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RUNOFF RATIO, PREFLOOD DISCHARGE RATE, AND RAINFALL INTENSITY - Hourly Data

BY

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SYNOPSIS

Runoff ratio f = Q/R (R : total rainfall and Q : total runoff) is shown to correlate well with the preflood discharge rate q_A and the rainfall intensity $\bar{r}_p$, compared with other conventional expressions, by a formula $f = 1-(A/\bar{r}_p) \times \exp(-Bq_A)$ where A and B are constants. It is shown that intensities of infiltration and loss also correlate well with q_A.

INTRODUCTION

Discharge of a flood Q (where Q means the total runoff volume exceeding base flow rate) is affected by several factors such as soil moisture (most effective factor) m, rainfall intensity r, total rainfall $R=\int r dt$, evapotranspiration rate e, vegetation coverge c, atmospheric temperature T, drainage basin area S and so on,

$$Q = F_n\ (m, r, R, e, c, T, S, \cdots\cdots) \tag{1}$$

Therefore, the rainfall-runoff ratio f = Q/R is written as

$$f = F\ (m, r, R, e, c, T, S, \cdots\cdots) \tag{2}$$

Runoff ratio or runoff factor f is one of the most important but the least discussed problems in hydrology. A problem in estimating the runoff ratio f is to find a factor which indicates soil moisture without directly measuring it.

PREFLOOD DISCHARGE AS AN INDEX OF SOIL MOISTURE

Since if the soil moisture is high the groundwater level would be high and the discharge rate may be large and vice versa, the discharge rate just before the beginning of flood (preflood discharge or initial discharge), q_A, may be used as an index of soil moisture (for instance, Linsley et al, 1949, p.413, p.420, Iwai & Ishiguro, 1970, p.342). Consequently, the ratio f is expressed as

$$f = F\ (q_A, r, R, e, c, T, S, \cdots\cdots) \tag{3}$$

The factors r and R may be of secondary importance, since it is known that the infiltration rate i is only affected by r at the beginning of rainfall and reaches soon an equilibrium state becoming $i \approx$ constant. As for the factors e, c, T, and S, we may put aside for the time being.

An alternative conjecture is that, roughly speaking, rainfalls infiltrate into soil to fill the remainder of soil moisture and the surplus part of rainfalls becomes runoff as rainfall excess Q. Thus, the rainfall loss L(=R-Q) may be considered rather as a function of soil moisture m or preflood discharge rate q_A ,

$$L = R - Q = f_n(q_A) \quad (4)$$

RESULTS ON RUNOFF RATIO

In order to examine the above mentioned conjectures, three representative drainage basins in Japan are chosen; i.e.,

(a) Yamanashi-Azusa River with drainage area $S = 0.396 km^2$. This small area is characterized by the peculiar runoff features. The loss rate is very high amounting 10 ~ 50%, and the delay time of runoff is very long (a few hour to seven or more hours) in spite of smallness of S.

(b) Kanna River with drainage area $S = 373.6 km^2$. Because of high quality and long recording period, the data of this basin is most frequently used as standard hydrologic data in Japan.

(c) Sagami River with $S = 1201.3 km^2$. The basin is covered by deep porous soil of volcanic loam clay.

The results of computation are shown, compared with the other relationships in Figs.1 through 3 ; i.e.,

(*i*)	f vs q_A [m^3/s]	(Fig.1 (a),(b) and (c))
(*ii*)	f vs R [mm] (and Q [mm] vs R [mm])	(Fig.2 (a),(b) and (c))
(*iii*)	f vs $\bar{r}_p$ [mm/h]	(Fig.3)

where $\bar{r}_p$ is a representative rainfall intensity for a duration of effective rainfall ($r > r_e$, r_e : minimum effective rainfall intensity below which runoff does not occur). The numbers inserted by circles indicate the record number of floods for each basin.

These figures show a remarkedly good correlation of f vs q_A compared with the other representations. The following expressions are derived.

