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Study on the Construction of Early Warning System for Reservoir Flood Discharge in China

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Abstract. To effectively respond to unforeseen events like dam breaches and to mitigate potential disasters resulting from downstream flooding that threatens human lives and property, a thorough analysis and research of the reservoir flood warning system are crucial. This article delves into the current state of reservoir flood management in China, marked by insufficient emergency warning infrastructure, incomplete flood warning systems, and irregular emergency response practices. It conducts a comprehensive examination of China's regulatory standards and practical implementations, encompassing the construction of the flood warning system, the delineation of responsibilities for managing flood impacts, and compliance with local regulations. Furthermore, this article offers a comprehensive summary and analysis of the existing reservoir flood warning systems in countries such as Switzerland, Japan, the United States, Australia, and the Netherlands. Drawing upon international experiences while considering China's unique circumstances, the article presents a set of recommendations aimed at fortifying the reservoir flood warning system, advancing the development of flood warning facilities, increasing awareness and readiness for flood warnings, and standardizing the management of downstream flood channels in China.

Keywords. Reservoir flood discharge, system construction, reservoir management, flood discharge warning

1. Introduction

With the intensification of global climate change, the uneven temporal and spatial distribution of water resources has become an urgent problem that plagues life on Earth, especially for flood control and scheduling work [1,2]. Reservoir flood discharge or power generation, irrigation release (from now on referred to as "flood discharge") may threaten downstream public safety. Since the flood control standard of the downstream flood channel is far lower than the flood control standard of the reservoir hydropower

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station, and with social, economic development and urbanization, the population and economic and social volume of the downstream of the reservoir hydropower station has increased, the public's water-friendly activities have increased, and the impact of flood discharge on life safety and related water disputes have increased [3,4].

The reservoir design phase considers the scheduling principle to avoid and reduce the impact of flood discharge downstream. It sets the flood limit water level and flood control high water level to meet the flood control requirements of the downstream flood control protection objects. During the average operation period of the reservoir, formulate dispatch operation regulations and a dispatch operation plan every year to standardize reservoir dispatch operation. Emergency plans for dam safety (flood control) have been developed and strictly implemented in response to emergencies such as dam failures. Based on the current situation of flood discharge management in China and the relevant international situation, this paper analyzes and looks forward to the flood discharge early warning system in line with China's national conditions (**Figure 1**).

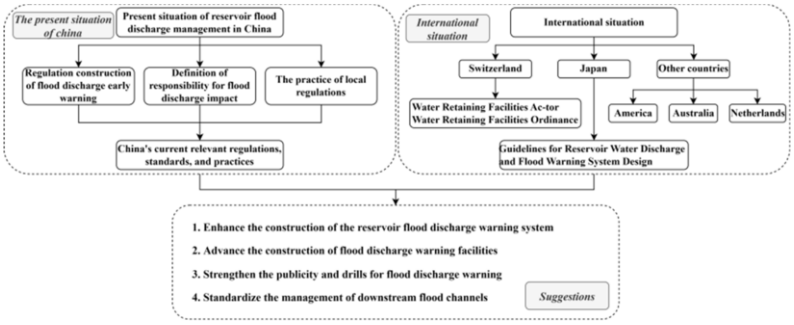

Figure 1. Technical route of reservoir flood discharge early warning system analysis.

2. Present Situation of Reservoir Flood Discharge Management in China

At present, the relevant departments and reservoir management units issue early warning information to the downstream before the flood discharge of the reservoir to warn the public to move in an orderly manner according to the flood discharge situation. The general practice is that, according to the flood control dispatching rules, the flood control and drought relief headquarters and the competent department of the reservoir issue flood warning information to downstream affected towns, village groups, units, and the public through telephone, text message, Internet, fax, radio, television, etc. before flood discharge [5]. Due to the insufficient hardware of early warning and emergency early warning facilities for reservoir flood discharge in China, only some places and a small number of projects have alarm systems. Flood discharge early warning needs to be more comprehensive and timely, and incidents of loss of life and property downstream due to flood discharge occur occasionally.

