Identification of the inter-basin water diversion project-effected local flood risk factor by using the fishbone-diagram method

Ren Minglei\textsuperscript{1}\textsuperscript{*}, Ding Liuqian\textsuperscript{1}, Wang Gang\textsuperscript{1}, Kan Guangyuan\textsuperscript{1}, Fu Xiaodi\textsuperscript{1}, Zhu YaFeng\textsuperscript{2}, Zhao Liping\textsuperscript{1}

\textsuperscript{1}State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin; China Institute of Water Resources and Hydropower Research, Beijing, 10038, China
\textsuperscript{2}Water conservancy and Hydropower Engineering, Tibet Academy of agriculture and animal husbandry, Nyingchi, Tibet, 540400, China
\textsuperscript{*}Corresponding author’s e-mail: renml@iwhr.com

Abstract: When carrying out the inter-basin water diversion project, we must face problems such as the long river routing distance and complex hydro-meteorological conditions along the main channel. Under the condition of the unchangeable standard of the designed rainstorm, the changes of the underlying surface could inflect the designed flood. As a result, the drainage channel is not as consistent as the designed condition, therefore the flood discharge condition in the upper and lower sub-reaches changes, and the actual flow capacity of the hydraulic structure is reduced compared with the designed conditions. The above-mentioned situations could cause risk event of the rising of designed flood level in the left bank and will cause local flood risk, and also cause corresponding economic losses and social impacts. In this study, for the first time, the fishbone-diagram method is applied to identify the local flood risk factors of the inter-basin water diversion project. By using this method, the changes of characteristic values of watershed above cross section, villages, factories or other buildings at the outlet location of the drainage structures etc. are identified as the local flood risk factors, and there are mainly eight types of local flood risk factors which can be taken into consideration when selecting engineering and non-engineering measures to reduce or eliminate the risk factors.

PACS: J0101

1. Introduction

1.1. Brief introduction
After the construction of the inter-basin water diversion project, some small rivers are merged and diverted and the natural flood discharge channels on the left bank of the water diversion project have been cut off or changed. Therefore, the conditions of the runoff generation and flow concentration have been changed, which switches the original overland flow into centralized outflows and may lead to river closure and water level rising\cite{1}. In the preliminary design stage of the water diversion projects, the local flood impact assessment has been carried out, and corresponding measures have been taken to treat the flood impact of local area and water diversion building itself. However, after the construction of water diversion projects, the social and economic development of the surrounding areas of the project is relatively fast. Local socio-economic conditions and the designed conditions of crossing rivers have...
taken some changes, especially the underlying surface in the project region has changed significantly. Therefore, under the primary designed standard of rainstorm, considering the change of underlying surface conditions in the flow concentration region, the condition of the drainage channel in the right bank dissatisfies the designed demand, the flood discharge condition in the upper and lower reaches changes, and the actual flow capacity of the discharge structure is reduced compared with the designed conditions, all the above situations can cause risk event of the rising of designed flood level in the left bank and will cause local flood risk, and also cause corresponding economic losses and social impacts. Therefore, it is necessary to identify the risk factors that cause local flood risk, so as to take corresponding engineering and non-engineering measures to reduce or eliminate the risk factors.

1.2. Overview of Risk Factor Identification of Local Flood Impact
The risk factors of local flood risk caused by the main canal variations mainly include three types.

(1) Change of underlying surface conditions in the basin:
These type of risk factors are mainly becoming remarkable with the increase of catchment area, the decrease of confluence path, the increase of river gradient, and the increase of the proportion of construction land area (including urban & rural residential land and industrial & mining enterprises land) in the catchment.

(2) Actual flow capacity of the discharge hydraulic structure and the discharge channel of upstream and downstream is less than the previously designed condition.
Such risk factors mainly include the narrow flood discharge section of upstream, the occupation of rural or urban constructions in the river, the project waste slag in the river channel; the drainage conditions of the right bank of the main channel are inconsistent with the designed conditions, the drainage is impeded, the exit of the left bank drainage structure directly facing villages and industrial and mining enterprise; drainage buildings themselves are blocked or easily clogging, there are piles of soil, project waste slag or domestic garbage near the entrance, the building itself has sediment accumulation and so on.

