Predictions in Ungauged Basins: PUB Kick-off (Proceedings of the PUB Kick-off meeting held in Brasilia, 20–22 November 2002). IAHS Publ. 309, 2007.

Design flood calculation for ungauged small basins in China

YUANFANG CHEN [1], GUOXIN CHEN [1], ZENGCHUAN DONG [1] & SHENGHUA GU [2], SHUJIAN LI [1]

1 *College of Hydrology and Water Resources, Hohai University, Nanjing, 210024, China*
chenyua6371@vip.sina.com

2 *General Hydrological Station of Shanghai, Shanghai, 200232, China*

Abstract The two main methods for calculating the design flood in ungauged watersheds are introduced in this paper. The Rational Method, which is widely used in China, is described. Its design storm formula form and parameter estimation method, the derivation process for the design peak flood, Q_{mp}, Rational Formulae, and a case study in Jiangxi province, are introduced and described in detail. A brief introduction to the second method, the Empirical Formula Method, is provided.

Keywords design flood calculation; ungauged basin; Rational Formula; Empirical Formula; case study

INTRODUCTION

In China, many reservoirs have been constructed and others have yet to be constructed. The statistics of the Minister of Water Resources show that a total of about 86 000 reservoirs were constructed in the past 50 years, of which 360 are very large; the majority of the reservoirs are middle- and small-sized ones.

The situation is that there is usually no data for discharge and precipitation in most of the small basins in China, especially for the years from 1960 to 1970. It is therefore necessary for us to pay more attention to the design flood calculation for ungauged small basins.

A lot of studies and analyses show that there are three features to the design flood calculation for small reservoirs in China:

(a) the method should be suitable for basins without flood and precipitation data;
(b) the method should be simple, since the number of reservoirs is so great, and designers for design flood calculation are usually not well specialized;
(c) the main focus is usually the design flood peak, not the design flood hydrograph.

Four methods (Zhang Daojiang, 2002) are used to calculate the design flood in ungauged small basins in China:

– the Chinese Rational Formula Method;
– the Empirical Formula Method;
– use of the Nash instantaneous unit hydrograph to do some regionalization work;
– the so-called investigation of historical floods method.

As a contribution to the IAHS PUB meeting, the first two, the most widely used methods, are introduced.

CHINESE RATIONAL FORMULA METHOD

The design storm formula, the derivation of the Q_{mp} rational formulae and a case study are described.

Design storm formula

The design formula has the form:

$$x_{tp} = s_p t^{1-n}, a_{tp} = s_p t^{-n} \tag{1}$$

where x_{tp} is the design storm in duration t hours with an exceedence probability p (mm); a_{tp} is the design storm density in duration t hours with exceedence probability p (mm h^{-1}); t is storm duration (usually $t \le 24$ hours); S_p is x_{tp} with $t = 1$ hour; n is the storm parameter, to be determined by the regionalization method, $n = 0.5–0.7$.

The parameter n is determined as follows: In a large region including the ungauged basins, the first step is to calculate the n value for basins with observed precipitation data in the region, then to determine the n value by the regionalization method for ungauged basins (by taking the mean value of n, or by division of sub-regional values of n, or use of an isogram of n). In practice, n may be obtained by reading up the relevant provincial and national hydrological handbooks which collect together the regionalization results of provincial or national ranges.

The determination of n in a basin with observed data is shown in Fig. 1. In Fig. 1, the x-axis is $\log(t)$, t is storm duration; the y-axis is $\log(a_{tp})$, and n is the negative slope of the curve.

In some cases, the slopes when $t \ge 1$ h and $t \le 1$ h are different, so n is usually divided into two values, i.e. $n = n_2$, when $t \ge 1$ h, $n = n_1$ when $t \le 1$ h.

