The research and application on calculation method of design flood in small basin

Fahong Zhang¹, Jing Guo¹, Qinghua Yue¹, Jiali Guo²*
¹ PowerChina Huadong Engineering Corporation, Hangzhou Zhejiang, 311122, China
² College of Hydraulic and Environmental Engineering, China Three Gorges University, Yichang 443002, China
*Corresponding author’s e-mail: jiali.guo@ctgu.edu.cn

Abstract. The flood in small basin specializes in quick confluence, high peak value, hard to forecast and serious destruction effect, and once the flood disaster happens, it will put a great threat to the safety of the lives and properties of the resident alongside the river. Rational determination of design flood peak is crucial to the determination of scale, safety and benefit of the projects such as regulation of small basin, river renovation, danger eliminating and reinforcement of dangerous reservoirs and so on. Most of the small basins in China either lack gauged flood data or the catchment area of the project is quite different from the catchment area of the hydro-station, while the rainfall (metrological) data within this basin is relatively abundant. So, rational utilizing available gauged flood data to calculate the design flood of the project place whose catchment area is quite different from the hydro-station’s and utilizing available rainfall data to figure out the design flood are becoming particularly important. The rational method, (comprehensive) instantaneous unit hydrograph, hydrologic analogy, regional comprehensive method, experience formula and some other often-used methods which are often used in the flood calculation of small basin are systematically introduced in this paper. Taking Tingxi Basin in Fujian Province as an example, the above mentioned methods are applied and verified in the four places of Zaoshui hydro-station (10.5km²), Lower dam basin of Xiamen pumping storage power station (12.1km²), Wufeng hydro-station (50.1km²), and Tingxi Water Reservoir (100.8km²), the rationality of the results are analyzed, and the difference of those methods are compared in this paper. On the basis of these things, the application scope and condition of these methods are concluded, and a set of design flood calculation methods of small basin are relatively systematically summarized.

1. Preface
Mountain floods and mudslides, landslides caused by it usually result in huge damage and loss to the national economy and people's lives and properties. To prevent the mountain floods disaster, the floods on small watershed should be analyzed and researched to propose targeted practical calculation methods and guidance program for flood prevention of small watershed.

The design flood calculation method in China is usually divided into two categories: deducing design flood from gauged discharge data and deducing design flood from gauged rainfall data. Most basins under 500km² lack gauged flood data, especially small basins under 50km², and they can’t use gauged discharge to calculate the design flood directly. After the founding of the PRC, China has been gradually formed a more perfect rainfall observing systems and rainfall data is relatively abundant. Therefore,
utilizing available rainstorm data to calculate the flood of small basin become more critical and important [1].

There are many methods for the calculation of design flood in small basin, and the ones which are often used at the present are as follows: experiential formula, hydrologic analogy method, rational method, (comprehensive) instantaneous unit hydrograph, regional comprehensive method, etc. These methods have their own characteristics and certain practicality, may be appropriate to choose to adopt according to the feature of basin. The small basin is characterized by the problems of big variability, with huge number spread in wide area, different flood control standard, and lacks of gauged discharge or rainfall data. So how to choose an appropriate method to calculate the flood, which can satisfy the reasonability of result as well as the requirement of safety and economy has become the main problem of the flood calculation in small basin.

According to the characteristics of these various methods, Tingxi small basin in Xia Men is chosen to be the researching sample area by the method of rational method, instantaneous unit hydrograph, hydrologic analogy method, comprehensive method to calculate the design flood of interesting place in the basin, and do the summary on the design flood methods which are suitable for different small basin.

2. Usual calculation method of design flood in small basin

The calculation of design flood in small basin is widely used in the design of moderate and small scale hydraulic engineering, such as building small water reservoir for farmland hydraulic engineering, flood-intercepting ditch, crossing building on the river such as culver, discharge release gate, etc. The design of small bridge and culvert on railway and road as well as the flood control engineering of urban, industrial and mining areas must do the calculation of design flood. Compared with big and moderate scale basin, the design flood of small basin is characterized by the following three aspects:

1) The number of construction works on small basin is very large, while it often lacks the rainfall and discharge data, flood peak data in particular.

2) Minor works generally have the relatively small flood regulation ability, and the scale of the project is mainly controlled by the peak flow, thus, the project has a higher requirement on the design flood peak discharge rather than the requirements of flood process.

3) The number of minor works are relatively large with wide distributions, so the calculation method should not be too cumbersome, and can be applied in different areas [2].

