Research progress on urban river landscapes and equilibrium profile

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Abstract. With the urbanization development, urban rivers have experienced great changes in the form and stability in the past 60 years, and the problem of urban water ecological security has been highlighted. Using a compilation of research results from more than 100 studies conducted globally, this paper is intended to do the following: i) describe variable river responses to urbanization in terms of river morphology, runoff and sedimentation system, stability, and other mechanisms; ii) summarize three major river classification systems in terms of methods including form-based method, process-based method and synthesis method; iii) evaluate evaluating the advantages and disadvantages of the above mentioned methods in judging processes like the degradation of river form, studying river hydrological process, predicting time periods on river evolution. Given that the evolving urban streams pose huge challenges for city management, successful strategies require a clear understanding of changing mechanisms of river form and stability in adjustment processes.

1. Introduction

Urban river morphology is an important part of surface morphology. Research on the evolution of urban rivers and their stability is one of the key issues in modern geographical sciences and hydrology and one of the important scientific frontiers at present [1]. As more than 50% of the world's population live in cities [2], the changes in land usage and continuous improvement of infrastructure carried out to adapt to the growing population has put a strain on the river system and resulted in its imbalance. Mastering the law of change of urban river morphology and stability is of significance towards the restoration of the ecosystem and management of a wide array of rivers [3,4].

Geomorphologists in UK and USA have been studying river morphology as early as the 1960s. Earlier studies focused on the hydrological and sedimentary effects of urban development on rivers [5]. Research on river systems in temperate regions of UK and USA that were carried in the 1970s laid a foundation for subsequent river evolution analyses. Along with the continuous improvement of research theories, research has gradually extended to the areas of river sedimentation, runoff and hydrologic climate changes in tropical regions such as Southeast Asia and Africa by the 1980s. Since urban rivers are located in special areas with frequent human activities, they suffer the most severe disturbance from humans. In recent years, scholars have switched their focus to the relationship between the degradation and restoration of urban rivers and the change of river system morphology [6], which generally includes the evolution characteristics and stability of riverbed and riverbank as well as river classification methods [7].

By reviewing relevant literature, this paper sorts out the law of change of the urban river sedimentary system and runoff system, evaluating the evolution of urban river morphology under intensive human activities, summarizes the research methods for river morphology and stability, and resolves two major issues. The first issue relates to the changes and change mechanism of river morphology and stability in the process of urbanization. The second issue is the classification method of river morphology and its contributions towards revealing the mechanism of river morphology and stability evolution.

2. Evolution process of urban river morphology and stability

River erosion, discharge and sediment changes river stability and decides the morphology of river evolution [8]. Strahler stated that, when human activities disturb the balanced state of a river system, erosion and sedimentation will occur and river morphology and stability will change significantly [9].

2.1. Change of sedimentary system

Watershed sediment yield is highly correlated with urban construction intensity. Most scholars believe that, within the same watershed, there is a big difference in the sediment yield among different land covers, and differences in the intensity of urban development also contribute towards this difference [5,10]. Results of the research on Tahiti and Maryland are listed in table 1. Research data suggests that areas under natural development have the lowest watershed sediment yield while areas under rapid development of urbanization have the highest watershed sediment yield. The smaller the watershed, the more obvious is this observation. In small watersheds, construction areas produce 80% of the sediment yield. Land development leads to increasing sediment yield, with the sediment yield of constructions areas being 10^2-10^4 times higher than that of forested areas. Once construction activities are completed, sediment yield will decline significantly to a level which is just 2-5 times higher than that of natural land cover [11].

Table 1. Comparison of sediment yield among areas at different development stages of urbanization.

Research area	Forest/rural areas			Areas undergoing rapid urbanization			Substantially urbanized areas		
	RN[a]	Area[b]	SY[c]	RN	Area	SY	RN	Area	SY
Tahiti [10], France	Matatia	8.6	59	Atiue	0.9	713	Vaiami	2.6	142
Maryland [5], USA	Broad Ford Run	7.4 ×10-6	4.2	Little Falls Branch	4.1 ×10-6	896	Stony Run	2.5 ×10-6	21

a River name;
b Area unit: km^2;
c SY: Sediment yield; SY unit: t km^{-2} yr^{-1}

