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Feasibility and Quantification Analysis of Floodwater Utilization

by

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Abstract

There has been a rapid increase in water shortage problems in conjunction with the extensive economic development that has occurred in China over the past 20 years. Evaluation of precipitation in areas subject to monsoons such as northeast China has revealed that asymmetrical precipitation distribution sometimes causes heavy flood disasters during the short rainy seasons and serious water shortages during the long dry seasons in such locations. Therefore, it may be possible to use floodwater to meet the increasing water demand in China. In this study, the natural features and feasibility of the use of floodwater as a resource was evaluated taking Songhua River as an example. In addition, a quantitative method was developed to analyze floodwater utilization in the middle or downstream portions of rivers, which generally do not contain a suitable site for construction of regulating equipment. The results of this study were as follows: (1) in the area of the monsoon precipitation zone, floodwater comprises the majority of the annual surface water entering the system; therefore, the use of floodwater resources is necessary; (2) division of the river water into four fractions, ecological water, safe water, risk water and disaster water, can enable quantitative analysis of floodwater utilization.

Keywords: Floodwater utilization, River water dissection, Feasibility analysis, Quantification analysis, Songhua River

1. Introduction

The amount of water available per capita is a key parameter in determining the quality of life and economic status of a population. As society and the economy develop, the amount of water

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used in a given area increases rapidly[1)]. Consequently, many water supply systems such as dams and pumping stations are constructed. However, the amount of useable water resources is limited in some areas, and the construction of facilities to meet the water demand has become more difficult. Accordingly, unusual water resources such as floodwater must be taken into account when necessary. River flow changes greatly with time in monsoon precipitation areas because most of the precipitation occurs during rainy seasons. This makes it difficult to use floodwater resources in the water supply system. Such situations become more serious in the middle or downstream areas of rivers, in which there is usually no proper site to build water regulation facilities. In this study, the utilization of floodwater was considered taking Songhua River as an example, after which a method of analysis designed to quantify the utilization of floodwater resources was developed.

2. Natural Features of Floodwater

Floods usually involve the overflow of water onto land that is normally dry. When a river floods, the water usually completely fills the river channel. Occasionally, large floods can result in water flowing over or breaking embankments, resulting in serious problems. Consequently, floods are regarded as a type of natural disaster. As society and the economy develop, the amount of water required for daily life, agriculture and industry increases rapidly. Indeed, many cities and areas in China are currently undergoing water shortages, and half of all cities nationwide do not have adequate water supplies[2)]. Therefore, it is necessary to identify novel water sources and make efficient use of the limited water resources that are available.

The processes of natural flow in different rivers vary greatly. These processes are also very different in rivers in different climate zones. For example, the basic flow of rivers in the south of China is larger than that of rivers in the north, and the flow over the course of a year is generally more uniform in the south than in the north. However, asymmetrical flow distribution can easily lead to flood disasters during rainy seasons and low flow in dry seasons, and this situation is more evident in monsoon precipitation zones.

Northeast China spans the cold-temperate, semi-humid and temperate-humid zones (**Fig. 1**). The region is characterized by short summers and long winters with spring drought, summer flooding and autumn frosts. However, the climate in this region is suitable for farming, and the most popular crops are corn, rice, wheat and potato. As a result, agricultural irrigation accounts for about 70% of all water use in this region.

Fig.1 Location of the research area.

The average annual rainfall for the study areas ranges from less than 400 mm in the west to more than 750 mm in the east. The water vapor resources are primarily from the Pacific Ocean, although the Okhotsk Sea and Southeast Ocean contribute as well. The meteorological genesis of storms is frontal rain, with a few events consisting of air-mass rain. Because the basin is located in the monsoon precipitation zone, most of the precipitation occurs during summer, with 70 – 80% occurring from June to September. Additionally, the amount of precipitation varies significantly among years, with the ratio of the largest annual precipitation to the smallest being 3. Continuous dry year series and continuous wet year series occur alternately in the area[3)].

As shown in **Fig. 2**, the average annual precipitation at Qiqihar and Harbin is 430mm and 535mm[3)], respectively. Furthermore, most of the annual precipitation clearly occurs during the rainy season. The outflow from a basin usually depends on several main rainfall events. **Figure 3 and 4** show the daily outflow process over a year at Qiqihar Station and Harbin Station, respectively.

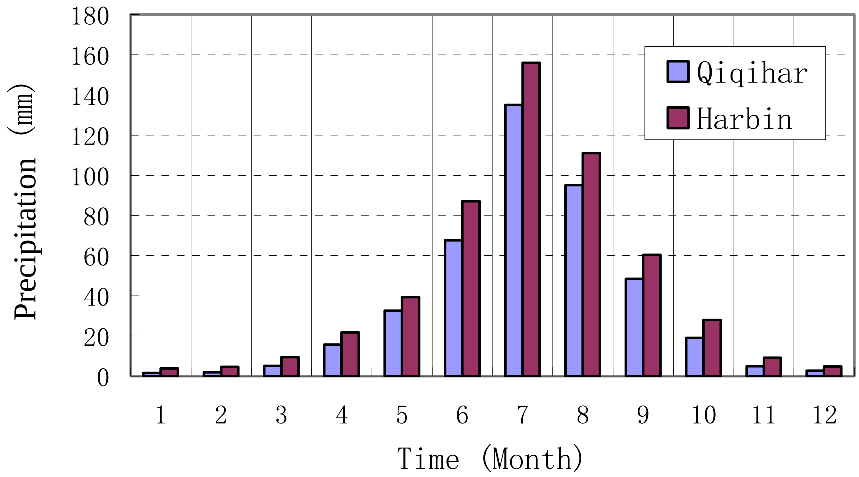

Fig. 2 Monthly precipitation distribution at Qiqihar and Harbin.

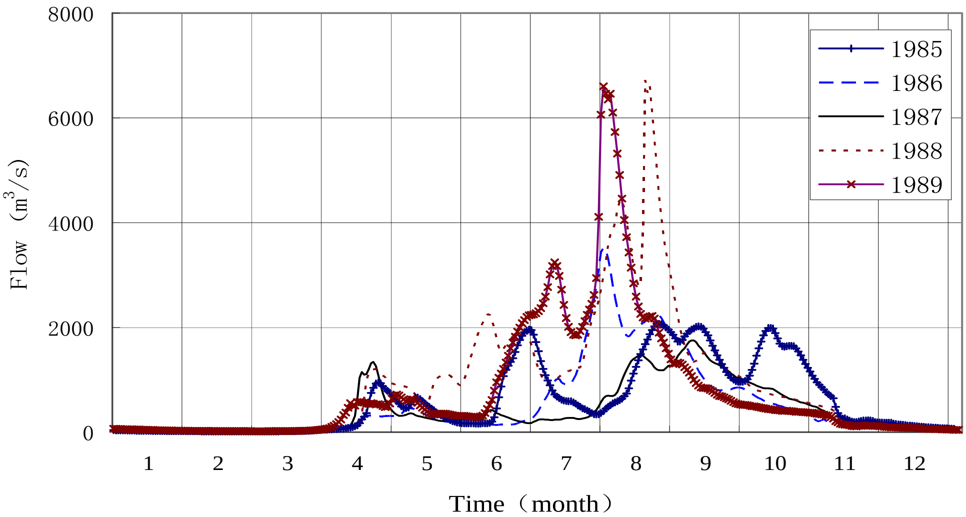

Fig. 3 Daily flow at Qiqihar Station from 1985 to 1989.

