A decision classifier to classify rivers for river management based on their structure in China: an example from the Yongding river

Yinjun Zhao and Aizhong Ding

ABSTRACT

River classification is a very useful tool for river management yet still a difficult task. This paper proposed a new decision classifier (DCF) to classify rivers for Chinese river management based on existing classification systems. Aimed at river function management, the DCF with the five-layers frame was developed on reach level in a spatially nested pattern that from top to bottom are natural province, basin, valley, reach, habitat and microhabitat. Five indexes (artificial degree, closeness, sinuosity, bed material texture, geomorphic units (GUs)) were selected and organized into the DCF according to the importance of the influence on river structure from macro to micro, large to small and top to bottom, because they represent main aspects of river structures and are easy to obtain. In addition, the closeness index is another good connector between valley level and reach level, and the GUs index links reach level to habitat level. The overall procedure to use DCF includes primary indoor classification and field validation. Remote sensing, geographical information system and global positioning system technologies were adopted in the process to dramatically reduce workload, especially fieldwork. Finally, the approach was applied to the Yongding river as a good example, and 17 river styles were identified.

Key words | decision classifier, river classification, river structure, Yongding river

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INTRODUCTION

River classification is a very useful tool to distinguish spatial and temporal disparities, and is a basic way to recognize a river's complexities. In order to better observe and describe the complexity of rivers, rivers are classified into several types according to their similarities and diversities. Many literature studies about rivers indicate that differences in time and space, dynamics and complexity in terms of the process and shape during the whole course along its formation, development and evolution were found. Therefore, the classification study is necessary. River classification is the first step in understanding the complexity of rivers and it also serves as a fundamental component of river management. The importance of river classification is as follows: (1) provides a basic unit for river management by dividing the river network into reaches with similar structures and functions (Rosgen 1994; Montgomery & Buffington 1997; Thorp *et al.* 2010, 2013; Veinott *et al.* 2013); (2) carries out resource cataloging according to river types, and to target different management goals for each river type; (3) chooses typical reaches to monitor to understand their structures, behaviors and function characteristics, which are extrapolated and applied to other similar reaches in the end; (4) promotes the communication between scholars and administrators with different backgrounds (Brierley *et al.* 2002, 2011; Rogers 2006; Tadaki *et al.* 2014); (5) establishes the 'reference state' for each river type and can also be regarded as the basis of river design (Brierley *et al.* 2002, 2011); (6) extracts the rules from same river types and predicts behaviors of rivers. Above all these points, important scientific value for river management is embodied by river classification.

Dozens of classification systems for rivers were developed on the basis of different purposes, perspectives,

doi: 10.2166/wst.2016.333

disciplines and space–timescales after Davis proposed the first stream classification method in 1899, but few methods are recognized by resource managers. According to the relationship between slope and discharge, scientists differentiated straight, meandering and braided channel patterns firstly. Then, another new channel type named anastomosed river was found, and rivers can be divided into four categories. Rohm *et al.* (1987) focused on the differences of the fish community and found six ecoregions by thinking about physical habitats and water chemical characteristics. Schumm (1977) recognized three geomorphic zones within a watershed based on the sediment transport process: erosion, transport, and deposition zone. He also provided a conceptual framework to couple channel type and channel response potential. Montgomery & Buffington (1997) classified streams into colluvial, alluvial and bedrock reach type in mountain drainage basins, and further broken down into colluvial, braided, regime, pool/riffle, plane-bed, step-pool, cascade and bedrock. The classification is very useful especially in focusing on small channels and is used in management activities in the United States, etc. According to indexes such as entrenchment ratio, width–depth ratio, the number of channels, sinuosity, slope and bed material, Rosgen (1994) classified natural rivers into eight primary types and 94 secondary types. Although Rosgen's and Montgomery–Buffington's classification have some shortcomings, they are generally accepted by the international community and have been widely used in the United States, Britain and other countries. With the deepening of river cognition, the process and spatial connection of rivers were paid attention. River processes occur at scales spanning 16 orders of magnitude (10^{-7}–10^{8} m spatially and 10^{-8}–10^{7} yr temporally), connecting the large area and microhabitat (Minshall 1988). This provides a good pointcut to build a hierarchical classification. Many river classifications have been developed based on a nested landscape. Brussock *et al.* (1985) developed a hierarchical system for large rivers that linked the river channel shape and the community structure. Frissell *et al.* (1986) adopted the nested levels (watershed, stream, valley segment, reach, habitat unit and microhabitat) to build an open hierarchical classification system. Also, Brierley *et al.* (2002, 2011) proposed a river style framework that adopted the nested spatial pattern (ecoregion, valley, landscape, river, geomorphic unit (GU), hydraulic unit and microhabitat) to be used in Australia for river restoration, which adopted indexes such as adjacency degree between the river and the valley, continuous channel, plane form, GU, and bed material to classify rivers. Thorp *et al.* (2010, 2013) described rivers as a set of large hydrogeomorphic patches from upstream to downstream, and recognized a variety of functional process zones including constricted, meandering and braided, anastomosed, leveed, reservoir, etc. Then, river ecosystem service functions of each river type were estimated according to hydrogeomorphic patches.

Several trends have developed in river classification research: (1) the indexes used to divide rivers changed from single factor to multiple factors; (2) dominant factors used to classify rivers have many disciplinary backgrounds; (3) many newer methods can predict river characteristics according to its type better than old descriptive classifications (Ni & Gao 2011); (4) a shift from qualitative classification to a combination of qualitative and quantitative classification; (5) a shift from single structure to hierarchical structure methods.

Most researchers want to develop a lasting classification system that contains a broad scale, integrates structural and functional characteristics of all kinds of interference conditions, transfers some information about control and response within the channel, provides comprehensive classification at the lowest cost, and will be accepted by resource managers. However, few classification methods can cover the multiple purposes and adapt to all river types. River classification also is facing a series of problems such as not considering big disturbance of human activities, difficulty in gaining some indexes like bankful discharge index, few managers involved in classification studies, difficult for river managers to apply (Rinaldi *et al.* 2016) and with heavy workload, which block the application and development of methods. River classification is still a difficult problem.

According to the first national census for water in China, there are 45,203 rivers with individual catchment area of 50 km^2 or above, and 22,909 rivers with individual catchment area of 100 km^2 or above. Rivers differ extremely from each other in regional backgrounds, scales, and behavioral characteristics. Traditionally, rivers in China have been cataloged according to water systems, and are simply divided into reaches of upstream, midstream and downstream (e.g. the length of Yangtze River is about 6,300 km; the upstream, midstream and downstream are 4,540, 955 and 938 km, respectively) or based on administration region, which was blamed for the poor management due to failing of classification management in the light of river characteristic differences. In China, we can only find Qianning's classification about stream pattern and the Chinese Academy of Sciences' Institute of Geographic Science and Nature

Resource Research classification on the base of the recharge condition in Chinese river management that are a single factor and qualitative classification methods, but they are too simple to adapt to diverse management demands.