The intensity of river sedimentation changes with the process of urbanization. In the early stages of urbanization, exposed surfaces and engineering construction would aggravate surface erosion [11,12] and significantly increase watershed sediment yield. A statistical analysis on the historical data of watershed urbanization process in the USA between 1960s ~ 1970s indicates that the annual average sediment yield per unit area is 1,194-55,000 t km^{-2} yr^{-1}, for watersheds smaller than 1 km^2. This is 45-300 times that of the level before the construction. For larger watersheds (98.4-128 km^2), the annual average sediment yield per unit area declines to 44-714 t km^{-2} yr^{-1} due to dilution effect [11]. This, however, is still 2-5 times of the level before construction [5]. Sediments generated from urban construction become the main reason for channel deposition. With the gradual completion of urban construction and the decrease in sediment yield, channel sedimentation intensity has seen a decline but erosion has increased. Trimble studied the information of the San Diego watershed in California from 1980 to 1993 and, after estimation, found that channel erosion provided two thirds of the total sediment yield and was the main source of sediment yield in urbanized area [13]. However, one should note the lack of sufficient quantitative studies in this topic.

2.2. Changes in runoff systems

Urbanization has resulted in increases in the scale and frequency of floods, which are mainly manifested in parameters such as increased flood peak discharge, shortened rising limb and flood duration and increased flood frequency [14-16]. Gregory's research on the hydrological effects of urbanization of a watershed around Exeter city in found that, from 1969 to 1972, the flood peak discharge of urban rivers had increased by 2-4 times, flood frequency had increased from 171/year to 423/year and lag time had decreased by 1/2 [17]. Shi Peijun *et al* carried out researches on Buji River in Shenzhen, which was a typical Chinese area undergoing rapid urbanization. They found that during the 20 years between 1980 and 2000, Buji River's runoff duration had shortened noticeably, its flood stage had uplifted significantly and its flood peak discharge had increased by 12.9% on average [18].

Changes in runoff effect also manifest as increases in surface runoff, total runoff and runoff depth in different degrees. Choi *et al* had carried out researches on a watershed which had undergone rapid urbanization around the capital of Indiana, USA using the Long-Term Hydrologic Impact Assessment model based on GIS technology. The results showed that, from 1973 to 1991, total runoff had increased slightly but runoff coefficient had increased by 16% [19], suggesting that the impact of urbanization on surface runoff is greater than its impact on total runoff. Kim evaluated the hydrological effects of urbanization with the modified Daily Hydrologic Model on the basis of TM data in 1986, 1994 and 2002. He found that the surface runoff in urban areas had increased more significantly than the total runoff and runoff coefficient [20].

There is still debate about whether urbanization changes base flow constant. Some scholars believe that, the increase in surface runoff will lead to a decrease in groundwater recharge, and as a result, a declining base flow [21]. But other scholars disagree with this view. They believe that soil evaporation decreases due to the expansion of built-up areas and therefore causing the reduction in groundwater loss [22]. Meanwhile, the construction of artificial drainage networks such as irrigation, subsurface drainage and inter-basin water transfer further mitigates the impact of groundwater loss on the refilling of base flow [23,24]. After carrying out researches on 6 urbanization watersheds (with a spatial scale of 25-200 km^2) in the center of Delaware, USA over 60 years, David found that only one research area had seen a decline in base flow. This indicates that urbanization and the increase of impervious surface cover did not lead to the decrease in base flow. The construction of underground water conservancy and drainage facilities has caused base flow in some areas to become more stable, hence resulting in an increase in base flow [25]. The study demonstrated the effect of artificial drainage network as base flow resources.

During the process of urbanization, the river runoff system changes significantly. The main reason for this is the increase in impervious surface covers and the decrease in permeability of pervious surface covers [26]. Due to the changes in land usage and the decrease in surface permeability, rainfall converts to surface runoff quickly before flowing into urban water systems via the drainage system, hence damaging the stability of rivers [27,28]. Changes in urban land usage and the structure of impervious surface covers has indeed become a simple and effective method to forecast the evolution of urban rivers [29]. Current research of scholars focuses on the proportion of impervious surface cover (ISC) in watersheds. When the proportion of ISC in forest watershed is less than 10%, the runoff system remains unchanged [30]. When the proportion of ISC increases to 10-20%, the surface runoff doubles. When the proportion of ISC increases to 35-50%, the surface runoff triples. When the proportion of ISC increases to 75-100%, the surface runoff increases by over 5 times [31]. Therefore, scholars believe that 10% is the critical value for ISC [32]. Degradation of many rivers had started with a proportion of ISC between 10%-20% [21]. However, the mechanism influencing such changes needs to be further studied.