Kanna River:

$$f = 0.0077 q_A + 0.656 \quad (5a)$$

$\gamma = 0.929$ (correlation coefficient)

$\sigma = 1.16 \times 10^{-3}$ (standard deviation)

Yamanashi-Azusa River:

$$f = 0.0530 q_A + 0.129 \quad (5b)$$

$\gamma = 0.966$

$\sigma = 4.9 \times 10^{-3}$

Sagami River:

$$f = 0.0033 q_A + 0.112 \quad (5c)$$

$\gamma = 0.967$

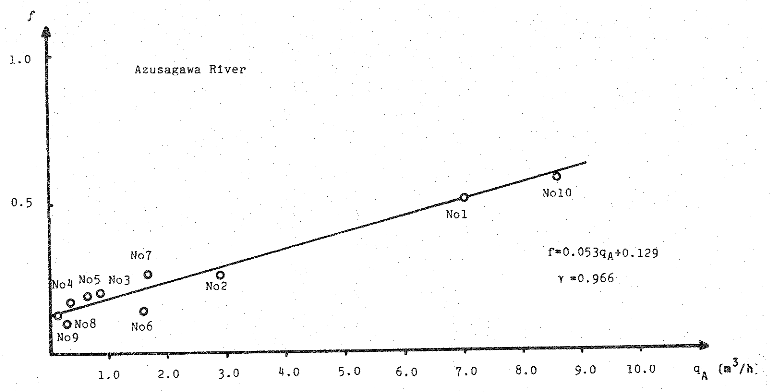
These representations are transformed into the forms of f vs q_A/S (specific preflood discharge rate) expressed as (Fig.4)

$$f = \alpha (q_A / S) + \beta \quad (5d)$$

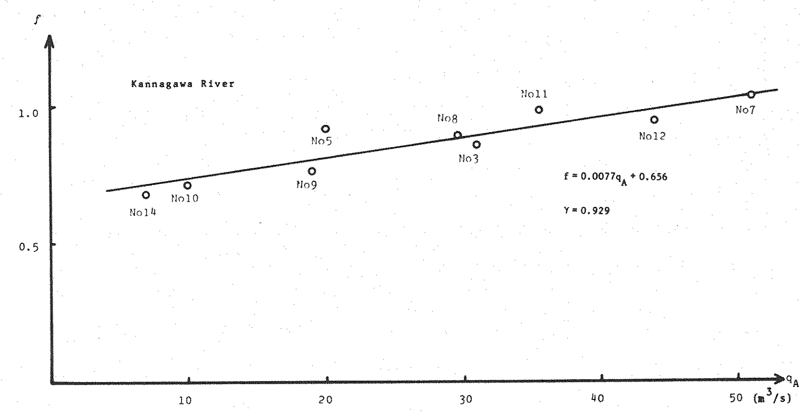
The values of α and β are as follows ;

	α	β
Yamanashi-Azusa River	75.56×10^3	0.129
Kanna River	2.88×10^3	0.656
Sagami River	3.96×10^3	0.112

Eq. 5 is derived rather empirically and intuitively. In the subsequent sections, a rational discussion and development based on the infiltration process will be given to include the effect of rainfall intensity as Eq. 14 .



(a)