For these reasons, this paper developed a decision classifier (DCF) to quickly divide rivers into different river types and visualize river types by using the global information system (GIS) technique based on its structures for the refined river management. In line with the trends of river classification, the DCF is a hierarchical system and quantitative method, which considers the influence of human activities as a classification factor that accommodates highly modified river systems.

DEVELOPING OF THE DCF

Technical process of developing DCF

The process of DCF development and application can be broken down into discrete stages (Figure 1). The first stage mainly builds a classification procedure to tell users how to classify rivers, which includes the idea, objective, scale, indexes, and rules about river classification. Based either on an a priori understanding of river system or cluster analysis on larger data sets to develop classification, theory analyzing is proposed as a good basis for further analysis in this paper. A given purpose of the classification should be followed by steps

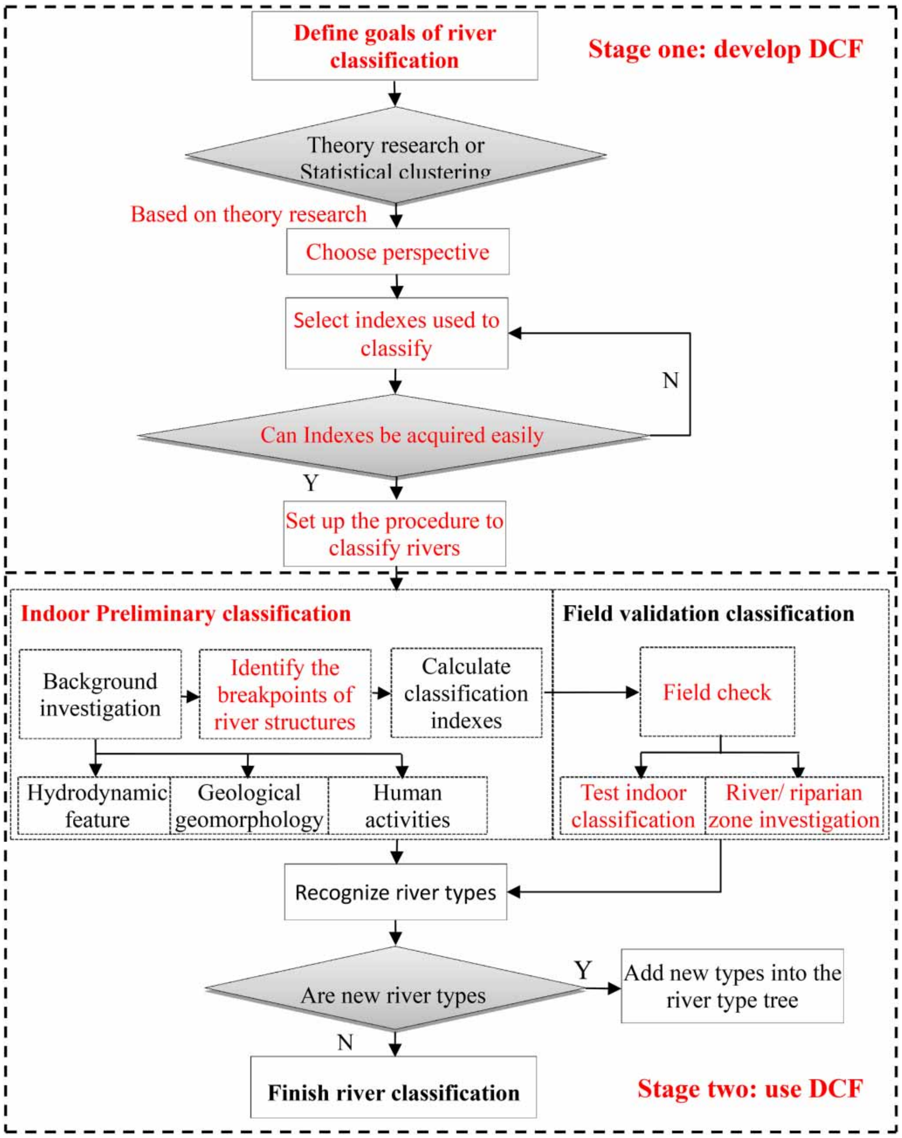

Figure 1 | The flowchart for developing the DCF.

such as choosing a proper scale, finding classification indexes, and building rules to organize the selected indexes under this framework (Figure 1). The second stage mainly develops methods and steps to tell users how to use DCF, which can be done through indoor preliminary classification and outdoor field validation classification. The specific indoor classification includes background investigating to establish basin recognition and collect data, finding break-points to divide the river network into reaches that are basic classification units, and calculating classification indexes to catalog reaches according to the classification procedure. In order to test indoor results, we need to review indoor results through fieldwork. Meanwhile, we must do some investigation of the river and riparian zone for further research of river functions (Figure 1).

Objective of DCF

The objective of river classification plays a decisive role in the subsequent selection of the scale, indexes and application range (Figure 1). For example, approaches using river management as classification purposes always are developed at the reach scale and think about the background watershed (Rosgen 1994; Montgomery & Buffington 1997), and using fishery management as a target often focuses on reach scale and selects species such as fishes as a specific classification index. In this paper, we developed a DCF to show the spatial distribution of river structures, and then studied river functions based on its own structure. So, river function management is confirmed as the purpose of the DCF.

The viewpoint of spatial scale of DCF

Fluvial systems can be viewed as inherently hierarchical, with smaller forms nested within larger ones. According to the above, many complex classification systems are developed with hierarchical structures (Gurnell *et al.* 2016), in which the high-level classification reduces the need to use low-level variables and can integrate multi-source data with different resolution. Based on specific goals we can choose appropriate resolution data. The hierarchical classification methods are more flexible. In spatial terms, low spatial levels are nested as higher levels, and higher spatial levels as the setting of low levels. High level confines the function and structure of low level in macro, and the functional structures in low layers combine to drive the functional structures of high layers. Each layer provides a river process context and comparative framework for the second layer. For example, hydrologic changes in watershed scale directly affect the structure and stability of river habitats and generally determine the river communities. The hierarchical view is in line with usual scales of scientific research.

It may be a suitable view to classify rivers using natural province, watershed, valley, reach, habitat and microhabitat based on previous work (Figure 2). We can choose freely the spatial layer according to the target for a specific area. In many areas, we need only classify rivers in 1–2 level. According to the objective of DCF for river function management, river functions mostly perform at reach level. Therefore, the study of DCF should locate at reach scale and regard valley scale as a large background of reach scale.

