Research on the hydrological emergency monitoring system of high-risk Barrier Lake based on PDCA theory

J Y Mei\textsuperscript{1,2}, M B Zhang\textsuperscript{1} and B Zhou\textsuperscript{1}

\textsuperscript{1}Bureau of Hydrology, Changjiang Water Resource Commission, Wuhan 430010, China

E-mail: 2280035532@qq.com

Abstract. In recent years, there have been some barrier lakes formed by earthquakes or landslides in China, such as the Tangjiashan barrier lake in 2008 and the Baige barrier lakes (twice) in 2018. The barrier lake often brings huge destructive risks to the upstream and downstream affected areas. In order to protect the lives and property of the people, it is necessary to carry out corresponding scientific disposal. The premise of disposal is to obtain detailed and reliable dynamic monitoring information. And hydrological monitoring information is the basis of various types of information. Therefore, hydrological emergency monitoring must be carried out to obtain the information. This paper summarizes and puts forward the design of the high-risk barrier lake hydrological emergency monitoring system based on PDCA theory, which can provide support and guidance for the implementation of hydrological emergency monitoring in the future, and it has a strong practical significance.

1. Introduction

1.1. Barrier lake and dam breach flood

The barrier lake is a lake formed by solid materials generated by landslides, collapses, mudslides, etc., which block the river to form a dam, and the upstream water flows continuously into the reservoir to store water. According to different risk levels, the barrier lake can be divided into high-risk type, steady-state type and immediate-eliminating type.

It is a high-risk barrier lake if the dam body completely blocks the river channel, the water flow can only enter, and the dam body has poor stability and it is not disposed, it will quickly collapse and form a dam-breaking flood. It is a steady-state barrier lake if the river channel is blocked, the water flow has a discharge channel, the dam body is stable, and the water flow reaches the equilibrium after entering and leaving, and the dammed lake is in a stable state. It is immediate-type barrier lakes that dam body blocks the river channel in a short time, and the dam body is very weak, it often was quickly washed away by the lake and restored to the natural river channel. In general, the steady-state barrier lake and immediate-type barrier lakes are less dangerous, and the urgency of emergency response is often much lower than high-risk barrier lakes. Therefore, this paper focuses on high-risk barrier lakes.

After the barrier lake is completed, the upper reaches will be inundated by the backwater before the dam collapses; the river below the dam will be completely blocked due to the river being completely blocked, resulting in a decrease or even dryness, causing a great impact of various types of water use such as ecological and irrigation. On the other hand, once the dammed body collapses and the dammed lake collapses, a flood peak will form in downstream, which is as destructive as the destructive force...
of the disaster; and the upstream reservoir slope will collapse due to the stage rapid collapse, and causing damage to the stability of various types of wading buildings, posing many safety hazards.

1.2. The necessity of emergency monitoring
In order to minimize the risks of the upper and lower reaches of the barrier lake, guarantee the lives and property of people, scientific and reasonable engineering or (and) non-engineering measures must be taken for emergency response. How to quantify the measures, how to evaluate the amount of engineering, and how the future water potential changes, all need dynamically monitor and evaluate of the hydrological elements of the barrier lake geometry and the affected area. Therefore, the hydrological emergency monitoring of the barrier lake came into being in this context.

2. Materials and methods

2.1. The PDCA cycle
The PDCA cycle was first proposed by Dr. Huh Hart, a US quality management expert. The ideological basis and methodological basis for total quality management is the PDCA cycle [1-3]. The meaning of the PDCA cycle is to divide quality management into four phases, namely plan, execute (do), check (check), and process (act). In the quality management activities, it is required to follow the plan, plan implementation, check the implementation effect, and then incorporate the success into the standard, and leave it unsuccessful to the next cycle. This working method is the basic method of quality management and the general law of all aspects of enterprise management.

2.2. PDCA quality management of hydrological emergency monitoring of the Barrier Lake
The hydrological emergency monitoring of the barrier lake can provide technical support for the emergency disposal of the barrier lake, and the quality of the monitoring data is particularly critical [4,5]. It is a technical problem that needs urgent research about how to improve the quality of the emergency monitoring results of the barrier lake in the harsh environment and poor control conditions. This paper uses the basic theory of quality management, introduces the PDCA (Plan Do Check Act) model of ISO quality management and emergency monitoring, and carries out research on the hydrological emergency monitoring system of the barrier lake based on PDCA mode. The PDCA model divides the quality management into four stage, that is, planning, execution, inspection, and processing.