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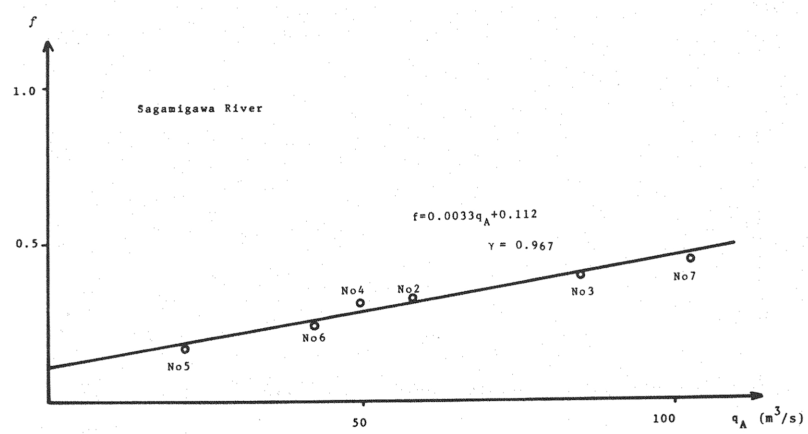
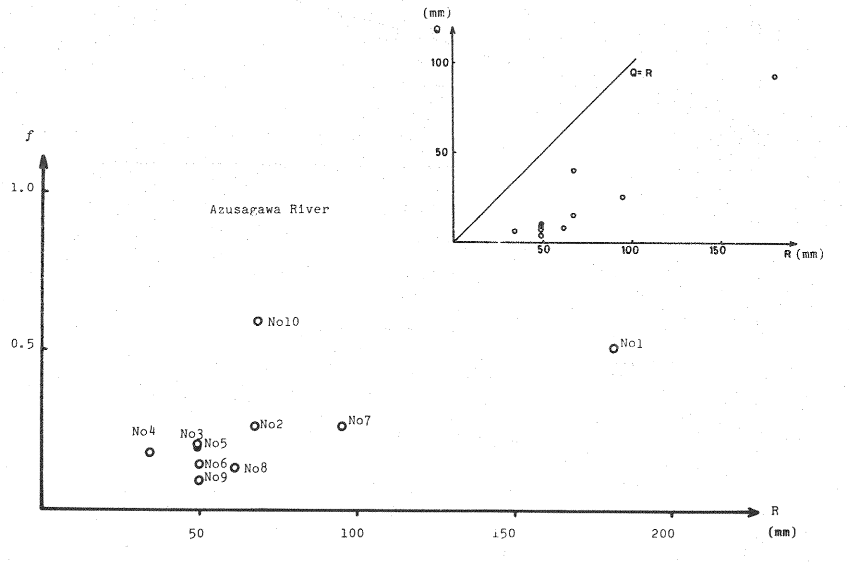
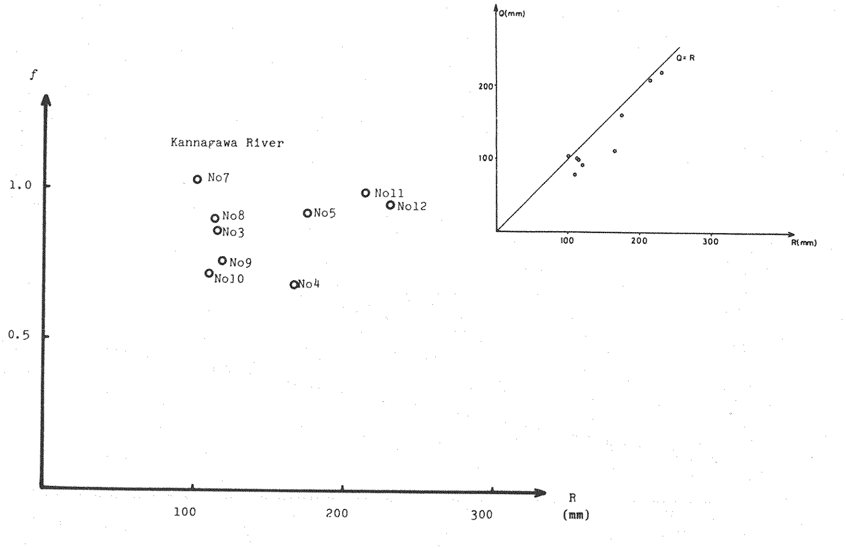


(c)

Fig.1 Relationships between the runoff ratio f and the preflood discharge rate q_A . (a) Yamanashi-Azusa River, (b) Kanna River and (c) Sagami River.



(a)



(b)

Fig.2 Relationships between the runoff ratio f and the total rainfall R, and those of Q (the total runoff) vs R, inserted in the rightside upper corner. (a) Yamanshi-Azusa River, (b) Kanna River and (c) Sagami River.

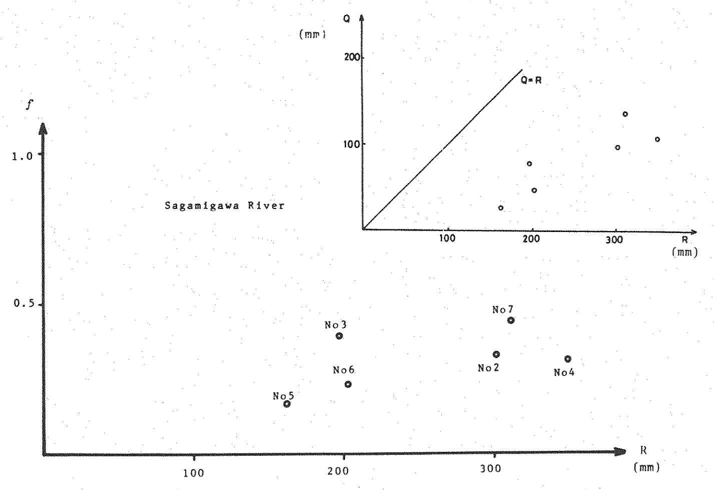


Fig.2 (c)