Indexes used to classify river

Selecting classification indexes is a key point to success in classifying rivers. A good index must reflect differences between rivers, and also be easily obtained at a low cost. The range of selecting indexes was decided early by the objective of DCF. Based on system theory, river functions are determined by the river's structure. Physical structure is relatively easy to measure, such as closeness, channel abutting valley margin, floodplain, channel number, slope, sinuosity, width–depth ratio, bed material texture (BMT) and GUs.

Closeness (CL): ratio of width of valley bottom (V_w) and full trough channel width (C_w), dimensionless, which means the limitation on the river channel by the valley (Equation (1)). CL is a connector of valley and reach level. The smaller the CL, more intense restriction on channels given by the valley. CL < 2 corresponds to severely closed; CL = 2–4, moderately closed; CL > 4, not closed (Montgomery & Buffington 1997).

$$\mathrm{CL} = \frac{V_W}{C_W} \qquad (1)$$

Sinuosity (S): ratio of L_r/L_v (L_r means channel length; L_v means valley length), and dimensionless. The range of river lateral motion is characterized by this ratio, and is related to bed rock, valley, channel, vegetation types, etc. Generally, sinuosity will increase with lessening of gradient and particle size. The length of more than 100 river widths is needed to measure the sinuosity, which can be obtained by remote-sensing image easily. S < 1.2 corresponds to low sinuosity; S = 1.2–1.4, moderate sinuosity; S > 1.4, high sinuosity.

$$\mathrm{S} = \frac{L_r}{L_v} \qquad (2)$$

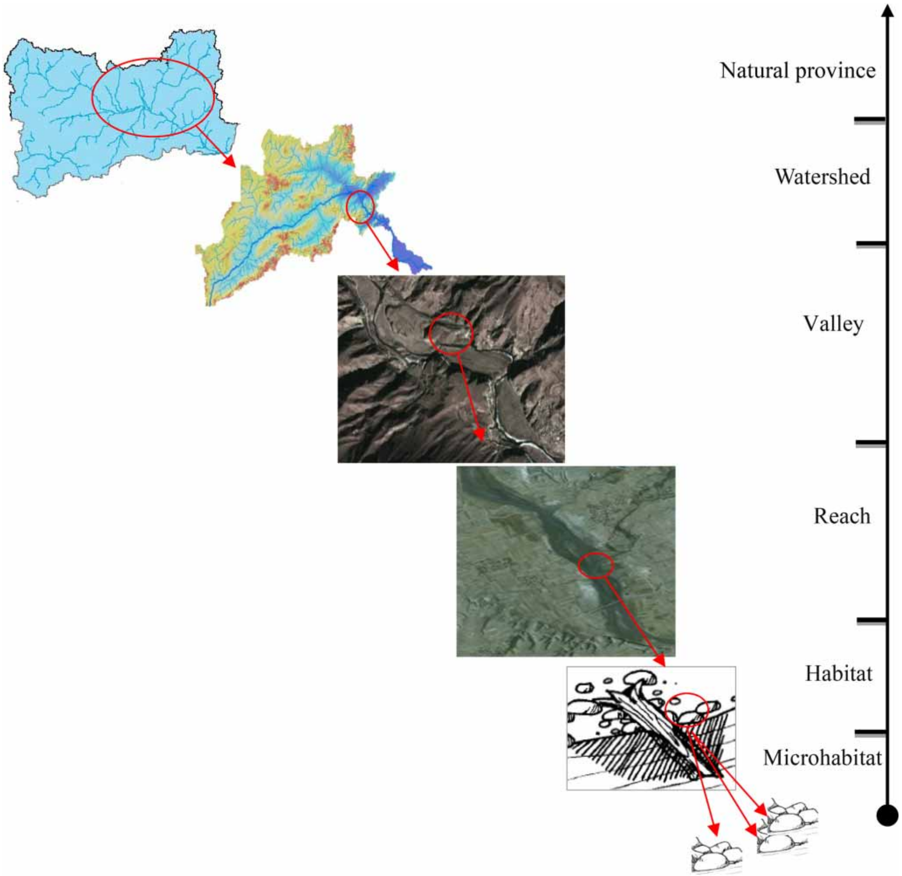

Figure 2 | Spatially nested pattern of hierarchical classification.

BMT. The material of the river sediment indicates roughness of the riverbed, which relates not only to sediment transport and hydraulic state, but also to river shape, plane, profile, stability, organisms, habitat, etc. An early classification method was developed according to riverbed material (Henderson 1963). So BMT was selected as a main index to classify rivers, and represented by the distribution of particle diameter (D_{50}), which is measured by pebble technology (Wolman 1954). The types of BMT come from China's standard procedure for analysis of grain size of sand according to particle size (China Ministry of Water Resources 2010) (Table 1).

Table 1 | Classification of riverbed material

Types of bed material	Particle size (D_{50}, mm)
Bedrock	
Boulder	> 250
Cobble	16.0–250.0
Gravel	2.0–16.0
Sand	0.062–2.0
Silt	< 0.004–0.062
Clay	< 0.004

GUs. A series of GUs are formed along the rivers under the force of erosion, transportation, deposition and eluviation. Due to impacts of climate, topography and land use, various natural and chemical conditions are formed, which determine systems with difference in metabolism, primary productivity, organic matter, inorganic ions and biogenesis. GUs primarily appear in the flow pattern and riverbed geomorphic feature. The usual flow patterns include waterfall, cascade, pool, riffle, step/chute, rapid, run, deadwater, glide, recalculating flow and percolating flow. Common riverbed GUs have pool, pothole, threshold, cascade, waterfall, riffle, point bar, channel bar, island, point bar at convex bank, floodplain, etc. Since the 1970s/1980s, extensive attention has focused on human-induced geomorphy with enhancement of human abilities to remold and utilize the nature. River geomorphic features formed by human activities mainly include fluvial geomorphology formed directly by mining (erosion) and construction (accumulation), and indirectly by impacting on the processes of river erosion and accumulation. Fluvial geomorphology expresses the combined effect of human activities and natural actions.

DCF to identify river type

The procedure to set up DCF is that the selected classification indexes are arranged to build a classification tree layer by layer according to the importance of their influence on river structure from macro to micro, large to small, and top to bottom (Figure 3).