![Figure 1. Overall architecture design of the hydrological emergency monitoring system of Barrier Lake.](image-url)
2.3. Overall architecture design of emergency monitoring system

For high-risk barrier lakes, in order to efficiently obtain monitoring results that meet the needs of accuracy, it is necessary to clearly state what is being monitored, what equipment to use, when to monitor, where to monitor, how to monitor, how to analyze the results, how to control the accuracy indicators, and how to ensure the technical elements such as the development of emergency monitoring. All of these technical elements are interconnected and mutually infiltrated to form a hydrological emergency monitoring system for the barrier lake. Based on the basic theory of ISO quality management, based on summarizing the experience of previous emergency monitoring, the overall architecture of the hydrological emergency monitoring system of the barrier lake based on PDCA model is proposed (see figure 1). The hydrological emergency monitoring system of the barrier lake mainly includes monitoring and investigation content, monitoring methods, data analysis, and technical equipment.

3. Results and discussion

3.1. Research on emergency monitoring system

3.1.1. Emergency monitoring plan. After the formation of the high-risk barrier lake, the hydrological department should positively respond and initiate emergency monitoring according to relevant regulations. This is the emergency monitoring preparation phase. The main technical aspects include the initiation of emergency monitoring plans, the deployment of monitoring stations, the formation of monitoring teams, the configuration of monitoring equipment and the preparation of emergency monitoring plans.

The contingency plan is a pre-programmed technical document that initiates different scenarios for different types of barrier lakes. The content covers response mechanisms, organizational systems, emergency monitoring, safeguards, security measures, and post-disposal.

The barrier lake monitoring stations is the “combat ground” for emergency monitoring. It is necessary to make full use of the existing stations and add monitoring stations as needed. For example, an unattended site can be set up on the dam or under the dam to perform hydrological element observation and video acquisition in a non-contact manner.

The emergency monitoring work of the barrier lake has the characteristics of environmental inconvenience, poor control conditions, and poor safety working environment. Under the current state of the art, monitoring is also mainly carried out by human resources. Monitoring team members should have good business ability and strong physical fitness.

It needs to be equipped with emergency equipment with excellent performance, good adaptability to the field environment, and portable equipment, including equipment, communication equipment, network equipment, application software and safety, transportation and living equipment. It should be equipped with a variety of equipment solutions. If a method fails, an alternative solution can be adopted in time to ensure the continuity and reliability of data monitoring.

The emergency monitoring program is an action guide for implementing emergency monitoring. It should be scientifically formulated according to the actual conditions of each monitoring site according to local conditions, and achieve “one station, one policy”. The content includes monitoring objects, scope of work, technical methods, technical equipment, organizational safeguards and quality control of results.

3.1.2. Emergency monitoring execution and inspection. From figure 1, it can be seen that after the emergency monitoring preparation is completed, the emergency monitoring program should be drilled before the formal implementation of the emergency monitoring to check the scientific rationality of the monitoring program. On the basis of optimizing and adjusting the monitoring plan, (Do) the hydrological emergency monitoring of the lake is implemented. This phase is the implementation phase of emergency monitoring.

- Drills of emergency monitoring
An emergency drill is a response exercise that simulates an emergency after a specific flood has occurred. Practice has proved that emergency drills can effectively reduce casualties and property losses in the event of an emergency. The emergency drills included stage observation drills, night time flow drills, buoy launch drills, and safe evacuation drills.

- Implement of emergency monitoring

The implementation of emergency monitoring is the core of the emergency monitoring of the barrier lake. Through the implementation of emergency monitoring, various types of dynamic monitoring information are obtained to provide real-time information for emergency response. According to the needs of emergency treatment in the barrier lake, emergency monitoring usually includes elements such as emergency station network, damming survey, channel topographic survey and hydrological factor monitoring.

- Deploy emergency control network

Plane positioning and elevation positioning are the basis for implementing technical aspects such as damming survey, section measurement, stage observation, and discharge measurement (figure 2). The area where the lake is located may lack plane and elevation control networks, or if the control network is damaged during landslides or earthquakes, the emergency control network should be deployed first. The same control system is required for both the planar positioning measurement and the elevation control measurement involved in the entire monitoring system to ensure data consistency and coordination. The emergency monitoring and control network can jointly measure the national or local control network in the survey area according to the actual situation and needs; the conditional areas can be connected to the national, local and industrial CORS systems; in the data-poor areas, the GNSS can be used to establish an unconstrained independent control network.

