Flood Routing Analysis and Numerical Simulation in the Upper Reaches of the Tarim River Mainstream: Postprint

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Abstract

The hydrological characteristics of the Tarim River basin have undergone profound changes over the past few decades, with the annual runoff from source streams showing an overall increase, while the frequency of magnitude floods and peak discharge in the main stream have also increased significantly, leading to continuously growing flood control pressure on the main stream. This study conducted a systematic analysis of the upper Tarim River main stream (Xiaojiake–Yingbaza) segmented by river reaches from three aspects: flood travel time, peak reduction rate, and water consumption rate, revealing the general laws of flood propagation in the upper main stream. Based on this, a one-dimensional mathematical model for water-sediment routing was constructed; after validation against the 2010 flood, the model simulated the flood routing process of the 2017 main stream flood. The high simulation accuracy demonstrates the rationality and broad application prospects of this mathematical model. The research findings not only scientifically reveal the flood characteristics of representative inland sediment-laden rivers in Central Asia, but also hold significant importance for flood control management and floodwater resource utilization in the Tarim River main stream.

Full Text

Preamble

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Abstract: This study systematically analyzes flood characteristics in the upper reaches of the Tarim River mainstream (Xiaojiahe-Yingbazha section) from three aspects: flood travel time, peak clipping rate, and water consumption rate. The results reveal the general laws of flood transmission in the upper reaches of the mainstream. The travel time of peak flood gathers from Aral to Xinqi in 1.5-5 days, with an average peak clipping rate of 24%. From Xinqi to Yingbazha, the travel time is 2-10 days, with an average peak clipping rate of 50%. The water consumption rate ranges from 36% to 56% from Xinqi to Yingbazha. In June and July, the water consumption rates at Aral-Xinqi and Xinqi-Yingbazha reaches are 36%-56%, while in August and September, they are 23%-28%. A one-dimensional mathematical model of water and sediment evolution is constructed. After verification using flood events in 2010, the model simulated the mainstream flood evolution process in 2017 with high accuracy when the flow peak at Aral exceeded 800 $\mathrm{m}^3 \cdot \mathrm{s}^{\ 1}$, demonstrating the rationality and broad application prospects of the model. The results scientifically reveal the flood characteristics of representative inland sandy rivers in Central Asia and have important significance for flood control management and floodwater resource utilization of the Tarim River.

Keywords: flood routing; water and sediment evolution; numerical model; Tarim River mainstream

1. Introduction

The Tarim River Basin is located in southern Xinjiang, covering a total area of 1.02 million km^2. The study area extends from the Aral hydrological station to the Yingbazha hydrological station, with a total length of 1,321 km. The river channel is characterized by a wide and shallow beach with a narrow and deep main trough, forming a typical wandering river pattern. The reach from Aral to Xinqi is 495 km long, with relatively well-developed embankments on both banks. The Xinqi to Yingbazha reach spans 398 km, with only sporadic embankments on the left bank. The Yingbazha to Qiala reach is 428 km long and lacks any embankment protection. The Aral and Xinqi stations were established in 1956, while the Yingbazha station was established in 1992. After 20 years of operation, the Xinqi and Yingbazha stations have accumulated 10 years of observational data. These long-term monitoring efforts provide a solid foundation for analyzing the hydraulic characteristics and flood propagation patterns in the Tarim River mainstream.

2. Data and Methods

2.1 Data Sources

Hydrological data were obtained from measured discharge and sediment records at the Aral, Xinqi, and Yingbazha stations. The data series from 1992 to 2010 were used, comprising 16 years of measurements (1996-2010). Based on these 16 years of data, the relationships between peak flood travel time and inflow were established for both the Aral-Xinqi and Xinqi-Yingbazha reaches [FIGURE:2, FIGURE:4].

2.2 Water Consumption Analysis

Analysis of water loss ratios between 2005 and 2016 reveals that during flood seasons, water consumption rates in the Aral-Xinqi and Xinqi-Yingbazha reaches range from 36% to 56% in June and July, and 23% to 28% in August and September . The average water loss per kilometer is 64,000 m^3/km in the Aral-Xinqi reach and 83,000 m^3/km in the Xinqi-Yingbazha reach. The peak clipping rates show significant variation, with values of 31.5%-64.4% in the Xinqi-Yingbazha reach, averaging approximately 50% [FIGURE:3, FIGURE:5].