First order. According to the degree of the human activity interference on the river, rivers can be divided into natural rivers and unnatural rivers. At present, comparing scour channel and sculpture terrain from natural geomorphology stress, human activities show more powerful impact. About 2.4 billion tons of sediment are transported into the sea from rivers each year while 300 billion tons of rock and soil are transported by artificial excavation (Yang & Li 2001). All kinds of hydraulic engineering construction give rise to the persistent and fundamental change of river system structure, and the impact is usually mutable and irreversible. Although hydraulic engineering projects such as irrigation canals and ditches usually are not considered as rivers, they possess some features of rivers and serve as a part of the river network. When conducting the classification of the river, impact of human activities is inevitable. Therefore, the classification of rivers should consider the interference degree of human activities in the first order.

Second order. Natural rivers are divided into three types as confined valley setting, partly confined valley setting and unconfined river valley based on CL index. For natural rivers, valley floor at the macro level roughly determines the river space structure and movement scope. The CL index properly presents the limitation relationship; thus it is firstly chosen for classifying rivers and determining three-dimensional structure of rivers. For an unnatural river, hydraulic engineering is the most influential form of human activity on the river structure. It is used to subdivide an unnatural river.

Third order. The natural river classification is subdivided based on S index. Considering the constraint of the valley to the river, the lateral movement of the stream becomes the major influence factor of river structure within the scope of the river space structure. Sinuosity that determines longitudinal bending structure and boundary conditions of the channel reflects the flat structure of rivers and plays an important role in the river

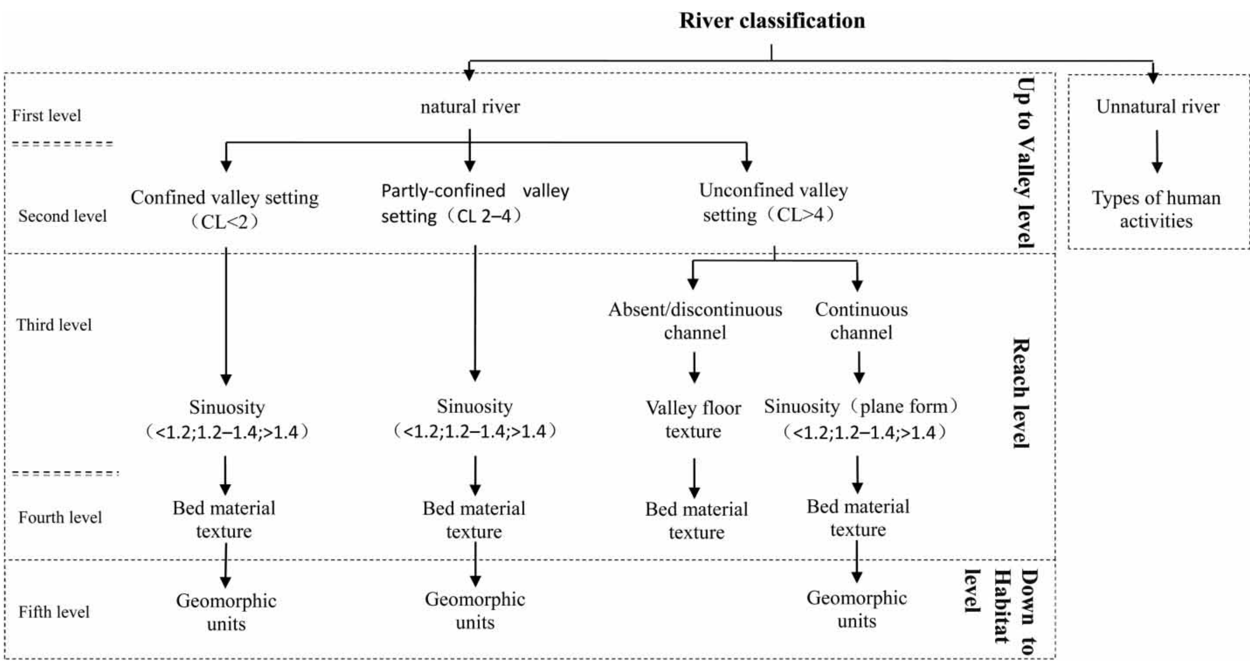

Figure 3 | DCF to classify rivers.

structures. Therefore, S index is used for further classification on the basis of the second order.

Fourth order. The river is subdivided based on BMT types. After the previous three levels of classification, macro spacial structure and flat structure are all fairly considered. Material types of riverbed reflect the vertical material composition of rivers and represent the bottom boundary of river structures, which have large significance to river structures. Therefore, BMT is determined as another classification index on the basis of the previous orders.

Fifth order. The river is subdivided based on GU index. By including this order an appropriate DCF may be established. The classification structure will be overly complex and the difference between reaches tends to be inconspicuous if a sixth order is developed to add into classification decision trees. Therefore, the fifth order should likely be the closure of the classification. In the last order, the spatial structure link between reach layer and habitat layer is necessary. GU in the reach actually constitutes the specific habitat and acts as interior units of river structure. Therefore, GU is determined as a classification index of this order for its proper function.

Moreover, the situation of an unconfined valley setting river is much more complex. In addition to the continuous channel, there are other situations such as no channel and discontinuous channel whose sinuosities are difficult to measure, thus requiring an extra classification index. Non-continuous and discontinuous channels mostly locate at the floodplain at the bottom of a valley differing them in morphology and riverbed sediment. Accordingly, the division of non- and discontinuous channels is based on valley material.

The identification of river type is not simply to classify rivers, but to gain a general understanding of rivers within their valley setting. When using DCF to classify rivers, we will build another tree that is called the tree of river types that records the process river classification (Figure 4). Because of limitations from the diversity, complexity and understanding of rivers, we cannot exhaustively list all river types. The DCF is designed as an open system; so we can add a new river type to the river type tree when we find a new type in specific studies.

Methods and steps of using DCF

Specific river classification is mainly divided into two steps: indoor preliminary classification and field validation classification. Remote sensing, GIS and global positioning system (known as 3S) techniques are applied in the first step to calculate indicators used to classify a river and analyze them comprehensively. The second step mainly relies on site investigation to verify the preliminary classification results, and finally determine the river classification.