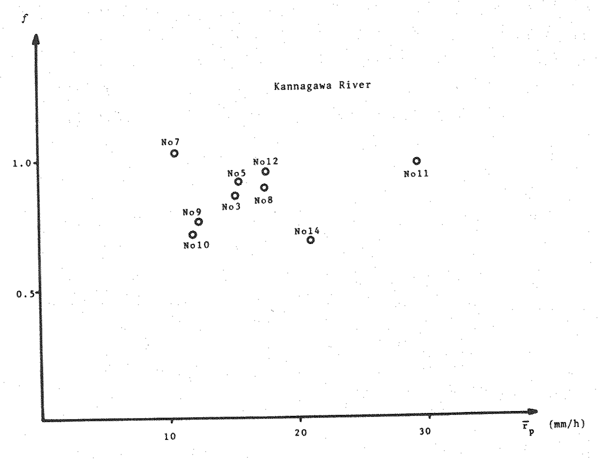


Fig.3 Relationship between f and $\bar{r}_p$ (effective mean rainfall intensity) for Kanna River.

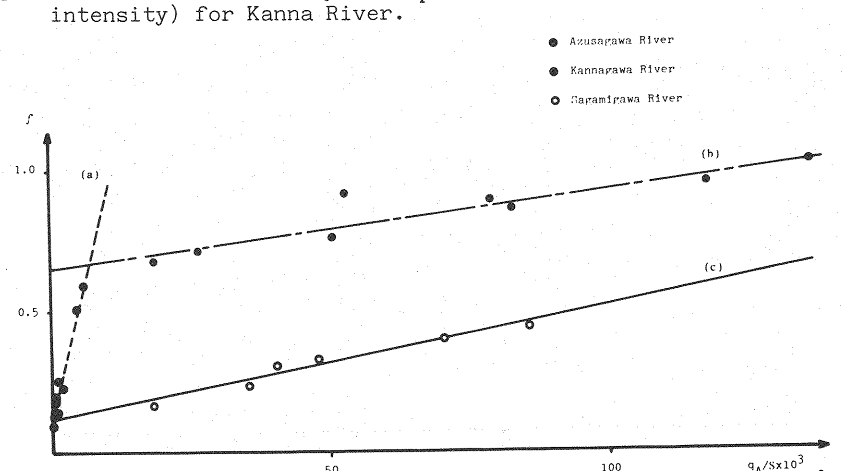


Fig.4 Relationships between the runoff ratio f and the specific preflood discharge rate q_A/S, for Yamanashi-Azusa River, Kanna River and Sagami River.

INFILTRATION AND LOSS INTENSITIES

Loss intensity is defined by

$$l = \frac{R - Q}{T_e} = \frac{L}{T_e} \tag{6}$$

where T_e is the effective rainfall duration during which the rainfall intensity r exceeds the minimum effective rainfall r_e.

On the other hand, the intensity of infiltration which supplies the groundwater component of river discharge as well as the loss components such as evapotranspiration, groundwater which flows the basin strata without appearing as river discharge and loss as runoff to neighbouring basins is given

$$l_G = \frac{R - Q_S}{T_e} = \frac{Q_G + L}{T_e} \tag{7}$$

where the volume of surface runoff and interflow Q_S is separated from a time series of river discharge by the method of low frequency cutoff numerical filter (for instance, Hino and Hasebe, 1979, English version 1981).

By subtracting Eq. 6 from Eq. 7, the intensity of infiltration which supplies purely the groundwater component of river discharge is derived

$$f_c = l - l_G = \frac{Q_G}{T_e} \tag{8}$$

Figure 6 through 8 plots these factors against the preflood discharge q_A, showing good correlations. Fig.6 through 8 states that the following empirical relationships hold;