(3) Regional socio-economic development of the inter-basin water diversion project:
This type of risk factor is mainly reflected in the increase of the affected population and assets caused by the social and economic development.

2. Methodology

2.1. Description of the fishbone diagram method
The Fishbone Diagram Method was proposed by Japanese Management Master Shikawa[2]. It is a method to find the "root cause"[3-4] of the problem. It can also be called "Ishikawa" or "Causality Diagram[5]".

The characteristics of the problem are always influenced by some factors. These factors can be found by using methods such as brainstorming[6] combined with the characteristic values, and are sorted out in a clear and ordered way according to their interrelation. After that, the important factors are marked out in a graph, which is called “the characteristic-factor diagram”. Because the shape of the diagram looks like the fishbone, it is therefore called “fishbone diagram[7]” (as shown in Figure 1), which is an analysis method to conclude the essence through phenomena[8].
2.2. Three Types of Fishbone Diagram

The fishbone diagram can be roughly divided into three types[9], the first one is the type of sorting problem fishbone diagram (There is no causal relationship between the factors and characteristic values, but the structural composition relationship exists); the second one is the type of causative fishbone diagram (fish head is on the right and the characteristic values are usually written as "why..."); the third one is the type of countermeasure fishbone diagram (head on the left and the characteristic values are usually written as "how to improve...").

2.3. Procedures for Generating Fishbone Diagram

There are three steps to generate a fishbone diagrams: analyzing the cause/structure of the problem, analyzing key points and drawing the fishbone diagram[10]. The specific procedures are as follows:

Step One, analyzing the cause/structure of the problem:
① Aiming at the key point of the problem, select the hierarchical method (such as people, machines, materials, methods, and environment, etc.);
② Identify all the possible causes (impact factors) by brainstorming for each level and category;
③ Categorize and sort out the identified elements and clarify their subordinate relationship;
④ Analyze and select important factors;
⑤ Check the description method of each element to ensure that the grammar is concise and the meaning is clear.

Step two, analyzing key points:
① When determining the major factors (big bone), the management problems generally start from the “object, event, time, environment, and resource” levels, which should be decided according to specific circumstances;
② The major factors must be described in neutral terms (not illustrated good or bad), and the middle and small factors must be judged by value (e. g. Undesirable);
③ When carrying out the brainstorming, we should try to find out not only the content that we can fully control or implement but also all the possible causes sufficiently. For human reasons, it is advisable to analyze from the perspective of action rather than thought and attitude;
④ There is a direct cause-problem relationship between the middle factor and the characteristic values, the small factor and the middle factors. The small factor should be clearly analyzed until the countermeasures can be taken directly;
⑤ If a reason can be attributed to two or more factors at the same time, then refer to the one with the strongest correlation. (If necessary, find out the most relevant cause by comparing the relative conditions.);
⑥ When selecting important reasons, do not exceed 7 items, and the most important cause should be identified.

Step three, drawing the fishbone diagrams:
① Fill in the fish head and draw the main bones;
Draw a big bone and fill in the major factor; ③Draw the middle and small bones, and then fill in the medium and small factors; ④Identify important factors with special symbols.

When drawing the diagrams, the angle between the big bone and the main bone should be set to 60 degree[11], and the middle bone should be parallel to the main bone.

