PRINCIPLES OF RIVER TRAINING AND MANAGEMENT

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ABSTRACT

River regulation and river training have been performed for various purposes and negative effects have been shown in numerous cases. In some cases the negative effects are so serious that humans have to consider to "renaturalize" the regulated rivers. Only by using the strategy of integrated river management the diverse river uses and natural fluvial processes and ecological systems may be harmonized. Based on analysis of case studies and data collected from literatures this paper presents the concept of integrated river management and four principles of river training. The integrated river management comprises: 1) taking the watershed, upper stream basin including the tributaries, middle and lower reaches and the estuary as an integrated entity in the planning, design and management; and 2) mitigating or controlling the negative impacts on hydrology, erosion and sedimentation, fluvial processes, land use and river use, environment and ecology while in achieving economic benefit from water resources development, flood safety management and hydropower exploitation. River training and management should be in accordance with the four principles: 1) extending the duration of river water flowing on the continent, which may be achieved by extending the river course or reducing the flow velocity; 2) controlling various patterns of erosions and reducing the sediment transportation in the rivers; 3) increasing the diversity of habitat and enhancing the connectivity between the river and riparian waters; and 4) restoring natural landscapes.

Key Words：River training, Integrated river management, Sediment, Erosion control, Ecological and landscape restoration

1 INTRODUCTION

River use has long been an important element in human activities and socioeconomic development. Water is used for domestic, industrial, and agricultural purposes. Hydropower is exploited to engine the industry, the river channel is used for navigation, and the fresh water fishery is a traditional resource. Moreover, rivers and the riparian waters are also used for recreation and leisure. To achieve the economic benefits and meet other demands of humans the rivers have been dammed and channelized. The natural fluvial processes and ecological systems within the river and riparian areas have thus been disturbed to a great extent. River regulation and river training have been performed for various purposes and negative effects have been shown in numerous cases. In some cases the negative effects are so serious that humans have to consider to "renaturalize" the regulated rivers. Only by using the strategy of integrated river management the diverse river uses and natural fluvial processes and ecological systems may be harmonized. This paper presents the principles for river training and management.

Modification of rivers dates from the earliest days of human settlement on the floodplains of the Nile, Indus, and Mesopotamian river systems and has increased throughout history with the reclamation of the valleys of most great rivers. Since about 3,000 B.C., efforts have been made to regulate rivers for the benefit of agriculture. Early floodplain farming utilized the natural seasonal flow variation to supply water to agricultural land and was soon supplemented by elaborate gravity-fed irrigation systems, which has made large-scale agriculture possible. Hydrologic engineering, in the form of irrigation ditches, was practiced as early as 3,200 B.C. in Egypt, which is also where the earliest known dam was built at Sadd el Kafara before 2,759 B.C. (Gore and Petts, 1989). In China, irrigation agriculture was established by 2000

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B.C. By the Qin Dynasty (ca. 250 B.C.), hydraulic engineering, including river channelization projects for navigation and flood control, had been well developed (IWHR and WUHEE, 1985).

Until approximately 1750, the scale of river regulation worldwide was small, and engineering works modified or affected the natural dynamics of rivers. Subsequently, beginning in Europe, major schemes sought complete control of rivers from headwaters to mouth. In North America, Ellett proposed the control of the Ohio and Lower Mississippi Rivers by using both headwater storage reservoirs and channelization of the lower river (Gore and Petts, 1989). Complete control of rivers has been achieved during the 20th century with the development of dam-building technology.

A 'large dam' is usually defined by the International Commission on Large Dams (ICOLD) as one measuring 15 m, or more from foundation to crest-taller than a four-storey building, or with reservoir capacity greater than 1 million m^3 (ICOLD, 1988). According to ICOLD the total number of large dams in 2003 is 49,697 in the world (Jia et al., 2004). There were only eight large dams in China in 1949. From 1950 to 1990 more than 19,000 large dams were constructed. In 2003 the country has 25,800 large dams, ranking the first in the world. The U.S. is the country with the second highest number of dams with some 5,500 large dams, followed by the ex-USSR, Japan and India.

Define reservoir index *RI*:

$$RI = \text{total capacity of reservoirs/annual runoff} \tag{1}$$

If the reservoir index *RI* is smaller than 10%, the river may be regarded natural; if *RI* is in the range of 10-50%, the river is regarded semi-natural; if *RI* is in the range of 50-100%, the river is a semi-controlled channel; and if *RI* is larger than 100%, the river is a controlled channel. Figure 1 shows the index *RI* and the total capacity of reservoirs on several rivers. The Yellow, Mississippi, Colorado and Nile rivers have become human controlled channels and the Yangtze and Pearl rivers can still be regarded as semi-natural rivers.

