Application of a reservoir operation model to the upper reaches of the Yellow River basin

Yoshinobu SATO[1], Xieyao MA[2], Yoshihiro FUKUSHIMA[1]

[1] Research Institute for Humanity and Nature (RIHN)
[2] Frontier Research Center for Global Change (FRCGC)

Abstract

A simple reservoir operation model was developed to estimate the influences of the artificial regulation of river runoff in the upper reaches of the Yellow River basin. The model controls discharges from the reservoirs using the following three parameters: (1) the amount of inflow to the reservoirs, (2) the amount of water storage of the reservoirs, and (3) the reservoir operating rules (standard monthly discharges). The monthly standard discharges were determined by analyzing the observed discharge obtained at downstream of the reservoirs (Lanzhou Hydrological station). The controlled discharges estimated by the model agreed well with the seasonal changes of the observed data. The simulated results indicated that the large dams constructed in the upper reaches of the Yellow River basin decrease the peak discharge in the wet season and increase the discharge in the dry season. It was also found that the river discharges are stabilized as the storage of the water reservoir dams increased. The model developed in this study will contribute as the effective tools for evaluating human activities on river discharges of the Yellow River basin.

1. Introduction

The Yellow River basin is the second largest river in China. In recent years, the river discharges have decreased rapidly particularly in the lower reaches because of dry climate conditions and heavy water demands. As a consequence, a drying up in the main river stream of the lower reaches had occurred since 1972. To mitigate the water shortage in the lower reaches of the Yellow River basin, it is important to control the water resources supplied from the upper and middle reaches. In the Yellow River basin, there are a lot of water reservoirs in the upper reaches. Because, the water reservoirs are one of the most effective means for controlling water supply and mitigating serious disasters such as flooding or drought. To clarify the hydrological process in the upper reaches of the Yellow River basin, a hydrological model can be used. However, it is difficult to apply existing hydrological models directly to the Yellow River basin because the river discharges are influenced by the artificial reservoir operations. Thus, we developed a simple model for forecasting the influences of the reservoir operations and applied it to the upper reaches of the Yellow River basin.

2. Study area

Figure 1 shows the study area of this study. The upper reach of the Yellow River basin is located upstream of Toudaoguai hydrological station (40.16°N, 111.04°E).

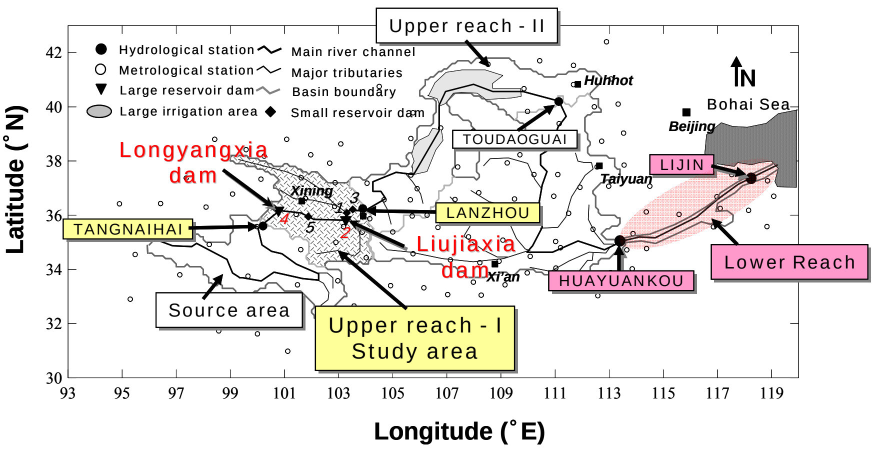

Figure 1 Yellow River basin

Based on the location of the large reservoirs and large irrigation areas, the upper reaches of the Yellow River basin can be divided into the following three sub-basins: (1) Source area (lying upstream of Tangnaihai (35.30°N, 100.09°E) hydrological station), (2) Upper reach–I (lying between Tangnaihai and Lanzhou (36.04°N, 103.49°E) hydrological stations), and (3) Upper reach–II (lying between Lanzhou and Toudaoguai hydrological stations). In particular, there are a lot of reservoir dams in upper reach–I due to the steep and narrow topological conditions. Thus, we focus on the upper reach–I to evaluate the influences of the reservoir operations on river runoff in detail.

