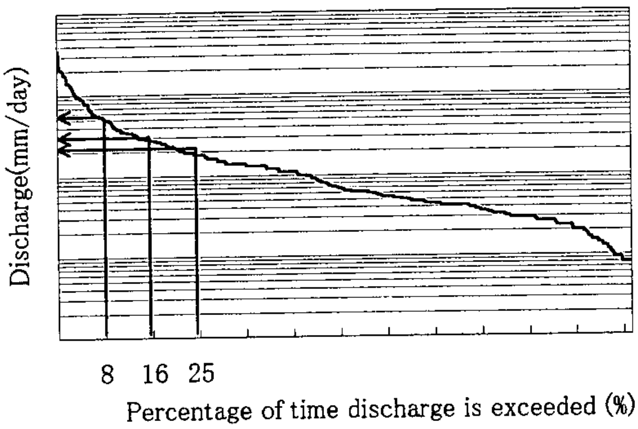


Figure 1. Example showing the reading of discharge values at suitable intervals of time.

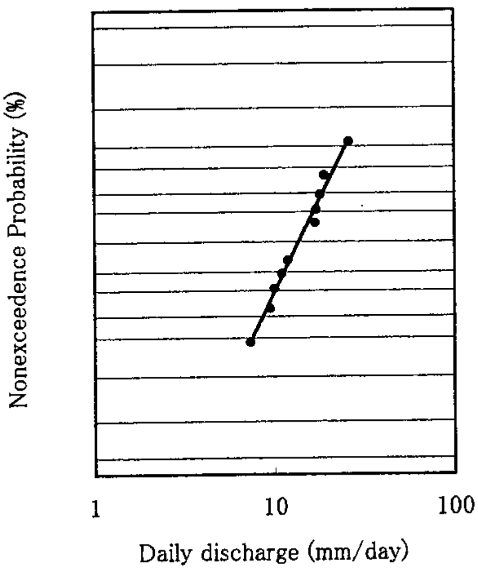


Figure 2. Fit for daily discharge on log-probability paper.

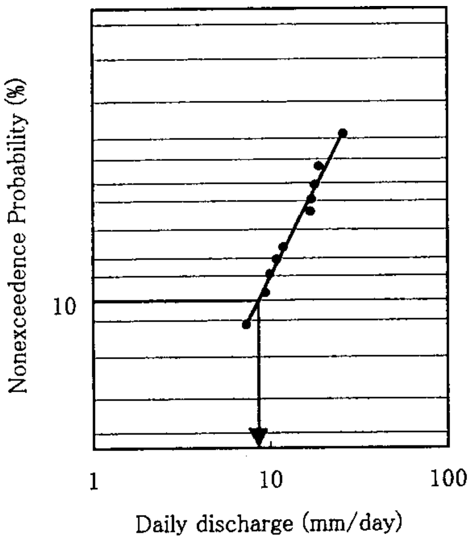


Figure 3. Reading the discharge value from the required probability.

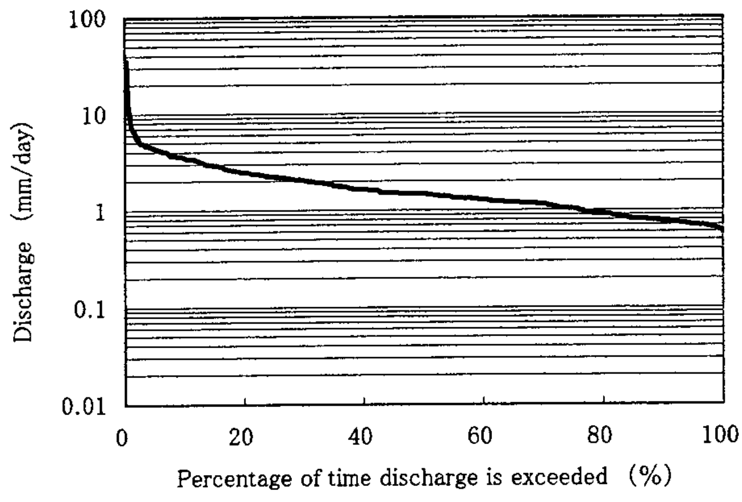


Figure 4. Example of a stochastic flow duration curve.