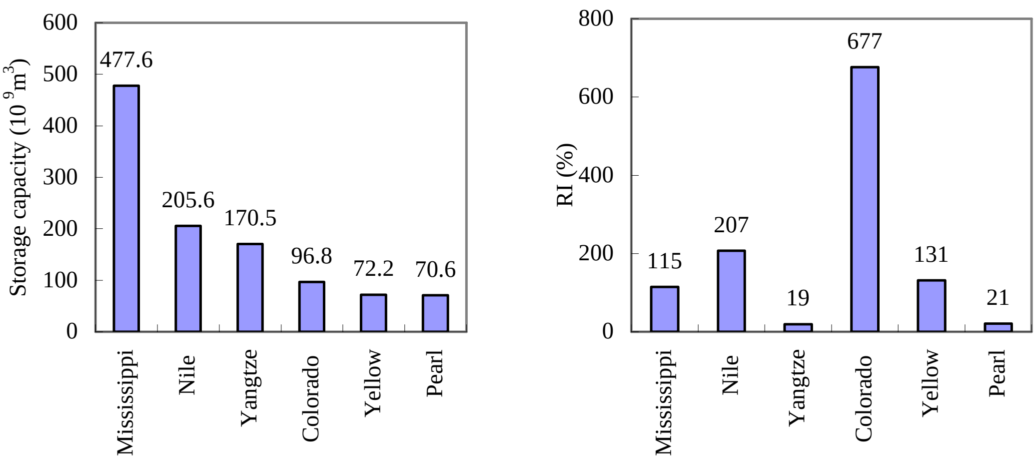


Fig. 1 Total storage capacity and reservoir index for several major rivers

Except for damming channel alignment and levee construction are the most commonly practiced river training engineering. The main aims are to lower flood level and enhance sediment-transporting capacity. The fluvial processes are changed and most of the effects are obviously intentional, since the natural rivers do not offer sufficient flood protection.

Scientists have taken an increasing interest in integrated river management coordinating various sectors of river issues. A developing country, like China, now strongly emphasizes the goal of flood control, water resources development, and environment and ecosystem protection in addition to reducing poverty by supporting efficient and sustainable development of agriculture and light industries. River sustains ecological systems, which also have economic value, and in turn generate a healthy hydraulic system (Wang et al, 2007). People are able under stress conditions to make cautious use of water, thus, not pre-empting the next generation from having similar benefits from the same water system.

Many traditional river training and management are not on the right track in the view of integrated river management, The principles of river training and management are presented in this paper, which indicate the right direction of human effort on river management.

2 INTEGRATED RIVER MANAGEMENT

In river management and training projects factors including sediment transportation, fluvial processes, ecology protection and fish migration have been taking in consideration (Maciej, 2002). The integrated river management comprises: 1) taking the watershed, upper stream basin including the tributaries, middle reaches, lower reaches and the estuary as an integrated entity in the planning, design and management; 2) mitigating or controlling the negative impacts on hydrology, erosion and sedimentation, fluvial processes, land use and environment while in achieving economic benefit from water resources development, flood safety management and hydropower exploitation; and 3) protecting, restoring or improving the natural river ecology and landscapes. The necessity of the integrated river management is learnt from the case studies for the Rhine, Yongding and Mississippi rivers.

Rhine River is the largest river in Germany and the second largest river in central and west Europe. In the past, the river changed its bed after each flood due to bed load transportation, the floodplain had a width of up to 10 km. In 1817, Tulla initiated the channelization of braided Alsatian section of the Rhine and his often quoted statement " As a rule, no stream or river needs more than one bed!" became general policy for hydraulic engineers (Gore and Petts, 1989). Tulla tried out techniques of cutting of bends and fortifying shorelines through dykes and shore protection measures. Only when he convinced himself of the effectiveness of these measures did he set out to straighten the Rhine River in the whole upper Rhine valley. The Rhine training project was completed in 1872. The length of the river course was reduced by 23% and the channel was deepened and narrowed (Yang, 2006). Another project was set up to increase the capacity of the river as a waterway by increasing the depth of the navigable channel up to Strasbourg and Basel, and this was done under the leadership of Max Honsell (Gore and Petts, 1989).

After the river bank was hardened, the resistance was reduced greatly and the flow velocity increased. The time of the flood peak passing from Basel to Karlsruhe was shortened from 64 hours to 23 hours. It met with the flood peak from the Neckar River and threatened the downstream area badly. On the other hand, the area of the flooded swampland and bottomland during the flood season decreased from 1,000 km^2 to 140 km^2. The capacity of the flood control facility in the downstream reaches was reduced from guarding against a 200-year flood to a 50-year flood (Jiang, 1998). The channel was scoured for several meters owing to the high velocity. Some reaches was scoured for 7 m during 1860−1960. The depression of ground water led to the deterioration of navigation channel, leaving the abstraction works and harbor constructions useless, and endangered the river bank and constructions along the river.

To solve these problems the government had to feed Rhine with gravel at a high cost. Every year 170−260 thousand tons of gravels were added into the river in the down reach of Iffezheim Dam (Kuhl, 1992). The hardened banks reduced the capacity of self-purification of Rhine and the increased flow velocity impacted the ecosystem of the river. The pollutions in Rhine stood out with the social and economic development and the river ecology was deteriorated badly (Wang, 2002). The nations in the Rhine River basin recovered the river primarily with a huge cost in the past 50 years (Jiang, 2002).