For the determination of S_p, the following formula is used:

$$S_p = X_{24p} / 24^{1-n} \tag{2}$$

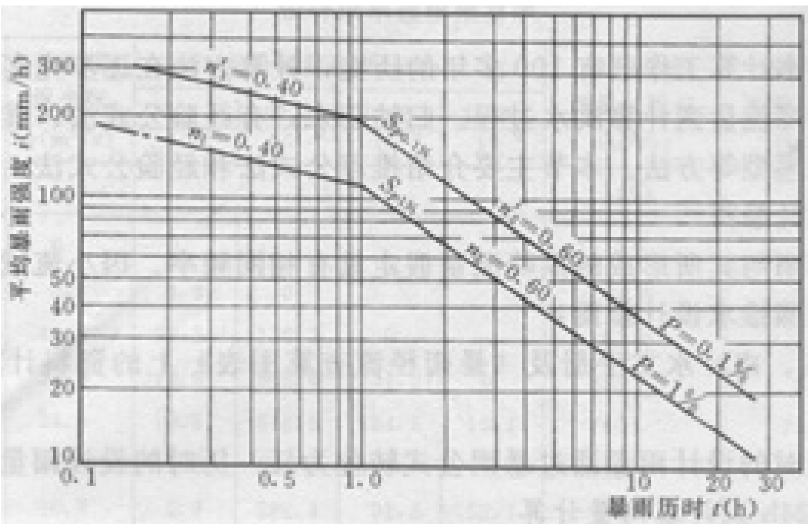

Fig. 1 Determination of n in a basin with observed data.

where X_{24p} is determined by the regionalization method. There are usually two ways:

- by using the isogram of the mean and Cv of the annual maximum 24 hour precipitation; Cs/Cv has an isogram in national and provincial ranges;
- by using the annual maximum daily precipitation data, $x_{24p} = k \times x_{1dp}$, where k is a coefficient that is larger than 1.

Derivation of Q_{mp} by the Rational Method

There are four steps to deriving the Q_{mp} Rational formulae: (a) the construction of the design storm process; (b) runoff generation time t_c and amount of runoff (hr) calculation formulae; (c) empirical calculation formula of basin concentration time τ; (d) Q_{mp} formula derivation by the rational principle.

Design storm process The design storm process curve constructed is indicated in Fig. 2 where the y-axis stands for the instantaneous precipitation density (i), and the x-axis is accumulated time of precipitation (x).

.

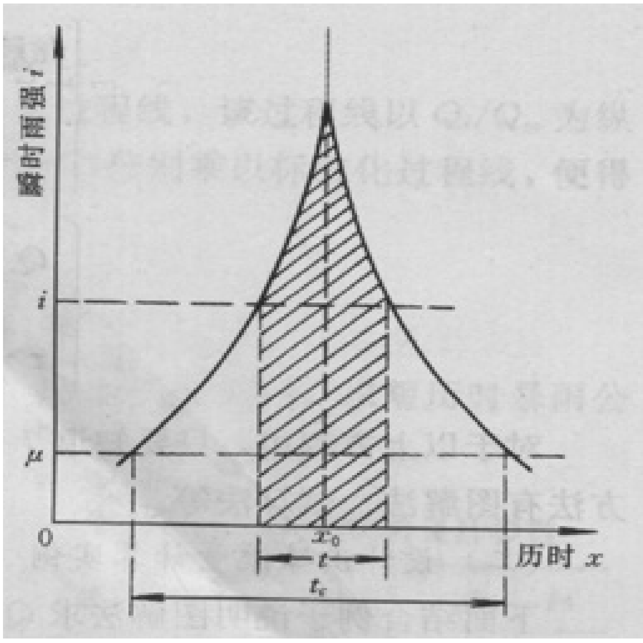

Fig. 2 Design storm process curve.

There are four features to the curve of design storm process:

- when x tends to the centre, x_0,$i(x_0)$ (the instantaneous precipitation density) is infinite;
- it is a symmetrical curve with a centre x_0;
- the shaded area A is equal to $x_{tp} = s_p t^{1n}$;
- there is no explicit formulation.

In fact, the same frequency method for all durations t is used to obtain the design storm process. It means that the maximal storm value for all durations t in the storm process curve is equal to the design storm value.