2.4. Solving Problems by using the Fishbone Diagram
The specific steps for solving the problem by fishbone diagram are as follows: First, find out the problems need to be solved; Second, write the questions on the head of the fish bones; Third, convene colleagues to discuss possible causes of problems and find out as many problems as possible; Fourth, group the same questions and mark them on the fish bones; Fifth, Seek opinions on different issues and summarize the correct reasons; Sixth, take any one question and study why such a problem occurs; Seventh, what is the answer to the question? This goes at least five levels (five questions in a row); Eighth, when going deep into the fifth level and think that you can’t continue, list the reasons for these problems, and then list at least 20 solutions

3. Results and discussion
The identification of local flood risk factors caused by inter-basin water transfer project is based on the above-mentioned fishbone-diagram method, which classifies and identifies the local area flood control risk in terms of the type of cross-structure of the main canal. According to the catchment area of the main canal and the cross-river, the structures of the inter-basin water transfer project can be divided into two categories: one type is the left bank drainage structure, which is the cross structure of the channel with the catchment area less than 20km$^2$ through the main canal, including the left drainage inverted siphon, the left drainage culvert and the left drainage aqueduct. The other one is the large-scale river-canal crossing structure with the catchment area of the cross-section river larger than 20 km$^2$, including river inverted siphon, flood discharge culvert, flood discharge aqueduct, channel inverted siphon, closed conduit, beam-type aqueduct, and culvert aqueduct etc. The structure of various water diversion projects is utilized for the control of the discharge of flood water, ensuring the flood control safety and normal operation of the main canals.

The change of underlying surface conditions, the reduction of actual flow capacity of structure itself and their upstream and downstream sub reaches compared with their original designed conditions, and the socio-economic development of the inter-basin water diversion project area will increase the risk of local flood risk, the above-mentioned three factors are main reasons in the fishbone-diagram. Among them, according to the different structural types and design conditions, small and medium factors are marked in the fishbone-diagram.

3.1. Left Drainage Structure
(1) Left drainage inverted siphon and Left drainage culvert
Among the risk factors affecting local flood risk caused by left inverted siphon and left drainage culvert, the change of underlying surface conditions in the studied watershed is taken into account as a major factor, the change of watershed characteristic values and increased proportion of construction land area are taken into account as the medium factors, the increase of flow concentration area, river channel bed slope and the shortening of flow concentration path are take into account as small factors.

The actual flow capacity of upstream and downstream rivers of crossing structure is less than the original designed conditions is also taken as major factor, the narrow flood discharge section of upstream, impeded drainage on the right bank and building self-clogging are taken into account as the medium factors. The waste dregs and piles of soil that occupied and blocked the river, construction and reclamation that crowded rivers, water blocking by new roads and houses are taken into account as the small factors.

Meanwhile, in terms of the clogging of structure itself, waste dregs, piles of soil near entrance, landslides and debris flows that are prone to occur near mountains, more garbage and floating objects near entrance, and sediment and garbage deposit in buildings are taken as the small factors.
The local flood risk factors for the left drainage inverted siphon and left drainage culvert are shown in the following figure:

![Fishbone Diagram](image)

Figure 2. The identification result of local flood risk factors of left drainage inverted siphon and left drainage culvert by fishbone diagram.

(2) Left drainage aqueduct

The local flood risk factors for the impact of the left drainage aqueduct are similar to those of the left drainage inverted siphon and left drainage culvert, except in that the building self-clogging only considering the waste dregs and piles of soil near entrance, landslides and debris flows that are prone to occur near mountains, more garbage and floating objects near entrance.

The flood risk factors for the left drainage aqueduct are shown in the following figure:

![Fishbone Diagram](image)

Figure 3. The identification result of local flood risk factors of left drainage aqueduct by fishbone diagram.
3.2. Large-scale river-canal crossing buildings

(1) River inverted siphon and flood discharge culvert
The building structural type of river inverted siphon and flood discharge culvert is the same as the left drainage inverted siphon and left drainage culvert. Thus, local flood risk factors for the impact of the left drainage aqueduct are similar to those of the left drainage inverted siphon and left drainage culvert.

(2) Flood discharge aqueduct
The building structural type of flood discharge aqueduct is the same as the left drainage aqueduct. Thus, local flood risk factors for the impact of flood discharge aqueduct are similar to those of the left drainage aqueduct.

(3) Channel inverted siphon, closed conduit, beam-type aqueduct, and culvert aqueduct
The building structural type doesn’t change the flow form of natural river, therefore, the construction of this building type will not increase the local flood risk.