The similar problems occurred in the Danube River after a series of river training projects, including meanders cutoff, bank hardening and dam construction. The regulated river channel is not as beautiful as the natural one and the flood wave propagates too fast for flood defense in the downstream reaches. So many people appeal to renaturalization of the Danube River.

The Mississippi River watershed, with 41% of the territory of the contiguous 48 states of U.S., had undergone massive transformations in the last 200 years (Milliman and Meade, 1983). The main engineering projects were stepped dams and ship locks, increasing the water depth for navigation. The middle and lower reach were channelized with hardened banks and numerous spur dykes (Su, 1997; Hou et al., 2001). The bend cutoff in the lower reach reduces the channel length by 30% (Xu, 2007; Dominic, 2004). The sediment transportation has been reduced and less than one third of the sediment is transported to the estuary. As a consequence the Mississippi Delta has been shrinking at a rate of about 60 km^2/yr in the past century. Restoration engineering has been appealed to stop the land loss and enable coastal Louisiana to become stable and self-sustaining.

In China, the Guanting Reservoir was built on the Yongding River with main purposes of flood control and water resources supply to Beijing in 1953, when about 2 billion m^3 fresh water flowed into the reservoir annually. Nevertheless, numerous dams have been constructed in the upper Yongding basin. All the river water is used before it flows to the Guanting Reservoir. Nowadays, the Guanting Reservoir receives only 0.2 billion m^3 of sewage water discharged from upstream cities and towns. The ecology has been impacted so seriously that there is almost no fish living in the river and the taxa richness of benthic invertebrates has been reduced from several tens to only a few species.

The three case studies show that integrated river training and management is needed. The river uses must be integrated with the management of the ecological system and the fluvial processes. An integrated river management index *I* is introduced (Wang et al, 2007):

$$I = w_0 R - w_1 H - w_2 S - w_3 G - w_4 E - w_5 L \qquad (2)$$

in which *H* is hydrology management index; *S* is sediment management index; *G* is fluvial process and landscape management index; *E* is ecological system management index; *L* is land use management index; *R* is river use index; and W_i is weighted value for *i*-th index.

The index *R* is the sum of economic benefit from power generation, navigation, water supply, tourism and recreation; *H* can be calculated as the relative change to the hydrological cycle; *S* is the intensity of complex influence on sediment budget (Wang et al., 2007); *G* is the induced instability of the river channel and change of landscape; *E* can be measured as the reduction in number of species of floral and faunal communities; *L* is a value of land use change. The weighted value of W_i must be determined from case studies. The assessment of integrated river management level of river training and management projects can be valued with the index *I*. The higher is the value of *I* the better the river management system. To achieve high level of integrated river management each river training and management scheme should obey the four principles discussed in the following sections.

3 PRINCIPLE I - EXTENDING THE DURATION OF RIVER WATER ON THE CONTINENT

The river is the carrier of lives and provides the creatures with various habitats. The floodplain and riparian wetlands are sites of high biodiversity that depend on flows from rivers. Extending the duration of river water on the continent may provide aquatic bio-communities larger and better habitats and provide humans longer time for river use, i.e. flood water utilization and water surface recreation. There are two management strategies for this purpose: 1) extending the river course; and 2) reducing the flow velocity.

Dam construction on rivers goes well with the principle because artificial lakes provide multiple and stable habitats for aquatic creatures, although it has some negative impacts on the ecology mainly due to cut off of the path of migratory vertebrate species to their spawning sites. The negative effects may be offset by building fish ladders. However, channelization, hardening of banks, cutoff of meanders, and removing obstacles from the channel and floodplain to reduce the roughness are against the principle. Such projects may damage the ecology, and cause the death or poor health of aquatic biota (Kingsford, 2000).

Meandering is the nature of the stream channel. Cutoff of meanders shortens the river course and is against the Principle I. After the cutoff of meanders the flow energy converges, which may result in intensive local scour and bank erosion, instability of channel, and damage of aquatic habitats. Recently an artificial cutoff has been suggested at the Paizhou Meander. The meander is located at the downstream of Tongting Lake and upstream of Wuhan City. There is a big argument between Tongting people and Wuhan people. The former supports the cutoff for reduction of flood risk. The latter worries about that a flood may come to Wuhan quickly and threaten the safety of the city. A flood wave may propagate through a shortened channel more quickly after cutoff but cause flooding problem to the downstream reaches. Moreover, meandering channel is better ecologically-sound than straight channel. Therefore, the artificial cutoff of meanders is not a good strategy.

The term channelization encompasses all the procedures of river channel engineering which are used to control floods, improve drainage, maintain navigation, or restrain bank erosion. These procedures include enlargement, realignment, hardening, embanking or protection of an existing channel, or the construction of new channels. Other channelization procedures classified as river channel maintenance include dredging, cutting, or the removal of obstructions.

