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ABSTRACT

River ecosystem evolution is one of key issues in earth science. With the increasing population size and rapid socio-economic development, the underlying surface conditions of almost river basins in the world have been seriously changed. Accordingly, the status of river ecosystem constantly evolves, and is followed by serious changes of the structure and function of river ecosystems. In the present study, the evolution and transition states of the river ecosystem in different stages have been analyzed, and guidelines for protection of the river water resources development have been proposed.

KEY WORDS: river ecosystem, human activities, ecological engineering, evolution.

INTRODUCTION

Humans have long been fascinated by the dynamism of free-flowing waters. Yet we have expended great effort to tame rivers for transportation, water supply, flood control, agriculture, and power generation. It is now recognized that harnessing of streams and rivers comes at great cost: many rivers no longer support socially valued native species or sustain healthy ecosystems that provide important goods and services (Poff, Allan, Bain, Karr, Prestegaard, Richter, Sparks and Stromberg 1997). With the increase of population and rapid development of social economy, the river system suffers increasing disturbances by various types of human activities, which results in alterations for both natural flow regime and ecosystem of rivers. In the process of transformation of nature and earth, there forms a project geographical circle created by human activities. This project geographical circle is nested in the atmosphere, hydrosphere, lithosphere and biosphere, and expanding with the progress of human activities. It is the key to view the river ecosystem as a whole, and focus on restoring the natural variation characteristics of both the ecological process and biological richness in management and restoration of the river ecosystem.

Despite the fact that several attempts have been made to assess the ecological or environmental status of waters or the influences they are suffered, in a dispersed or integrative manner, significant gaps still exist on understanding river ecosystem structures and functions and their response to human pressures. Ecosystem service concepts can offer a valuable approach for linking human and nature, and arguments for the conservation and restoration of natural ecosystems. In this study we review and analyze the current literature and propose an approach for assessing and valuing ecosystem services in the context of water management. In particular, to study the link between multiple pressures, ecological status and delivery of ecosystem services in aquatic ecosystems under different scenarios of measures or future changes Grizzetti, Lanzanova, Liquete, Reynaud and Cardoso 2016). Ecological models are currently one of the strongest approaches used to predicting and understanding the consequences of anthropogenic and climate-driven changes in the natural environment. The use of robust and appropriate indicators that can assess whether an ecosystem and its services are well maintained and sustainably used (Layke 2009) has been recognized as an essential step for the practical implementation of conservation and management policies (Rombouts, Beaugrand, Fizzala, Gaill, Greenstreet, Lamare, Loc'h, McQuatters-Gollop, Mialet, Niquil, Percelay, Renaud, Rossberg and Féral 2013). In addition, there are also lots of hydrologists or ecologists studied on river ecological runoff or environmental flow (Suen 2011),(Guo, Xia, Lin and Wang 2009), (Gillespie, Desmet, Kay, Tillotson and Brown 2015), such as minimum ecological flow, optimal ecological flow, etc, as the limitation to protect river ecosystem or develop water resources. However, there are very few researches on evolution characteristics and protection theory of river ecosystems, and even less studies both at home and abroad on balance relationships between river water resource development and its ecosystem protection from the perspective of engineering ecology.

In the present study, impacts of human activities (especially water conservancy project) on the river ecosystem evolution and measures to protect the river ecosystem have been analyzed theoretically. Results of this work may provide the guidance of sustainable development for the future development and management in river water resources, and pave the way for in-depth theoretical study of river ecology.

THEORETICAL BASIS

Engineering Ecology Theory

With the development of society and economy, the impact of human activities (especially the engineering construction) on geographic circle expands from the deep interior of the earth until to the outer space. A new man-made system - engineering circle has been created beyond the terrestrial ecosystems (atmosphere, hydrosphere, geotechnical, and biosphere), that is, the engineering - natural geographical system constructed by the global human activities.

