River Classification in Line with China’s New Requirements of Water Resources Management

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Abstract. River classification facilitates efficient management of rivers. Due to the complexity and variety of river morphology in China, classification of Chinese rivers has never developed maturely. The current river classification system used in China becomes even less qualified for new management requirements aiming to environmental protection and restoration as a response to the worsening environmental conditions represented by the deterioration of river functions and the scarcity of water resources, which have been greatly exacerbated by the impressive growth of Chinese economy. Moreover, some well-known classification methods discussed internationally cannot adapt to Chinese specific conditions appropriately, although they have been developed beyond the Chinese ones. This thus highlights the necessity to establish an updated classification system that is adequate for the emerging river management requirements of China. In these circumstances, this paper summarizes the currently representative river classification methods and proposes a pathway to improve river classification methodology for China.

1. Introduction

River system is an outcome of the Earth’s evolution. Rivers flow by gravity on the surface or underground regularly or intermittently. Rivers play an important role in the Earth’s water cycle and a major freshwater resource. They are not only a main type of habitats for aquatic organisms, but also a critical foundation of the development of human society and economy, being considered as the birthplace of human civilization[1]. Rivers provide water resources for human life and production, meanwhile transport, dilute and degrade pollutants discharged. Another important component of terrestrial water resources, lake water, also depends on water supply from rivers. It denotes that river health is closely related to the development and prosperity of society. However, due to the large population and rapid economic development in China, many rivers have been irrationally and unscientifically overexploited and utilized. River health has been jeopardized coinciding with deteriorated ecological function and intensified water pollution. Unfortunately, river managers have not developed a perfect approach to fully responding to these issues. It is not uncommon to observe frequent violation of water policies, elevated flood risk, mismatches between water resources supply and demand in upper and lower reaches, left and right banks and main and tributaries of the rivers, and increased disputes over water rights.

In recent years, China has started to emphasize environmental protection, advocated sustainable development and harmonious coexistence between humans and nature, proposed ecological civilization, and strengthened water resources protection through rational development and utilization. River classification is an important means of understanding rivers. It is the basis of conducting river
health assessment, the foundation of river pollution control and ecological restoration, and the premise and assurance of scientific river management and comprehensive development and utilization of river basins[2]. Based on the above requirements, this paper discusses typical river classification methods. The discussion is made through the lens of the current Chinese river situations, associated with the requirements of integrated river basin management. It puts forward the ideas to improve river classification methods suitable for China, which can provide reference for the follow-up research.

2. Importance of river classification to China
In recent years, China has paid more attention to the protection and restoration of river environment, the harmonious coexistence of humans and water, and the sustainable development of river basins. Promulgation and implementation of water function zoning is a new means of river management, which is helpful to the improvement of river water quality and the protection of ecological environment[3]. In the report of the Eighteenth National Congress, the Central Committee pointed out that the construction of ecological civilization should be placed at the same important position as the construction of political, economic, cultural and social civilizations. In 2013, the Ministry of Water Resources proposed to accelerate the construction of water ecological civilization. Water ecological civilization advocated the concept of human-water harmony and realizes the sustainable utilization of water resources, which is embodied in strengthening the protection of water sources and the control of total water use, promoting water recycling, and building a water-saving society. Nowadays, the idea of environmental water demand and the study of ecological restoration have also been emphasized. The environmental water demand is to protect the long-term stability and balance of ecosystems, with to the greatest extent meeting the water demand of economy and society, and realizing the rational allocation and sustainable utilization of water resources[4]. River water ecological restoration aims to restore the damaged river ecosystem structures and functions, making it sustainable to provide ecological services, and realizing the harmonious coexistence of people and rivers[5].