2.3. Characteristics of morphological change

Various urban activities such as changes in land use as well as the construction of water conservancy facilities and drainage network affect the morphology and evolution process of rivers [33-36]. Although differences in location and urbanization are the dominant factors affecting river morphology and stability [5], there remain certain universal traits to the evolution of urban rivers on a macro level. They include: urbanization causes a decrease followed by an increase in river flow, a general decrease in river sinuosity, increase in drainage density and bed material armouring.

During the early stages of urbanization, significant quantities of sediments would be generated by urban construction, leading to an increase in urban river sediment discharge and river contraction, thereby damaging the river stability. As a result, river morphology changes in just a few months and years and lag time is also shortened. Compared to rivers in their natural state, the lag time of such rivers is often shortened to 1/5-1/2 of that before urbanization [5,21]. In addition, an increase in sedimentation intensity leads to riverbed elevation, and in turn, it leads to the growth of shoal and dune [37], decline in flood land line water level and expansion of flood plains [38].

Thereafter, urban river discharge increases, especially in humid tropical zones and temperate zones [5]. This is the main reason why the banks and beds of urban rivers are reinforced for the purpose of restricting the expansion of urban rivers and protecting infrastructure and urban architecture from the destruction of river expansion [26]. However, there is a noticeable spatial difference in the mode and degree of river expansion. Gregory has made a statistical analysis on a number of typical urban rivers and found that the flow expansion rate of these rivers varies from 1.0 to 4.0. The expansion rate of rivers in tropical and temperate zones is remarkably higher than those in arid regions. Urban rivers in tropical and temperate zones usually expand 2-3 times and even up to 15 times [5,39] that of their counterparts in arid regions, mainly because the heavy rainfall in tropical zones causes a stronger erosion effect on river banks although the viscidity of soil in humid tropical zones is higher and has fewer erosion features [4,18].

An increase in river discharge is manifested as river broadening or deepening. In general, river expansion manifests as river widening and channel width can increase by 26% on average [40], but it can also manifest as channel deepening and narrowing [41]. Compared to the USA and the rest of the world, rivers in usually become deeper and narrower. This may be attributed to the lower sediment content in rivers in the UK, higher adhesiveness of the soil and special vegetation on the river beds and banks [5]. It is known that river expansion increases the shear stress of river bank. Booth and Henshaw's research in western Washington, USA shows that the incision rate of urban rivers is 1-20 mm yr-1 which is clearly greater than the rate in forested state before urbanization [42]. Simon conducted researches on the water system in western Tennessee, USA over 20 years from 1959 to 1978 and chose the watershed which was suffering from the most severe human disturbance. During the 10^{th}-15^{th} year when the watershed suffered intensive human impact, the upper river system had degraded and the river bed had declined by 1-6m. At the same time, due to excessive incision and slope decline, sediment in the lower reaches had changed by 10-12m [43], resulting in the morphological changes of several channels and branches [44].

Urbanization may also change the particle size characteristic of river bed material [45] and often lead to bed material armouring. Finkenbine's research shows that bed material armouring of urban rivers is likely a result of increasing flood peak discharge and fine sand erosion [40,46]. However, bed material armouring does not happen in all urban rivers [40] as a great quantity of sediments will be brought into the channel during urbanization [47].

Improvements in water conservancy projects enhanced the flood control and navigation capacity of rivers, but artificial straightening had led to the general decrease in river sinuosity. Compared to rural rivers, the sinuosity of rivers in the southeast of Pennsylvania, USA had decreased by 8% [40]. During 1935–1973, the sinuosity of the River Bollin had decreased from 2.34 to 1.37 [48].

Construction activities have a great impact on the density of urban water system. During the early stages of urbanization, small channels would be buried and drainage density would decrease dramatically [49,50]. With the acceleration of urban construction, drainage density of urban rivers would increase and this is mainly manifested in two aspects: on one hand, the construction of artificial drainage networks such as water conservancy and drainage facilities would lead to the significant increase in drainage density from 50% to 808% [17,51-53]. On the other hand, the construction of infrastructure and changes in land usage would result in channel incision which subsequently leads to the formation and development of gullies and an increase in drainage density. Similar to large-scale natural hazards, human disturbance causes an imbalance in the hydrodynamics of upper and lower reaches, thereby shortening the time and process of river incision [54]. For example, gullies are often formed next to the construction site of roads, bridges and drainage facilities to cause local erosion and incision of urban rivers, change of original boundaries of the rivers, decrease its gradient and increase drainage density [17,55]. Restoration of degraded rivers will facilitate river development as well because river restoration behavior is also considered a human disturbance to the natural development of rivers [5].