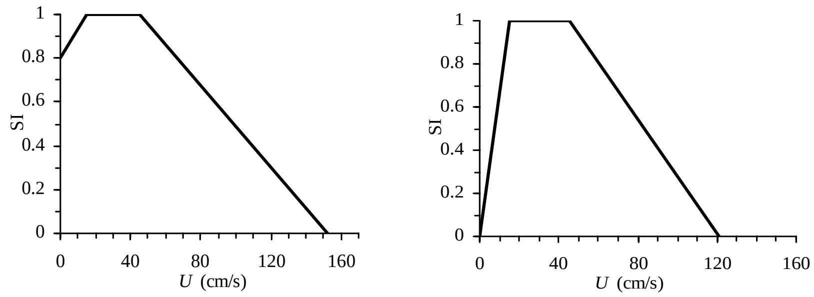
The application of conventional channelization methods can adversely affect the morphological and biological characteristics of river channels. In many rivers, the river banks are hardened and smoothened with concrete and stones, so to enhance the flow velocity for draining flood water quickly. This practice is against the Principle I and not really provides better flood safety. The smooth banks have much smaller roughness than the natural vegetation banks, so high velocity current may directly assault the banks and break the levees. To enhance the bank roughness for controlling high velocity current people stick big stones on the smoothened banks to create high resistance, as shown in Fig. 2.

Fig. 2 Hardened bank is roughened by sticking stones on the surface on the Blue Nile River in Sudan

Floodplain vegetation is a type of resistance factor against flood flow. Such vegetation behaves an obvious obstacle on the flood propagation. A number of studies on flood flow and sediment transport in rivers with riparian vegetation have been conducted to understand the mechanical effects of riparian vegetation on river hydraulics and geomorphology (Ikeda and Izumi, 1990; Thorne, 1990; Ikeda ea al., 1991; Thornton et al., 2000; Carollo et al., 2002). Riparian vegetation promotes geomorphic stability via increased flow resistance and reduced near-bank velocity (Andrews, 1984; Hey and Thorne, 1986). Riparian vegetation also increases the strength of bank and flood plain materials via buttressing, arching, and root reinforcement (Waldron, 1977; Gray and Leiser, 1982). Communities of riparian vegetation can promote entrapment and deposition of fine sediment around river bank and on flood plains (Abt et al., 1994; Lee et al., 1999; Elliott, 2000).

According to the studies on bio-community in the river ecosystem the water flow should be maintained at a velocity below 3 m/s, even for the flood flows. Most of aquatic animals live in lentic or low flow velocity waters. Suitability index, *SI*, is defined as the suitability of physiochemical conditions of the habitat for species to live and spawn. *SI*=1 represents the best conditions and *SI*=0 means the worst conditions. In fact *SI*=0 implies that the species can not live in the habitat. Figure 3 shows the suitability index for Chinese Sturgeon as a function of velocity. The best flow velocity for the species is 0.2−0.6 m/s and *SI* reduces to zero for velocity higher than 1.5 m/s.

From literatures we have collected the distributions of suitability index as a function of velocity for most important vertebrate species in rivers. Table 1 lists the values of critical velocities of U_{c1}, U_{c2}, U_{c3}, of which U_{c1} is the critical velocity for *SI* increases to 1; U_{c2} is the critical velocity for *SI* begins to reduce from 1 down; U_{c3} is the critical velocity for *SI* reduces to zero. The value of *SI* equals to 1 for velocity between U_{c1} and U_{c2}. The velocity range of *SI* for adult, fry, and juvenile fishes and spawning is different for different species. Figure 4 shows the statistical distributions of the three critical velocities for adult, fry, and juvenile fishes and spawning. The vertical axis is the percentage of the statistical species at which the critical velocity smaller than U_c. The stripe shaded area is the range for *SI*=1, or, the best range of



(a) (b)

Fig. 3 Suitability index for Chinese Sturgeon as a function of velocity for (a) adult; and (b) fry and juvenile

Table 1 Critical velocities for *SI* increases to 1, begins to reduce and reduces to zero for 36 species of fishes in the world rivers