Runoff generation time t_c and runoff *hr* calculation For simplicity, the loss rate of precipitation is considered as a constant μ.
According to the analysis, the relationship between instantaneous precipitation density i and storm duration t is as follows:

$$i(t) = \frac{dx_{tp}}{dt} = \frac{d(s_p t^{1-n})}{dt} = (1-n)s_p t^{-n} \tag{3}$$

Let $i(t) = \mu$, in this case , t is equal to t_c.

$$t_c = \left[\frac{(1-n)s_p}{\mu}\right]^{\frac{1}{n}} \tag{4}$$

The amount of runoff generating *hr* of design storm during t_c

$$hr = s_p t_c^{1-n} - \mu t_c = s_p t_c^{1-n} - (1-n)s_p t_c^{1-n} t_c = ns_p t_c^{1-n} \tag{5}$$

Calculation of basin concentration time, τ Using the empirical formula proposed by Chinese hydrologists:

$$\tau = 0.278\, L/(mJ^{1/3}Q_{mp}^{1/4}) \tag{6}$$

where L is river length (km); J is average longitudinal gradient; m is the concentration parameter; and Q_{mp} is the design peak discharge ($m^3\,s^{-1}$).

Q_{mp} formula derivation by the rational method The General Rational formulae of Q_{mp} has two cases, $t_c \geq \tau$ and $t_c \leq \tau$ (Fig. 3).
For $t_c \geq \tau$, then:

$$Q_{mp} = 0.278(a_\tau - \mu)F = 0.278\left[\frac{h_\tau}{\tau}\right]F \tag{7}$$

For $t_c \leq \tau$, then:

$$Q_{mp} = 0.278\left(\frac{h_r}{\tau}\right)F \tag{8}$$

The rational formulae proposed by Chinese hydrologists use combinations of equations (1), (5), (6), (7) and (8).
For $t_c \geq \tau$, then:

$$Q_{mp} = 0.278(s_p \tau^{-n} - \mu)F$$

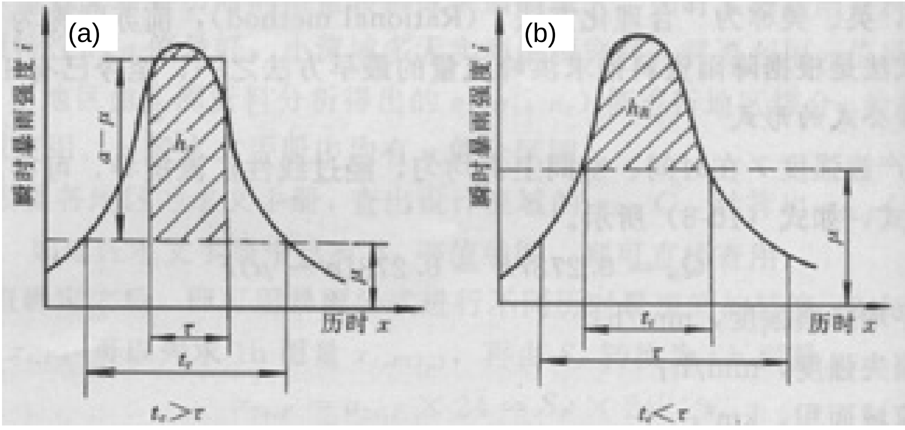

Fig. 3 Design storm process in cases of $t_c \geq \tau$ and $t_c \leq \tau$.

and $\tau = 0.278 L/(mJ^{1/3}Q_{mp}^{1/4})$,The former pair of equations are called equations (a).

For $t_c \leq \tau$, then:

$$Q_{mp} = 0.278(\frac{ns_p t_c^{1-n}}{\tau})F$$

and $\tau = 0.278 L/(mJ^{1/3}Q_{mp}^{1/4})$. These two equations are called equations (b)

In order to solve the above equations, one needs to know the following seven parameters: F, L, J, n, S_p, μ and m.

The recommended procedure for solving equations(a)(b) is as follows:

- Determine the above seven parameter values.
- Assume $t_c \geq \tau$, then use the diagram method (Fig. 4) to solve equations (a), when Q_{mp} is solved, use equation(4) to calculate t_c value. If $t_c \leq \tau$, it indicates that the above assumption is correct. So the Q_{mp} calculated is the result expected, or else turn to solve another set of equations (b)