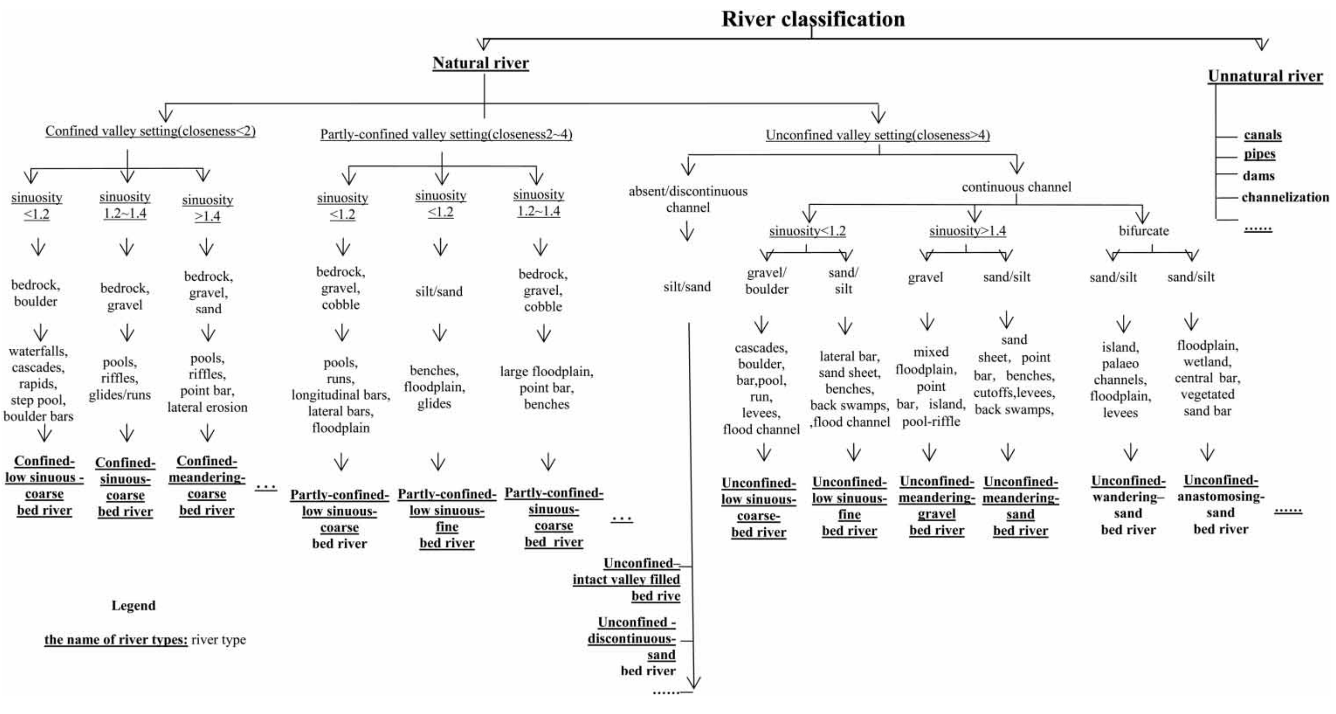

Figure 4 | The river type tree by using DCF to classify rivers.

Step one: indoor preliminary classification

(1) Background check of basin. Spatial data, such as topographic maps, a digital elevation model (DEM), remote sensing images, geological maps, drainage maps, land use maps and administrative regions, must be collected, followed by transform formation, correcting, registering, clipping, relating and building database, etc., which is preparing for later spatial analysis. In addition, it is necessary to gather hydrological stations' flow, sediment, precipitation, temperature and other information studied by previous researchers to analyze the temporal and spatial variations of runoff, sediment, precipitation and temperature, and set up the background view of the specific basin.
(2) Identify the breakpoints of river structure. The breakpoints in this paper refer to points where there are big changes in river structures, including geomorphic breakpoints such as major changes in elevation (Figure 5), closeness, sinuosity, the converging point of the river system, and artificial points from direct water conservancy projects. These breakpoints may represent major changes in river structures and motion ability, and can be used as river dividing points for preliminary classification to break rivers into segments that are basic classification units. We could merge the same and consecutive river types when we finished the classification.
(3) Calculate classification indexes of every river segment according to the DCF on the table. On the basis of the broken segments, we can first identify unnatural river types such as reservoirs, canals, and channels from remote sensing images. Then we calculate the CL index and sinuosity index and roughly interpret riverbed material and GU layer by layer to classify the natural river according to the DCF.

On the basis of DEM, surface analysis tools in ArcGIS can be utilized to analyze the slope and aspect, and pick up valley lines. Measuring tools can be used to obtain the distance that is the length of the vertical line along the river orientation between valley sides (Figure 6). According to Equation (1) or comparing the width of the bottom of valley and channel (Figure 7), the CL could be estimated, and further defines the grade of confining degree.

In view of high-resolution remote sensing maps, processing software (such as ERDAS and ENVI) of remote-sensing data are available to interpret the river system and measure the river length and valley width. The level of calculated sinuosity can be determined based on Equation (2).

Bed material, riverbed shape, fluvial GUs along the longitudinal section can be interpreted roughly based on the high-resolution remote sensing map, land-use map, geological map and DEM. River type can be defined and a tree of river types can be set up according to the classification program (Figure 3).

Step two: field validation classification

In accordance with the established tree of river types in step one, a field investigation point should be set up for every river type. Along the rivers, observe and measure average width, depth, velocity, geomorphic features of rivers and

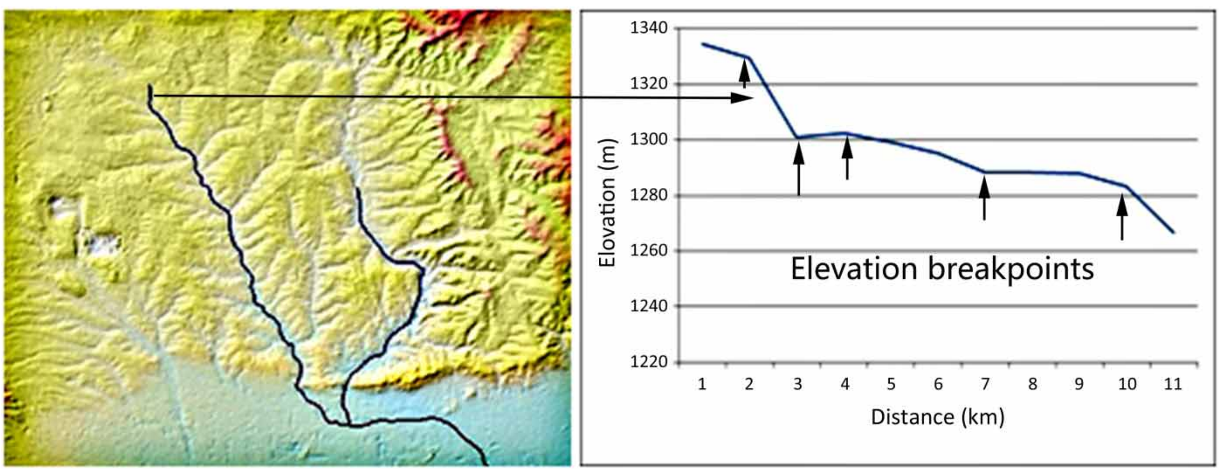

Figure 5 | Diagrammatic sketch of elevation breakpoints.