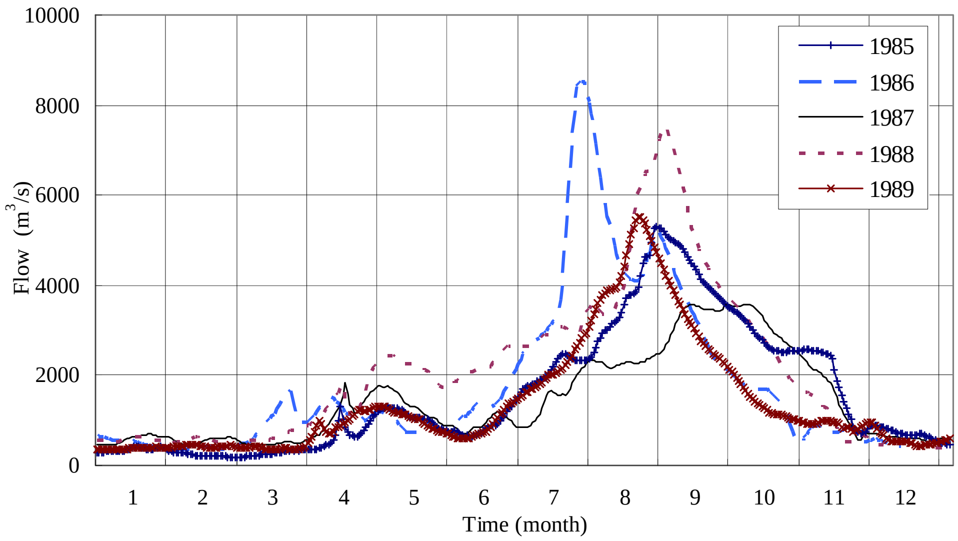

Fig. 4 Daily flow at Harbin Station from 1985 to 1989.

When considering the use of floodwater in this region as a type of useful water resource, it is important to note some general features of flow:

(1) The precipitation and flow are concentrated from June to September. For example, in the period from 1953 to 1989, the average flow at Harbin Station from October to May of the next year is 737 m^3/s, while the average flow from June to September is 2640 m^3/s, indicating that the average flow during the rainy season is three times greater than that of the dry season and two times greater than the annual average flow. As indicated in **Fig. 5**, which shows the flood distribution at Harbin Station from 1953 to 2002, almost all of the large floods have occurred between July and September.

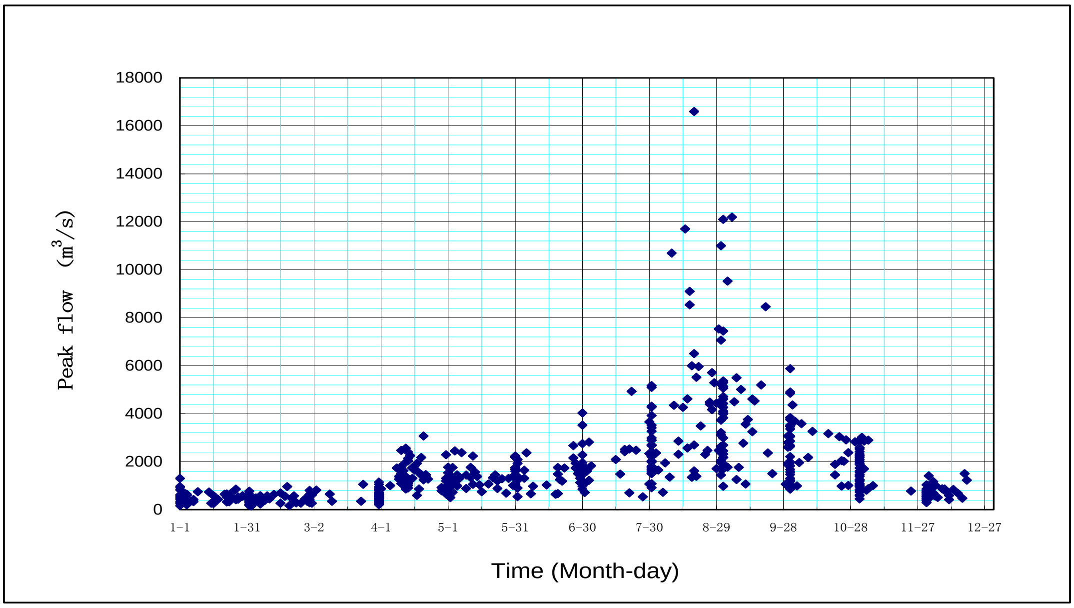

Fig. 5 Flood distribution at Harbin Station (1953-2002).

(2) At Harbin Station, the maximum flow in any given year can be 10–30 times greater than the minimum flow, while the annual average flow is four times greater than the minimum flow and 25% of the maximum flow. This extreme difference makes flood control and water supply more difficult.

(3) The flow processes in downstream portions of the river are flatter than in upstream portions when there are no big branch entrances along this part of the river. This is especially true in rivers with wide river channels and middle islands. Even though two floods have clear peaks in the upstream region, they can become one process downstream with smaller peaks. **Figure 6** shows the flow processes for the same year 1989 at Qiqihar and Harbin stations[5)]. It is well known that at Harbin Station, which is downstream of Qiqihar Station on the Songhua River, the flow processes have smaller peaks, larger volumes and longer standing times than at Qiqihar Station.

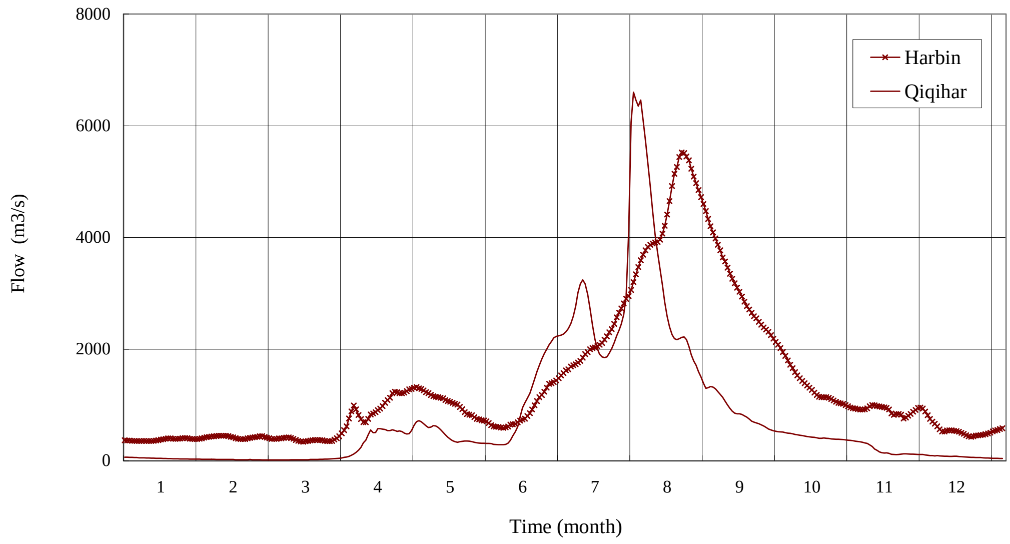

Fig. 6 The daily flow process at Qiqihar and Harbin stations in 1989.