![Figure 2. Deploy emergency control network.](image)

- Damming survey

The damming survey information is the basis of dam breach flood calculation, hydrological forecast, and flood control calculation. The monitoring elements include the geometry of the tampon (the width of the raft, the width of the bilge, the length of the corpus callosum, the thickness of the corpus callosum, the average height, and the volume), sputum slope ratio and so on. The monitoring range covers areas where the topography changes before and after the formation of the plug body. Surveys are carried out using advanced techniques such as digital topography, drone digital image measurement and 3D laser scanning (figure 3).
The channel topographic survey of the barrier lake includes two parts: topographic survey of the reaches below the dam and the survey of the reservoir. The topographic data of the lower reaches of the dam is used for dam breach calculation, hydrological forecast, flood calculus, etc. The topographic survey of the reservoir is mainly used to estimate the storage capacity curve and dynamically analyze the characteristics of scouring and silting in the reservoir area. According to the survey conditions and precision requirements, the topographic method and the section method can be used for the channel topographic survey (figure 4). In the emergency, the DEM data can also be used for section extraction.

**Figure 3. Damming survey.**

- **Channel topography survey**

  The channel topographic survey of the barrier lake includes two parts: topographic survey of the reaches below the dam and the survey of the reservoir. The topographic data of the lower reaches of the dam is used for dam breach calculation, hydrological forecast, flood calculus, etc. The topographic survey of the reservoir is mainly used to estimate the storage capacity curve and dynamically analyze the characteristics of scouring and silting in the reservoir area. According to the survey conditions and precision requirements, the topographic method and the section method can be used for the channel topographic survey (figure 4). In the emergency, the DEM data can also be used for section extraction.

**Figure 4. Channel topography.**

- **Hydrological element monitoring**

  The monitoring of hydrological elements (figure 5) relies on the network of hydrological monitoring stations to carry out high-risk flood monitoring of warehousing floods, dam breach floods and downstream rivers. The main hydrological elements of the hydrological emergency monitoring of the barrier lake are stage and discharge. Each hydrological element observation instrument should adopt a non-contact method as much as possible, which is portable, accurate and highly automated. The stage can be observed by self-recording instruments and new technologies such as drones. If the self-recording instrument fails, the prism-free total station can be used for stage observation. The discharge measurement can be performed by non-contact test using ADCP, drone radar, side-scan radar, and space photography. It should be noted that the location of the barrier lake is often located in the alpine valley. The road conditions, communication conditions, power supply and other conditions are very harsh. Therefore, it is necessary to equip with transportation, communication, power supply
and other security equipment to facilitate the smooth development of emergency monitoring.

![Diagram](Image)

**Figure 5.** Hydrological element monitoring.

### 3.1.3. The disposal of emergency monitoring

The disposal of emergency monitoring includes on-site test data, that is, measurement and integration, submission, analysis and collation of the hydrological emergency monitoring data, and summarization and archiving.

The data processing results of the hydrological emergency monitoring in the barrier lake include the results of emergency control measurement, dam body survey, hydrological element monitoring and channel survey. The on-site monitoring data should be inspected according to the “calculation, collation, analysis soon after observation” mode. On the basis of the single station rationality analysis and the multi-station comparative comprehensive analysis, the results are reported to the demand side soon after the observation is completed. During and after the emergency monitoring process, results should be organized, reorganized and summarized. The summary includes overview, project organization, resource allocation, monitoring plan, monitoring implementation, monitoring results, safeguards, conclusions and recommendations.

### 3.2. Emergency monitoring implement of "11•03" Baige Barrier Lake

On November 3, 2018, Baige Village, Jinsha River, reoccurred a landslide at the “10•11” barrier lake to block the river to form a barrier lake. After the formation of the barrier lake, the Yangtze River Committee responded positively and immediately set up a hydrological emergency monitoring team, forming 7 monitoring teams to rush to the emergency monitoring station, and the Hydrology Bureau sent a team of experts to coordinate emergency monitoring. Stations such as Polo, Yebatan, Batang, Benzilan, Tacheng, Shigu and Shanghai Leaping Gorge are used as emergency monitoring stations. On the basis of fully understanding the characteristics of each station, an emergency monitoring plan is formulated and emergency drills are carried out according to the plan. After the collapse of the dammed, the stations carried out hydrological emergency monitoring, and carried out stage observation and discharge measurement by means of prism-free total station, drone and buoy method. The collection of reliable and complete hydrological emergency monitoring data provided data support for the emergency disposal of the barrier lake [6,7]. The hydrological emergency monitoring of the barrier lake is based on the specific application of the PDCA model emergency monitoring system [8-11].