The catchment area of this region is 100,636 km^2, which occupies about 13% of the Yellow River basin. The characteristics of the major reservoir dams constructed in the upper reach–I are summarized in Table I. Among them, we can see that there are two larger reservoir dams: Liujiaxia dam and Longyangxia dam. The river discharge observed downstream of these dams must be influenced by their operations. Thus, we focus on these two reservoir dams because the influences of other small reservoirs can be negligible.

Table I. Characteristics of major reservoir dams located in the upper reaches of the Yellow River basin

Code in Figure 1	Name	Begging of operation	Storage capacity ($10^8 m^3$)		
			Maximum	Regulating	Minimum
1	Yanguoxia	1961	2.2	0.1	2.1
2	Liujiaxia	1969	57.0	41.5	15.5
3	Bapanxia	1975	0.5	0.1	0.4
4	Longyangxia	1987	247.0	193.5	53.5
5	Lijiaxia	1998	16.5	0.6	15.9

3. Model structure

3.1. Hydrological model

The hydrological model used in this study is based on SVAT–HYCY model developed by Ma and Fukushima (2002). The model was modified to estimate the heat and water balances more precisely (Sato et al., 2007). The basic structure of the model is shown in the Figure 2. As the input parameters for the model, meteorological dataset from 1960 to 2000 were obtained from the China Meteorological Administration. The dataset includes 128 meteorological stations within or adjacent to the Yellow River basin at a daily temporal resolution. Meteorological parameters included precipitation, air temperature, wind speed, air pressure, vapour pressure, and sunshine duration. All the dataset was interpolated into a 0.1 grid scale over the Yellow River basin. Monthly discharge data observed at Tangnaihai and Lanzhou hydrological stations from 1960 to 2000 were obtained from the Yellow River Conservancy Commission (YRCC).

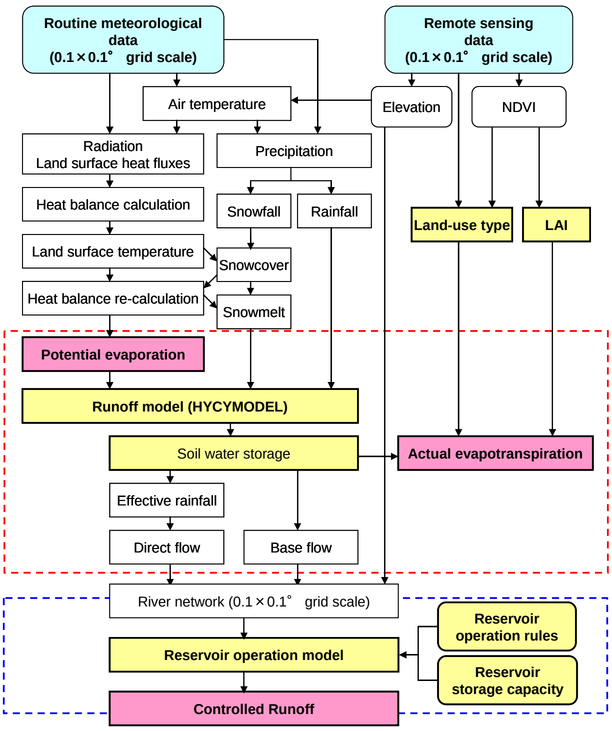

Figure 2 Basic structure of the hydrological model

3.2. Reservoir operation model

To detect the influence of the reservoir operation in detail, the period of analysis were divided as follows: (1) Period-I (1960-1968): There were no large dams in this period, (2) Period-II (1969-1986): The Liujiaxia dam controlled the river discharge in this period, and (3) Period-III: (1987-2000): The Longyangxia dam controlled river discharge together with the Liujiaxia dam in this period. The simple structure of our reservoir operation model is shown in Figure 3. In this model, the controlled outflow (*Qout*) from reservoir was regulated by the following three parameters: (1) the amount of inflow into the reservoir (*Qin*), (2) the amount of water storage within the reservoir (V), and (3) the standard monthly discharge patterns from the reservoir (*Qstd*), which can be correspond to the reservoir operation rules. The inflow into the reservoir (*Qin*) were calculated by the