$$l = \frac{L}{T_e} = f_l\,(q_A) \tag{9}$$

$$l_G = \frac{Q_G + L}{T_e} = f_G\,(q_A) \tag{10}$$

$$f_c = \frac{Q_G}{T_e} = f_c\,(q_A) \tag{11}$$

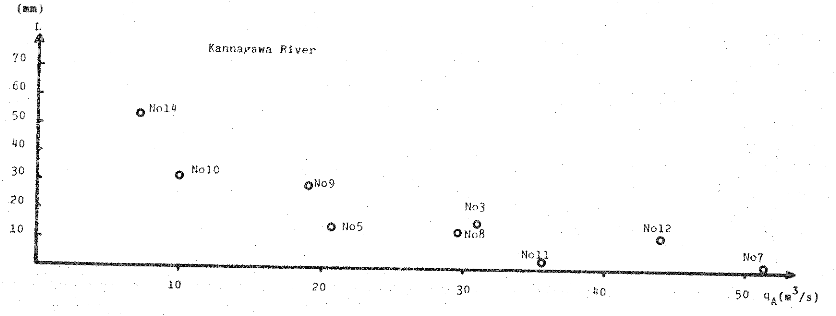


Fig.5 Relationship between the total loss L and the preflood discharge rate q_A for Kanna River.

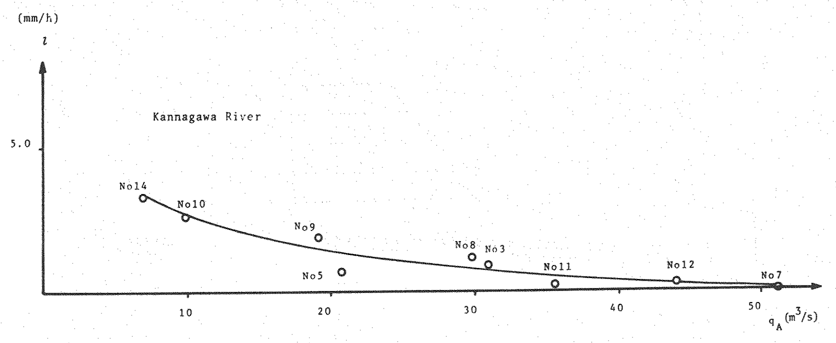


Fig.6 Relationship between the loss intensity l defined by Eq. 6 and the preflood discharge q_A (for Kanna River).

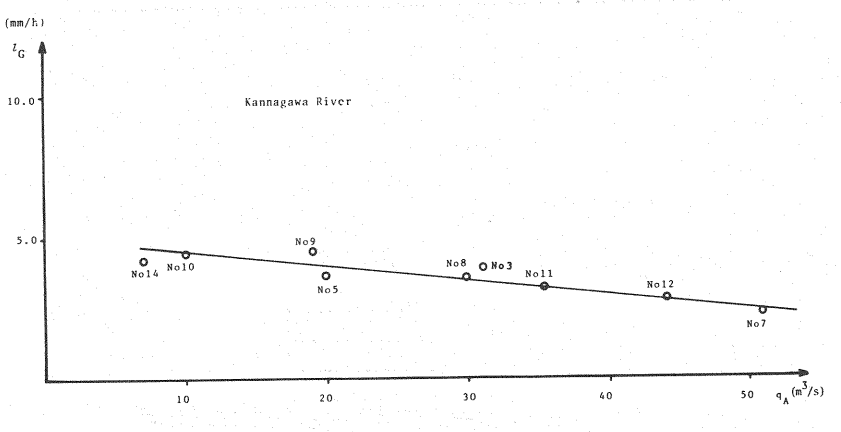


Fig.7 Relationship between the infiltration intensity l_G defined by Eq. 7 and q_A (for Kanna River).