Based on China’s new viewpoints and requirements for river water resources management in the new era, classifying rivers scientifically becomes very important. Classification is the process of grouping or categorizing a series of complex objects according to similarity or relationship using established criteria[2]. River classification is the process of grouping rivers according to their features. It is the first step to understand the complexity of rivers and the basis of scientific and effective management of rivers. Its significance lies in: (1) predicting the behaviour of rivers according to the morphology of rivers; (2) understanding the relationship between important parameters of rivers according to the monitoring data of typical river sections; (3) extrapolating the known river data according to the mechanisms to estimate similar river conditions; and (4) providing a unified and consistent information platform for the exchange of professionals in different disciplines. The ultimate goal of river classification is to understand rivers scientifically and to manage them efficiently by dividing rivers into sections with similar structures and functions[3,6]. Therefore, river classification is the first step to realize rational development, utilization and protection of rivers. At this stage, it should be in line with the requirements of ecological protection and sustainable development.

3. Typical river classification methods
The earliest and most well-known classification of rivers was proposed by Davis in 1899. He divided the river channels into three stages according to the geomorphological evolution: youth stage, maturity stage and old age stage, which were equivalent to the highland, lowland and coastal areas in space [7-8]. Since then, during the research and development for more than a century, scholars have proposed dozens of classification methods, based on geomorphology, river bed sediment, characteristic species, ecology, landscape, protection and utilization, etc. Among them, classification methods based on the theory of geomorphology and river dynamics are the most systematic and well-developed[2-3]. Since river morphology and sediment process are inseparable, many scholars consider these two factors together to classify rivers. This paper considers the classification methods based on geomorphology and sediment characteristics into one category. This category can be subdivided into many different
types. The representative methods are summarized in Table 1. The methods have developed in a trend from simple to complex, incorporating multiple factors, levels, and disciplines, and become more quantitative[3]. Due to the limitation of space in this paper, it is impossible to enumerate each classification method. Here, only a few representative methods are outlined.

Table 1. Typical river classification methods based on geomorphological and sediment characteristics

| Classification basis | Indicator | Contributor | Classification outcome | Notes |
|----------------------|-----------|-------------|------------------------|-------|
| River network link    | Stream order | Horton[9]; Strahler[12]; Schumm[11] | First-, second-, third orders, etc. |       |
| Sediment              | Sediment transfer, morphology | Montgomery[12] | Erosion, transport, and deposition zones |       |
| Sediment              | Sediment transfer, morphology | Schumm[15] | Colluvial, confined, and floodplain channels |       |
| Sediment              | Sediment transfer, morphology | Church[16] | Suspended, mixed, and bed loads | For alluvial rivers |
| Sediment              | Sediment transfer, morphology | Whiting and Bradley[17] | 35 types, denoted using letters and numbers | Headwater rivers |
| Channel pattern       | Planform geometry, slopes, and flow rate | Leopold and Wolman[16] | Straight, meandering, and braided patterns | For alluvial rivers with floodplains |
| Floodplain morphology | Water energy, grain size, and geometry | Nanson and Croke[17] | High-energy non-cohesive, medium-energy non-cohesive, and low-energy cohesive floodplains, then subdivided into 13 types | For alluvial rivers with floodplains |
| Hierarchical classification | Reach-scale morphology, slope, and channel material | Rosgen[6] | First classified into 8 groups, according to entrenchment ratio, width/depth ratio, and sinuosity; then subdivided into 94 types based on slope and channel material | For small-scale mountain streams |
|                      | Channel morphology and geometry | Montgomery and Buffington[20] | First classified into colluvial, bedrock, and alluvial types; the alluvial type were then divided into cascade, step pool, plane bed, pool riffle, and dune ripple | Mainly focusing on Australian rivers |
|                      | Geometry, channel morphology, sediment | Brierley and Fryirs[19]; Brierley et al.[20] | Channels divided into a series of river styles linking to cross-section and floodplain evolution. |       |