For the calculation of design flood in gauged small basin, P-III type frequency curve can be used to calculate the design flood. The research for the design flood of ungauged small basin has been carried out for more than 100 years, and the calculating methods have gradually strengthened and developed, including the rational method, (comprehensive/ instantaneous) unit graph method, experiential formula, regional comprehensive method, hydrological models, etc.

Combining the engineering experience of hydrological design of practical projects, the several methods such as rational method, instantaneous unit hydrograph method, hydrologic analogy method ,regional comprehensive method which are mainly used in daily engineering designs are introduced in this paper.

2.1. Rational method

As for the small basin whose area is smaller than 50 km² (or 100 km², or 200km², different value in different regions), the rational method is often used to calculate design flood. Rational method is a formula which calculates the flood peak at the outlet place of basin directly from the continuous and kinetic equations of flow after uniformly generalized the producing and converging condition of the basin. The main assumptions used in the generalization are: (1) net rainfall intensity within the basin confluence time $\tau$ is constant, which means it can be expressed by the average net rainfall intensity $i$; (2) convergence area curve $F(\tau)$ is generalized into a rectangle, and the same speed is invariable along the way the converging.

According to hydraulic and hydroelectric engineering design flood calculation manual, the calculation formula of rational method is as follows:
Due to the variations of spatial and temporal distribution of the rainfall, sometimes the flood peak discharge is formed by the confluence of the entire basin, which is called entire basin confluence. While sometimes, the flood peak discharge is formed by the confluence of the partial basin, which is called partial basin confluence.

The equation for calculation of confluence time is as follows:

When $t_c > \tau$, belongs to whole basin confluence,

$$Q_m = 0.278 \frac{h}{\tau} \times F$$

When $t_c \leq \tau$, belongs to partial basin confluence,

$$Q_m = 0.278 \frac{h_R}{\tau} \times F$$

Where: $h_t$ is maximum net rain within $\tau$ period; $h_R$ is the net rain for a single flood peak. In the calculation process of design flood of small basin, net rain period $t_c$ is usually larger than confluence time $\tau$, so the entire basin confluence is mainly happened. In the situation of whole basin confluence, the equation can be transformed into:

$$Q_m = 0.278 (\frac{H_t}{\tau} - \mu) \times F$$

$\tau$ is calculated by the following equation:

$$\tau = 0.278 \frac{L}{J^3 m Q_m^{1/4}}$$

Where: $Q_m$ — peak flow (m$^3$/s); $\tau$ — confluence time (h); $h$ — net rain within the confluence time (mm); $F$ — basin area (km$^2$); $L$ — river (km); $J$ — river average slope; $m$ — confluence coefficients; $H_t$ — design rainfall within $\tau$ period; $\mu$ — the loss rate. The confluence parameter $m$ is a comprehensive parameter which reflects basin characteristics, which can be got from the analysis and calculation of available gauging rainfall and discharge data as well as the investigating data of them. $m$ is usually the function of $\theta$. $\theta$ is the parameter made up of $F$, $L$, $J$, which reflect the shape characteristic of the basin, and the description about the calculating relationship between $m$ and $\theta$ can be found in the rainfall and flood calculation manual of each province$^{[3]}$.

The combining solution of the above equations can figure out the design flood peak for every frequency. The value of each parameter in rational method and the calculation procedure can refer to the rainfall and flood calculation manual of each province which is got after the analysis and calculation on the rainfall and flood of this province, as well as the rainfall and flood calculation manual compiled by Hydro China of Ministry of Water Resources.

2.2. Instantaneous unit hydrograph

As for the small basin whose area is bigger than 200 km$^2$ (or 500km$^2$, different value in different regions), the instantaneous unit hydrograph is often used to calculate design flood.

The one often used is Nash instantaneous unit hydrograph method, whose mathematical equation is as follows:

$$U(t) = \frac{1}{K \Gamma(n)} \left( \frac{t}{K} \right)^{n-1} e^{-t/K}$$

Following this two-parameter confluence model, as long as figuring out the $n$ and $K$ of the basin, the instantaneous unit hydrograph can be get. In practical application, the instantaneous unit hydrograph is transformed into the finite-period unit graph by $S$ graph($S$ graph is a cumulative graph for unit graph, the time length of unit graph can be converted into), and the basic formula is:
\[ U(\Delta t, t) = \frac{1}{\Delta t} (S(t) - S(t - \Delta t)) \]

\[ S(t) = \frac{1}{\Gamma(n)} \int_0^{t/K} \left( \frac{t}{K} \right)^{n-1} e^{t/K} d\left( \frac{t}{K} \right) = f(n, t/K) \]