At the same time, due to lax management, some downstream flood passages of some reservoirs have been encroached on and even engaged in development, utilization, or production and operation in violation of regulations, hindering normal flood discharge, endangering flood control safety and quickly causing flood discharge disputes. After losses and disputes occurred due to the lack of basis for the provisions

of the flood discharge system and the definition of responsibilities, conflicts and disputes were aggravated, and difficulties in handling were exacerbated. In 2018, the flood discharge of three reservoirs in Shouguang, Shandong Province, caused downstream inundation losses, and it was difficult to define the responsibility and explain the disposal. In short, it is necessary and urgent to strengthen the early warning system for reservoir flood discharge.

3. China's Current Relevant Regulations, Standards and Practices

The regulations, technical standards, and facilities related to flood discharge warnings in reservoir hydropower stations must be more comprehensive in China. The relevant requirements are scattered across various regulations and need more specific and practical guidelines. As a result, the existing rules are more principle-based and need more operational solid guidance. According to the “Flood Control Law of the People's Republic of China” [6], local governments at all levels are required to establish and improve flood control systems, hydrological, meteorological, communication, early warning, and flood monitoring systems based on flood control planning and flood defense schemes. The aim is to enhance flood defense capabilities and actively involve relevant units and residents in flood control efforts within flood-prone areas. Adapted flood control and diversion measures should be taken based on local conditions.

The “Emergency Response Law of the People's Republic of China” [7] stipulates that the state shall establish and improve an emergency communication support system, enhance public communication networks, establish an emergency communication system that combines wired and wireless technologies, and coordinate essential telecommunications networks with mobile communication systems. The goal is to ensure smooth communication during emergency response operations. The law also encourages and supports educational, research institutions, and relevant enterprises to research and develop new technologies, equipment, and tools for the prevention, monitoring, early warning, emergency response, and rescue in emergencies. The “Regulations on the Safety Management of Reservoirs and Dams” [8] stipulate that the dam management unit and relevant departments should be prepared for flood control, emergency materials, and meteorological and hydrological forecasts. They should ensure smooth communication for hydrological information dissemination, warning, and coordination between the dam management unit, dam supervisory authority, and higher-level flood control command agencies. In the event of a risk of dam failure, all necessary measures must be taken to issue warnings to the anticipated inundation areas and carry out evacuation procedures.

Regarding defining responsibilities and resolving disputes related to the impacts of flood discharge, the relevant regulations only provide general or principle-based provisions. The “Water Law of the People's Republic of China” [9] stipulates that water-related disputes between entities, individuals, or between entities and individuals should be resolved through consultation. If the parties involved are unwilling to negotiate or if the negotiation fails, they may apply for mediation by the local people's government at or above the county level or its authorized department. Alternatively, they can directly initiate civil litigation in the people's court. Suppose the local government mediation is unsuccessful at or above the county level or authorized department. In that case, the parties may bring the topic to the People's Court for civil

litigation. Before resolving the water-related dispute, the parties involved can only change the situation if they are in charge.

The awareness of local governments, reservoir hydropower station supervisory authorities, and management units regarding constructing flood discharge warning systems has been increasing. In some regions, policies are gradually being introduced to actively promote establishing flood discharge warning systems for reservoir hydropower stations. This has led to the initial development of upstream-downstream linkage mechanisms for flood discharge in reservoirs and the timely dissemination of warning information to downstream affected areas. In response to the need for flood control measures, the Guizhou Province Flood Control Command issued the "Interim Measures for the Management of Flood Discharge Warning for Large Reservoirs (Hydropower Stations) in Guizhou Province." In Zhejiang Province, some reservoirs have taken further steps to refine their warning mechanisms by formulating upstream-downstream linkage emergency response plans for flood discharge. In regions such as Lishui, efforts have been made to implement flood insurance systems to mitigate the social and economic losses caused by flood discharge and ensure stable social and economic development. Wenzhou issued the “Notice of Wenzhou Municipal People's Government Office on Printing and Distributing the Emergency Water Discharge Warning Plan for Reservoirs under Municipal Management [10]” The notice requires Shanxi Economic Development Limited Company and its subsidiary Shanxi Hydropower Plant (from now on referred to as Shanxi Company and the Plant) to install warning signs along the riverbanks within the downstream project management protection zone of the hydroelectric station. When flood discharge is initiated, they must organize early warning operations, and the notification also specifies the procedures and content of the early warning (**Figure 2**).