Engineering Ecology is a new gradually developed discipline based on the integration of subjects of society, science and technology, ecological environment, and many other disciplines (Hu and Ma, 2008). It focuses mainly on the application of ecological security theory in the engineering constructions. The main issue concerned with in this subject is the comprehensive strategic issue of the coordination development among human beings- social and economics - natural environment. It puts attention on production, consumption, and development patterns of the whole society, and pursuits the coordinated development among humanity - social and economic - environment, the core part of the ecosystem. In which, the core is the ecosystem. The goal of Engineering Ecology is the protection of the global nature environment, sustainable use of natural resources and sustainable development of the economic society. Study on a certain specific object (such as hydraulic engineering) can not only focus on its production process, we should concern the entire life cycle including its raw materials, production (construction), products, services, and until finally abandonment.

In the perspective of Engineering Ecology, the principle of nature environmental protection is that, the risk of destroying the balance in regional and nationwide nature (environment) is regarded as a comprehensive standard to reflect the ecological effects of human beings ‘production activities. The risk refers to the potential unrecoverable losses (or irreversible process), and the degree of the loss is associated with human activities. The nature environmental protection refers to the minimization of the accumulated loss both for the living substances and abiotic environment. It is embodied as the followings, ① Minimization of the irreparable losses beyond recovery limit which will result in the extinctions of the some species or transformation of the biogeocenose. ② Minimization of the quality losses for the abiotic environment compared with the original size, such as structural change of the soil fertility, soil denudation, hydrogeological change, soil degradation of the ecological fragile zone, and so on.③ Minimization of the abiotic environment losses within the context of self-healing or reversibility of artificial restoration.

According to ecosystem reliability theory, the emergence of any kinds of damage has a certain allowable value. Under the engineering perspective, we call this damage as engineering disturbance. In the range of allowable values, the damage or interference causes chronic damage of the system, but all the natural objects have a protection mechanism to answer and guarantee the local countermeasure, adaptation, and compensation.

Low impact development pattern in urban development

Low Impact Development (LID) is current a popular new concept in the urban development. Low Impact Development is a comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds. The accelerating urbanization and the continuous growth of population, to the natural environment, especially water environment has brought great pressure, caused huge pressures to the natural environment, especially to the water environment. But unfortunately, traditional methods of urban development failed to ease the pressure, and even make things worse. In the end of 1990s, on the basis of technologies of heavy rain management and non-point pollution treatment, design and engineering technology of urban rain flood comprehensive management emerges at the right moment. This is known as the background of LID.

LID is a development approach with the aim of sustainable water protection. Its main objective is to maintain a reasonable land use to minimize the adverse impact on the environment. Under the guideline of considering land development with environmental issues, the main idea of low impact development is to fundamentally change the land development mode, and minimize the negative effect on the environment and the local ecology. Similarly, the idea of LID provides a new thought to restore and protect the river ecosystem, and also offers a reference mode for utilization and transform of river system.

As a concept and guiding ideology in the modern society's development, low impact development has become a kind of advanced guidance idea in the aspects of urban development and land use. This provides a good reference for us in development, unitization, and protection other resources, such as water resources in rivers, lakes and other water bodies.

DIFFERENT DEVELOPMENT STAGES OF RIVER ECOSYSTEM AFFECTED BY HUMAN DISTURBANCES

Evolution of river ecosystem under the influence of human activities

Fig. 1 shows river ecosystem evolution caused by human interference in different development phases. According to history evolution of water system, the status of river ecosystem can be divided into history status and current status. According to the extent of stress of the river ecosystem born and that of the recovery goal could be achieved, the status of river ecosystem could be subdivide into four categories, the best state, slight disturbance state, minimum interference state, and serious interference state. Main factors considered in these classification methods for river ecosystem status include, whether the river ecosystem is disturbed by human beings, to what degree human activity developed (economic level), to what level theory & methodology of water ecosystem restoration developed (technical level).