Classifying rivers into different orders according to the relationship between main and tributaries is the most commonly used qualitative classification method, put forward by Horton[9] and Strahler[10]. Similar methods are often used in describing the relationships between the main and tributaries of China’s rivers. The river order can be combined with physical parameters such as the length of a river sections, the area of a river basin, the slope and size of a river course. Although this method visually and concisely represents the river network structure, it does not reflect the different morphological characteristics and evolution processes of rivers of the same order[21].
Sediment transport is an important natural function of rivers. Sediment transport mode and characteristics play a key role in the evolution of river morphology, and become the leading factor and entry point of river classification. Schumm proposed in 1977 that rivers can be divided into erosion, transport, and deposition zones according to sediment transport processes[21]. Based on this, Montgomery[12] indicated that rivers could be further divided into colluvial channels, confined valleys with larger slopes, and unconfined floodplains with smaller slopes. This classification system roughly correlates the morphological characteristics of river reaches with aquatic habitats. For example, habitats in unconfined floodplains are more diversified than confined valley area. On the other hand, the sediment factor can be combined with other river factors for classification. For example, Schumm[13], proposed a conceptual framework for classifying alluvial rivers that related channel pattern and stability to sediment particle sizes, sediment transport mode, ratio of bed load to total load, channel slope, and width-to-depth ratio. Church[14] improved Schumm’s classification system and introduced it into mountain rivers with large slopes. According to the grain size of sediment, the rivers were divided into six types. The morphological characteristics, stability and sediment transport dynamic characteristics of each type of rivers were given and sketched in schematics. Whiting and Bradley[15] developed a process-based classification protocol for headwater rivers based on bed mobility characteristics. Associating sediment particle size with channel size and valley stability, the headwater rivers were sorted into 35 types. However, this method has some limitations and can only be applied to rivers in source areas[21].

Most river classifications have been developed involving channel patterns (i.e., planform geometry) and combined qualitative and quantitative analyses. It is because to obtain river morphological parameters is relatively easy. For example, Leopold and Wolman[16] divided rivers into straight, meandering and braided categories, and proposed thresholds to distinguish meandering rivers from braided rivers based on discharge and channel slope. Subsequent investigations modified this method to distinguish anastomosing and wandering channels by considering many parameters, such as grain size, sediment load, riparian vegetation, channel roughness, width, and depth. In recent years, the application of new technologies such as GIS, such as Beechie et al.[22], has also promoted the progress of river morphological classification development. Both qualitative and quantitative analyses of river morphological characteristics are found to be used. However, most of quantitative data are empirical and can be only used in limited circumstances[21]. On the other hand, the planform geometry of rivers is closely related to the floodplain morphology, which also links to the energy of river water. For example, Nanson and Roke[17] classified rivers into three types according to river water energy – high, medium and low – and further divided the river into 13 types according to the grain size of floodplain sediments and the topography of riparian zones. Kellerhals et al.[23] predicted the evolution process of large rivers (bankfull width > 20 – 30 m) by combining the planform morphology of mountain rivers with channel pattern/sinuosity, frequency of channel islands, bar type, and lateral activity of the channel and floodplain. The Forestry Department of British Columbia (FPC) of Canada, on the other hand, classified the small to intermediate channels (bankfull < 20 – 30 m) into three types: riffle-pool, cascade-pool, and step-pool[21]. It can be seen that the combination of the river morphology and the surrounding zones can predict the river evolution trend and provide a reference for human engineering work along the river. However, most of these methods are limited to specific types of river sections, and their applications are relatively narrow[21].

Hierarchical classifications are probably the most comprehensive and widely accepted classification methods. Hierarchical classification theory was first proposed by Frissell et al.[24]. Large-scale temporal and spatial systems (primarily for stream habitats) were divided into many small-scale elements and associated with watershed geomorphic features and events. The most representative and widely used hierarchical classification method was proposed by Rosgen[6]. In this method, rivers were first divided into 8 major stream types based on entrenchment, width-to-depth ratio, and sinuosity, followed by subdivision into 94 minor channel types for different landscapes. Another widely accepted hierarchical method was proposed by Montgomery and Buffington[18]. According to field observations, small-scale mountain rivers were divided into seven types: colluvial,
bedrock, cascade, step pool, plane bed, pool riffle, and dune ripple. The stability of the river channel and its response to environmental changes were predicted by the surrounding topography and river bed sediments. Brierley and Fryirs[19] and Brierley[20] modified Rosgen's method to make it more suitable for Australian rivers. They developed a River Style Framework, according to land type and degree of confinement, river character, and river behavior, which can be used to establish a relationship between river evolution process and ecological change process, and to preliminarily predict the evolution trend of rivers and the potential of ecosystem restoration. However, this method is mainly based on the case study of Bega River in Australia, and is doubtful about the adaptability in other areas.

