Safety information perception, forewarning & forecast of Chinese small reservoir based on risk classification

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Abstract. In order to effectively manage more than 90,000 small reservoirs in China, aiming at their characteristics, based on engineering classification, this article established a system of safety information perception, early warning and prediction based on safety risk classification in terms of the safety risk factors such as occurrence environment, structural materials, supervision and management, and accident loss. It solved the standardization and pertinence problems of small reservoir risk management in China.

1. Introduction
According to China Water Statistical Yearbook 2018 [1], by the end of 2017, China has a total of 98,795 reservoirs, including 94,129 small reservoirs. Although small reservoirs have played a key role in irrigation, water supply and improvement of the ecological environment, most of these small reservoirs were built in the 1960s to 1970s, not only do they have uncertain factors such as inadequate surveys, irregular designs and difficulty to guarantee construction quality, but also problems such as long operating time, large state differences, incomplete data, irregular operation and maintenance and insufficient investment of resources, at the same time, small reservoirs have the characteristics of small storage capacity, rapid water level change, discrete operating environment and high probability of accidents. According to statistics, the average risk ratio of small reservoirs in China is as high as 53.3%. Since 1954, there have been more than 3,500 dam-breaks in China, of which small reservoirs account for 97%. Analysis shows that many of the above-mentioned reservoir accidents were caused by inadequate management, and the specific manifestations were that they did not understand the safety status of the project and did not take corresponding measures in time. Therefore, it is necessary to establish a safety management system of small reservoirs based on risk analysis to improve the level of refinement of small reservoir management.

This article establishes a feasible system of small reservoirs management based on risk analysis by establishing a classification and standardization system, and coordinates through various means.

2. Safety information perception
Perceived content and frequency should be determined according to level, safety and sensitivity to change of the risk. Perceptual methods include perambulation inspection (including remote sensing),
instrument monitoring and detection. At the same time, related information classification and multi-terminal statistics, retrieval and query system should be established.

For regional weather, climate, dam overtopping water level and other occurrence environmental risk factors, the perceived cost is low, so priority should be given to implementation. When it is difficult to fully perceive the risk of environmental factors in field investigation, the safety risk status can be analyzed through supervision status and engineering status. For the shared management facilities, personnel and institutions, considering the cost control, priority should be given to the way of reservoir group.

2.1. Perceived content and methods
The content of safety information perception includes four aspects: major hazard source of occurrence environment, amount of engineering response and state sensitive response, targeted indexes of supervision system and important factors of consequence assessment. In order to reduce investment, information perception should use public data or information as much as possible, such as weather information, groundwater information and other research results. Different from scientific research, perception object, scope and accuracy only need to consider the needs of engineering safety analysis, the region-wide perception is unnecessary.

(1) Perambulation inspection. Perambulation inspection is a process of collecting and analyzing all kinds of safety information including the occurrence environment, the state and response of structural material, supervision and management (such as the working state of personnel in key positions, the working state of monitoring instruments and equipment, the classified management and preservation state of monitoring data) and the loss of accident through professionals or machines. Manual perambulation inspection mainly uses the knowledge and feelings of professional personnel. Machine perambulation inspection includes remote sensing, acoustic, radar detection, underwater multi beam and other machines, mainly using their advantages of fast, large-scale and ability to achieve harsh environment.

(2) Instrument monitoring and detection. Instrument monitoring and detection includes conventional instrument monitoring, irregular detection and video image monitoring, in which video image is used to monitor the input, response, human operation and intrusion of key parts of the project (including key mechanical and electrical facilities and water retaining metal structure) by using visible light, infrared light, gleam or remote sensing. The parts that should be set up for video monitoring also include: the spillway that undertakes the task of discharge, the parts that are easy to failure, such as the flow scour area, the electromechanical interface that supporting rotation and hoisting/closing of the gate; the intake of the discharge structure that the velocity in it may be affected by the upstream deposited floating objects when the flood season comes; the discharge area that has potential safety hazards.