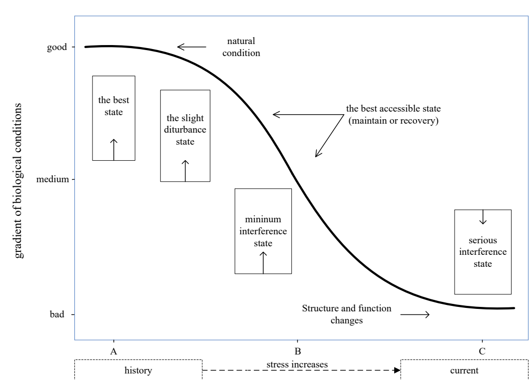

Fig. 1 Schematic of different development stages of river ecosystem affected by human disturbances

The history status refers to a state the river kept in a history moment. If there were no human disturbances in the selected history moment, the river ecosystem is in a natural status with features of optimal physical, chemical, and biological habitat contained in a nature stream, that is the 'the best state'. If there were certain degree of human disturbances in the selected history moment, while the river ecosystem maintains its integrity and diversity, this status is 'slight disturbance state'. The 'slight disturbance state' is a best estimate of biological integrity.

The current status refers to a state the river kept under the conditions of current economic and social development. When the river ecosystem suffered a certain degree disturbance by human activities under the current condition, although it could evolve towards the direction of deterioration, but the river ecosystem can keep the current status or recover to a certain extent under the current technical level, which will maintain the integrity and diversity of river ecosystem within a certain range. Therefore, this status is 'minimum interference state' (also known as low impact state or. low impact development model). The 'minimum interference state' is a best accessible state under the current condition. While, if the structure and function of river ecosystem suffered serious degree disturbance by human activities under the current condition of social-economic development, it is difficult for the river ecosystem to restore to a good state. Therefore, this status is 'serious interference state'.

Reference state

The reference state aims to define and characterize a river state under the natural condition, and is increasingly used as the benchmark to evaluate the disturbance caused by human activities. As to the evaluation of river ecosystem status, we can compare the current status of the river ecosystem with the reference state. This can be used to identify the deviation degree of the current status with the reference state, including structure, composition, function and diversity. So this deviation degree can be used as a metric to estimate the health of river ecosystem. The reference state of river ecosystem should be theoretically a kind state of original and with no human interference or change. But, due to the depth and breadth of human influence since modern times, there are currently very few river ecosystems still in the original status.

According to Stoddard's definition of reference state Stoddard, Larsen, Hawkins, Johnson and Norris 2006) "the reference state of ecological integrity" is considered as the reference state in this study. In Fig.1, there are different levels of human interference in different ecological zones (or different types or scales of river), so there is big difference in setting the reference state. With the continuous development of society and economics, and along with the increasing disturbances on the water body come from the surrounding, as to the river system suffered serious disturbance, it is almost impossible to consider the best state under natural condition or the light distribution state as the reference state. However, it should be feasible to restore the river ecosystem from a serious interference state to a minimum interference state with the support of current technical level, or it should at least be feasible to maintain the status quo and not continue to deteriorate. This can meet the normal function of the river ecosystem.

Mathematical methods were employed to express the evolution of river ecosystem function s in different stages

The structure, function and dynamic process of river systems are characterized by time-space interaction, and the response of river ecosystem to natural or human disturbances also shall be conducted in a certain time and space scales. After suffered by distribution from human activities, functions of the river ecosystem will change accordingly. Fig.2 shows the process of function conversion of the river ecosystem under different stages of human beings' development.

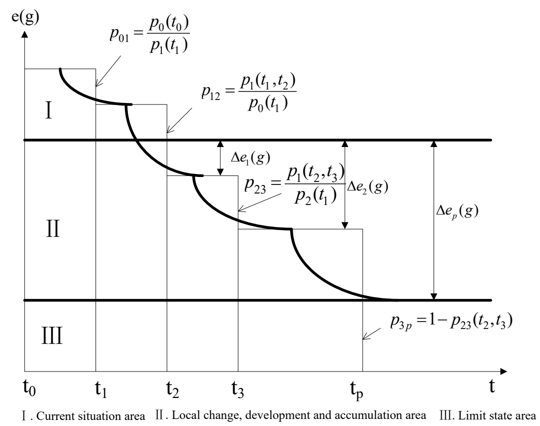

Fig. 2 Transition of the ecosystem function in different stages of human activities

The issue of the status of river ecosystem transfers from one state to another is based on the addition theorem of probability in the methodology. Strictly speaking, this conditional probability depends on the degree of the river ecosystem function changed. The transition of conditional probability in the system show as follows.