3. Research methods on river morphology and stability

The contradiction between the ecological, economic and social functions of rivers in urban areas and river degradation grows with each passing day. Many scholars focus on relieving this contradiction through river restoration. They classify the morphology and evolution process of rivers in order to provide the basic theories and research methods for the evolution of river morphology and stability, which will offer basic information and design ideas for the restoration of urban rivers. By summarizing relevant literature data, table 2 categorizes the classification methods which are applicable to urban rivers as follows: morphology-oriented classification method, process-oriented classification method and comprehensive classification method which combines the morphological and evolutionary processes.

Table 2. Review of existing urban river classification systems[a].

Existing Classification System	Description of Features
Morphology-Oriented Classification Method	
Horton (1945)	Empirical classification method which classifies rivers into several grades according to Horton law, gradient and river length.
Leopold and Wolman (1957)	Rivers are classified into three modes according to river morphology: straight river, meandering river and braided river.
Strahler (1957)	Watershed scale classification method which classified rivers according to the number of upstream tributaries that enter given drainage area.
Culbertson, Young, and Brice. (1967)	Rivers are classified according to deposition characteristics, vegetation, drainage network shape, bending, sinuosity, river bank height, embankment composition and river types.
Khan (1971)	Quantitative classification is conducted on rivers with gravel bed according to bending, gradient and channel mode.
Brice (1973)	Channel modes are classified according to bending and the forking degree and characteristics of confluence and tributary.
Kellerhals, Neill and Bray. (1972, 1976), Galay	The function of aerial image and the gradual transition of river types are described and applied to rivers in Canada.

Existing Classification System	Description of Features
Kellerhals and Bray (1973), Mollard (1973)	
Brice and Blodgett (1978)	Rivers are classified into four modes: braided river, braided point bar river, wide-bay point bar river and equivalent width point bar rivers.
Nanson and Croke (1992)	Does not require analysis to determine if the subject possesses all characteristics of the prototype. Three main river types are defined according to energy and river bed resistance (parameters such as particle size, river bed morphology and type of rocks on river bank). River reach type is classified according to the degree of coincidence.
Rosgen (1994)	Geomorphologic classification framework is put forward according to the geometric features of the channel. It classifies rivers into 8 primary types and 94 secondary types. The system classification relies on objective measurement data and belongs to quantitative classification method (see the text for details).
Process-Oriented Classification Method	
Davis (1899)	Rivers are classified into three types based on the theory of "geographic cycle" and according to the maturity stage of river geomorphology: youth, matured and aged.
Wolman (1967)	River evolution is a cycle and responses are made for each of the three urbanization stages: When the area focuses on agriculture or forest landscape, the river will maintain its initial stable stage. During urban construction, exposed land causes soil erosion and thus affect river morphology and its evolution process. After the completion of urban construction, a new urban drainage system which consists of roofs, paved roads, drains and underground drainage system. would be established and rivers would arrive at a balanced state once again.
Schumm (1963,1977,1981)	Three models, i.e., sediment source area, transport area and accumulation area, are put forward according to the large-scale sediment transport process and based on channel stability (stability, erosion or sedimentation) as well as sediment discharge mode (minimum sediment discharge, suspended load, bed load).
Hill (1979)	A multivariate data program is set based on channel type to generate an orderly bidirectional table and to achieve a double-span classification.
Brice (1981)	Channels are classified into degradation, deposition, broadening, or lateral migration of bilateral or unilateral river bank.
Simon (1989)	The anti-disturbance evolution of rivers is classified into six stages and widely applied to urban river restoration in the USA (see the text for details).
Downs (1994, 1996)	Classification shall be performed by combining observed trends, adjustment modes and the evolution process of rivers and sediments to explore the key factors for river changes.
Miall (1996)	Rivers are classified into three types by identifying the sedimentation environment and according to the main characteristics of existing rivers. New types can be added when new examples appear. It is a method which defines types with specific examples.
Woolfe and Balzary (1996)	The processes of rivers are classified into eight types, representing the deposition and degradation map from channel to flood plain.
Comprehensive Classification Method	
Rhodes (1977)	Empirical classification method based on channel hydrodynamics.