(4) In the middle and downstream portions of the Songhua River, the land is quite flat and the slope of the river bed only ranges from 0.1% to 0.01%. In addition, there are many wetlands and deserted lands in these areas. Some of these systems are historical natural flooding detention or retention areas. The presence of these lands provides an opportunity to save floodwaters with these low harvest lands.

3. Feasibility Analysis of Floodwater Utilization

3.1 Increasing water demand due to changes in society and the economy

As society and the economy develop, water demands for daily life, industry and agriculture increase continuously. As a result, most cities must plan and construct new water supply projects. Indeed, the amount of water resources for any given area is limited. However, when the water supply increases to a level greater than the common basic flow, floodwater can be used to meet the water demand during dry seasons. Generally, it is more convenient to develop floodwater than other types of unusual water resources. **Figure. 7** shows the redistribution of water within a year in which floodwater is used to fill the gap between river flow and water demand.

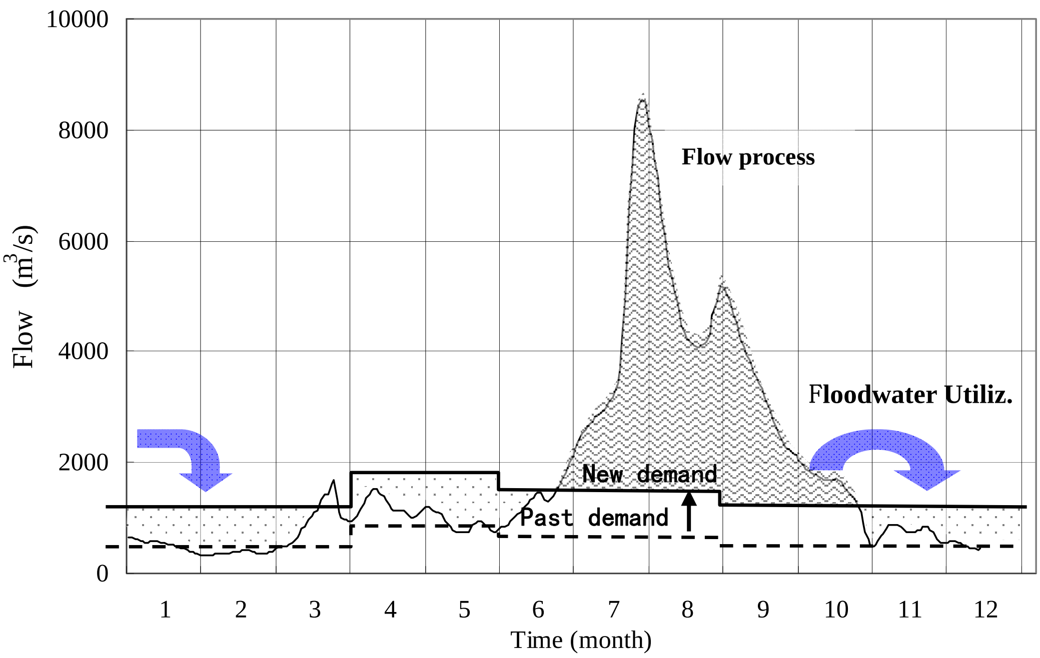

Fig. 7 Redistribution of water flow as water demand increases.

3.2 Water demand associated with ecosystem improvement

The water demand of an ecosystem is one of the main items that must be considered in comprehensive water resources plans. In northeast China, there are many inland wetlands, including two of the seven systems that have been listed in the Ramsar Convention since 1992 (Zhalong and Xianghai wetlands along the Nen River, which is the main tributary of the Songhua River). Both of these wetlands are national nature reserves and are of special importance because they serve as breeding sites and migratory staging sites for a large number of birds, many of which are endangered or threatened species.

It is well known that water is a very important factor required to maintain good ecological conditions in wetlands. Nevertheless, reductions in water supply have threatened the wetlands in the study area for a long time. For example, $0.46\times10^9 m^3$/year of water entered the Zhalong wetland until about 50 years ago. However, as social and economic development has occurred along the Wuyur and Shuangyang rivers, the amount of water that enters the Zhalong Wetland has decreased to $0.2\times10^9 m^3$/year. The ecological situation has also changed gradually in response to the water supply condition. To protect and restore the ecosystem of these wetlands, it is necessary to identify a new water source. According to wetland conservation and restoration theory, wetlands not only need a regular water supply, but also require disturbance by flood pulses. Flood pulsing is associated with the spatial movement of plants, animals and detrital materials. Fish, which are adapted to the flood pulse, follow the seasonal water pulse from the channel to the floodplain with the spatial movement of organic matter and insects [4)].

Accordingly, greater attention should be given to the importance of flood pulsing and disturbance in the restoration of wetlands. However, these ideas are completely ignored in the regulatory process. Nevertheless, natural floods have created wetlands over very long historical periods, and there is a strong relationship between floods and wetlands. Therefore, there is the potential to use floodwater to actively preserve and restore wetlands.

3.3 Utilization of floodwater resources

Floodwater resources development is feasible by implementing a variety of measures. Due to the fact that floods can lead to disaster or provide resources[6~9)], the development of techniques to utilize floodwater as a resource should fully consider the characteristics of floods and proper ways to use the waters associated with flood events effectively. Floodwaters are a type of continuously moving and changing water resource. Therefore, remote sensing, dynamic monitoring, integrated information and decision making techniques should play a great role in the control and management of floodwaters.

(1) Floodwater utilization in areas containing regulation equipment

Floodwater can generally be regulated by the use of water storage projects at the proper locations, such as reservoirs or pools, with systems with larger storage capacities having greater abilities to regulate floodwaters. Floodwater stored in these facilities can then be used for planned purposes. However, dams are usually built in the upstream portions of rivers, which makes it difficult to use the excess floodwater resources in the middle or downstream portions of the river.

(2) Floodwater utilization in areas without regulation equipment

Nonstructural measures to develop floodwater resources do not involve the construction of large objects to control the floodwaters. For example, diverting water gates and channels can be used to transfer floodwater in the main stream of rivers to wetlands at lower levels. Because wetlands can accept all kinds of water at any given time, the use of floodwater to restore wetland ecosystems is encouraged for floodwater resources development [10)].

(3) Risk analysis of floodwater utilization

The utilization of floodwater resources generally poses a great many risks associated with flooding, construction and general operations. Accordingly, proper risk analysis is one of the basic tasks involved in floodwater resources development planning and operations.

(4) Control and management measures

Owing to the dynamic characteristics of flood processes, the control and management of floodwater resources is very difficult. If control is convenient, the floodwater can serve as a useful resource; however, if the control and management is insufficient, the chance to retain the floodwater will be lost. Even worse, poor planning could lead to a larger flood disaster than no-control. Therefore, modern GIS, GPS and RS techniques and other advanced information and control measures should be employed in the practical control and management of floodwaters.