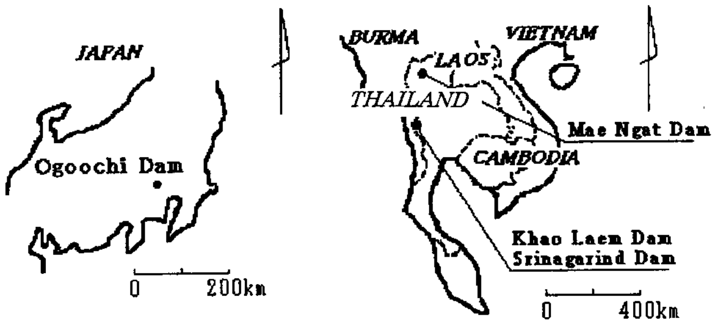


Figure 5. Location of research catchment areas.

Table 1. Description of the research catchment basin areas

Dam station	Stream	Catchment Area (km²)	Period of record stream flow	Drought discharge (mm/day)	Recession constant (d^{-1})	Predaminant rock type
Srinagarind	Khae yai	10,880	1982～'98	0.05	0.013	Limestone
Khao Leam	Khwae noi	3,720	1988～'98	0.09	0.024	Limestone
Mae Ngat	Mae Nam Pin	1,260	1967～'78	0.05	0.0145	
Ogoochi	Tama	263	1959～'97	0.98	0.012	Grataceous-Paleogene

⑥ Read the discharge value down from the best fit line at the required probability value on the ordinate (Figure 3).

Continue above-mentioned ③→⑥ at suitable intervals from 0 to 100 percent on the time axis.

⑦ Plot discharge values against point of time discharge is exceeded (Figure 4).

3. RESEARCH CATCHMENT AREA AND DATA

Four dammed catchment areas were selected with the restriction that there are no regulation or diversion structures in the upper reaches of streams. Approximate locations of the selected four dams are shown in Figure 5. The Srinagarind Dam (S-Dam) and the Khao Laem Dam (K-Dam) basin areas are located in the upper reaches of the Mae Klong River in western Thailand, and the Mae Ngat Dam basin area (M-Dam) is located in the upper reaches of the Mae Nam Ping River in north eastern Thailand. The Ogoochi Dam basin area (O-Dam) is located in the upper reaches of the Tama River.

Daily stream flow data is employed for the following analysis. Table 1 gives basin area and hydrological data for the research basin areas. From these specifications, the range in catchment areas is 263-10,880 km^2, the range in record lengths is 11-39 years, and the annual runoff depth averaged for the period of record ranges 316-1364 (mm/y). Although various geological divisions are present in each catchment area, only the main geologic type is shown in this table.

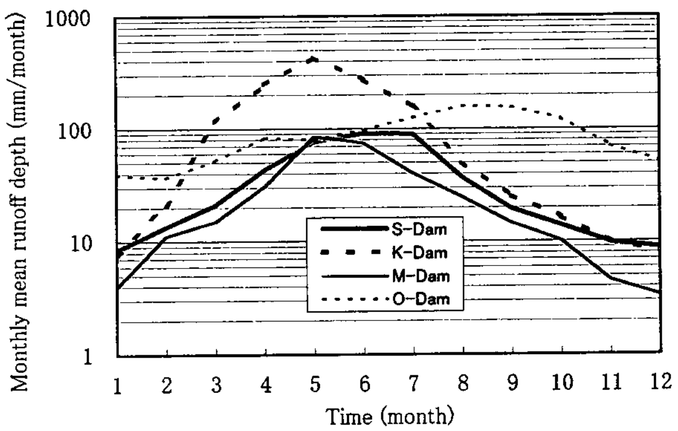


Figure 6. Comparision of monthly mean runoff depth.