Where: \( U(t) \) — vertical height of instantaneous unit hydrograph at \( t \); \( K \) — reflects the confluence time of basin, also named as storage coefficient; \( n \)—regulate times or regulate coefficient; \( \Gamma(n) \) — order’s incomplete gamma function; \( t \) — time; \( \Delta t \) — period length, according to the basin size, it can be 1hr, 3hr, 6hr, etc.; \( n \) is the number of cascade reservoirs in Nash Model, which should be integer in principle, but it can be used in non-integer in practice, or even less than 1; \( K \) is the stagnation time of the reservoir; \( nk \) means \( m \), the first moment of unit graph or unit line stagnation, which is a measurement for average propagation time of the basin or the average speed, with a clear physical meaning. The value of this parameter is relatively steady, and it changes regularly \(^4\).

The combining solution of the above formulas can figure out the design flood peak for every frequency. The value of each parameter in rational method and the calculation procedure can refer to the rainfall and flood calculation manual of each province which is got after the analysis and calculation on the rainfall and flood of this province, as well as the rainfall and flood calculation manual compiled by Hydro China of Ministry of Water Resources.

2.3. East China extreme-small basin method

This method is based on the principal of rational method, and researches the rain-flood characteristic and varying rules of the parameter of extreme small basin on the analysis on the flood characteristic of large amount of gauging stations in east of China. According to the type of underlying surface, the flood parameter of different basin are divided into 5 category, individually establish calculating equation for flood parameter of each type, and then get the design method for flood peak discharge.

East China extreme-small basin method is mainly applied in the basin within 10km\(^2\), which actually is a rational method which has made some “East China Extreme-small basin” improvement on \( \theta \) and \( m \) in the calculating method, and has obtained a relatively good application in engineering practice.

2.4. Hydrological analogy method

If the flood record of the hydrological station within or near the engineering basin with a close basin area and underlying surface condition is available, the design flood of the station can be get by the method of calculating design flood from gauging discharge, and then transfer the result of the gauging station to the project place. The equation is:

\[ Q_{\text{Project, place}} = \left( \frac{F_{\text{Project, place}}}{F_{\text{Hydro-station}}} \right)^n \left( \frac{P_{24h, Project, place}}{P_{24h, Hydro-station}} \right) Q_{\text{Hydro-station}} \]

where: \( Q_{\text{Hydro-station}}, Q_{\text{Project, place}} \) — flood peak at hydro-station and project place; \( F_{\text{Hydro-station}}, F_{\text{Project, place}} \) —the basin area for hydro-station and project place; \( P_{24h, Hydro-station}, P_{24h, Project, place} \) —average annual maximum 24h rainfall for hydro-station and project place; \( n \)—attenuation modulus for flood peak, calculated from regional comprehensive method.

It is better that the project site and the hydro-station locate at the same basin, and the area ratio is within 0.5–2. The value of flood attenuation modulus \( n \) should be figure out by regional comprehensive analysis on the design flood when apply the hydrological analogy, rather than simply getting the often using value of 0.67. In the region without gauging record, \( n \) often equals 0.67 in moderate size basin, and less than 0.67 in small basin. If referring hydro-station locates at the nearby basin, attention should be paid to whether the rain flood characteristics of the two basins are quite different. If the difference is
obvious, the ratio of annual maximum rainfall for 24h of the two basins should by multiplied as a modifying coefficient [5].

2.5. **Regional comprehensive method**

Regional comprehensive method for design flood is to find out the relationship between flood discharge and basin characteristic value and establish their relationship correlation equation, according to the gauging and investigating flood material at the project basin and the nearby region. These equations are experientially formulated in accordance with the gauging data of a certain area, and they are only suitable for these regions, so they are called regional experiential formula. Regional experiential formula is usually divided into single-factor formula and multi-factor formula [6].

Single-factor formula is used more often in daily engineering hydrology, which has established the correlation equation between design flood peak and basin area of the different frequency, that is:

\[ Q_m = C \cdot F^n \]  \( (10) \)

Where \( C \) — comprehensive coefficient varying with the region and the design frequency; \( n \) — area ratio index (peak attenuation modulus). The advantage of the formula is simple and intelligible, with strong region applicability, and has been more widely used. The disadvantage of the formula is ignored inter-basin differences in topography, landform, underlying surface conditions and so on, with fewer parameters in the basin, and the accuracy is relatively not very high when there is big difference between basins.