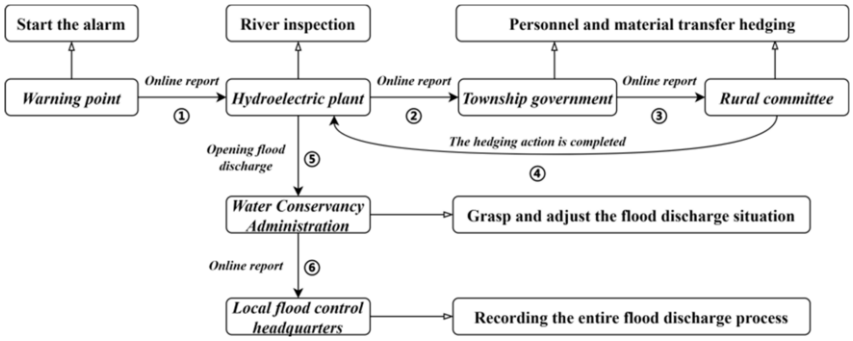

Figure 2. Warning procedure and content of reservoir flood discharge in Wenzhou.

4. International Situation

Some countries internationally have reservoir flood discharge and warning systems worth learning from. Switzerland, Japan, the United States, Australia, the Netherlands, and others have well-defined regulations regarding reservoir hydropower station flood discharge warnings and the delineation of flood discharge responsibilities. They have established relatively comprehensive warning and alert facilities.

4.1. Switzerland

In Switzerland, reservoir flood discharge warning and emergency alert systems are incorporated into the "Water Retaining Facilities Ac-tor" [11][11] and the "Water Retaining Facilities Ordinance" [12]. They have established systematic flood warning facilities and conduct regular maintenance, testing, and drills to ensure proper functioning.

Switzerland has a total of 1200 reservoirs and hydropower stations. The flood discharge warning work is jointly carried out by the owners of the reservoirs, state governments, the Swiss Federal Office of Energy (SFOE), the Federal Office for Civil Protection (FOCP), and the Federal Emergency Center (NEC) (**Table 1**). The owners and state governments are the main responsible entities for emergency management.

Table 1. Swiss Reservoir flood discharge early warning workflow.

Unit name	Main work content
Owners of the reservoirs	Developing reservoir flood discharge inundation maps, conducting risk analysis, and preparing emergency plans; Installing, operating, and maintaining flood warning systems and activating flood warnings.
State governments	Creating emergency evacuation plans, Incorporating personnel evacuation into the emergency system, and Initiating comprehensive warnings.
SFOE	Reviewing the flood discharge schedules and emergency regulations prepared by the owners, Specifying the types of flood warning systems required in certain areas, and determining the nearby zones where flood warning systems need to be installed.
FOCP	Proposing technical requirements for public protection and installing comprehensive warning devices.
NEC	Issuing warning messages and behavioral requirements; Collecting, analyzing, displaying, and disseminating relevant information.

Switzerland's reservoir hydropower station flood discharge warning facilities are highly comprehensive. The warning system includes three types of alerts: flood warnings, complete warnings, and mobile warning systems. These different warning systems are installed in various designated areas. As of 2013, 4,700 sets of flood warning and comprehensive warning systems were installed throughout Switzerland, along with 2,800 groups of mobile warning systems. Based on the impact of reservoir flooding, the warning areas are divided into two categories: the nearby zone (referring to areas that could be affected by the flood within 2 hours) and the distant site.

4.2. Japan

Japan has established a comprehensive reservoir warning system and corresponding regulations [13]. Japan's efforts in early warning, construction of flood discharge warning systems, and multi-department cooperation in disseminating warning information are precious for reference. Their reservoir flood discharge warning work is meticulous. Before flood discharge, flood discharge alerts are issued, and advance notifications are made through telephone and fax. Warning vehicles announce warnings along the routes, and warning devices or signs are strategically placed in key areas—specially assigned personnel guard critical locations to ensure public safety.

Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) has established the "Guidelines for Reservoir Water Discharge and Flood Warning System Design." All the reservoirs under its jurisdiction have implemented warning systems

primarily based on warning broadcasts (**Table 2**). For instance, at Nomura Reservoir, 21 flood discharge warning signs and 11 warning stations have been installed in downstream river towns. Similarly, at Kano River Reservoir, 22 warning stations have been established.