1) Hydrometeorology and hydrogeology. Hydrometeorology and hydrogeology are the main fast-changing factors of the occurrence environment, which are related to geographical location, topography, landform and other factors, and have obvious influence on the project safety risks, such as the dam front water level, rainfall and reservoir inflow, as well as the temperature of the arch dam and the wind load on the tall and large thin-walled water retaining structures. Whether such factors as mountain torrents, landslides, earthquakes and debris flows need to be perceived depends on whether such risks constitute the main risks of engineering safety.

2) Structural material status and response. The structural state includes not only the material parameters, porosity, compactness, plastic zone distribution and contact state of the supporting structures, but also the deformation, the opening of the rusted gate, position, load, current / voltage, vibration, noise, oil level, oil pressure, oil temperature of the gates and metal electromechanical structures that taking on the important tasks of water retention and flood discharge. Structural responses generally include deformation and seepage, and stress and strain on high-risk areas are also the content to be perceived. The state mainly includes the mechanics, thermodynamics, seepage mechanics parameters and overall coordination of material and structure.
The contact seepage damage of the soil and concrete binding site is a common cause of accidents in small reservoirs. Between the bottom plate of flood discharge structure, buried pipes under the dam and the main structure, the monitoring item of uplift pressure or contact seepage pressure must be set up. When monitoring finds a problem, it should be determined whether it needs to be tested according to the risk level that the problem may cause to provide a basis for analyzing the cause of the problem or judging the level of hidden danger. When problems are found during testing, in addition to taking engineering measures based on the severity of the problem, monitoring items and points should be set up for long-term monitoring if necessary.

3) Supervision and management. The supervision and management includes 8 aspects: the integrity and clarity of responsibility division, the rationality of safety management process, the coverage of personnel, equipment, facilities and engineering supervision, the normalization and closed-loop degree of event operation and disposal, the pertinence and effectiveness of emergency measures, the engineering familiarity and professional level of technical and managers, the accuracy and timeliness of data analysis, and the assurance rate of fund implementation.

4) Accident loss. Communication with relevant units, UAV surveys, public information or web crawlers and other legal methods should be used to perceive the size of the affected area by the reservoir failure risk, the type of loss, and the level of the total loss, and the population, industry, agriculture, economy, ecological and environmental data of the affected area should be figured out and analyzed in time to provide a basis for reservoir safety risk assessment.

2.2. Monitoring item settings.
The setting of monitoring items and the arrangement of monitoring points should be determined according to the risk level of the project, the characteristics of risk sources and the sensitivity of the project response to the evolution of safety risk. The monitoring method needs to select the method with small risk according to the application risk of different monitoring methods in specific projects. In general, see Table 1 for the setting of monitoring items according to the total risk level of the reservoir, and the specific setting of the project should be determined according to the impact of this factor on the total risk of the reservoir.

| Monitoring item | Risk level | High risk | Medium risk | Low risk | Slight risk |
|-----------------|------------|-----------|-------------|----------|------------|
| Perambulation inspection | ⊕$^a$ | ⊙ | ⊙ | ⊙ | ⊙ |
| Hydrometeorology and hydrogeology | ⊙ | ⊙ | ⊙$^b$ | ⊙$^c$ |
| Engineering structure (including metal and electromechanical) | ⊙ | ⊙ | ⊙ | ⊙ |
| Supervision and management | ⊙ | ⊙ | ⊙ | ⊙ |

$^a$ ⊕ indicates that it must be set.

$^b$ ⊙ indicates that it can be simplified.

$^c$ ⊙ indicates that it is unnecessary.

$^d$ For the "must be set up" project, it also needs to be determined according to the risk category of the reservoir.

The monitoring item of high-risk reservoirs should adopt automatic monitoring, and the patrol inspection should be mainly completed by professional technical personnel. If necessary, UAV, underwater multi beam and other patrol inspection systems can be equipped to patrol the parts inconvenient for personnel to reach, and an information management system can be established [2].
The hydrometeorology and hydrogeology of medium (low) risk reservoirs should adopt automatic monitoring, and engineering structure monitoring can simplify the setup. Non-dangerous period inspections can be replaced by UAV and other methods, but in flood or dangerous periods, professional inspections should be conducted.

Slight risk reservoirs only need to use UAV or personnel inspections to obtain reservoir safety information.