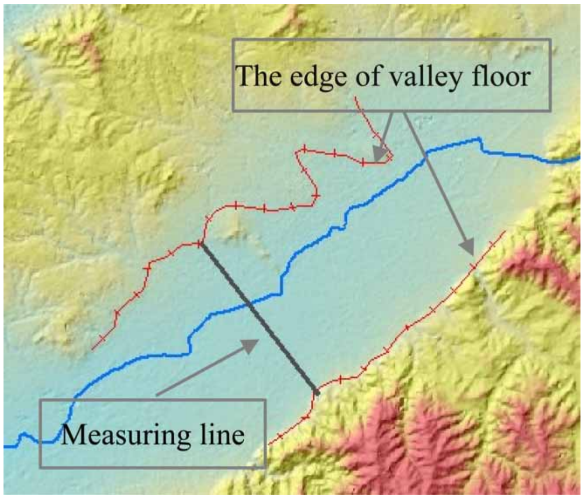

Figure 6 | Estimation of the width of the valley bottom.

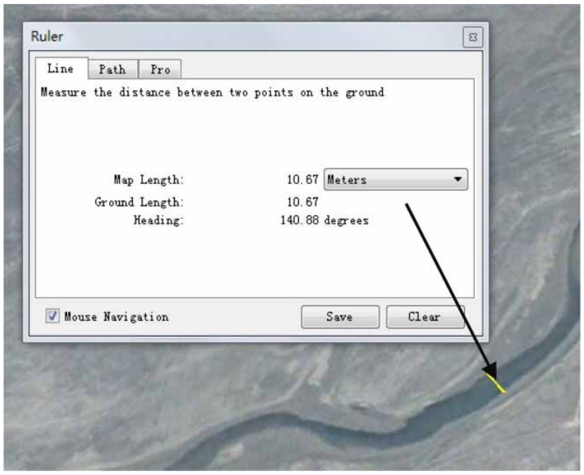

Figure 7 | Estimation of channel width.

the adjacent relationship with valley, etc., and then validate the indoor classified river types according to DCF and adjust the boundary lines of river types.

In addition, the field survey is mainly to investigate natural characteristics, active abilities, conditions of the river type and human activities surrounding it, and to collect data for further evaluation of functions of the river type. The length of the field survey area should be no less than 10 to 20 times the river width or more than the length of two meanders. The starting point and ending point of the survey should be the same fluvial GU. The survey area should not include areas which have significant effects on stream-power or sediment characteristics of the river, such as bridges or culvert.

THE CLASSIFICATION OF THE YONGDING RIVER, CHINA

Study area

The Yongding river originates from Guancen Mountain, Ningwu County, Shanxi Province and flows through Shuozhou, Datong, Zhangjiakou, Beijing and Tianjin. It is the biggest river of Beijing city, makes great contributions to Beijing's economic and social development, and is honored as the 'mother river' of Beijing. It is located in between 112°15′E–117°10′E and 38°51′N–41°13′N (Figure 8). The Yongding river bridges Shanxi province, Inner Mongolia Autonomous Region, Hebei province, and Beijing and Tianjin municipalities, and the total area is up to 47,000 km^2. The area of Hebei, Shanxi, Inner Mongolia, and Beijing is respectively 18,000, 5,000, 5,000, and 3,000 km^2, and it flows through three cities and 33 counties.

Main data sources

According to the characteristics of the Yongding river system, seven hydrological stations were chosen at the mainstream as shown in Figure 9, and data of runoff and sand (1956–2003 period) were collected from the hydrological statistical yearbook of China and the Center of Hebei hydrological resource. Based on the basin area, 32 meteorological

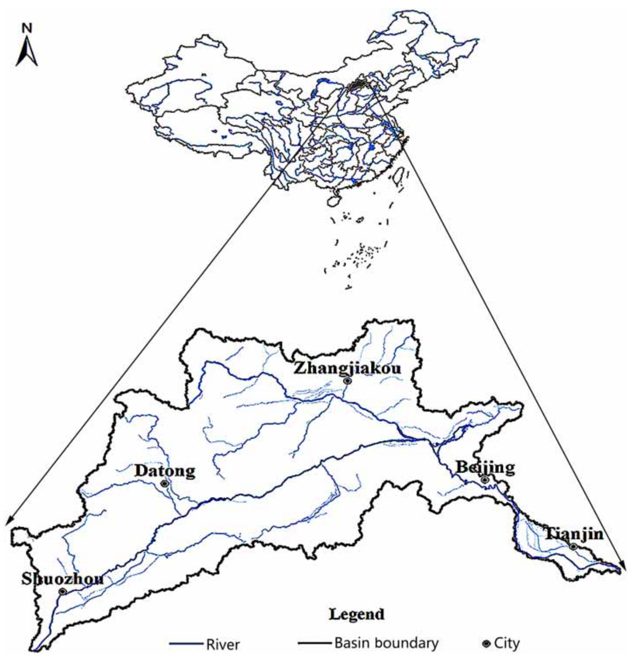

Figure 8 | The geographical location map of Yongding river.

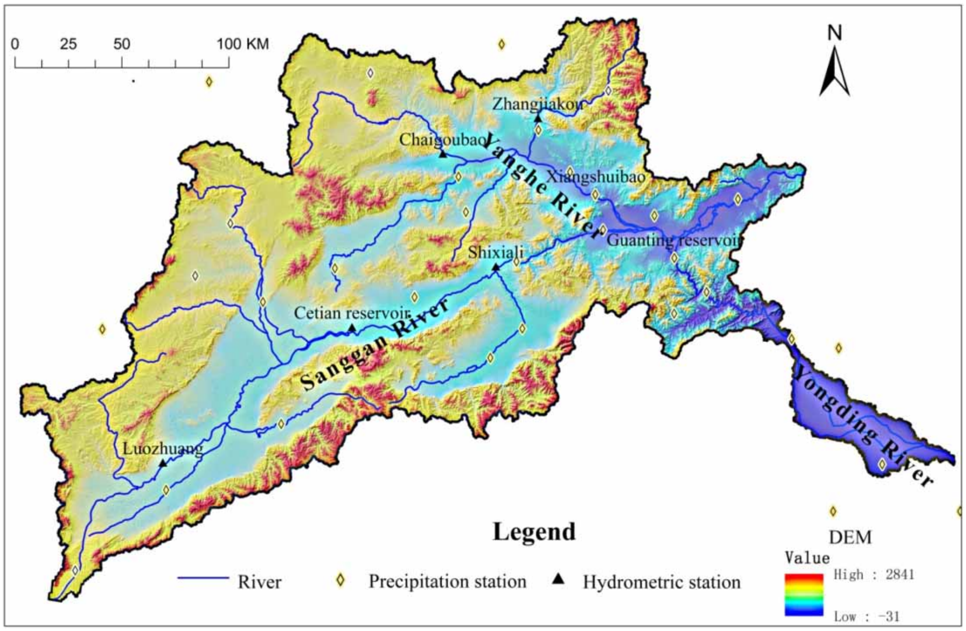

Figure 9 | DEM and the location of hydrological and meteorological stations at Yongding basin.