4. Method of River Water Dissection

When considering the utilization of floodwater, it is important to determine how much water can be used and what the impacts of removing a given amount of water from the system are on the river ecosystem and other users downstream.

To properly evaluate and develop floodwater resources in rivers, a method of river water dissection (RWD) was developed to enable quantification of floodwater utilization[11)]. This method, which considers the situation along the river embankment and ecosystem at each river section, dissects the water in a river into four fractions, an ecological water fraction (EWF), a safe water fraction (SWF), a risk water fraction (RWF) and a disaster water fraction (DWF). Based on the information obtained from this analysis, a utilization plan for floodwater resources can be made. Naturally, while developing a resources development plan, analysis of the history of floods and a great deal of on-site investigation is necessary.

4.1 Dissection of river water

In certain river sections, the condition of the river embankment determines the loss and risk of floods, while the conditions of the water determine the ecosystem state and the benefits to society and the economy. As shown in **Fig. 8**, the river water can be dissected into four parts based on the features, functions and actions of river water; the ecological water fraction, safe water fraction, risk water fraction and disaster water fraction. After defining the boundary flow, Q_{B1}, $Q_{B2}$and Q_{B3}, the relationship between EWF, SWF, RWF and DWF can be described by Equation (1).

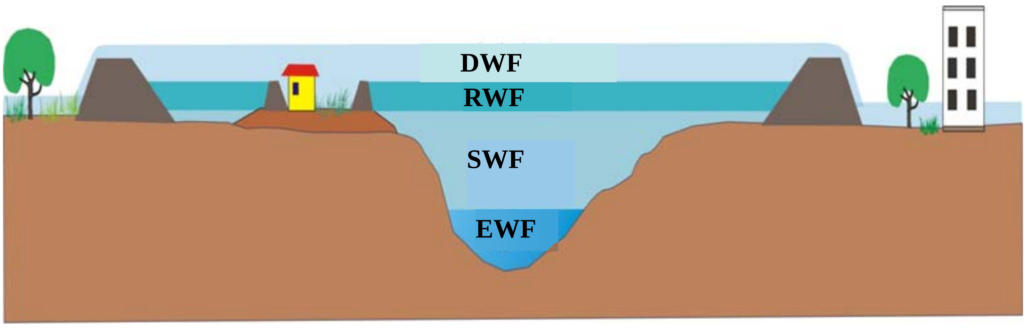

Fig. 8 Structural dissection of river water.

$$\begin{cases} Q_R \le Q_{B1} & \text{Flow belonging to EWF} \\ Q_{B1} < Q_R \le Q_{B2} & \text{Flow belonging to EWF and SWF} \\ Q_{B2} < Q_R \le Q_{B3} & \text{Flow belonging to EWF, SWF and RWF} \\ Q_R \ge Q_{B3} & \text{Flow belonging to EWF, SWF, RWF and DWF} \end{cases} \quad (1)$$

where, Q_R is the actual flow of the river; $Q_{B1}$is the boundary flow between the EWF and the SWF; Q_{B2} is the boundary flow between the SWF and the RWF; Q_{B3} is the boundary flow between the RWF and the DWF.

Figure 9 shows the results of applying the presented river water dissection method to three example annual flow processes at the Harbin hydrological station. After the boundary flows of Q_{B1}, Q_{B2} and Q_{B3} at a certain river section are determined, the each of four water fractions with specific function can be made out and treated with proper ways. Generally, the EWF may fully keep in the river course for the evolution use of river ecosystem. The SWF can be removed from the river for social and economical development or other purposes. If the RWF and DWF are removed from the river, the flood risk in the river may decrease. Therefore, the use of these fractions of water in a proper manner should be encouraged.

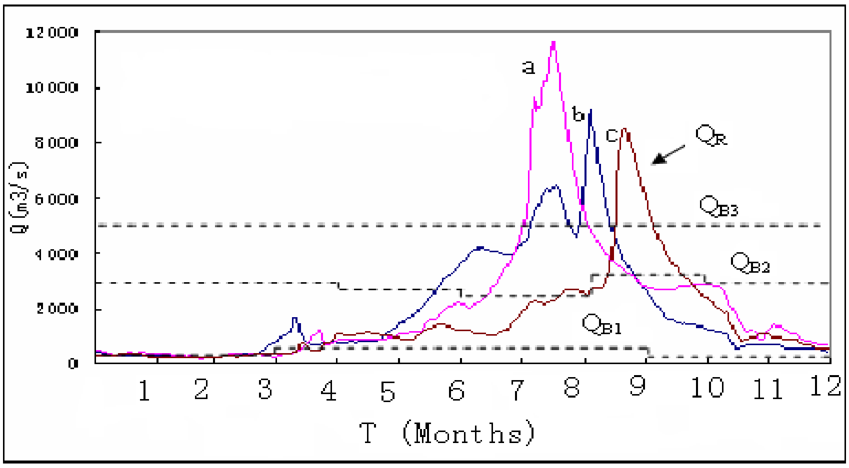

Fig. 9 The examples of river water resources dissection.

4.2 Definition of the four fractions of river water

To determine the RWD, it is necessary to define the four types of river water. The characteristics of the four river water fractions with consideration of the characteristics and function of river water are described below.

Ecological water fraction (EWF): The EWF occupies the basal position of the RWD. Based on a summary of the currently available data[12, 13)], the EWF can generally be described as the fraction of the river water that is required to maintain the rudimentary ecological environment and ensure the lowest material balance among river organisms while maintaining the water level in the main river course at a certain level to satisfy the criterion for the ecological environment at a given time and space. To avoid breakdown of the rudimentary ecological environment, the river water must satisfy the condition $Q_R > Q_{B1}$ for all conditions, especially during low water periods. However, if it is unavoidable that the Q_R becomes lower than the Q_{B1}, some measures must be taken to supply water to the river portion from reservoirs, lakes or other rivers. It is apparent that the upper boundary of the EWF has variable values in different seasons, which reflects differences in the water demand of the river ecosystem among seasons.

Safe water fraction (SWF): The SWF is the part of the river water that is between the EWF and the RWF. This fraction of the water directly links the safety of the river and the economic consumptive use of the water. At the point of the river safety, when the river water $Q_R < Q_{B2}$, no measures are necessary to avoid a decrease in the standard of living or adverse effects on the economy. At the point of economic consumption, the volume of the SWF reflects the amount of water that can safely be removed from the river. This fraction of water plays a very important role in the RWD. Indeed, the SWF occupies the greatest proportion of the river water and most of the economic consumptive water is taken from this part. This fraction of water can be increased by improving river embankments and flood control measures.

Risk water fraction (RWF): The RWF usually occurs during flood seasons. Under natural conditions, floodwater is an active factor that maintains the health of a river. Indeed, small or medium scale floods often occur several times a year, which can bring some risks to the river embankment and reservoirs. Moreover, large floods also appear occasionally. Accordingly, there is always a risk of flood disaster. However, there is also a continually increasing demand for water to maintain a stable economy. As a result, the RWF may be useful as a water resource. Based on the discussion above, even though the RWF can be used for economic development, it can also lead to flood disasters if no proper measures are taken to control it.