2.3. Perception frequency
Different information perception frequencies are adopted according to the overall safety risk level of the reservoir, as shown in Table 2. In specific operations, it should be refined according to the impact of sub-items on the overall safety risk.

3. Early warning and forecast

3.1. Indexes and thresholds of early warning
Perambulation inspection: Coverage (A1), coverage frequency (A2), lag time of abnormal reporting of inspections (A3), ability to discriminate the severity of hidden dangers (A4), and ability to discover the threats of hidden dangers in time (A5).

| Monitoring item                           | Risk level     | High risk | Medium risk | Low risk | Slight risk |
|------------------------------------------|----------------|-----------|-------------|----------|-------------|
| Perambulation inspection                 | Daily: once every 10 days high-risk period: once a day | Daily: twice a month high-risk period: once a week | Daily: once a month high-risk period: once every 10 days | Daily: once a quarter high-risk period: once or twice a month 
| Occurrence environment (hydrometeorology and hydrogeology) | Daily: once a day high-risk period: once an hour | Daily: once a week high-risk period: once a day | Daily: once every 10 days high-risk period: once a week | Daily: once a month high-risk period: once every 10 days |
| Structural material (state and response) | Daily: once a week high-risk period: once a day | Daily: once a month high-risk period: once a day | Daily: once a quarter high-risk period: once every 10 days | / |
| Supervision and management               | Twice a year | Once a year | Once 2 years | Once 3 years |

Remark: This is the minimum requirement, of which the frequency of geological risk is determined according to whether it is an extreme situation. Due to video images use the methods of snapshot or monitoring continuously, there is no frequency problem.

Hydrometeorology: the water level in front of the dam (B1), with each control water level as the early warning threshold; the rainfall (B2) includes the maximum rainfall, accumulated rainfall, maximum duration rainfall and other indexes, it can be determined according to B1 in combination with the hydrological model, or according to the requirements of scouring and landslide; the threshold of the reservoir inflow (B3) which has a significant impact on the reservoir water level, mainly considers the requirements of landslide and B1. Whether to set early warning indexes of typhoon, freezing and spring flood is related to the occurrence environment of the specific location of the reservoir.

Structural material: Displacement and deformation (C1), seepage flow (C2), contact seepage pressure (C3), potential slope drop (C4), and interface pressure (C5) of typical or likely accident sites. For high-risk reservoirs, when detection methods are used to diagnose structural and material state parameters,
early warning indexes and thresholds such as compactness, porosity, corrosion rate, cover thickness, and elastic modulus can also be established.

The above thresholds are determined based on the theory of stability and strength. Figure 1 shows the process of determining dynamic thresholds based on data-driven for high-risk reservoir pivotal project.

![Figure 1. Determination process of early warning threshold of structural material based on measured data](image)

Video image: landslides or cracks (D1), electromechanical equipment (D2), gates and metal structures (D3). Video image early warning can use image and video series data to recognize and alarm abnormal states through methods such as (personnel, animals, motor vehicles and ships) intrusion detection and pattern recognition.

Metal electromechanical: through the data of factors in Table 3, the status of equipment and facilities (E1), electromechanical emergency standby (E2), hidden danger analysis and fault alarm (E3), effectiveness of lightning protection and anti-interference measures (E4) are obtained. According to the normal working range of shaft displacement, limit and voltage stability, the thresholds can be determined by setting certain safety factors.

### Table 3. Classification of early warning indexes

| Risk level       | Reservoir types | Perambulation inspection | Hydro-meteorology | Structural material | Video image | Metal and electromechanical | Supervision and management |
|------------------|-----------------|--------------------------|-------------------|---------------------|-------------|-----------------------------|----------------------------|
| High risk        | A1~A5           | B1~B3                    | C1~C5             | D1~D3               | E1~E4       | F1~F5                       |                            |
| Medium risk      | A1~A5           | B1~B3                    | C1~C2             | /                   | E1          | F1~F3                       |                            |
| Low risk         | A1~A3           | B1~B2                    | /                 | /                   | /           | F1~F2                       |                            |
| Slight risk      | A1~A5           | B1                       | /                 | /                   | /           | F1                          |                            |

**Remark:** The selection of specific indexes should be determined according to the impact of indexes on the safety risk of the reservoir and its sensitivity [3].