Table 1. Water loss ratio from Aral to Yingbazha (2005-2016)

River Reach	Length (km)	Water Loss Rate (%)	Peak Clipping Rate (%)
Aral-Xinqi	495	23.0	6.4-10.8
Xinqi-Yingbazha	398	27.8	31.5-64.4

3. Model Construction

3.1 Basic Principles

A one-dimensional mathematical model for water and sediment transport was developed based on the following governing equations:

Continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q_L$$

Momentum equation:

$$\frac{\partial Z}{\partial x} + \frac{\partial}{\partial x}\left(\frac{Q^2}{2gA^2}\right) + \frac{Q|Q|}{K^2} = 0$$

Sediment continuity equation:

$$\frac{\partial (AS)}{\partial t} + \frac{\partial (Q_s)}{\partial x} = -\alpha \omega B(S - S^*)$$

Where: - Q = discharge (m³/s) - A = cross-sectional area (m²) - Z = water level (m) - S = sediment concentration (kg/m³) - S^* = equilibrium sediment concentration (kg/m³) - K = flow modulus - α = recovery saturation coefficient - ω = settling velocity (m/s) - B = channel width (m) - q_L = lateral inflow per unit length (m³/s · m)

3.2 Model Validation

3.2.1 Flood Event Selection Two typical flood events were selected for model validation: the 2010 flood and the 2017 flood. The 2010 flood event lasted from June to October, with a peak discharge of 882 m³/s at Aral station (June 21, 16:00). The flood peak occurred between July and September, with a duration of approximately 130 days. The 2017 flood event was used for model verification after parameter calibration with the 2010 event.

3.2.2 Simulation Results The model was applied to simulate the 2010 flood propagation process. Results show that when the peak discharge at Aral exceeds 800 m³/s, the simulation accuracy is high, with relative errors in peak discharge and travel time within 10% [Figure 6: see original paper]. The water consumption rates simulated by the model are 23% for the Aral-Xinqi reach and 35% for the Xinqi-Yingbazha reach, which are consistent with observed values [Figure 7: see original paper]. The model successfully reproduced the flood evolution process in 2017, demonstrating its reliability for flood forecasting and water resources management in the Tarim River Basin.

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English Abstract

The hydrological characteristics of Tarim River Basin, Xinjiang, China have undergone profound changes in the past decades. The annual runoff of the origin increased while the frequency and the peak discharge of magnitude floods in the mainstream increased significantly, which lead to the increase of flood protection pressure. In 2001, the Tarim river ecological rescue project was implemented, and the recent governance project of the Tarim River mainstream was carried out after 2002. After the boundary conditions and water and sediment conditions changed significantly, there is still a lack of quantitative analysis and research on the flood travel time and peak-clipping rate of the mainstream Tarim River. This paper systematically analyzed flood characteristics in the upper reach of the mainstream of the Tarim River (Xiaojiake-Yingbazha reach) from three aspects: Flood travel time, peak-clipping rate and water consumption rate, which revealed the general law of flood transmission in the upper reaches of the mainstream. The travel time of peak flood is gathered in 1.5-5 d from Aral to Xinqi, and the average peak-clipping rate is 24%. The travel time of peak flood is gathered in 2-10 d from Xinqi to Yingbazha, and the average peak-clipping rate is 50%. The water consumption rate is gathered in 36%-56% from Xinqi to Yingbazha, and the average peak-clipping rate is 50%. The water consumption rates are 36% ~56% at Aral-Xinqi and Xinqi-Yingbazha reaches in June and July. In August and September, the water consumption rates of the two reaches are gathered in 23%-28%. A one-dimensional mathematical model of water and sediment evolution is constructed. After the verification period using flood events in 2010, the model simulated the mainstream flood evolution process in 2017 and the simulation results with high accuracy was obtained when the flow peak of Aral exceeds 800 $m^3 \cdot s^{-1}$, which indicated the rationality and wide application prospect of the model. The results of this study have scientifically revealed the flood characteristics of representative inland sandy rivers in Central Asia, and have important significance for flood-control management and flood-water resource utilization of the Tarim River.

Keywords: flood routing; water and sediment evolution; numerical model; mainstream of Tarim River