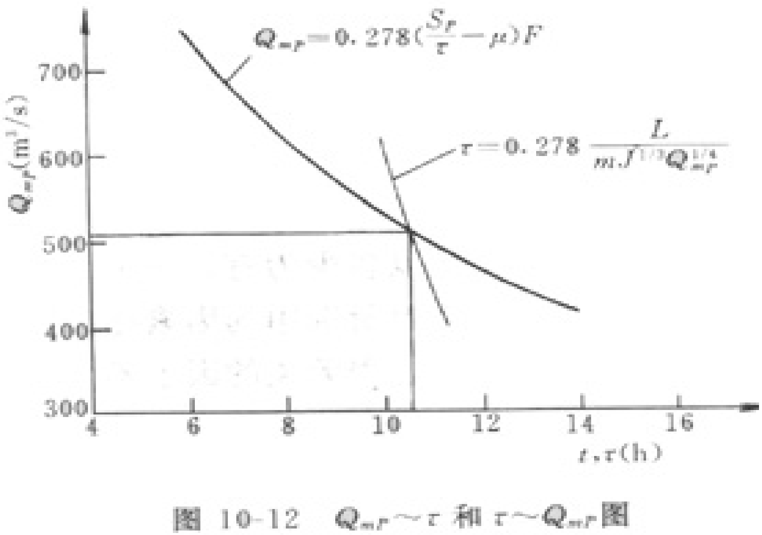

Fig. 4 Diagram method to calculate Q_{mp} for rational formulae.

CASE STUDY

A small reservoir is to be constructed in Jiangxi province, China. Calculation of the design peak discharge with the return period of 100 years by the rational method is required.

The procedure of Q_{mp} calculation is as follows:

Determination of basins parameters *F*, *L* and *J* Using to topographic map, it is easy to measure F and L. For the basin studied, F = 104 km^2, L = 26 km, J = 0.0875.

Determination of storm parameters *n*, *Sp* In terms of the hydrological handbook of Jiangxi province, n_2 is 0.60. The parameters of annual maximal daily precipitation are:

$$\bar{x}_{1d} = 115mm, Cv_{1d} = 0.42, Cs_{1d} = 3.5Cv_{1d}$$

$$x_{24p} = 1.1x_{1d,p}$$

$$s_p = x_{24,p} \times 24^{n_2-1} = 84.8mm/h$$

Determination of μ and *m* According to hydrological handbook, the value of μ is 3.0 mm h^{-1}, and m = 0.7.

Use diagram method to solve rational equations Assume $t_c \geq \tau$, so Q_{mp} and τ can be determined by solving the following two equations:

$$Q_{mp} = \frac{2451.7}{\tau^{0.6}} - 86.7$$

$$\tau = \frac{50.1}{Q_{mp}^{1/4}}$$

Table 1 Relationship of Q_{mp} and τ.

$Q_{mp} = f(\tau)$		$\tau = f(Q_{mp})$	
τ	Q_{mp}	Q_{mp}	τ
8	617.4	400	11.2
10	529.1	450	10.9
12	465.3	500	10.6
14	416.6	600	10.1

From the Fig. 3, Q_{mp} = 510 m^3 s^{-1}, and τ = 10.55 h. Check t_c and τ.

$$t_c = \left[\frac{(1-n_2)s_p}{\mu}\right]^{\frac{1}{n_2}} = \left[\frac{0.4 \times 84.8}{3.0}\right]^{\frac{1}{0.6}} = 57h$$

since τ = 10.55 h < t_c = 57h, the above assumption is correct.

So the design peak discharge Q_{mp} = 510 m^3 s^{-1} (p = 1%).

OTHER Q_{mp} CALCULATION METHODS FOR SMALL UNGAUGED BASINS

The Empirical formula method is briefly described below. For other Q_{mp} calculation methods for small ungauged basins, please refer to other references.

Single factor formula

$$Q_{mp} = C_p F^n$$

where C_p is the comprehensive coefficient, n is an empirical index that is related to basin area.

Multiple factors formulae

$$Q_{mp} = C h_{24p} F^n$$

$$Q_{mp} = C h^{\alpha}_{24p} f^{\gamma} F^n$$

in which f is equal to F/L^2; h_{24p} is the design annual maximal excess rain for 24 hours (mm); α, γ and n are indexes; and C represents comprehensive coefficients.

CONCLUSION

It is very important to research the design flood for ungauged small basins. Some simple methods including the rational formula and empirical formula have been developed and are practised in China. These may also be used in basins outside of China, but it is still necessary to do some work in order to modify them because there are some assumptions which are not suitable to real cases.

REFERENCE

Zhang Daojiang, Ye Shouze *et al*. (2002) *Engineering Hydrology*. China Water Conservancy and Hydropower Publishing House, Beijing, China.