Fish species	Adult			Spawning			References
	U_{C1}(m/s)	U_{C2}(m/s)	U_{C3}(m/s)	U_{C1}(m/s)	U_{C2}(m/s)	U_{C3}(m/s)	
Chinese Sturgeon	0.15	0.45	1.52	1.15	1.5	2.6	Yi, et al., 2007
Chinese carps (Black carp, grass carp, silver carp and big head carp)				0.27	0.9	4.15	Yi, et al., 2006
American Shad	0.2	0.9	1.5	0.3	0.9	1.3	Stier and Crance, 1986
Gizzard Shad	0	0.2	1.2	0	0.1	0.6	Williamson and Nelson, 1985
Arctic Grayling Riverine Populations	0.3	0.9	1.2				Hubert,et al., 1985
Bluegill	0	0.09	0.43	0	0.08	0.36	Stuber,et al., 1982a,b,c
Blacknose Dace	0	0.3	0.86	0.2	0.45	0.65	Trial,et al., 1983a,b
Longnose Dace	0.45	0.65	1.23				Edwards, 1983a,b
Brook Trout				0.3	0.6	0.9	Raleigh, 1982
Brown Trout	0.2	0.2	1.8	0.2	0.5	1.2	Raleigh,et al., 1986a,b
Cutthroat Trout				0.3	0.6	0.9	Hickman and Raleigh, 1982
Rainbow Trout	0.15	0.6	1.07	0.3	0.7	0.9	Raleigh,et al., 1984
Common Shiner	0.15	0.2	0.5				Trial,et al., 1983a,b
Flathead Catfish	0	0.3	1.97				Lee and Terrell, 1987
Channel Catfish				0	0.15	0.43	McMahon, and Terrell, 1982
Chinook Salmon				0.3	0.85	1.15	Raleigh,et al., 1986a,b
Pink Salmon				0.5	0.7	1.5	Raleigh and Nelson, 1985
Longnose Sucker				0.3	1	2.7	Edwards, 1983a,b
Green Sunfish	0	0.1	0.25	0	0.1	0.15	Stuber,et al., 1982a,b,c
Redear Sunfish	0	0.01	0.1				Beghart,et al., 1984
Largemouth Bass	0	0.06	0.2	0	0.03	0.1	Stuber, et al., 1982a,b,c
Smallmouth Bass	0	0	0.6	0	0.4	0.9	Edwards,et al., 1983
Spotted Bass	0	0.06	0.85	0	0	0.3	McMahon, et al., 1984a,b,c
Inland Stocks of Striped Bass				0.5	1.2	4	Crance, 1984
Paddlefish	0	0.1	0.7	0.6	3.7	4.6	Hubert and Anderson, 1984
Yellow Perch	0	0.03	0.12	0	0.09	0.15	Krieger,et al., 1983
Pink Salmon	0	1.22	2.04				Raleigh and Nelson, 1985
Shortnose Sturgeon	0.16	0.45	1.52	0.3	0.76	1.52	Crance, 1983
Slough Darter	0	0.05	0.24				Edwards, 1982
Southern Kingfish	0.2	0.5	0.75				Sikora and Sikora, 1982
Walleye	0	0.06	0.9	0.76	0.9	1.1	McMahon,et al., 1984
Warmouth	0	0.06	0.25				McMahon, et al., 1984
White Sucker	0.1	0.15	0.4	0.3	0.6	0.9	Twomey,et al., 1984
White Crappie	0	0.2	0.4				Edwards, 1982a,b

Note: U_{c1} is the critical velocity for *SI* increases to 1; U_{c2} is the critical velocity for *SI* begins to reduce from 1; U_{c3} is the critical velocity for *SI* reduces to zero. The velocity between U_{c1} and U_{c2} is the best for the species. The species can not live for velocity larger than U_{c3}.

velocity for the species to live and spawn. As shown in Fig. 4 (a) and (b), 100% of the species have the *SI* value less than 1 and about 90% of the species can not live if the velocity is higher than 2 m/s for adult, and 100% of the species have the *SI* value less than 1 and about 85% of the species can not process if the velocity is higher than 2 m/s for spawning. Figure 4 (d) shows that 100% of the species have the *SI* value equal to zero for juvenile fishes if the velocity is higher than 2 m/s.