Disaster water fraction (DWF): The DWF appears during flood seasons when the discharge is much greater than the common flow and the permissible flow capability of the corresponding river section. While the DWF is present, flooding can still produce disaster damage or lead to increased costs associated with flood protection.

The DWF is the fraction of the river water that corresponds to the river flow that exceeds the critical flow level of the river embankment. The DWF usually cannot be used directly, but it can cause great losses to the economy and society. Within the monsoon zone of China, rivers often flood due to centralized precipitation. After the flood season, the flow in the rivers decreases rapidly and can be maintained at low levels for up to 75% of the year. If some or all of the floodwater can be utilized, water shortages may be alleviated. Therefore, the DWF is of an important disaster feature and water resources feature. This fraction can also be used to dilute pollution water, flush out watercourses and irrigate wetlands.

4.3 The relationship between the flow and the water fractions

Flow is an important indicator of the river states that influences the river water volume. The relationship between these factors can be described by equation (2). Because most of the river water levels are based on flow, it can be regarded as a basic parameter when dissecting the river water.

$$V = \int Q_R(t)\, dt \tag{2}$$

where V is the river water volume; Q_R (t) is the actual flow of a river; and t is time.

Based on equation (1) and (2), the four water fractions for any given different situation can be derived as follows:

If $Q_R < Q_{B1}$

$$V_1 = \int_{t_1}^{t_2} Q_R(t)\, dt \tag{3}$$

If $Q_{B1} \le Q_R < Q_{B2}$

$$V_1 = Q_{B1} t$$

$$V_2 = \int_{t_1}^{t_2} \left[Q_R(t) - Q_{B1}\right] dt \tag{4}$$

If $Q_{B2} \le Q_R < Q_{B3}$

$$V_i = Q_{Bi} t, \quad (i=1, 2)$$

$$V_3 = \int_{t_1}^{t_2} [Q_R(t) - Q_{B2}] dt \tag{5}$$

If $Q_R \ge Q_{B3}$

$$V_i = Q_{Bi} t, \quad (i=1, 2, 3)$$

$$V_4 = \int_{t_1}^{t_2} [Q_R(t) - Q_{B3}] dt \tag{6}$$

$$V = V_1 + V_2 + V_3 + V_4 \tag{7}$$

where V_1, V_2, V_3, V_4 express the water volumes of EWF, SWF, RWF and DWF respectively; V is the water volume of a river; Q_R is the actual runoff of the river; Q_{B1}, Q_{B2}, Q_{B3} are the boundary runoff values between the EWF and SWF, the SWF and RWF and the RWF and DWF, respectively; $Q_R(t)$ is the instantaneous runoff of the river; and t_1 and t_2 are the start time and stop time of the computation, respectively.

Because it is difficult to continuously record the flow in a river, the average flow, $\overline{Q}$, of a certain time interval is commonly used for flow analysis. Equation (8) is the difference equation of equation (2). Similarly, the volumes of the EWF, SWF, RWF and DWF can be derived by referring to equations (3) to (7). Equation (8) is as follows:

$$V = \sum_{i=1}^{n} \overline{Q}_{ti} \Delta t_i \tag{8}$$

where n is the number of the calculation time intervals; $\overline{Q}_{ti}$ is the average river flow in time interval, i; and Δt_i is the time span of the time-interval, i.

5. Case Study of River Water Dissection

River monitoring was conducted for cross sections that each represented the state of the corresponding stream segment. The Songhua River is the largest river in northeast China, with a catchment area of 566,000 Km^2 and a length of 3,300 km. The main stream of the Songhua River crosses the Songnen Plain, where the landscape is wide and flat. The river basin also contains a great many wetlands, lakes and river channels. To analyze the flood features and flood management strategies, data collected from four hydrological stations (Jiangqiao, Dalai, Xiadaiji and Harbin) that were representative of various sections were investigated (**Fig. 10**).

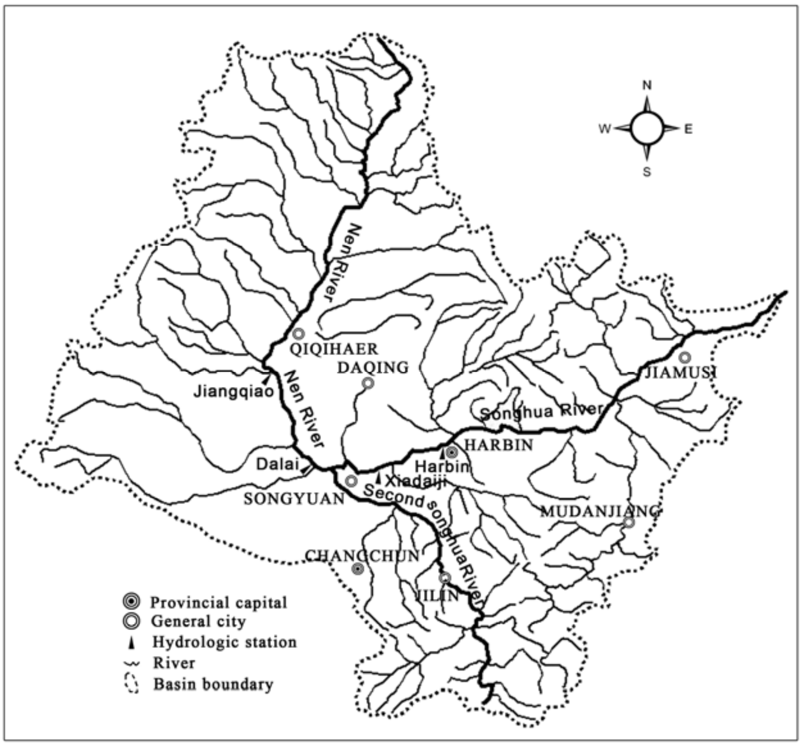

Fig. 10 The location of four representative hydrological stations.

5.1 Calculation of the EWF

The Songhua River is a typical seasonal river in which the flow varies greatly within and between years. The river requires less water to maintain a healthy ecosystem during the low flow period (from October to March) and more water during the high flow period (from April to September). Therefore, the value of Q_{B1} is larger during the high flow period than the low water period. In this study, the Q_{B1} required to maintain the health of the river environment and properly exploit the river water resources was taken to be 30% of the average discharge during the low water period and 60% of the discharge during the high water period. Based on hydrological data[3)] collected from 1953 to 1989, the boundary flow, Q_{B1}, of the EWF was calculated and the results are shown in **Table 1**.

Table 1 Boundary flow (Q_{B1}) of the EWF.

Time Period	Representative hydrological stations			
	Jiangqiao	**Dalai**	**Xiadaiji**	**Harbin**
Q_{B1} during low water period (m^3/s)	204	207	360	419
Q_{B1} during high water period (m^3/s)	408	414	720	837

5.2 Calculation of the SWF

The low boundary flow of the SWF is the upper boundary flow of the EWF. The upper boundary flow (Q_{B2}) of the SWF is the flow rate that is large enough to maximize the consumptive water of society and economy without causing damage. Consequently, the Q_{B2} can be determined from the full discharge of the main channel. For rivers with low sediment concentrations, the flow capacity of the main river channel generally changes slightly after the flood season. Therefore, the water level of the channel at full discharge is considered to be steady and the channel full discharge is taken as the value of the boundary flow Q_{B2}. The actual flood data observed at Jiangqiao hydrological station from July 30 to August 31 in 1988 support this supposition.