The coefficient of variation for annual runoff depth at O-Dam is 0.28, and while for drought discharge (97% of time discharge is exceeded) the coefficient is 0.16. In comparison, the coefficient of variation for annual runoff depth at the three dam catchment areas of Thailand is 0.30-0.37, and that of drought discharge is 0.60-1.47. The coefficient of variation for these variables for the Thai basin areas is greater than that for the O-Dam. This difference means that the runoff condition in the upper reaches of rivers in Thailand is less stable than that for the O-Dam in Japan. That means each catchment basin area in Thailand has very different watershed characteristics.

In Figure 6, a comparison of monthly runoff depth in the research basin areas is shown. It is shown that the S-, K- and M-Dams have seasonal characteristics such as a dry and a wet season, and with the seasonal fluctuation of the K-Dam being the strongest among the three basin areas. Also, figure 6 realistically shows the difference between discharge fluctuations in a tropical region and that of the temperate region.

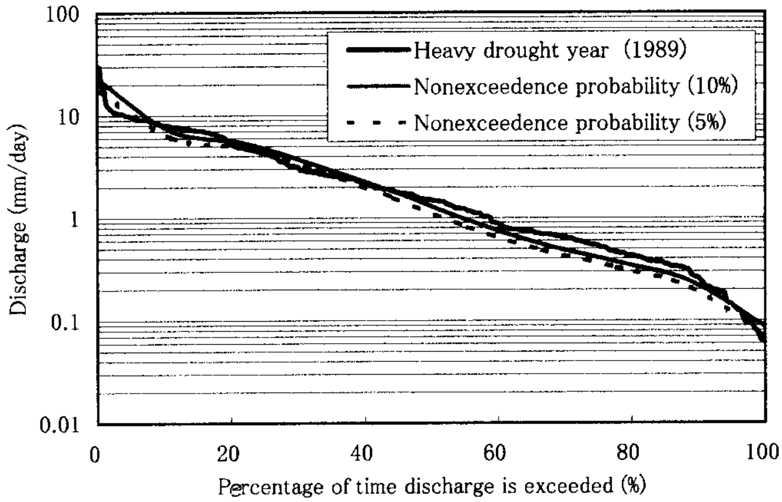
4. APPLICATION TO THE RESEARCH BASIN AREAS AND DISCUSSION

The stochastic flow duration curve method was applied to daily streamflow time series observed at the research dam sites. Figure 7 shows that for flow duration curves with probability values of 5 and 10 percent, the daily discharge will be less than the amount indicated. In these figures, the flow duration curve of the heavy drought year in each basin area is also drawn in order to examine and compare the drought situation. By examining and comparing the shape of the three curves around the time percent (97%) (drought discharge), it is shown that the drought situation of S-Dam basin area is less severe than that of the K- and M-Dam basin areas. In particular, the drought situation of the heavy drought year(1996) at the O-Dam basin area is very severe. It is concluded that in the design of water resources facilities, the nonexceedence probability of 10 % may be needed for the S-Dam basin area, and the nonexceedence probability of 5% for the K, M and O-Dam basin areas.

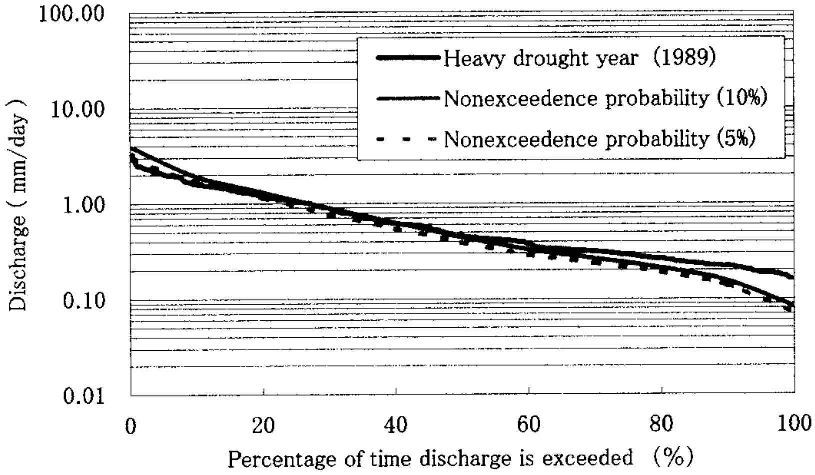
By applying the new construction method (Appendix) of the master recession curve to the research dam basin areas, the recession constants were automatically and objectively estimated. An example of the master recession curve drawn with the procedure presented is shown in Figure 8, with the recession constants for the research dam catchment areas given in Table 1. Although there is a relationship between the recession constants and the shape of the lower half of the flow duration curve, in this paper the magnitude of drought discharge was qualitatively examined using results for four research catchment areas. Full discussion was not carried out for the reason that the collected hydrological data is poor. However, the results suggest that these relationships may be strong.