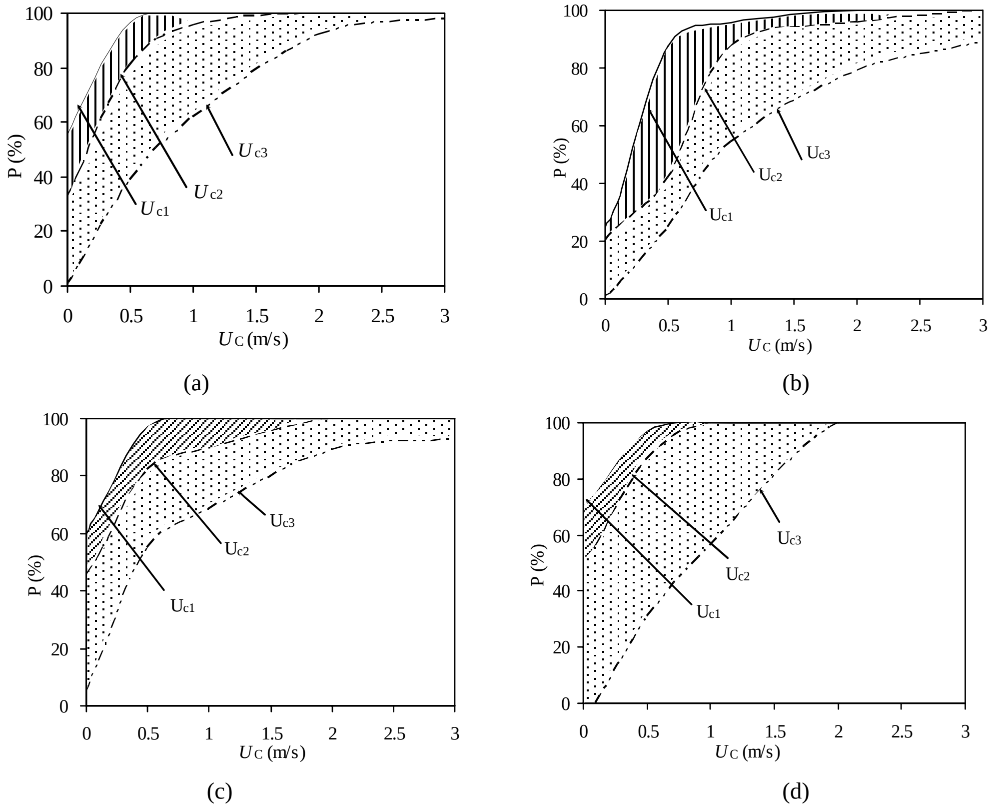


Fig. 4 Statistical distributions of the critical velocities for *SI* increases to 1 (U_{c1}), begins to reduce (U_{c2}), and reduces to zero (U_{c3}) for 36 species of adult fishes (a); spawning (b); fry fishes (c); and juvenile fishes (d)

In summary the rivers should be trained and managed to reduce the velocity including flood flow velocity. The actions to remove obstacles from the channel, floodplain and banks to enhance the flow velocity are not on the right track and are against the Principle I. On the contrary, the concept of resistance construction should be introduced in the river training and management projects. If the resistance structures are constructed on the whole river system including the upper, middle and lower reaches the flood wave propagation will be slowed down. The flood safety can be improved due to the low scouring energy and enhanced levees. Moreover, the aquatic habitat will become stable and the suitability index of the river habitat will increase to one.

4 PRINCIPLE II – CONTROLLING EROSION AND REDUCING SEDIMENT TRANSPORTATION

Sediment is the core for the fluvial processes. Sediment movement starts from soil erosion. Therefore, erosion control is essential for stabilization of river network. Sediment load of rivers comes from the mountainous area due to slope erosion, rill erosion, gully erosion and channel bed and bank erosions. Erosion is also the essential cause of the geological disasters of landslide and debris flows. After the sediment is eroded from upstream watershed and transported by the river flow, it will also be deposited somewhere in the river basin or at the river mouth. Erosion changes the upstream landscape and impairs or even destroys the vegetation, and sediment deposition also changes the river morphology and buries the substrate of the aquatic habitat.

Channel incision in the mountain rivers increases the slope of gullies and banks, thus is the essential cause of various erosions. The most important strategy to control erosion is to develop the resistance structures to control channel bed incision. Mountain streams may develop natural resistance structures to mitigate channel incision under some conditions, such as step-pool system, ribbing structure, bank stones, star-studded matrix and cobble clusters. In streams with slopes in the range of 0.5−3% ribbing structures often develop, enhancing the flow resistance and mitigating channel incision. Cobbles and boulders overlap with each other and form ribs extending out from the banks. Figure 5 shows two bridges on a tributary of the East River in Guangdong Province, southern China. In the downstream section of the river boulders and cobbles have been mined as building material and there is no ribbing structure, thus the channel bed is eroded down by about 2 m and the bridge is endangered by the incision (a). In the upstream section with ribbing structures the channel bed remains stable, no channel incision has occurred, and the bridge is safe (b).

(a) (b)

Fig. 5 (a) In a section of a tributary of the East River without ribbing structures the channel bed is eroded down by about 2 m and the bridge is endangered by the incision; (b) In another section of the same stream with ribbing structures the channel bed remains stable.

Experiments and field investigations have proved that the development of step-pool systems increases the flow resistance, consumes the flow energy, protects the streambed from erosion, and supports high diversity of bio-community (Wang et al., 2006). The results of flume experiments have extended this role in suggesting that step-pool systems not only increase flow resistance but also maximize it (Whittaker et al., 1982; Abrahams et al., 1995; Wang and Xu, 2004). Their innovative experiments and field observations led Abrahams et al. (1995) to conclude that step-pool system, evolves towards a state of maximum resistance because it implies maximum stability. Thus, an explanation of why step-pool systems develop and why they have a particular morphology can be couched in terms of their effect on energy dissipation. Moreover, step-pools may provide high diversity of habitats for aquatic bio-communities. The flows over the steps adsorb oxygen from the air and increase the concentration of dissolved oxygen, which is important for the aquatic ecosystem.

In the experiments the resistance and the bed roughness increased in the process of bed erosion. In streams with step-pool system the bed is stable. In streams in the Cascade Mountains of Washington state, U.S. the resistance caused by the step-pools comprises more than 90% and the grain resistance and channel form drag make up less than 10% of the total flow resistance (Curran and Wohl, 2003). Wang and Xu (2004) demonstrated that the resistance increases linearly with the development degree of step-pools.