Table 2. Japan reservoir flood warning system.

Warning Level	Early warning information
Prepare for Shelter	When the meteorological department issues a heavy rainfall forecast.
Advisory to Evacuate	When the outflow discharge from the reservoir is increased from 300 m^3/s to 400 m^3/s, Vulnerable individuals need to evacuate immediately.
Order to Evacuate	In case of an anticipated exceptional flood, warnings are issued three hours before disaster prevention operations begin, requiring all individuals to evacuate immediately to safer locations.

4.3. Other Countries

Almost all United States have enacted legislation requiring downstream warnings during reservoir flood discharge [14]. Under the jurisdiction of the Bureau of Reclamation, Davis Dam and Parker Dam have established warning release schedules that include water discharge plans for the next three days, with discharge times accurate to the hour and discharge volumes measured in cubic feet per second. Even if flood discharge deviates from the planned schedule, the flood discharge warning system is activated, and people in the endangered areas are evacuated. Additionally, all 31 hydroelectric power stations under the Tennessee Valley Authority in the United States have installed flood discharge warning systems at their hazardous locations. Each site is equipped with warning devices, flashing lights, warning signs, and electronic screens with flashing lights and warning signs.

In Australia, some reservoirs utilize modern communication technology to disseminate reservoir flood discharge and water release information to the affected public through various channels such as phone calls, text messages, and emails, which can be added or removed anytime. Residents or tourists only need to register an account on the official website, choose from all or specific reservoirs, and they can receive information on hourly water discharge rates from gated dams and the stoppage time for water release or reminders of hourly overflow rates from ungated reservoirs. This service will issue special safety reminders for dangerously high downstream water levels. Registered users can also adjust the frequency of reminders, for example, only receiving alerts when significant changes in water release rates occur.

The Netherlands has established a comprehensive warning system covering various emergencies, including reservoir flood discharge. Every month, the country conducts regular tests of the alert system to remind and familiarize the public with the warning procedures, aiming to enable them to respond effectively during actual emergencies. On the first Monday of each month at noon (excluding major holidays), the Netherlands conducts a nationwide 1-minute and 26-second uninterrupted alert test. This test ensures the proper functioning of the alert system and helps everyone understand the distinction between the test alert and emergency alert. Government departments also inform the public that if the alert sounds at other times, they should turn on their televisions or radios to receive emergency broadcasts and take necessary safety measures. The Dutch government has dedicated crisis websites and mobile applications that provide emergency measures for various situations, such as floods, earthquakes, fires, explosions, and terrorist attacks. These resources facilitate the public

in finding relevant information and correct actions in emergencies. The mobile application also delivers warning messages to keep citizens informed.

5. Suggestions

5.1. Enhancing the Construction of the Reservoir Flood Discharge Warning System

Strengthen the construction of the reservoir flood discharge warning system. The Ministry of Water Resources shall collaborate with relevant departments such as emergency management and energy, conduct thorough investigations and research, draw lessons from international experiences, and expedite the construction of the reservoir flood discharge warning system in line with the current situation. The examination shall be conducted on reservoir flood discharge warning signs, flood discharge warning facilities, warning decision-making and dissemination mechanisms, and the delineation of related responsibilities to promote establishing the reservoir flood discharge warning system.

5.2. Advance the Construction of Flood Discharge Warning Facilities

Standardize the construction standards of flood discharge warning facilities for reservoirs and hydropower stations, increase investment in construction, and systematically set up flood discharge warning facilities based on the risk and impact level of the pools. Accelerate the construction of flood discharge warning facilities.

5.3. Strengthen the Publicity and Drills for Flood Discharge Warning

Enhance the management of reservoir and hydropower station scheduling and flood discharge warning, strengthen training, promotion, and exercises for flood discharge warning, and improve the flood discharge warning and public flood prevention and risk avoidance capabilities for reservoirs.

5.4. Standardize the Management of Downstream Flood Channels

A thorough review and rectification will be carried out to address the issue of unauthorized encroachments in downstream flood channels of reservoirs and hydropower stations. Furthermore, efforts will be made to standardize the daily supervision and management of flood channels to ensure a smooth flow in the downstream flood channels.

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