5. CONCLUSION AND FUTURE RESEARCH

A flow duration curve describes the statistical distribution of daily mean stream flows for a period of years. The lower half of the duration curve is significant in

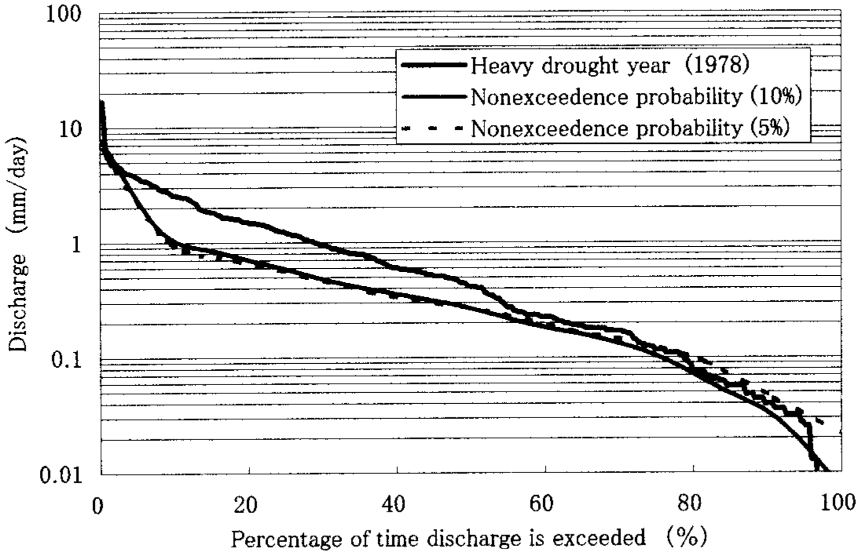


(a) K-Dam basin area

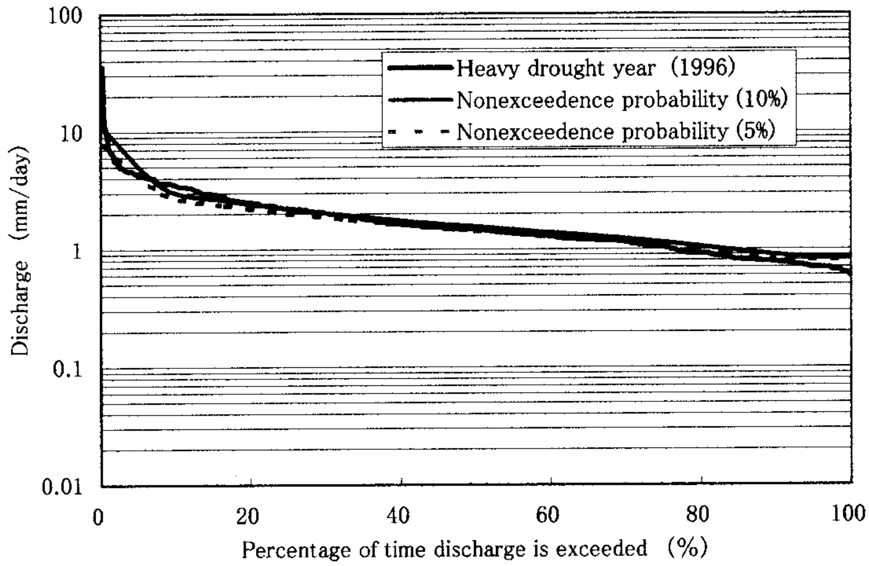


(b) S-Dam basin area

Figure 7. Examples of a comparision between the stochastic flow duration curves(10and5%) and the duration curve for a heavy drought year.