In addition to considering the basin area, the multi-factor formula also considers some other factors such as the river length, slope, experiential convergence index, experiential comprehensive coefficient and so on. For example, the comprehensive basin flood peak experiential formula for mountain hilly region in Anhui Province is:

\[ Q_m = C \cdot h_{24}^\alpha \cdot J^\beta \cdot f^\gamma \cdot F^n \]

\( (11) \)

Where \( f \) — the shape coefficient of the basin (\( f = F/L^2 \)); \( J \) — the average slope of the main river, \( h_{24} \) — design annual maximum net rainfall for 24 hours; \( \alpha, \beta, \gamma, n \) — experiential convergence index; \( C \) — the experiential comprehensive factor. In the practical application of design flood calculation of small basin, the multi-factor formula is used not very often because it needs the relatively large number of parameters and there are many regional experiential parameters in it.

2.6. **Other methods**

In addition to the above mentioned methods, many methods such as regional experiential formula, historical flood marks estimation method, hydrological model, Lin Pingyi method, Tieer Yuan method, SCS model method and so on, have different extent of the application in the practical engineering project and scientific research.

These methods have obtained a good application in a certain historical period as well as a certain engineering scope and region. With the development of hydrological sciences and the enhancement of level of domestic hydrologic design, these methods which need many parameters and have certain kind of limitations have gradually replaced by the methods which are widely used both in home and abroad such as rational method, instantaneous unit hydrograph and other methods [4].

In addition to the various experiential formulas, semi-experiential semi-theoretical formulas listed above, in hydrological research work at home and abroad in recent years, some hydrological model such as Xinanjiang model, northern Shaanxi model, NAM model, TANK model, SCS model are used to calculate design flood has gradually been more widely promoted. Because hydrological model often needs the relatively more basic information, and the calculation process is relatively cumbersome, this paper no longer expands the description on the how to use hydrological model to calculate the design flood.
3. Calculation sample for design flood in small basin
Most of the coastal rivers in Fujian province are montanic river, which located in mountain and hill region, and their flow is rapid with a short original line and an obvious variation in different seasons within a year because of the effect of terrain and climate.

![Figure 1. Tingxi river system and the distribution of hydraulic projects.](image)

Most of the small coastal basin in Fujian province lack gauging discharge record, and the design flood is often calculated by the approach of deducing design flood from gauged rainfall data. The small basin of lower dam site of Xiamen pumping storage power station, Wufeng hydro-station, dam site of Tingxi water reservoir with different area were chosen to calculate their design flood individually by the approach of rational method, East China extreme small basin method, instantaneous unit hydrograph, hydrological analogy method, regional comprehensive method, and analyze the reasonability of the results from different calculation methods.

Maolin Stream is one of Tingxi Stream’s headstreams, originated from Yunding Mountain, and flows into Tingxi water reservoir. Wufeng hydro-station is located at Maolin Stream, with an area of 52.1km², river length of 10.77km, and average slope of 97.0 ‰. Planning Xiamen Pumped Storage Power Station is located in the tributary of Maolin Stream, the area of its lower dam is 11.78km², with a river length of 7.24km and average slope of 113 ‰. Another main tributary of Tingxi Stream is Zaoshui Stream,
originated from Tiefeng Mountain, and flows into Xidong water reservoir which flows into Tingxi water reservoir eventually. Tingxi water reservoir has an area of 100.8 km², river length of 10.77 km, and average slope of 97.0 ‰. Zaoshui hydro-station is located in Zaoshui stream, with an area of 10.5 km², river length of 10.5 km, and average slope of 61.6 ‰. Tingxi stream flows into Xixi stream, and then flows into Xiamen Bay Ocean eventually. The rivers of Tingxi basin have a typical mountain river characteristics, boulder bed, gravel bed and steep slope, and the basin has a dense vegetation with less influence of human activities. Tingxi river system and the distribution of hydraulic projects are shown in Figure 1.

3.1. Verification of formula
To verify the accuracy of rational method, East China extreme small basin method, and instantaneous unit hydrograph on the calculation of design flood in small basin, the 1h, 6h, 24h’s rainfall record of the flood season in 1996 and 1997 are chosen to calculate the design flood at Zaoshui hydro-station, Wufeng hydro-station and Tingxi water reservoir by the above three methods. The parameter value of each method is get from rainfall flood calculation manual of Fujian Province. The rainfall process chooses typical rainfall process of Fujian Province, and the short time rainfall value of each station in 1996, 1997 and flood verification result are shown in table 1.