The channel full discharge can be determined from the rating curve of each hydrological station. When the water level reaches the channel full stage, a slight increase in the water level will cause a great increase river flow. In addition, there is a clear inflection point on the rating curve at the channel full stage. Therefore, the rating curve can be used to identify the channel full stage and the channel full discharge. **Fig. 11** shows the rating curve of the four hydrological stations, which can be used to determine the channel full stage and the bank full discharge of the four hydrological stations (**Table 2**).

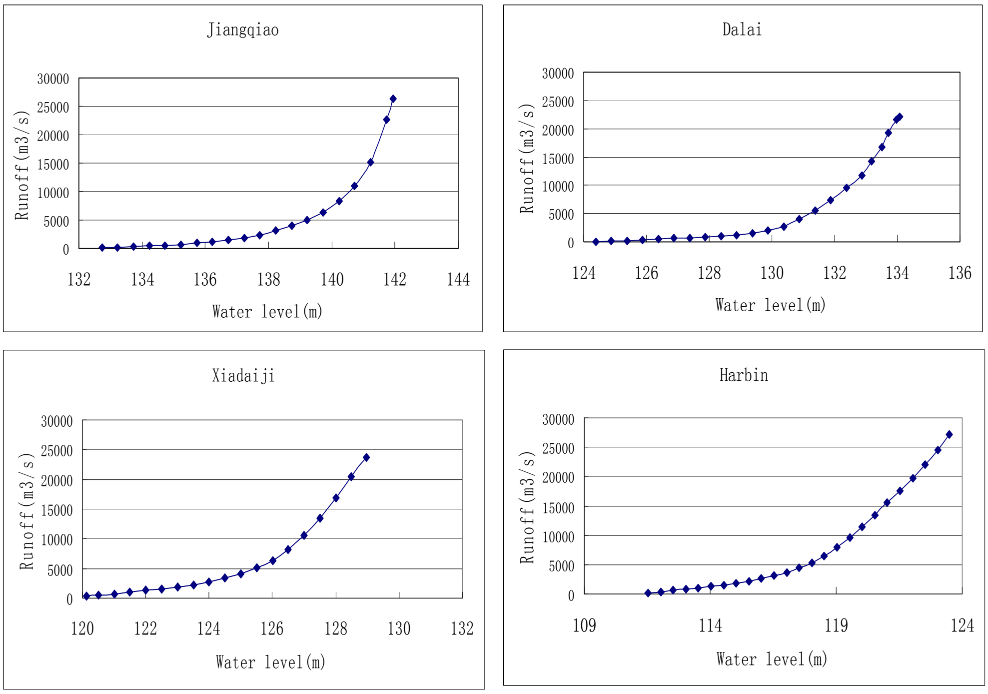

Fig. 11 The rating curves of the four hydrological stations.

Table 2 The upper boundary flow (Q_{B2}) of the SWF.

Stations	Jiangqiao	Dalai	Xiadaiji	Harbin
Channel full stage level (m)	138.00	130.36	124.38	116.80
Channel full discharge, Q_{B2}(m^3/s)	2750	2722	3250	3430

5.3 Calculation of the RWF and DWF

To determine the boundary flow (Q_{B3}) between the RWF and DWF, the specific water level required for flood prevention should be determined. Indeed, the warning water level is an important index of flood prevention, which is the highest water level before flooding occurs. The warning water level may be taken as the boundary water level between the RWF and DWF. For this study, the boundary flow (Q_{B3}) corresponding to the warning water level can be determined based on the rating curves of the four hydrological stations. The results are shown in **Table 3**.

Table 3 Boundary flow (Q_{B3}) between the RWF and DWF.

Station	Elevation datum	Warning water level (m)	Corresponding flow Q_{B3}(m^3/s)
Jiangqiao	Yellow Sea	138.36	3300
Dalai	Yellow Sea	130.80	3800
Xiadaiji	Yellow Sea	125.37	4500
Harbin	Yellow Sea	118.10	5200

5.4 Calculation of the four water fractions

After determining the values of the boundary flows, the volumes of the four water fractions were calculated based on hydrological data from each hydrological station.

5.4.1 Variation in annual runoff

Figure 12 shows the variation in annual runoff from 1953 to 1989 at the four representative hydrological stations. The annual runoff processes at the four stations showed similar fluctuations, even though the Second Songhua River enters the main stream between Dalai and Xiadaiji. This phenomenon indicates that the Second Songhua River has relatively more uniform flow processes than the Nenjiang River. This is likely because there are many large reservoirs on the Second Songhua River, but none on the Nenjiang River. The results presented here also demonstrate that the water volume was much higher in high water years than low water years, and that the maximum volume could be 6-7 times greater than the minimum value.

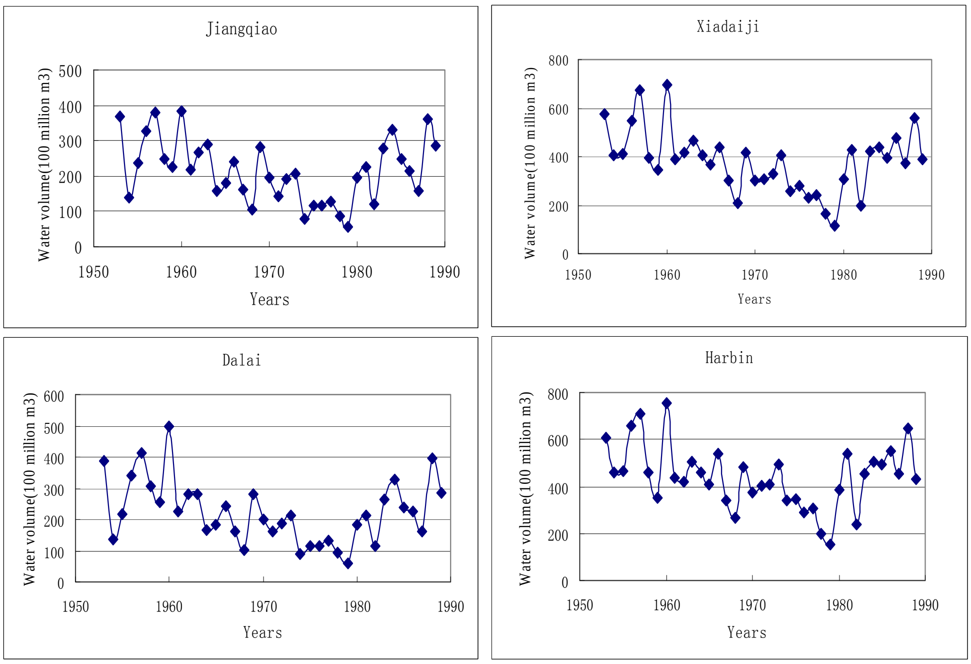

Fig. 12 Variation in annual runoff at the four stations.