(c) M-Dam basin area



(d) O-Dam basin area

Figure 7. (continued).

representing the low flow characteristics. However stochastic information for stream flow can't be extracted from a flow duration curve drawn with observed daily discharge. An improved procedure is proposed for the construction of the flow duration curve. It is concluded that the new procedure presented may be useful for an evaluation of the drought condition in the upper reaches of streams. In further studies of the relationship between these variables, this extension would be carried out quantitatively.

APPENDIX: **Construction of the master recession curve**

The following equation is quoted as the expressional equation that represents the recession limb during period without rain. The curve constructed by combing an individual recession limb is termed the master recession curve.

$$Q_t = Q_0 \exp(-\lambda t) \qquad (2)$$

where Q_t is the discharge at time t, Q_0 is the initial discharge, and λ is the recession constant.

This appendix describes a rational and/or objective construction method of the master recession curve. The steps are as follows:

1. Smooth the daily discharge data during the period of record with the moving average method.
2. Extract the discharge recession limbs resulting for the prescribed non-rainfall period.
3. Pick out the maximum discharge value from the end of the extracted recession limbs (see Figure 9a). Particularly, pick out discharge on point C. It is convenient that the maximum discharge is hypothesized as the initial discharge (Q_0) of the equation (2).
4. Set up any recession constant after fixing the maximum values obtained with the above-mentioned procedure as a point of origin (point C in Figure 9b) and draw a common recession line (L1 in Figure 9b). The first value most likely will be small for any recession constant. The author supposes the first value to be 0.001(d^{-1}) because it is said that many basin areas have a recession constant greater than 0.001 (d^{-1}).
   Next, try to superimpose and adjust horizontally the extracted hydrograph recession limb with respect to the time axis until the lowest part of that limb overlaps the setting common recession line (see Figure 10). Extract the limb if the residual that subtracts the corresponding discharge values on the setting common recession line is equal to 0 or small. This procedure is shown in Figure 10. Move curve (a) in parallel with respect to the time axis with the computer program, and if the difference between the discharge value for the lowest part of curve (a) and one on the setting common recession line does not exceed ± 0.01 (mm/d), extract curve (b).
5. Repeat the same procedure (Step 4) by resetting a recession constant if this trial (in the case of λ=0.001) was done for all the extracted individual hydrograph recession limbs. It is expected that the interval range ($\Delta\lambda$) for the trial is $\Delta\lambda$