Supervision and management: organization and responsibility (F1), personnel and equipment configuration and working state (F2), emergency capacity and process standardization (F3), reaction rate and drill (F4), and fund guarantee (F5). Supervision and management can adopt marking method, the Analytic Hierarchy Process (AHP) and other methods, through the comprehensive evaluation of the pertinence, timeliness, reliability and anti-interference of the four aspects of organization, safety, operation and funds, and on this basis, combined with the risk level and sensitivity, determine the overall threshold and sub threshold.

In a word, the actual engineering bearing capacity and acceptable risk must be considered to determine the early warning threshold. The specific determination methods include consulting...
regulations and specifications, engineering analogy and reference, expert knowledge and experience, data statistical analysis and numerical simulation.

3.2. Prediction model and method

The prediction model and method should select simple to complex model and method according to the corresponding risk from low to high. The specific prediction factors (dependent variables) and the influence degree of the factors on the reservoir safety risk should be determined in combination with section 3.3.1.

3.2.1. Occurrence environment. The calculation of design flood mainly includes instantaneous unit hydrograph method, reasoning formula method, regional empirical formula method and historical flood investigation and analysis method [4]. The applicability of the specific method is related to the region where the reservoir is located [5] and the type of reservoir (mountain or plain reservoir) [6].

The State Flood Control and Drought Relief Headquarters, together with China Institute of Water Resources and Hydropower Research, has given the specific steps of calculating critical rainfall and risk grade division for the analysis and evaluation of mountain torrent disasters in basins below 200km² [7], which can be used to determine early warning indexes for rainstorm.

Aiming at the high-risk occurrence environment, with the help of forecast data from American Global Forecasting System (GFS), China Meteorological Observatory and Japan Meteorological Agency, using the assimilation with the measured data and downscaling analysis will significantly improve the foreseeability of the risk.

3.2.2. Structural material. For reservoirs that structural material is their high-risk factor, the prediction model can be established according to the following methods, and the prediction and early warning can be realized through the optimal prediction model and confidence interval [8]:

1) Feature analysis of safety. Through the analysis of measured data, field investigation, combined with relevant calculation, the characteristics of each building are analyzed to lay the foundation for the following selection of a reasonable way for prediction and early warning.

2) Selection of numerical model. For the project without monitoring data, the material and structure parameters are drafted by large data analysis, and the prediction and early warning are realized by numerical model.

3) Feature analysis of measured value sequence. When there are reliable measured data or when the measured data are accumulated to a certain extent, the methods of stepwise regression, random forests, relevant vector machine and neural network can be used to establish the prediction and early warning model.

For different dam types, different monitoring items and measuring point information, according to the correlation analysis of time and space and mechanical mechanism analysis, the corresponding model and model factors are selected, and the optimal monitoring model is determined through the test. The optimal model test indexes include forecast time test, forecast accuracy test and forecast stability test.

The dynamic monitoring indexes of single measuring point can be obtained by inputting the corresponding measured factors into the model and adding the model errors. The forecast value is calculated according to the early warning model, and compared it with the measured value, when the difference value is oversize, an early warning is generated.

3.2.3. Supervision and management. We can make full use of intelligent app, video information collection, test and assessment, and information management system, and establish expert committee and supervision committee to assess risk of flood control, management, structure, seepage, personnel, operation, equipment and facilities. For the entrusted reservoirs, the implementation of responsibilities should be extended for evaluation, and for the low-risk reservoirs, the evaluation items can be reduced.
4. Conclusions
Small reservoirs in China are characterized by large number, high-risk and low pertinence of management mode, etc. In order to do well in the safety management of small reservoirs, it is necessary to realize grade division according to the safety risk of reservoirs and implement targeted dynamic management. In this paper, a set of small reservoir management model is proposed by combining single reservoir risk with regional characteristics, standardization and dynamic management through the specific measures, for example, small reservoir safety risk assessment method and engineering classification standard, risk perception system design, multi-source information fusion, etc.

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