stations were selected as shown in Figure 9 to collect data (1956–2009) of precipitation and temperature from China Meteorological Data Sharing Service System and Institute of Geographic Sciences and Natural Resources Research. Moreover, a DEM was derived from International Scientific Data Service Platform of Chinese Academy of Sciences Computer Network Information Center, and its resolution was about 30 m. We also collected land-use maps from the 1980s, 1995 and 2000 from Resources and Environment Science Data Center of Chinese Academy of Sciences.

The process of using DCF in Yongding river

Through background check of the basin, we found a clear trend of decreasing annual runoff, which was verified through significance test of seven hydrological stations' annual runoff by using the Mann–Kendall test. The maximum rate of decline is located at Xiangshuibao station with 3.22 million m^3/a. The incoming sediment that flowed into Guanting reservoir mainly from the Sanggan river and Yanghe river has sharply dropped to 267 thousand tons from 75,300 thousand tons in the 1950s. As for trends in precipitation, we found that eight meteorological stations' precipitation have significant declining trends and others are non-significant through using Mann–Kendall test. The population living in Yongding basin grew rapidly from 6 million in the 1950s to 14 million in 2003. The degree of water resources development and utilization increased steadily with 790 small, medium and large reservoirs with the total capacity of up to 5.6 billion m^3. In general, the Yongding river basin has declined significantly in the annual runoff and sediment discharge and decreased indistinctively in precipitation, but has increased in population and water conservancy projects since 1956. Human activities should be a major factor affecting the Yongding river system. At present, the Yongding river is facing a series of problems including serious water resources shortage, riverbed deposition and atrophy, channelization and annual dryness in the upstream of the Sanggan river and Yanghe river and in the downstream of Yongding river. The functional structure of the Yongding river was seriously damaged and river management faces great challenges.

According to DCF described in the 'Developing of the decision classifier' section, we found 68 breakpoints, and a broken river network at breakpoints (Figure 10); then we finished primary classification for the Yongding river by using 3S techniques. Based on the primary classification, 33 outdoor survey points were selected to validate indoor results by the following rules: every river type has at least an investigation point; the investigation point must be easy to access, with a relatively evenly distribution (Figure 10).

Results and analyses

Yongding river was eventually divided into 17 river types through two steps (Figure 11) and classified as follows

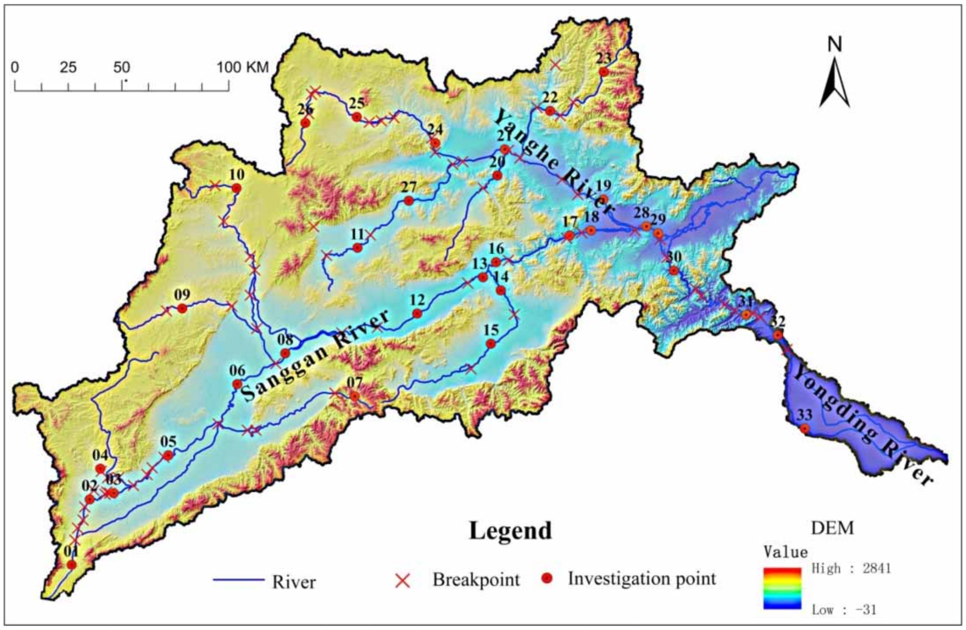

Figure 10 | The distribution of breakpoints and outdoor investigation points.

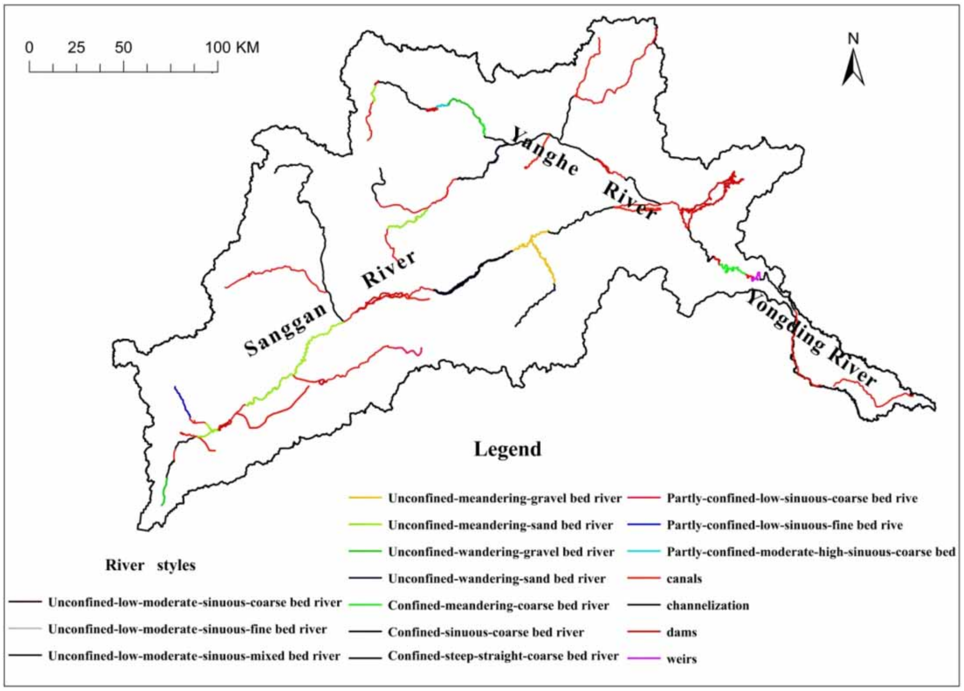

Figure 11 | River types in Yongding river.