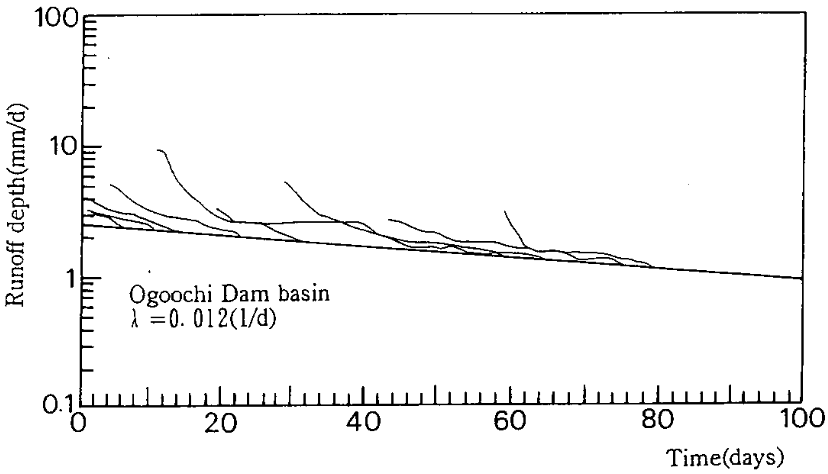
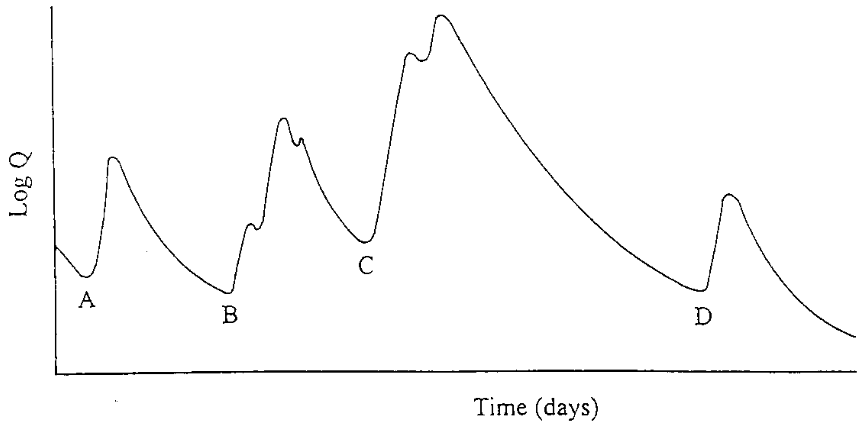
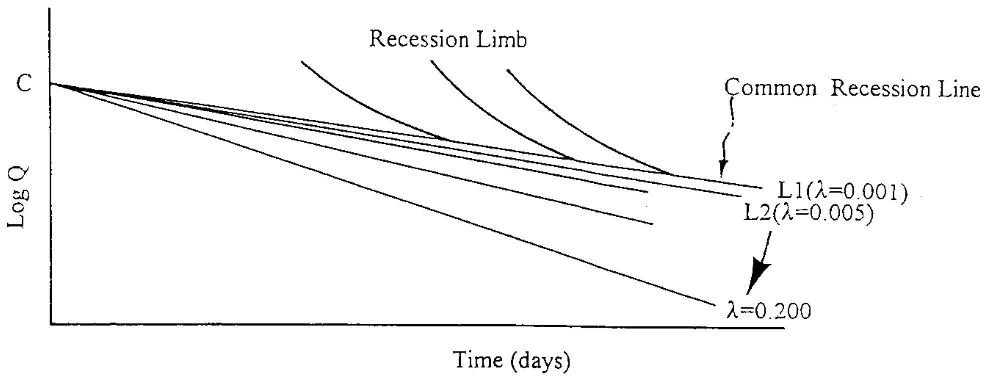


Figure 8. An example of the master recession curve drawn with the procedure presented.



(a) Continuous discharge hydrograph.

Figure 9. Schematic representation for constructing the master recession curve.



(b) Setting of common recession lines.

Figure 9. (continued).

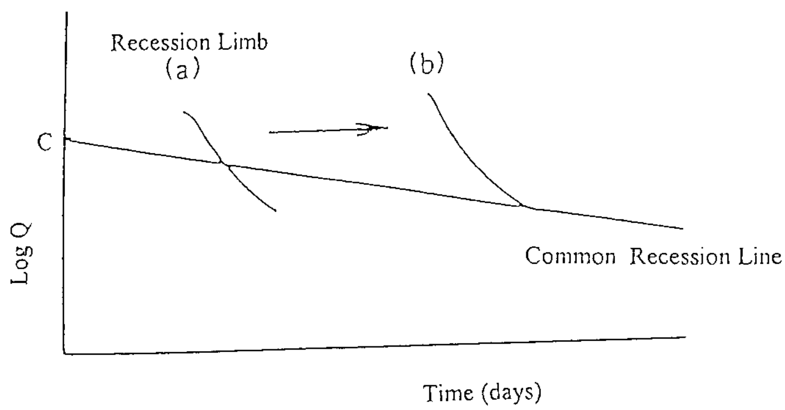


Figure 10. Movement of the recession limb(a) in parallel with respect to the time axis.

=0.005. According to the interval range (△λ=0.005), the recession constant (λ) for the next trial (L2) is 0.005(d^{-1}) (see Figure 10b).

6. Repeat the above-mentioned procedures (Steps 4 and 5) until the recession constant λ is equal to 0.200 since the recession constant(λ) in many dam catchmmts areas is 0.200 (d^{-1}) or less (see Figure 10b). Define the setting common recession line, which can be applied to the greatest number of hydrograph recession limbs, as the master recession curve.
7. Draw the common recession line and the extracted hydrograph recession limbs that determined the master recession curve with the tool of the application program.

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