Existing Classification System	Description of Features
Mosley (1987)	After reviewing several river classification methods, it was concluded that: All classification methods must be able to reflect the spatial distribution and change frequencies of river evolution, not just the average value of these characteristics (probability review).
Brookes (1988)	Classification basis: river bed degradation, extent of curvature, river branching and river bank erosion.
Raven, Fox, Everard, Holmes and Dawson (1997)	River habitat survey: National River Habit Classification Method of the UK. Main basis: terrain and image material, morphology of mainstream and tributaries, river bed dimension, type of rocks on river bed and bank, natural and artificial characteristics.
Schueler (2000)	Urban rivers are classified into three main types based on the proportion of impervious surface cover: sensitive rivers (impervious surface cover ≤10%), degraded rivers (11%–25%) and rivers that require immediate change (>25%).
Anne Chin （2005）	Urbanization damaged the balanced state of rivers. There is an adjustment period for rivers to transform from current unstable state to a new stable state. The evolution process of rivers is mainly characterized by five main indexes, namely, sediment yield (S), area of impervious surface cover (I), hydrological effect (runoff) (H), river morphology (M) and river degradation degree (including physical degradation and biological degradation) (D). (see the text for details)

[a] This is a revision of Reference [6].

3.1. Morphology-oriented classification method

The morphology-based river classification method is able to provide a visual representation of the basic geomorphologic information of rivers. A typical example is Rosgen's water system classification method. Rivers can be classified into 8 primary types based on their natural morphological characteristics and their similarity in geomorphology. Their characteristics can be described using 6 parameters, i.e., channel incision ratio, width-depth ratio, sinuosity, channel number, water surface gradient and particle size of bed material. Each type of river has different parameters. 450 rivers in the USA, Canada and New Zealand are classified in ascending order of scale. Such classification is applied to river development management aspects such as water conservancy project, fish habitat protection and river regulation [56].

Rosgen's classification system has developed from a simple descriptive tool to a predictive tool and has been adopted by a number of government departments [56] and widely used in river geomorphology research and river regulation works [57]. Despite its success, there are still limitations in the morphology-oriented "natural river design" method as it cannot be used for the quantitative evaluation of reasons for river instability as well as the quantification of causality of river response and accurate prediction of geomorphologic shapes when the river arrives at a stable state again [58,59]. This mainly includes:

- Rosgen changes the classification method from a descriptive tool to a predictive tool based on the promise that rivers with similar morphology have similar evolution patterns, but there is a great controversy on whether this premise is correct [59].
- Weaknesses exist in the "natural river design" method: Firstly, the flood land line water level of natural rivers cannot be measured accurately [60]. "Natural" rivers do not always coincide with "stable" rivers - A natural river may still be in an unstable state and confirmation of the flood land line water level could be difficult, thus making it hard to conduct an effective comparison between restored rivers and natural rivers. Secondly, bed material load is not clearly defined [61] - The particle size of rocks on river bed is mixed with that of rocks on the

river bed and a coincident characteristic value is obtained by such mixture. As a result, different rivers may obtain the same bed material road index and thus a great impact is exerted on river regulation scheme [62].

- The classification method ignored the dynamic characteristics of channel restoration: Restoration will induce river channel deposition, but a river filled with sediments is still an open system which can conduct self-regulation according to water and sand and arrive at a balanced state. Ignoring certain key driving force and resistance [56] in the morphological evolution of rivers will lead to regulation of the designed river and major technical problems in the engineering scheme.

As Rosgen's classification method simplifies the complexity of river systems, it is unable to reflect the mutual adjustment of dynamic state and morphology of rivers and the process of rivers and other complex processes. It is therefore unable to provide a reasonable explanation on some key issues and is more suitable for describing river morphology rather than diagnosing river instability mechanism. In particular, this method is unsuitable for the prediction of river response under external disturbance such as the urbanization of river.