4. Conclusion
After the completion of the design and construction of the inter-basin water diversion project, the local risk factors for flood control in the flood operation phase are identified for the first time. The local flood risk in flood operation stage mainly comes from the factors such as the changes of the underlying surface conditions, the changes of upstream and downstream flood discharging conditions, and the differences between factual location of structure exit and designed conditions. In this study, for the first time, the fishbone-diagram method is applied to identify the local flood risk factors of inter-basin water diversion project. The main local flood risk factors are identified as follows:

1. The changes of characteristic values of watershed above cross section (For instance, the catchment area increases, the river length decreases compared with the designed value, and the construction land area increases in the catchment.).
2. There are villages or factories at the outlet location of the drainage structures, and there is no drainage outlet on the right bank, or the drainage channel is not smooth due to the occupation of flood channel in some villages.
3. Human activities occupied and blocked flood discharge channel at the outlet of crossing buildings and reduced flood discharge capacity.
4. Entrancement of the canal-crossing buildings is easily blocked (domestic waste, firewood floats, and landslides & debris flows, etc.).
5. Self-silting of canal-crossing buildings.
6. Landslide and debris flow may occur at the entrance of cross-buildings.
7. The upstream and downstream flood discharge section of the river-canal crossing buildings are narrow and the flood discharge capacity is reduced.
8. Socio-economic factors (population and asset distribution) in flood-affected areas.

Acknowledgments
This research was funded by the National Key Research & Development Program of China (2018YFC1508003); IWHR Research & Development Support Program (JZ0145B022017); National Natural Science Foundation of China (51809281).

References
[1] IWHR. Assessment Report on the Impact of Main Channel on Local Flood Control in Engineering Area. 2018.
[2] Chuchu Zeng, Yu Qian, Yongsheng Liu. Domino effect index for chemical plants based on fishbone analysis. 4th Annual 2016 International Conference on Material Science and Environmental Engineering, December 16-18, 2016, Chengdu.
[3] Shinde Dnyandeo Dattatraya, Ahirrao Shwetambari, Prasad Ramjee. Fishbone Diagram: Application to Identify the Root Causes of Student-Staff Problems in Technical Education. Wireless Personal Communications, 2018, 100, (653-664).

[4] Abhishek Jayswal, Xiang Li, Anand Zanwar, Helen H Lou, Yinlun Huang. A sustainability root cause analysis methodology and its application. Computers & Chemical Engineering, 2011, 35(12), 2786–2798.

[5] Xingling Li. Construction of Key Performance Evaluation Index System for Scientific Research Funds Management in Public Hospitals-Based on Fishbone Diagram Analysis, China Collective Economy, 2015, 28, 54-55.

[6] Jinying Wang. The Optimization Strategy of Literature Acquisition in University Library Based on Fishbone Diagram. Library Theory and Practice, 2018, 36-38.

[7] Theodoros H. Varzakas. Application of ISO22000, failure mode, and effect analysis (FMEA) cause and effect diagrams and pareto in conjunction with HACCP and risk assessment for processing of pastry products. Critical Reviews in Food Science and Nutrition, 2011, 15(8), 762–782.

[8] Chunjie Lin, Jianyun Liu, Yong Li. Application of "Fishbone Diagram" Analysis Method in Comprehensive Assessment of Professional and Technical Personnel, Chinese Market, 2006, 10, 94-95.

[9] Yuhui Zhao, Bei Qiao, Jun Xu, Yi He. Main Causes of Urban Gas Operation Risk Based on Fishbone Diagram Analysis, Petroleum and Natural Gas Chemical Industry, 2015, 4 (44) 119-124.

[10] Tongyuan Luo, Chao Wu, Lixiang Duan. Fishbone diagram and risk matrix analysis method and its application in safety assessment of natural gas spherical tank. Journal of Cleaner Production, 2017, 1-12.

[11] Yali Wang, Pengfei Wang. Application of task-driven method based on Fishbone Diagram in NC Fault Diagnosis and Maintenance Course, Industrial& Science Tribune, 2019, (18) 8,168-169.