(Table 2). Three river types including unconfined-wandering-sand bed river, unconfined-low-moderate-sinuous-fine bed river and channelization have the greatest distribution and respective length of 433.3, 308.1 and 234.7 km, which represent 22.8, 16.2 and 12.4% of the total classified length shown in Table 2.

Unconfined-wandering-sand bed river has a large distribution for the following reasons. (1) There are abundant

Table 2 | Classified river types for Yongding river

River types	Length (km)	Percentage of total length
Unconfined-wandering-sand bed river	433.3	22.8
Unconfined-low-moderate-sinuous-fine bed river	308.1	16.2
Channelization	234.7	12.4
Unconfined-meandering-sand bed river	161.9	8.5
Canals	160.3	8.4
Unconfined-low-moderate-sinuous-coarse bed river	142.8	7.5
Unconfined-low-moderate-sinuous-fine bed river	109	5.7
Confined-sinuous-coarse bed river	102.7	5.4
Unconfined-meandering-gravel bed river	67.7	3.6
Unconfined-wandering-gravel bed river	44.1	2.3
Confined-meandering-coarse bed river	39	2.1
Partly-confined-low-sinuous-coarse bed river	35.3	1.9
Partly-confined-low-sinuous-fine bed river	20.2	1.1
Weirs	16	0.8
Unconfined-low-moderate-sinuous-mixed bed river	11.9	0.6
Partly-confined-moderate-high-sinuous-coarse bed river	8.6	0.5
Confined-steep-straight-coarse bed river	3.4	0.2
Dams		

sources of sand. Yongding river basin develops primarily in a loess hilly region with lower vegetation coverage (Figure 12) and can provide enough sand for forming a wandering river through serious soil erosion. According to remote sensing interpretation, the vegetation coverage was only 18.8% above the Guanting reservoir of Yongding river in 2000. (2) Yongding river has shallow flow during the dry season and has much higher fluctuations of water level during the rainy season. This brings large amounts of sediment into the channel, which are deposited. (3) The riverbed has a large gradient. For example, the slope of the Yiliu river, which is a tributary of the Sanggan river in the upstream, is about 1.48%. (4) Loose rock has developed widely along river bank, which is composed of soft clay, silty sandstone formed in the Holocene lacustrine period and sallow and mousy siltstone formed in the Holocene.

Unconfined-low-moderate-sinuous-fine bed river is rarely confined by the valley and usually develops in the U-valley or the floodplain. The Yongding river basin developed a large area of alluvial plain and river banks with a dual structure composed of quaternary sediments, which thus have a certain resistance to erosion but are still able to collapse back, and the supply of sediment is lower within some regions of the basin. For all the above reasons, the river type has a wide distribution.

The channelization river type is an unnatural river constructed for human purposes. It is difficult to see that people do not live along the Yongding river system, from remote sensing interpretation and the field investigation, even in the headwaters of the Hunhe river, which is a tributary of the Sanggan river. Rivers were reinforced by residents along the Yongding river in order to control floods, protect

Figure 12 | The vegetation coverage of Xionger mountain in Yongding river basin.

river banks, utilize land resources, etc., and these reinforced rivers are mainly distributed in regions where people are concentrated, e.g. in towns and villages. For this reason, the channelization type has very wide distribution in Yongding river.

DISCUSSION

The greatest contribution of river classification is to simplify river problems by putting diverse streams into several groups. It provides a very useful tool for cataloging management and understanding of a river, and offers a management unit for specific practices. The similar structural characteristics of the same river types are revealed by river classification, which is more intuitive and easy to understand and measure. Most of the work can be completed indoors based on 3S techniques, which dramatically reduces the volume of work.

The purpose of managing rivers is to sustainably use river functions; these functions are determined by river structures that can be identified by river classification based on DCF. The same river types should have similar river structures, which confirms their potential function. Managers can regulate river restoration and development based on river types' potential function as a reference to maximize the utility of river functions.

Based on 3S technology, we can easily finish classification work by DCF. At present, rivers are impacted increasingly by human activities. The structure of many rivers is marked by human activities, and many rivers become unnatural rivers. Unnatural rivers are also one of many possibilities in the process of river evolution, and it is often difficult to go back to a natural river type. Unnatural river types are relatively single in structure and function. Compared with the natural river, they often highlight one river functions and damage other functions of rivers. Meanwhile, we should also realize the purpose of river classification is just to simplify the problem and mark rivers, and is the first step to understand the rivers. River structure is the intermediate product in the process of river evolution and only records the evolution process of rivers, but it cannot characterize control factors of the process and the natural process. Over a long timescale, river structure will constantly change and the river types will also be correspondingly changed. The increase in scientificity and practicability of river classification will be a long-term process that continuously adapts to the key problems identified by national river management.

CONCLUSIONS

From the view of a spatially nested pattern including natural province, watershed, valley, reach, habitat, and microhabitat, a DCF used to classify rivers was developed on a reach scale with a five-layered structure that was organized by interference degree of human activities, confined degree of valley to river, plane form, GUs, BMT, etc. The DCF is an open system and it only provides classification rules because the river system is very complicated and we cannot recognize all river types at present. In practice, we should constantly find new river types based on the DCF to expand the usual river types.

The process of river classification includes two stages: indoor primary classification and field validation. Primary classification mainly involves calculation of indexes according to the DCF based on 3S techniques on the table, and builds a river type tree for the specific river system. Field validation is to review the river type tree developed in the indoor classification. The classification reduces the amount of work necessary, especially outside work, and makes it possible to classify a large rive system.

According to the DCF and the developed method in this paper, the method was used in Yongding river and 17 river types were found including the most widely distributed of unconfined-wandering-sand bed river, unconfined-low-moderate-sinuous-fine bed river and channelization.

ACKNOWLEDGEMENTS

This study is supported by the project of Natural Science Foundation of China (41461021) and Opening Fund of Key Laboratory of Environment Change and Resource Use in Beibu Gulf, Ministry of Education (Guangxi Teachers Education University) (2014BGERLXT15).

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First received 20 April 2016; accepted in revised form 23 June 2016. Available online 29 July 2016