3.2. Process-oriented classification method

As river development trends cannot be deduced accurately with morphology-oriented river classification method, a river evolution process-oriented classification method may prove to be more effective for river evaluation, fluvial geomorphic response prediction and relevant ecological process discussion. Simon's classification method was used for channelized river and degraded rivers initially and a river evolution process-based classification method is proposed for river restoration. (I) Natural river stage: it is assumed that river bed and river bank are the result of the combined function of natural river erosion, siltation and land usage. (II) New channel construction, including renovation of existing banks or reconfiguration of water conservancy facilities of the whole channel (such as setting up flood drainage channel). Urban rivers are usually hard or channelized and are included in this type. (III) Degradation stage after construction: this stage is mainly characterized by rapidly eroded river bed and elevated river bank. (IV) Threshold stage: river incision and sub-erosion strengthen continuously. Channel broadening becomes the main characteristic of this stage. (V) Sedimentation increases, extent of curvature increases, river folks, channel gradient and flow velocity decrease continuously. (VI) Re-stability stage: an important sign is that the flood land line water level drops significantly mainly because of river bed deposition and enhanced sedimentation on the side of the lower bank [43]. In addition, Simon also regards the different stages of river evolution similar to the 6 types distributed longitudinally from upstream to downstream: The source of the river is in pre-disturbance state. An increase in water power and the accumulation and broadening of the channel will lead to the creation of a new balanced state downstream.

Simon's classification method can help assess the river evolution stage and key evolution process as well as also predict future river responses according to the dynamics of sediment and runoff. Thus, the method is widely used in degrading urban rivers. However, this method has limitations with respect to its application in channelized and degraded rivers: On one hand, the continuous change of land usage and the construction of infrastructure such as artificial bank revetment causes lateral contraction of urban rivers and therefore, it is hard to find that the river experiences sedimentation and re-stability stage (Stage V and VI). On the other hand, if there are sufficient time and space for spontaneous river evolution without human disturbance, the incised river may re-experience all stages during the process from instability to stability and as a result, the restoration plan will be out of order. Therefore, Simon's classification method is more suitable for the primary stages of urban water system restoration plan [6].

3.3. Comprehensive classification method

Combining the morphology adjustment and evolution processes organically and evaluating river response in different stages of urbanization comprehensively is the research method that many scholars are exploring now. Chin established the conceptual model of river morphology evolution on the basis of Wolman's model through a statistical analysis on the results of changes during 1956-2006 of rivers in more than 100 regions across the world. Through the model, Chin not only analysed the relationship between river morphology and evolution process but also stressed the theoretical cycle time of river adjustment under the disturbance of urban activities: Non- deformation - deformation - reaching a new stable state after the completion of urbanization. At the same time, the curve takes the variable and complete change into account comprehensively, representing an approximate trend and presenting the variation law of peak value [5].

Chin believes that, in the early stages of urban construction, land development will lead to enhanced surface erosion and increased channel sediment yield. With the continuous improvement of urban construction, impervious surface covers such as pavement and structures increases, sediment yield decreases and surface runoff increases, all of which lead to river erosion and increased channel [63]. Meanwhile, channel sinuosity decreases, bed material experiences armouring, and drainage system density increases. After the completion of urban construction, urban rivers will reach a new balanced state.

This model recognizes the time factor with respect to urban river adjustment. After the completion of urban construction, urban rivers will reach a stable state again, but the time range of adjustment period needs to be further studied. As shown in figure 1, the response period (a) (the river system will not respond immediately after it has been disturbed by urban activities and it will take a while before morphological adjustments can be made) starts when the surface cover formed during the early stages of urban construction is removed and ends when the river morphology starts to change. Relaxation period (b, c, d) marks the entire process of the channel contracting, then increasing and then reaching a new stable state. Thus, it can be concluded that, urban rivers need to get bigger to adapt to the increasing urban runoff so as to reduce river velocity and shear stress and further ensure that river erosion does not happen anymore and reach a new balanced state.