Table 1. The short time rainfall value of each station in 1996, 1997 and flood verification result.

| Year | Place                  | Area (km²) | 1h  | 6h  | 24h  | Flood peak (m³/s) | Gauged value |
|------|------------------------|------------|-----|-----|------|------------------|--------------|
|      |                        |            |     |     |      | East China extreme-small basin | Rational method | Instantaneous unit graph | Gauged value |
| 1996 | Zaoshui Station        | 10.5       | 68.8| 153.4| 359.2| 159              | 178          | 97            | 169          |
|      | Wufeng Station         | 52.1       | 69.2| 226.0| 449.0| 673              | 728          | 610           | 671          |
|      | Tingxi Water reservoir | 100.8      | 61.5| 179.4| 373.3| —                | 901          | 825           | —            |
| 1997 | Zaoshui Station        | 10.5       | 91.7| 181.8| 276.0| 168              | 151          | 121           | 157          |
|      | Wufeng Station         | 52.1       | 96.5| 174.2| 288.6| 769              | 914          | 642           | 943          |
|      | Tingxi Water reservoir | 100.8      | 92.5| 173.1| 276.6| —                | 1080         | 974           | —            |

As can be seen from the above table, the flood verification result of Zaoshui hydro-station by the approach of East China extreme-small basin method is most chose to the gauged value, and this is consistent with the provision that this method is mainly suitable for the basin within 10 km²; the flood verification result of Wufeng hydro-station and Tingxi water reservoir by the approach of East China extreme-small basin method is also relatively desirable, and this is consistent with the provision that this method is mainly suitable for the basin between 10 km² and 200 km². As for the basin area of the above sites are all smaller than 200 km², so the results of instantaneous unit hydrograph are not very desirable. The above calculation results also indicate that the recommending parameter value and its calculating formula in rainfall flood calculating manual have the relatively high reliability.

3.2. Calculation sample for design flood
The Xinghou, Wangqian, Luoxi, Zaoshui, Wufeng rainfall stations within Tingxi basins have an available gauging short time rainfall material more than 30 years, and do the frequency calculation for each station by P-III type curve, and then calculate the design surface rainfall for other places within the basin by the Thiessen polygons method. Typical rainstorm process for 24h adopts the rainfall process recommended in the Fujian rainstorm runoff calculation manual (rational method). The design rainfall results for every project place in Tingxi basin are shown in Table 2.
Table 2. The design rainfall results for every engineering place in Tingxi basin.

| Basin                                | Period | Mean value (mm) | Cv  | Cv/Cs | 1% (mm) | 2% (mm) | 5% (mm) | 10% (mm) | 20% (mm) |
|--------------------------------------|--------|-----------------|-----|-------|---------|---------|---------|---------|---------|
| Lower dam basin of Xiamen pumping storage power station | 1h     | 58.1            | 0.25| 3.5   | 116.6   | 107.6   | 94.7    | 84.1    | 55.4    |
|                                      | 6h     | 121.4           | 0.38| 3.5   | 319.5   | 283.8   | 236.3   | 199.2   | 107.2   |
|                                      | 24h    | 216.6           | 0.40| 3.5   | 609.7   | 536.2   | 440.8   | 366.7   | 189.3   |
| Wufeng station                       | 1h     | 56.7            | 0.27| 3.5   | 113.4   | 104.4   | 92.1    | 80.8    | 53.8    |
|                                      | 6h     | 110.8           | 0.39| 3.5   | 285.5   | 254.2   | 212.7   | 180.8   | 99.5    |
|                                      | 24h    | 192.8           | 0.40| 3.5   | 517.3   | 457.8   | 379.2   | 318.3   | 169.7   |
| Zaoshui station                      | 1h     | 58.8            | 0.32| 3.5   | 117.3   | 108.6   | 94.7    | 84.1    | 55.3    |
|                                      | 6h     | 119.4           | 0.42| 3.5   | 287.7   | 258.1   | 218.7   | 187.4   | 108.5   |
|                                      | 24h    | 203.4           | 0.44| 3.5   | 504.0   | 450.3   | 378.3   | 323.5   | 181.3   |
| Tingxi reservoir                     | 1h     | 57.5            | 0.29| 3.5   | 117.0   | 107.4   | 94.2    | 83.4    | 54.3    |
|                                      | 6h     | 114.9           | 0.38| 3.5   | 280.8   | 251.7   | 212.2   | 181.9   | 103.8   |
|                                      | 24h    | 198.6           | 0.40| 3.5   | 508.2   | 452.5   | 378.0   | 320.0   | 176.5   |

The parameters of rational method adopt the recommending value in Fujian rainstorm runoff calculation manual (rational method), the value of confluence parameter \( m \) choose the calculation formula for coastal region, as: when \( \theta \geq 1.5 \), \( m = 0.053 \theta^{0.809} \); when \( \theta < 1.5 \), \( m = 0.062 \theta^{0.384} \), where: \( \theta = L/(J^{1/3}F^{1/4}) \). The steady infiltration value \( f_c \) under different net rain intensity \( i \) can be get by referring to the relationship table in manual. Following the calculation process of rational method, design flood for each basin can be figured out, shown in Table 3.