5.4.2 Variation in the four water fractions

Figures 13 (a), (b), (c) and (d) show the results of the river water dissection. Based on the water dissection method, the total water volumes at Jiangqiao, Daliai, Xiadaiji and Harbin stations were each divided into the EWF, SWF, RWF and DWF. **Figure 13** shows the variation in the four fractions at the four representative hydrological stations.

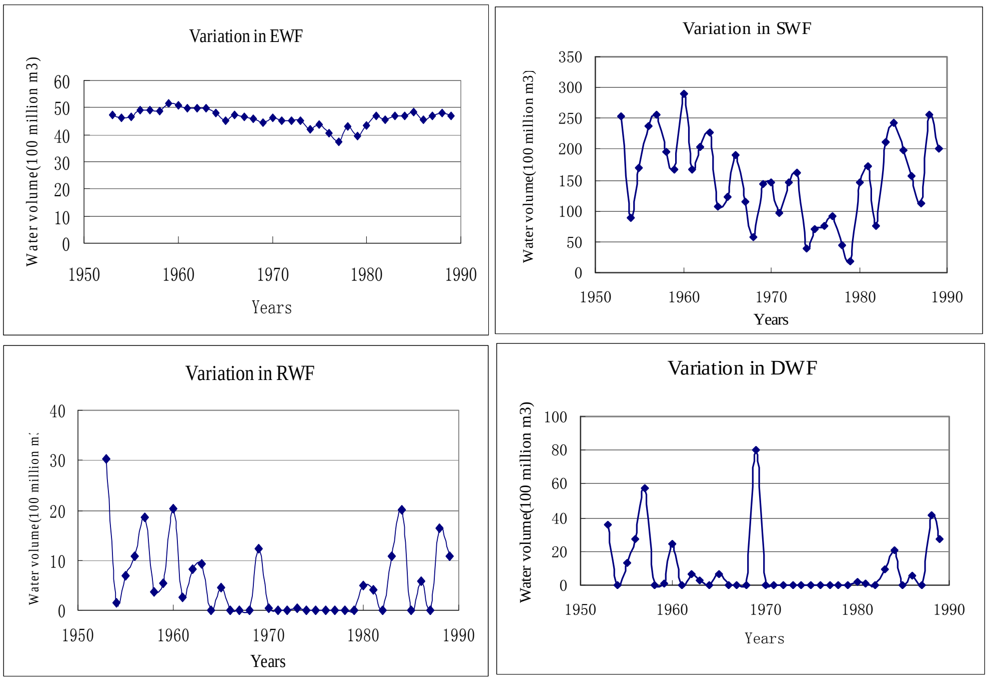

Fig. 13(a) EWF, SWF, RWF and DWF at Jiangqiao Station.

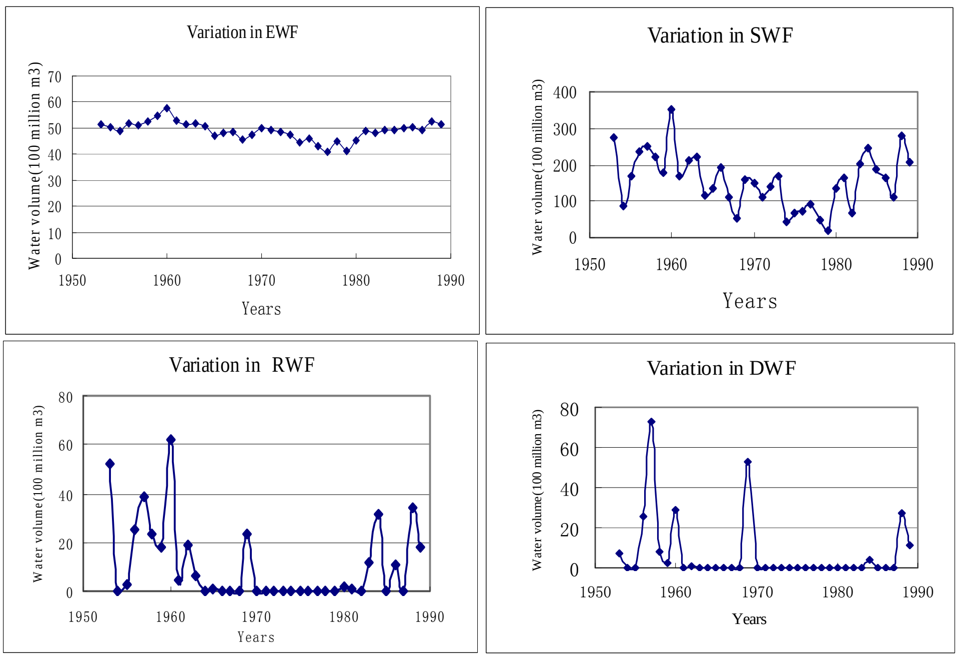

Fig. 13(b) EWF, SWF, RWF and DWF at Dalai Station.

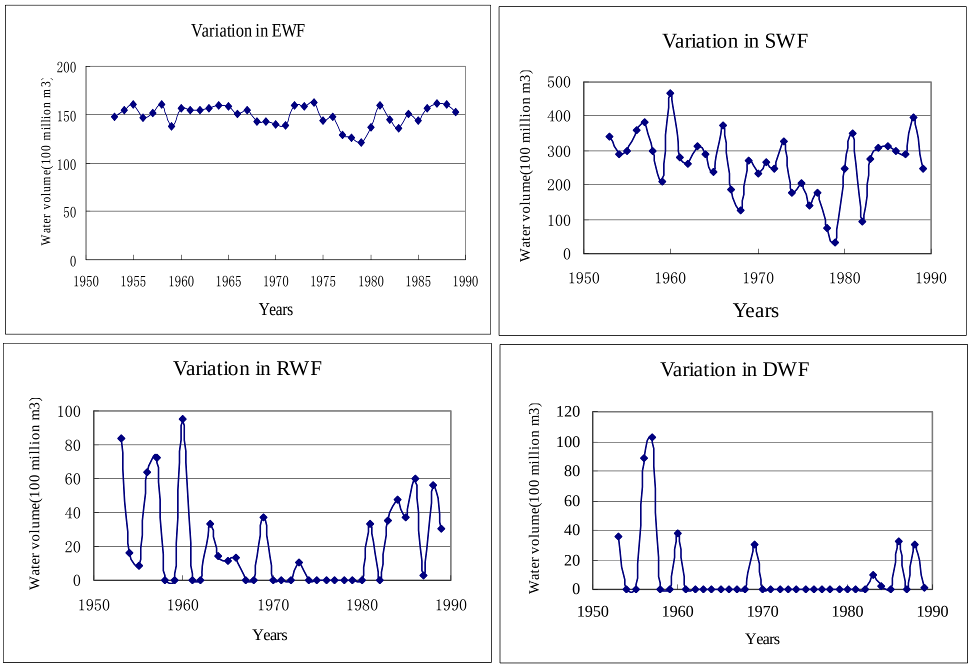

Fig. 13(c) EWF, SWF, RWF and DWF at Xiadaiji Station.