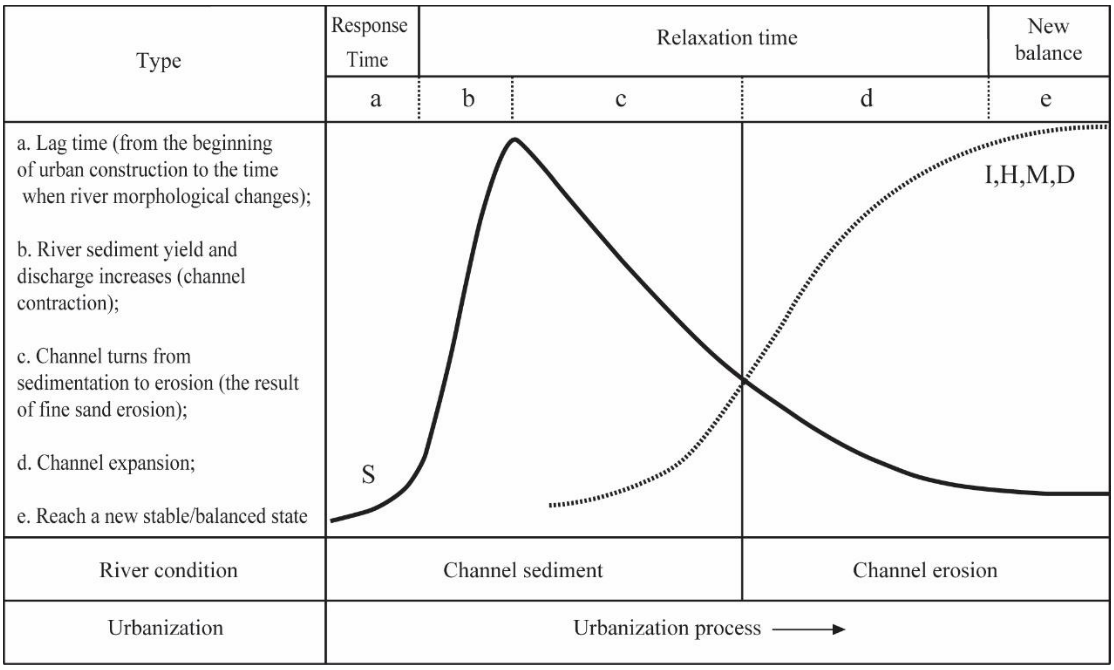

Figure 1. A Conceptual Model of River Evolution by Chin (2006, S Sediment yield and discharge; I Area of impervious surface cover; II Hydrologic variable + runoff variable - lag time; M River morphology; D River degradation. source: Reference [5]).

4. Conclusion

Urbanization changes the look and natural evolution process of rivers. In particular, urban rivers are most affected by human activities. In view of this issue, this paper sorts out relevant research results by reviewing relevant literatures, summarizes the main characteristics and mechanism of urban river morphology and stability evolution, sums up relevant research methods, and draws the following conclusions:

First, the change of sedimentary system and runoff system is the main reason for the change in river stability change. In the early stages of urbanization, construction activities lead to an increase in sediment yield, channel deposition, a decrease in river discharge and a contraction in river morphology. With the continuous increase in human disturbance, the increase in impervious surface covers and the decrease in permeability of pervious surface covers significantly changes river runoff system. This leads to changes such as increased channel erosion, flood peak discharge, flood duration, surface runoff and base flow change, as well as accelerated changes in river morphology. With the completion of urban construction, rivers will reach a new stable state again and characteristics such as river morphology expansion, river sinuosity decrease, discharge density increase and bed material armouring will change.

Secondly, in order to make better use of the evolution mechanism of river morphology and stability in river restoration, scholars have developed various river classification systems which can be summarized as three categories: morphology-oriented classification method, process-oriented classification method and comprehensive classification method. (1) The morphology-oriented river classification method is able to provide a visual representation of basic geomorphologic information of rivers. A typical example is Rosgen's water system classification method. But this method still has its limitation. For example, it cannot be used for quantitative evaluation of reasons for river instability and it is unable to quantify the causality of river response and accurately predict the geomorphologic shape when the river reaches a stable state again. (2) Simon's classification method is a representative of the process-oriented classification method. With this method, scholars can master a large amount of information at different river evolution stages as well as key channel evolution processes based on changed sediment and water flow input so as to predict future river responses. This method applies to degrading rivers but its application to channelized rivers and urban water systems is limited since it ignores the relationship between the debugging time of degraded urban rivers and different urbanization development stages. (3) To avoid the disadvantages of two classification methods above, scholars combine river morphology and evolution process to come up with a comprehensive classification method. Chin built the conceptual model of river evolution on the basis of Wolman's model and emphasized the three stages of river adjustment under the disturbance of urban activities: "non-deformation - deformation-reaching a new stable state after the completion of urbanization". But the time range of the adjustment period needs to be resolved through more quantitative studies.

Acknowledgments

This study was supported by the Guangdong Provincial Natural Science Foundation (2015A030313852), the National Natural Science Foundation of China (41301183 and 41471001), the Scientific Research Foundation for Qingjiang Scholars, Jiangxi University of Science and Technology (JXUSTQJBJ2017002), and the Major Basic Research Development Program of Ganzhou (2017) for Youcun Liu.

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