The parameter of instantaneous unit graph adopts the recommending value in Hydraulic Engineering design flood calculate manual, the value of confluence parameter \( m \) choose calculation formula for coastal region, as: when \( m_1,10 = 2.8F^{0.137}J^{0.24} \), \( b = 0.262F^{-0.07}J^{0.126} \), \( n = 4.05F^{0.062}J^{0.141} \). Following the calculation process of instantaneous unit graph method, design flood for each basin can be figured out, shown in Table 3.

The paramter of East China extreme-small basin method adopts the recommending value in flood parameter research on extrem small basin in East China, the value of confluence parameter \( m \) choose the calculation formula for region II-2, as: \( m = 0.395L^{0.130} \), where \( \theta = L/J^{1/3} \). The value of steady infiltration value \( f_c \) equals to rational method in Fujian province. Following the same calculation process as rational method, design flood for each basin can be figured out, shown in Table 3.

Maximum flood peak of Wufeng station from 1981~2009 has been collected, as well as the historical flood 2090m³/s in the year of 1867; Maximum flood peak of Zaoshui station from 1968~2009 has been collected. After calculate the design flood of the two stations by P-III type curve, the design flood for each place within the basin can be figured out by hydrologic analogy method, where flood attenuation modulus \( n \) is obtained from regional comprehensive relationship. Considering basin is small, there is no need to consider rainfall modification between different places.

According to the average flood peak at Wufeng and Zaoshui hydro-station for many years, a regional comprehensive relationship with basin area are established and get flood attenuation modulus \( n \) is 0.807 after the analysis, and the design flood for every frequency at under the dam site of Xiamen pumped storage station, Zaoshui station and Wufeng station are figure out by hydrologic analogy method. Applying the same process to Tingxi water reservoir, getting the flood attenuation modulus \( n \) of 0.730 and the design flood for Tingxi water reservoir. The \( F~Q \) regional comprehensive picture for every station is shown in Figure 2.

Similarly, the regional comprehensive relationship between \( Cv \) of the annual maximum flood peak at Wufeng hydro-station, Zaoshui hydro-station as well as other nearby hydro-stations and their basin area are established, as shown in Figure 3. After figure out annual average flood peak discharge \( Q_m \) and
For every place, the design flood at every place can be calculated by frequency calculation, as shown in Table 3.

Meanwhile, according to the relationship between design flood peak and basin area obtained from regional comprehensive analysis, design flood of various frequency at every place can be figured out by this relationship, as shown in Table 3.

Table 3. The calculation results of design flood of different methods.

| Basin                        | Area (km²) | Item/Method                                      | Mean value of $Q_m$ (m³/s) | $C_v$ | Flood peak (m³/s) 1% 2% 10% |
|------------------------------|------------|--------------------------------------------------|----------------------------|-------|------------------------|
| Zaoshui station              | 10.5       | Rational Method                                  | —                          | —     | 236 218 171            |
|                              |            | East China extreme-small basin method            | 273                        | 247   | 181                    |
|                              |            | Instantaneous unit hydrograph                    | 182                        | 165   | 119                    |
|                              |            | Frequency calculation for gauged data            | 85.0                       | 0.86  | 360 303 174            |
|                              |            | Hydrological analogy. Referring Wufeng station   | 95.9                       | 0.95  | 476 388 199            |
|                              |            | Mean value for all methods                       |                            |       | 305 264 169            |
| Wufeng station               | 50.1       | Rational Method                                  | —                          | —     | 995 925 728            |
|                              |            | Instantaneous unit hydrograph                    |                            |       | 896 808 583            |
|                              |            | Frequency calculation for gauged data            | 300                        | 0.84  | 1270 1070 614          |
|                              |            | Hydrological analogy. Referring Zaoshui station  | 266                        | 0.76  | 1065 931 612           |
|                              |            | Mean value for all methods                       |                            |       | 332 300 217            |
| Lower dam basin of           | 12.1       | Hydrological analogy. Referring Zaoshui station  | 95.3                       | 0.85  | 423 351 191            |
| Xiamen pumping storage power station |          | Hydrological analogy. Referring Wufeng station   | 95.4                       | 0.94  | 468 382 197            |
|                              |            | Regional comprehensive. Referring Zaoshui station| —                          | —     | 404 340 195            |
| Tingxi water reservoir       | 100.8      | Regional comprehensive. Referring Wufeng station | —                          | —     | 408 344 197            |
|                              |            | Mean value for all methods                       |                            |       | 407 343 199            |
|                              |            | Rational Method                                  | —                          | —     | 1630 1450 1050         |
|                              |            | Instantaneous unit hydrograph                    | —                          | —     | 1610 1330 950          |
|                              |            | Hydrological analogy. Referring Zaoshui station  | 443                        | 0.72  | 1672 1417 841          |
|                              |            | Hydrological analogy. Referring Wufeng station   | 500                        | 0.79  | 2100 1730 980          |
|                              |            | Regional comprehensive. Referring Zaoshui station| —                          | —     | 2198 1850 1063         |
|                              |            | Regional comprehensive. Referring Wufeng station | —                          | —     | 2222 1872 1074         |
|                              |            | Mean value for all methods                       |                            |       | 1905 1608 993          |
4. Result selection and rationality analysis