In terms of China, the river types are complex and diverse, because of great regional disparity in geography, climate, environment, economy, culture and management measures. However, the research on river classification in China is relatively insufficient with slow development[2-3]. Most of the classification methods only consider single factor and scale and qualitative descriptive indicators, for example, based on destination, flowrate, flow velocity, source of water, etc. This can only give a general idea about China's river system, but cannot meet the increasingly strict river management requirements[3].

4. Recommendations of future river classification development for China

The river classifications proposed by other countries have been developed ahead of Chinese ones, whereas they are found to be difficult to apply in China. This is mainly because China's geography and river characteristics are out of the scope of these studies. Some classification indicators working well in the original regions are not suitable for Chinese cases. Secondly, foreign research is supported by detailed historical data and a large number of field observations, while similar data in China are relatively scarce, which makes it difficult to be used. Thirdly, most of these classifications are based on the characteristics of rivers from the perspective of a certain discipline, such as geology, river dynamics, hydrology, hydraulics, ecology and so on. However, under the condition that China is stressing ecological protection and sustainable development, these classification methods are not a perfect fit. It is required to classify rivers for the sake of river protection and restoration. This is what the endeavor should be made on, but still short of discussion.

As mentioned above, China is paying more attention to the protection of ecological environment, sustainable development and harmonious coexistence between humans and nature. When we study the river classification, we should take this goal into account and find an appropriate river classification approach to facilitating river water resources protection and sustainable development and utilization. Specific recommendations are as follows.

4.1 River classification should be in alignment with river management requirements

According to the needs of environmental protection and sustainable development, there are two major tasks of river management for China: fulfilling environmental flow requirements and conducting ecological restoration. Ensuring environmental flows can maintain long-term stability of river ecosystem and achieve the goal of sustainable development. The ecological restoration of damaged rivers aims to improve the structure and function of river systems. Therefore, we should explore how river classification can help us to complete these tasks. This requires a clear understanding of important river indicators for environmental flows and ecological restoration, from which rivers can be classified accordingly.

4.2 River classification should be based on field observation and monitoring data

Due to the lack of historical river data in China, it is impossible to develop classification methods using a large number of data, while data-based classifying could be the most rational approach. Therefore, striving for long-term collection of river data across multiple disciplines is desired, including hydrology, hydraulics, water quality, geomorphology, ecology, etc. Scientific classification cannot be achieved without sufficient data. In addition, social and economic data should be also
included. The statuses of social and economic development, production and living conditions, and future plans directly determine water consumption, hence affects the achievement of environmental flow and ecological restoration goals. Among river data, ecological data may be the scarcest. Scientifically and continuously collecting ecological data of rivers is highly demanded.

5. Conclusions
The complexity and diversity of natural, geographical and human factors in China make China’s river system very complicated. Degradation of river function and shortage of water resources, accompanied by rapid economic development, urge China to improve the environment and protect ecosystems. However, Chinese river classification is not suitable enough to meet the requirements, while the methods of other countries do not well adapt to Chinese cases. Therefore, it is imperative to find a scientific and appropriate way to classify the rivers to meet our current river management requirements. We should proceed from the key factors that need to be considered for river environmental flow demand and ecological restoration, and try to establish a data-based classification system. In this sense, river classification should be simultaneously developed with the theory and practice of environmental flows and ecological restoration.

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