In many incised mountain streams there is no step-pool system. Artificial step-pool system has been used for mountain stream stabilization and ecological restoration in Germany, Austria, United States and China. A field experiment using artificial step-pool system for channel bed incision control, landslide and debris flow control and aquatic ecology restoration was carried out on the Diaoga River on the Yunnan-Guizhou Plateau, Southwest China (Wang and Yu, 2007). The artificial step-pools were designed to mimic the natural step-pools developing in a neighboring ravine. Stones were laid out one overlapping another to ensure the stability of the step structure. The artificial step-pool system increases the flow resistance, controls channel incision effectively, debris flows was reduced to hyper-concentrated flows when passing through the experiment section, and the hazards were mitigated greatly. Figure 6 shows a cross section of the experimental reach of the river. With the artificial step-pool system constructed on the channel, the incision was effectively controlled; some sediment even silted up on the channel, so the elevation of the cross-section rose. Moreover, the artificial step-pool system increases the water surface area, expands the range of water depth and flow velocity, thus forms diversified habitat. The improvement of habitat creates a favorable aquatic environment, thus promotes the development and growth of benthic invertebrates. The number density of individual invertebrates, taxa richness (number of benthic invertebrates species) and bio-community diversity all rise with the increase of habitat, thus the aquatic ecology in the experimental reach is improved markedly.

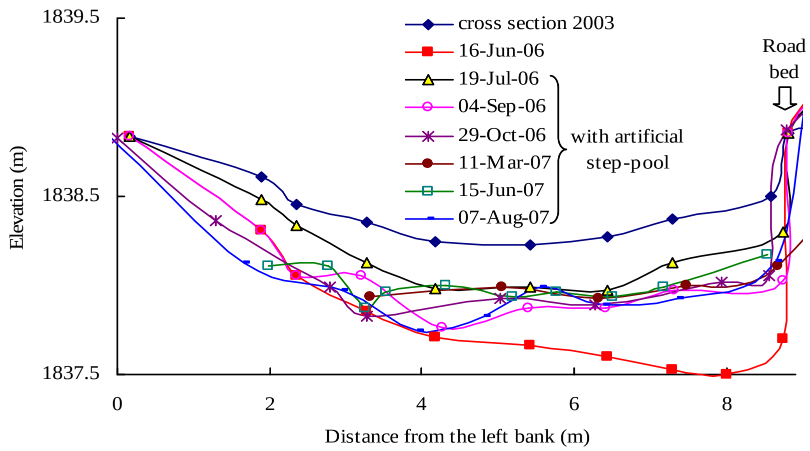


Fig. 6 Fluvial processes at a cross section in the experimental reach of the Diaoga River with an artificial step-pool system, which was constructed on June 16−18, 2006

The second important strategy to control erosion and reduce sediment transportation is reforestation. Selected species for reforestation are more effective for soil erosion control. For instance, there is an area of more than 11,000 km^2 in the northwest China, which is covered by a kind of loosely bonded sandstone formed in the Tertiary. The sandstone is hard when it is dry and changes into sand when it is put into water. The area has a very high erosion rate (more than 20,000 t/km^{2}yr) and very poor vegetation. *Seabuckthorn* has been successfully used to reforest the gullies and control erosion in the area. Field investigations have been performed in the Xizhao Gully to study the effects of the species on sediment trapping and ecology improvement (Bi, 2002). It is found that the *Seabuckthorn* mutualizes *Clinelymus dahurcus Turcz* and the two species form a dense double-layer vegetation with well developed middle and understory plant communities. The vegetation cover in the gullies reaches 95%. The vegetation has trapped almost all sediment since *Seabuckthorn* forest developed in the late 1990s (the species was introduced in 1995), in other words, the sediment trapping efficiency is more than 90%. Rainstorm water has been also stored in the gully within the trapped sediment. The water content in the vegetated gully is about two times higher than the comparing plot. The understory community of the *Seabuckthorn* vegetation is much better than the poplar forest area and the willow forest area. The taxa richness and the thickness-coverage of the sublayer vegetation in the *Seabuckthorn* area are about two times higher than the latter two.

Construction of numerous sediment trapping dams on the loess plateau is in accordance with the Principle II. More than ten thousands of sediment trapping dams on the loess plateau have remarkably reduced the sediment load into the Yellow River. In the past decades, Chinese rivers have experienced the great sediment load reduction (Liu et al., 2007). Gradual reduction of sediment transportation in rivers may improve the river health, but abrupt reduction may also cause stress on the river management, land creation and ecology.

River training projects to enhance sediment-transporting capacity are against the Principle II. If sediment transportation in a reach is intensified, local sedimentation may be controlled but an abnormal stress is put on the downstream reaches. Moreover, high sediment-transporting capacity is very fluctuating and is difficult to manage. In the Ming Dynasty, Jixun Pan proposed the strategy of narrowing the Lower Yellow River and confining the flood within the stem channel in order to raise the velocity and keep high the sediment-carrying capacity, preventing sediment from depositing and even promoting bed sediment scouring. He regulated the levee system, blocked many branches of the river and made the river flow in a single channel in the period 1565-1592. Nevertheless, the strategy of narrowing the channel was difficult to apply and soon after Pan's projects the sediment deposition in the downstream channel sped up to 5−10 cm per year.

Freeman (1922) supports the idea of Pan to enhance sediment transporting capacity. He visited the Yellow River in 1917 and proposed to build cross dykes extending from the existing levees of the lower Yellow River, which were more than 6 km apart, and to build new levees near the tips of the dykes, 800 m apart (Freeman, 1922). Freeman's suggestion rekindled the century's debate on whether the levees should be close or far apart as they were at the time. Engles conducted physical model experiments, authorized by the Chinese National Economic Council in 1931−1934. The test results indicated that with the levees set far apart, a somewhat more stable main channel was produced than when the levees were close to the main channel edges (Engels, 1932). Franzius conducted another physical model experiment and obtained different results. Yen (1999) indicated that Franzius' experiments were conducted without tail gate regulation and the results are not reliable as those of Engels. River training projects for enhancing sediment-transporting capacity are against the Principle II and should be abandoned.