4.1. Result selection

As for Wufeng and Zaoshui hydro-station, both of them have gauging flood record and the investigation data about historical flood, so it’s better to calculate the design flood for these two stations by the frequency calculation on their gauged flood data.

As for lower dam site of Xiamen pumping storage power station, which is located in the same basin with Wufeng hydro-station, but their basin area are quite different; it is not in the same basin with Zaoshui hydro-station, but their basin area are very close. Both hydro-stations have abundant short time rainfall material, but no history rainfall data. Thus, the three methods are feasible for this place, and the calculation results are expected to be close. Considering Xiamen pumped storage power station is located in the heavy rainstorm center of Xiamen city, which is easy to occur big rainstorm and flood, so finally adopt the safer result which is calculated by the method of hydrological analogy referring to Wufeng hydro-station with the consideration of safety of project.

As for Tingxi water reservoir, which is located at the downstream of Wufeng hydro-station with a close basin area, it’s better to calculate by the method of hydrological analogy referring to Wufeng hydro-station, and this result is closest to the mean value of the results of these methods.

Because historical rainfall is not taken into account in the design rainstorm series, so the result of rational method is a little bit smaller than the results of hydrological analogy method and regional comprehensive method which have consider the historical flood. If the historical rainfall data is available, the results of rational method and other two methods can be expected to close to each other.

4.2. Rational analysis

Compare the design flood results and their flood peak modulus of each place in Tingxi basin which are get from the rainfall and flood data of Zaoshui and Wufeng hydro-station, with the design flood results and their flood peak modulus of the hydro-stations located in the southeast coastal basin of Fujian province, draw the regional comprehensive picture and analyze the result, as shown in Table 4, Figure 5, Figure 6.

The figures show that the mean value of flood peak of Zaoshui and Wufeng hydro-station located on the upper area of regional comprehensive line, and its flood peak modulus is obvious greater than other hydro-stations. Referring to the short-duration rainstorm isoline of Fujian province, the rainfall in southeast of Fujian declines from the coastline to the inland, and the isoline is basically parallels to the coastline, and several rainstorm centers are located in coastal zones. No matter seeing from 1h’s, 6h’s or 24h’s rainstorm, both Tingxi basin in Northern Xiamen and the upper stream basin of Weitou Bay which is adjacent to its northern border are belonging to closed local rainfall centre. The basin of lower dam of Xiamen pumping storage power station finally takes the safer design flood result, which also accord with the distribution characteristics of rainfall and flood in project areas.
The design flood peak modulus of Zaoshui hydro-station, Wufeng hydro-station and lower dam of Xiamen pumping storage power station are relatively larger than the hydro-stations in other small basins, and all the results basically locate in a straight line, which accord with the distribution characteristics of rainfall and flood in southeast zone of Fujian. Therefore, the design flood of this time can be considered to be reasonable and credible.

Figure 4. Design flood results of station in Tingxi and its nearby basins

Figure 5. Design flood peak module results of station in Tingxi and its nearby basins
Table 4. The design flood results in Tingxi and its nearby basins

| Place                          | Area (km²) | Flood peak (m³/s) | Flood peak module (m³/s/km²) |
|-------------------------------|------------|-------------------|-------------------------------|
|                               |            | P=1%  | P=2%  | P=10% | P=1%  | P=2%  | P=10% |
| Zaoshui station               | 10.5       | 360   | 303   | 174   | 34.3  | 28.9  | 16.6  |
| Lower dam basin of Xiamen power station | 12.1     | 468   | 382   | 197   | 38.6  | 31.5  | 16.3  |
| Wufeng station                | 50.1       | 1270  | 1070  | 614   | 25.3  | 21.4  | 12.3  |
| Tingxi reservoir              | 101        | 2100  | 1730  | 980   | 20.8  | 17.2  | 9.7   |
| Dongzhang reservoir           | 200        | 1920  | 1656  | 1060  | 9.6   | 8.3   | 5.3   |
| Zhaoan station                | 430        | 3660  | 3100  | 1840  | 8.5   | 7.2   | 4.3   |
| Naixi station                 | 1070       | 4910  | 4220  | 2640  | 4.6   | 3.9   | 2.5   |