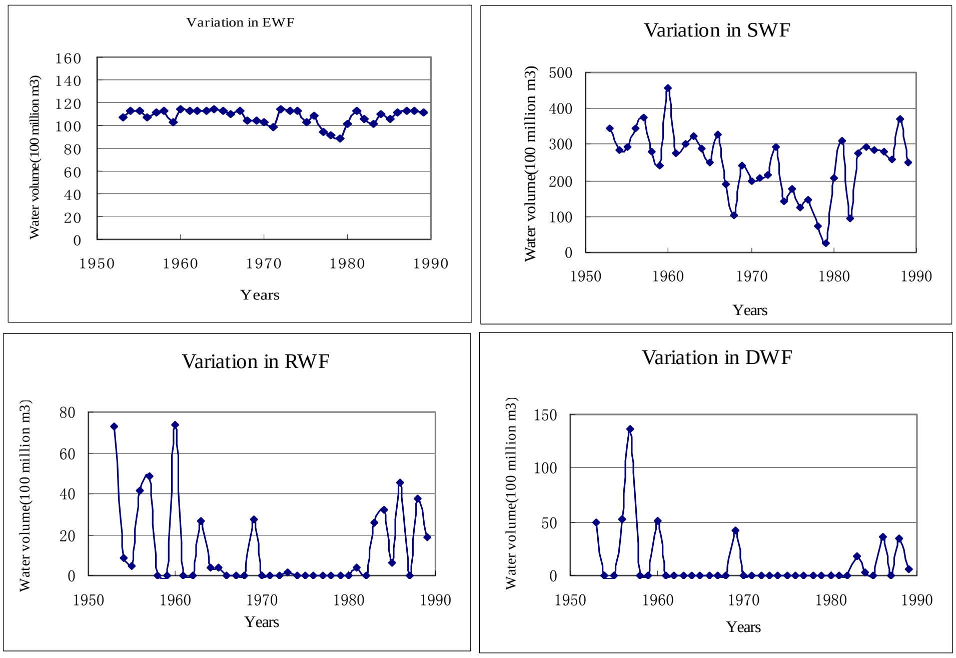

Fig. 13(d) EWF, SWF, RWF and DWF at Harbin Station.

Fig. 13 Variation in the water fractions at each hydrological station.

The variations in the water fractions were similar at each of the four stations. Specifically, the flow recorded at each station could satisfy the EWF for all of the years evaluated. The SWF comprised the greatest proportion of the total flow and accounted for the obvious fluctuation, which was similar to the variation in the total water volume of the river. The RWF and DWF were only observed during high water years. The possibility of the RWF occurring was only slightly higher than that of the DWF occurring, and they both occasionally occurred in continuous years.

5.4.3 Analysis of the proportions of the four water fractions

Figure14 shows the proportions of the four water fractions at Jiangqiao, Dalai, Xiadaiji and Harbin stations. The SWF comprised about 60-70% of the total water volume, while the EWF accounted for about 20-30% of the total. Additionally, the RWF and DWF only accounted for 6-8% of the total water volume; however, they are the key factors involved in flood prevention because they only appear during flood season and may cause the water level of the river to rise in a very short period. Furthermore, the DWF can account for 16% of the total water during years with large floods. As a result, if measures are implemented to control RWF and DWF a large amount of floodwater can be utilized without harm to the system while decreasing the risk of flood disaster to the corresponding sections and downstream areas.

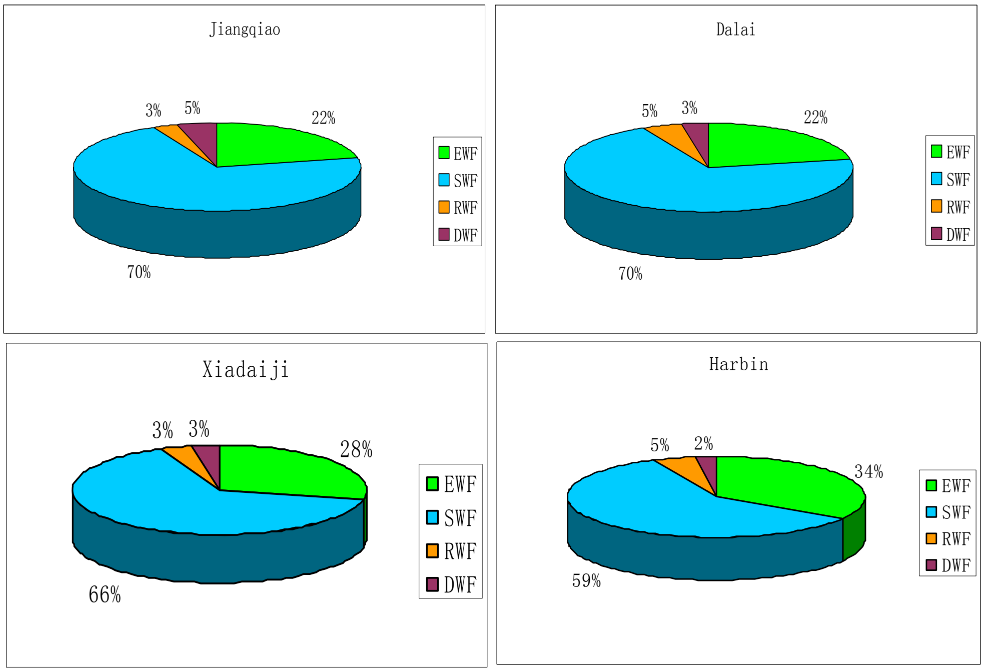

Fig. 14 Proportion of each of the four water fractions.

6. Conclusion and Discussion

In monsoon precipitation zones such as northeast China, floodwater accounts for the majority of the annual flow; therefore, it acts as both a threat to the local area and an important water resource. Investigation of the flow processes in the Songhua River revealed that the natural features of the system could be characterized as follows: (1) the precipitation and flow are concentrated in the short rainy season; (2) the flow values in the rainy season and the dry season are very different, with the former comprising the majority of the annual water resources and all of the flood risk. As society and the economy develop, the water demands increase rapidly. Therefore, measures should be implemented to enable floodwater to be treated as an important water resource in the study area.

The construction of dams and reservoirs are common methods of developing water resources in rivers. Unfortunately, there are seldom suitable sites for the construction of such facilities in the midstream and downstream portion of rivers. To make proper use of river water resources under these conditions, a method of dividing the river water resources was developed in this study. In this method, the characteristics of the bed, embankment, ecosystem and flow of a river were used to divide the total volume of the water into an ecological water fraction (EWF), safe water fraction

(SWF), risk water fraction (RWF) and damage water fraction (DWF), which each correspond to different functions. A case study of the Songhua River based on 40 years of data revealed that the SWF occupied about 60-70% of the total water volume for each section, while the EWF comprised about 20-30% and the sum of the RWF and DWF only accounted for 6-8% of the total volume. However, because most overflow damage is associated with the RWF and DWF, the implantation of measures to control these fractions can enable a large amount of floodwater to be utilized without harm to the overall health of the ecosystem while preventing flood disasters. Consequently, by use of the river water dissection method, the floodwater at a river section can be quantitatively divided and separately treated with corresponding to the features and functions of different water fractions. As natural flood processes change very much every time in flood periods, floodwater utilization might meet some risks. It is important to update the exact prediction of flood processes and keep the all flood control equipments in a good condition.

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