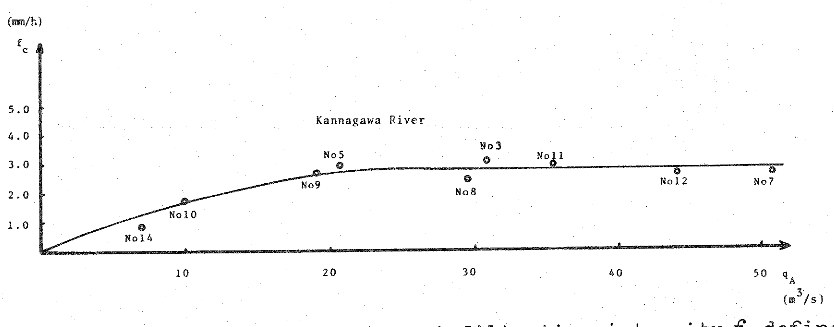
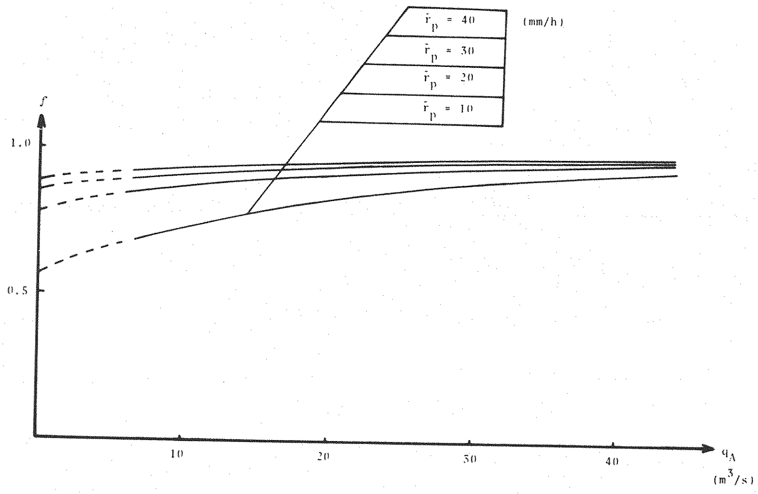
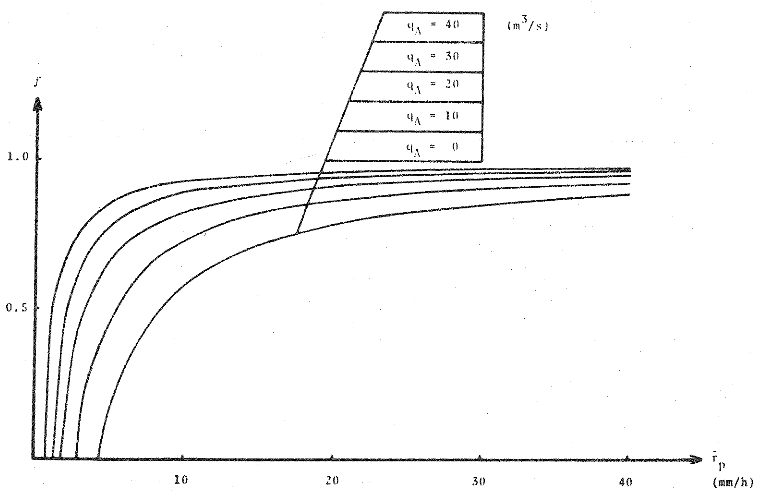


Fig.8 Relationship between the infiltration intensity f_c defined by Eq. 8 and the preflood discharge q_A (for Kanna River).



(a)



(b)

Fig.9 Parametrical representation among f, q_A and $\bar{r}_p$.
(a) f vs q_A by Eq. 14 , (b) f vs $\bar{r}_p$ by Eq. 14 .

and the function $f_l(q_A)$ is expressed by an equation such as

$$f_l(q_A) = A e^{-Bq_A} \qquad (12)$$

where in the case of Kanna River A = 4.237 and B = 0.045.
These relations seem considerably reasonable from a physical viewpoint that the infiltration ratio is determined depending on the soil moisture or q_A.

A RUNOFF RATIO FORMULA

If we rewrite Eq. 9 considering $L = R - Q$, the following equation is derived, showing the effect of rainfall intensity on runoff ratio, as

$$f = 1 - \frac{1}{\bar{r}_p} f_l(q_A) \qquad (\text{for } \bar{r}_p \geq f_l(q_A)) \qquad (13)$$

where $\bar{r}_p = R/T_e$.

Consequently, f is given by

$$f = 1 - \frac{A}{\bar{r}_p} e^{-Bq_A} \qquad (\text{for } \bar{r}_p \geq A e^{-Bq_A}) \qquad (14)$$

The relationship is shown in Fig.9 (a) and (b). Comparing Fig.9 (a) with Fig.1 (b) which is derived empirically, one would see that the effect of rainfall intensity $\bar{r}_p$ is not clear because of the small difference in $\bar{r}_p$.

Of course, the applicability of the above equaiton is limited within a certain range so that f is included in the range from zero to unity. Expanding $\exp(-Bq_A)$, Eq. 14 is approximated by

$$f \cong 1 - \frac{A}{\bar{r}_p} (1 - Bq_A)$$

$$= \left(\frac{AB}{\bar{r}_p}\right) \cdot q_A + \left(1 - \frac{A}{\bar{r}_p}\right) \qquad (15)$$

Thus Eq. 5 previously derived is understood to be an approximation to Eq. 14 .

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