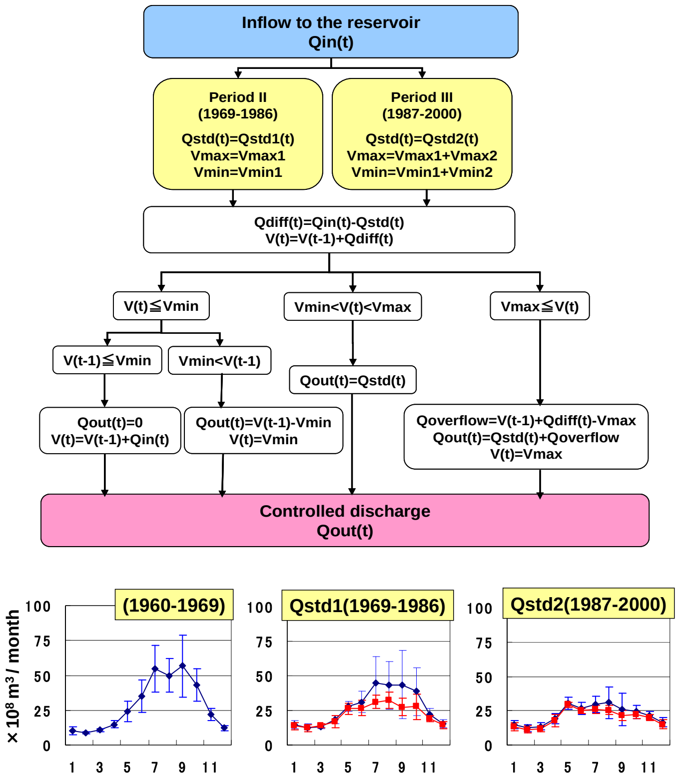

Figure 3 Outline of the reservoir operation model

hydrological (modified SVAT-HYCY) model. The standard monthly discharge patterns from the reservoir (*Qstd*) were estimated from the monthly discharge data observed at Lanzhou hydrological station. The two types of *Qstd* used in this study are also shown in Figure 3.

The controlled outflow from the reservoir (*Qout*) was calculated by the following procedures.

At first, the difference of Qin and Qout is calculated as follows.

$$Qdiff(t) = Qin(t) - Qstd(t) \qquad (1)$$

where *Qdiff* is the parameter which indicates the amount of surplus or deficit water, when the reservoir releases the amount of *Qstd*.

Then, *V*(*t*) and *Qout*(*t*) are calculated as follows.

$$V(t) = V(t-1) + Qdiff(t) \qquad (2)$$

$$Qout(t) = Qstd(t) \qquad (3)$$

When the value of *V*(*t*) exceed the maximum reservoir storage capacity (*Vmax*) in the equation (2), *V*(*t*) and *Qout*(*t*) are modified as follows.

$$V(t) = V\max \qquad (4)$$

$$Qoverflow = V(t-1) + Qdiff(t) - V\max \qquad (5)$$

$$Qout(t) = Qstd(t) + Qoverflow \qquad (6)$$

where Qoverflow is the overflow discharge from the reservoir dams.

When the value of *V*(*t*) decreases less than the minimum storage capacity (*Vmin*) in the equation (2), *V*(*t*) and *Qout*(*t*) are modified as follows.

If the amount of reservoir water storage in the previous time step is also less than Vmin, then

$$V(t) = V(t-1) + Qin(t) \qquad (7)$$

$$Qout(t) = 0 \qquad (8)$$

else

$$V(t) = V\min \qquad (9)$$

$$Qout(t) = V(t-1) - V\min \qquad (10)$$

The initial storage capacity of the reservoir *V*(0) was set as 0 m^3. The values of *V*(*t*) were also set as 0 m^3 until the Liujiaxia dam began its reservoir operations. Then, during the period-II (from 1969 to 1986), the following parameters were used.

$$Qstd(t) = Qstd1(t) \qquad (11)$$

$$V\max = V\max 1 \qquad (12)$$

$$V\min = V\min 1 \qquad (13)$$

In the same way, during the period-III (from 1987 to 2000), the following parameters were used.

$$Qstd(t) = Qstd2(t) \qquad (14)$$

$$V\max = V\max 1 + V\max 2 \qquad (15)$$

$$V\min = V\min 1 + V\min 2 \qquad (16)$$

4. Results and discussion

4.1. Hydrological simulation–1

Figure 4 shows the result of hydrological simulation using the original hydrological model which does not take the influences of reservoir operation into consideration. According to this result, it was found that the original hydrological model could not estimate the change of observed hydrographs.