5. Method compare and conclusion

(1) According to verification from the 1996 and 1997 flood of Zaoshui hydro-station and Wufeng hydro-station, rational method has higher accuracy in the small basin with an area from 10km² to 200km². For the extreme small basin within 10km², East China extreme-small basin method has higher accuracy. For the basin whose area is more than 200km², the instantaneous unit hydrograph method is recommended. The application area of rational method, the instantaneous unit hydrograph are different in each provinces according to the characteristic of rainfall and flood as well as underlying surface condition, which are described in detail in the rain flood calculation manuals of each province.

(2) The parameters of rational method and instantaneous unit hydrograph method in rain flood manual, getting from the comprehensive calibration of design flood results of practical projects for many years, have the relatively high accuracy, and can be cited directly without calibration any more. The calibration of 1996, 1997’s flood of Wufeng and Zaoshui hydro-stations in the paper also prove this point.

(3) As for the calculation for the normal frequency flood, deducing design flood from gauged rainfall data has the relatively higher accuracy, and its calculation results are basically consistent with the gauged flood discharge. At the rare frequency, because of the lack of historical extreme-big rainfall data, deducing design flood from gauged rainfall data has the relatively big difference between the gauged flood discharges. While gauged flood discharge can get the materials about historical flood from historic documents and field investigation, the results from the frequency calculation are more believable.

(4) If the basin area between project place and reference hydro-station doesn't have a big difference, with an area ratio from 0.5 to 2, utilizing hydrological analogy can be expected to obtain the desirable results. The determination of area ratio n needs to do regional analysis on design flood results of the hydro-stations within or nearby the project basin. If the design flood results for many hydro-stations are unavailable, n usually equals 0.67. If the area ratio is bigger than 2, the error of hydrological analogy may be relatively big.

(5) Because there is difference in rain flood characteristics, underlying condition, topography and terrain condition, regional comprehensive results from establishing regional comprehensive relation between area and flood peak often cannot reflect the frequency calculation results precisely, but still have the relatively accurate results for mean value of flood peak and its Cv and the result can still be used as reference. In addition, establishing the regional comprehensive relation for the design flood for a certain frequency is often used in practical project design, and observe whether the design flood result for a certain place deviate significantly from the regional comprehensive line to judge the reasonability of the result.

(6) The regional comprehensive method is often used to determine flood attenuation modulus and judge the reasonability of design flood result. The rain flood characteristic and underlying surface condition have certain degrees of difference between basins, if using the result of different hydro-station directly to make regional comprehensive analysis and calculation without a clear cognition on rain flood characteristics of the region, it may cause the relatively big error in design flood for the project basin, especially for the Southeast coastal small basin which are significantly affected by typhoons and storms.
(7) The mean value of different results are more useful in reasonability analysis and result selection, but the means value and the frequency result from it are not recommended to take as the adopting value of project design, while the calculation results of the certain method which are believed to be more reasonable after the analysis is recommended.

Acknowledgments
This research was supported by the project of Power Construction Corporation of China (DJ-DZX-2016-02).

References
[1] Ye L., Zeng X. (2008) On Flood Estimation and Flood Control in Small Watershed. J.Zhejiang Wat.Cons&Hydr.College, 3 (20): 39-42.
[2] Zhan D., Xu X., Chen Y. (2010) Engineering hydrology. Shuilishuidian Publishing, Beijing.
[3] Hu L., Wang L., Su Y. (2009) Improvement of Rational Formula Calculation Method in Zhejiang. J. Zhejiang Hydrotechnics, 162: 4-6.
[4] Wang X. (2004) Improvement of Limingyi method in Small Drainage area’s Flood Calculation. Qinghai Electric Power, 23(1): 42-43.
[5] Zhang H. (2004) The discussion about the calculation method for small basin in Western Zhejiang Hydrotechnics. Zhejiang Hydrotechnics, 6: 41-43.
[6] Ji G. (2009) The calculation method for design flood of coastal small basin in Fujian Province. Water Conservancy Science, 2: 15-17.