### 4. Conclusions

This paper introduces the main types and characteristics of the barrier lake and the basic characteristics of the dam break flood, and introduces the necessity of hydrological emergency monitoring. It is pointed out that the barrier lake is mainly divided into the steady-state type, the immediate-killing type and the high-risk type, and the high-risk type barrier lake is very harmful, which is the main research object of this paper. It is pointed out that the danger of the barrier lake is that it blocks the river channel so that the water flow continues to accumulate in the upstream. Once it breaks down, the resulting flood has great destructive power and is extremely prone to devastating
disaster. Emergency disposal must be taken to reduce or eliminate such hazards, and emergency response needs to rely on hydrological emergency monitoring to obtain appropriate information.

On the basis of summarizing the experience of previous emergency monitoring, this paper proposes the overall structure of the hydrological emergency monitoring system of the barrier lake based on the PDCA theory. The overall process of emergency monitoring is divided into three stages: planning, implementation (Do, Check) and summary (Act). The main links in the preparation phase include launching emergency plans, deploying monitoring station networks, setting up monitoring teams, configuring monitoring equipment, and preparing emergency monitoring plans. The implementation phase mainly includes conducting emergency drills and implementing emergency monitoring (laying emergency control network, damming survey, waterway topographic survey, hydrological factor monitoring and emergency monitoring and handling). The summary stage includes on-site test data, i.e. measurement and integration, submission, analysis and collation of the hydrological emergency monitoring data in the lake, and summary and archiving. The system was summarized and detailed in each stage, and the overall thinking of the hydrological emergency monitoring in the barrier lake was clarified, which provided strong support and guidance for the scientific and orderly development of the hydrological emergency monitoring in the future. It has a strong practical significance.

In addition, this paper gives a brief introduction to the hydrological emergency monitoring of the Baige Village on November 3, 2018, which was carried out on the monitoring system based on PDCA mode. And it confirming the practicability of the hydrological emergency monitoring system.

Acknowledgments
This work is supported by National Key R & D Program of China (2017YFC0405701), National Key R & D Program of China (2018YFC1508002).

References
[1] Schroeder P 1992 Using the PDCA cycle Nurs. Qual. Connect 2 1-8
[2] Frakes W B and Fox C J 1996 Quality improvement using a software reuse failure modes model IEEE Transactions on Software Engineering 22 274-9
[3] Ou Y J and Du Y N 2014 Practice of GB/T19001-2008 in hydrological quality management J. Econ. Water Resour. 2014 54-8
[4] Wang J 2011 Construction of hydrological emergency management system Yangtze River 2011(s1) 1-6
[5] Hydrology Bureau of Yangtze River Water Resources Commission 2018 Quality Management System Procedure Document (Wuhan: Hydrology Bureau of Yangtze River Water Resources Commission)
[6] Wang J 2011 Hydrological Emergency Practical Technology 1st ed. (Beijing: China Water Resources and Hydropower Press)
[7] Cheng H Y 2019 Hydrology emergency monitoring and forecast on Baige Barrier Lake of Jinsha River on November 3 Yangtze River 50 23-7
[8] Chen M 2019 Experiences and inspirations of reservoir regulation in urgent treatment of Baige barrier lake on Jinsha River Yangtze River 50 10-4
[9] Wang M, Lu J Y, Yao S M et al 2019 Study on dam break flood forecast error and improvement for Baige barrier lake on Jinsha River Yangtze River 50 34-9
[10] Huang Y, Ma Q, Wu J Y and Zhang L M 2019 Dammed lake information acquisition and dam breaking flood forecasting Yangtze River 50 12-9
[11] Cai Y J, Luan Y S, Yang Q G et al 2019 Study on structural morphology and dam break characteristics of Baige barrier dam on Jinsha River Yangtze River 50 15-22