(Ⅰ-Ⅰ) Balance development stage of the ecosystem. In the absence of accumulated changes from human activities, ecosystem transfers from one state to another state. The balance of the river ecosystem was not destroyed. The probability of ecosystem balance (ecological stability) is expressed by p_{01}.
(Ⅰ-Ⅱ) Balance development stage of the ecosystem (the equilibrium is not damaged). Ecosystem transfers from an absolute stable state to a relatively stable state with a few obvious accumulated changes caused by human activity. The probability of ecosystem balance (ecological stability) is expressed by p_{12}.
(Ⅱ-Ⅱ) Partly damaged stage of the ecosystem balance. The stage of the ecosystem varies with effects of human activities from Δe_1 level to Δe_i level, and $\Delta e_i > \Delta e_1$. The ecosystem balance has been partly damaged. The probability of ecosystem balance (ecological stability) is expressed by p_{2i}.
(Ⅱ-Ⅲ) Fully damaged stage of the ecosystem balance. The stage of the ecosystem varies with effects of human activities from Δe_2 level to Δe_p limit level, and $\Delta e_i > \Delta e_1$. The ecosystem balance has been fully damaged. The probability of ecosystem balance (ecological stability) is expressed by p_{3p}.

PRINCIPLES OF RIVER ECOSYSTEM PROTECTION IN WATER RESOURCES DEVELOPMENT AND UTILIZATION

Normalized human activity to identify a reasonable reference state

The premise to determine a reasonable reference state is to firstly determine a reasonable scope of threshold value to evaluate the affected river hydrological characteristics by hydraulic engineering. In different stages of human being's development, the structure and function of river ecosystem vary with the hydrological characteristics, habitat characteristics and hydraulic characteristics of rivers. Within the scope of the threshold value, these changes will not beyond the allowable scope in natural condition, so the status of river ecosystem is sustainable. Otherwise, if the disturbance from outside the river system makes the change degree of structure and function of river ecosystem beyond the allowable threshold, the ecosystem will neither be healthy nor sustainable.

In analyzing and evaluating the evolution of river ecosystem, the reference state should be selected reasonably. The reference state will determine the recovery level of the river ecosystem when distributed during human being's development and management of water resources.

Low impact development model in development and utilization of river water resources

Combined with low impact development pattern in urban development and the natural environment protection concept in engineering ecology, we can get the low impact development model in development and utilization of river water resources. This model can be used to analyze the availability level of river water resources. Under the condition of no serious human interference, it is such a natural regime of growth, change and the related ecosystem changes for a river, and also the same for the rise and death for a river. While, in case of human activities, it will disturb the natural water cycle seriously, result in the unhealthy of the river system, and so accelerated the decline of the river. This is the core issue of river health which should be paid more attention to. The degree of the water resources development and utilization should not be controlled by the minimum ecological runoff as the critical value. In order to maintain the stability of river ecosystem and recoverability, the principle of water resources should be that the runoff retaining utilization should not make the river flow less than the optimal ecological runoff in wet years, and the runoff retaining utilization should not make the river flow less than the minimum ecological runoff in dry years. The low impact development model in development and utilization of river water resources proposed in the study is just the protection standard and rules, which is applicable to all rivers.

CONCLUSIONS

In the present study, the evolution and transition states of the river ecosystem under the influence of human activities in different stages have been analyzed. Furthermore, based on the main concepts in restoration ecology and ecological engineering, guidelines for the protection of the river water resources development have been proposed. Results could provide a theoretical basis for river ecological protection and water resources adaptability management.

This article is just a preliminary study carried out in theory. A certain typical river basin should be chosen to conduct empirical analysis in the future. In this study, river ecosystem has been selected as the object. While, in fact, the research ideas, methods and conclusions in this study are also applicable to other aquatic ecosystems, such as lakes and wetlands.

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