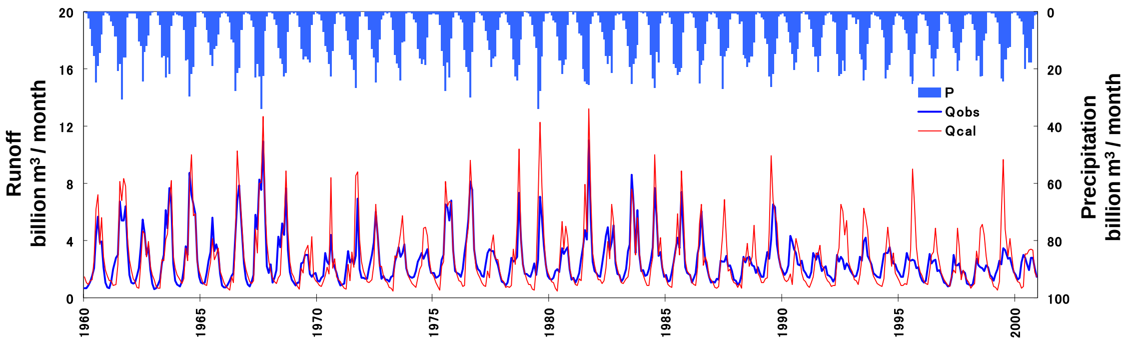

Figure 4 Hydrological simulations using the original hydrological model which does not include reservoir operations. Qobs: observed runoff, Qcal: calculated runoff, and P: precipitation

4.2. Hydrological simulation–2

However, by applying a reservoir operation model, the simulation performance was improved significantly (Figure 5).

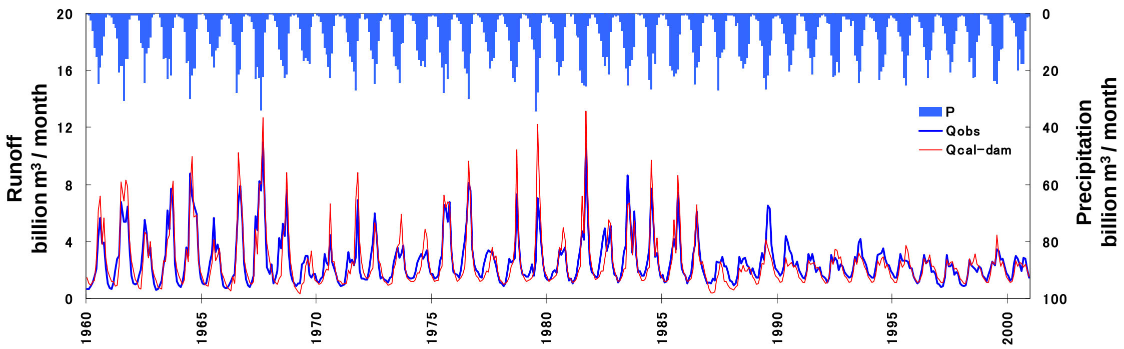

Figure 5 Hydrological simulations using a new hydrological model which include the reservoir operation model. Qobs: observed runoff, Qcal: calculated runoff, and P: precipitation

5. Conclusion

The results obtained in this study are summarized as follows:

1. The seasonal change of natural runoff coming from source area of the Yellow River basin were strongly regulated after the large reservoirs had constructed in the upper reaches of the Yellow River basin. Thus, our original hydrological model could not capture the observed hydrographs.

2. The influences of the reservoir operation can be estimated by the following three parameters: (1) inflow to the reservoir, (2) the storage of the reservoir, and (3) reservoir operation rules.

3. The simulated discharges calculated by our new model including reservoir operation model agreed well with the observed hydrographs.

4. The model developed in this study can be contribute as one of the useful tool for evaluating the influences of reservoir operations, such as the reduction of peak discharge and the stabilization of monthly discharges.

References

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