5 PRINCIPLE III – INCREASING DIVERSITY AND CONNECTIVITY OF HABITATS

The streams provide habitat for benthic macro-invertebrates and fishes, and on the other hand, the stream habitat can be rapidly assessed with benthic macro-invertebrates or fishes. Macro-invertebrates, include worms, snails, and insects larvae such as mayfly, caddis fly, dragonfly, and midge, is in the middle of the chain in the aquatic ecosystem. Investigations and sample analysis show that streams with abundant macro-invertebrate have good water quality and high self-purification capacity because many species of macro-invertebrate may consume some pollutants, bacteria and algae, which are the causes of bad water quality. Benthic invertebrates are used as the most important indicate species for rapid bioassessment, which is to evaluate the overall biological condition, optimizing the use of the benthic community's capacity to reflect integrated environmental effects. According to research results the biodiversity is directly proportional to the stability and diversity of the habitats. The river training works should increase the habitat diversity. To gain it, the two aspects must be met: 1) increase the water surface area in the river course and riparian waters and connectivity between water bodies; 2) increase the water area with low velocity and various water depths, such as bays and lakes.

The physical conditions of stream habitat are mainly 1) the substrate; 2) water depth, and 3) flow velocity (Gorman and Karr, 1978). Different physical conditions support different bio-communities and diversified physical conditions may support diversified bio-communities. A habitat diversity index, H_D, is proposed as follows：

$$H_D = N_h N_v \sum_i \alpha_i \tag{3}$$

where N_h and N_v are numbers for water depth diversity and velocity diversity, and α is the substrate diversity with values for different substrates: α =6 for boulders and cobbles; α =5 for aquatic grass; α =4 for fluid mud; α =3 for coarse gravel; α =2 for fine gravel; α =1 for silt; α =0 for sand. If a stream has three water areas: 1) shallow water, in which the water depth is in the range of 0−0.1m; 2) mid depth water, in which the water depth is in the range of 0.1−1m; and 3) deep water, in which water depth is larger than 1 m, and each of the three areas is larger than 10% of stream water, N_h=3. If a stream has only shallow water and mid depth water, and each of them is larger than 10% of stream water, N_h=2. The value of N_h for other cases can be analogously obtained. If a stream has three water areas: 1) lentic area, in which the flow velocity is smaller than 0.3 m/s; 2) mid velocity area, in which the flow velocity is in the range of 0.3−1m/s; and 3) lotic area, in which the velocity is larger than 1 m/s, and each of the three areas is larger than 10% of stream water, N_v=3. If a stream has only lentic and mid-velocity areas, and each of them is larger than 10% of stream water, N_v=2. The value of N_v for other cases can be analogously obtained. Results of field investigations and sample analysis indicate that the higher is the habitat diversity, the higher is the biodiversity of the ecosystem. A river training project increasing the habitat diversity may result in better effect on ecology.

Some river training works result in the fragmentation and isolation of habitats. Figure 7 shows the concrete banks of an urban channel in Beijing, which has very bad effect on the ecology. The aquatic creatures living in the sediment bed lose their shelter and thus have disappeared off the channel. Only a species of mosquito, which may survive in seriously polluted water, is found in the channel. Recently the Beijing government has decided to abandon the concrete channel bed and banks and to use sediment bed and stone and vegetation banks instead for ecological improvement. It is reported that after the concrete banks and bed were replaced by sediment bed and stone and vegetation banks the water volume consumption to maintain a good water quality has been halved.

Fig. 7 Concrete banks and bed of an urban channel in Beijing result in vanishing of many species

Fig. 8 Cut off of flow in the Baoxing River in southwest China for power generation

Dam construction and hydro-power exploitation cut off the migration of fishes from downstream to upstream for spawning and impair the ecology. Fish ladders have been built on many large dams to mitigate the impact. Figure 8 shows the cut off flow in the Baoxing River, a tributary of the Dadu River in the upper Yangtze River basin. A low dam has been built and all the river water is diverted to the Xiaoguanzi Power Station through a pipe line, which is about 20 km downstream of the dam. Thus, the flow between the dam and the power station is cut off. The stream is dry up and the river ecology is deadly impacted. On many rivers in southwest China, numerous power projects have fragmented the river habitat. Such a type of power exploitation is against the Principle III and should be abandoned.

Figure 9 shows the Yangtze River and numerous riparian lakes with different sizes. Naturally these lakes connected with the Yangtze River and formed a huge habitat in the past. Humans cut the connection for flood defense and aquatic farming, thus fragmented the habitat. The fragmentation of habitat has resulted in deterioration of ecology and extinction off some species. Proposals have been made to construct connection channels between lakes and river for ecological restoration.

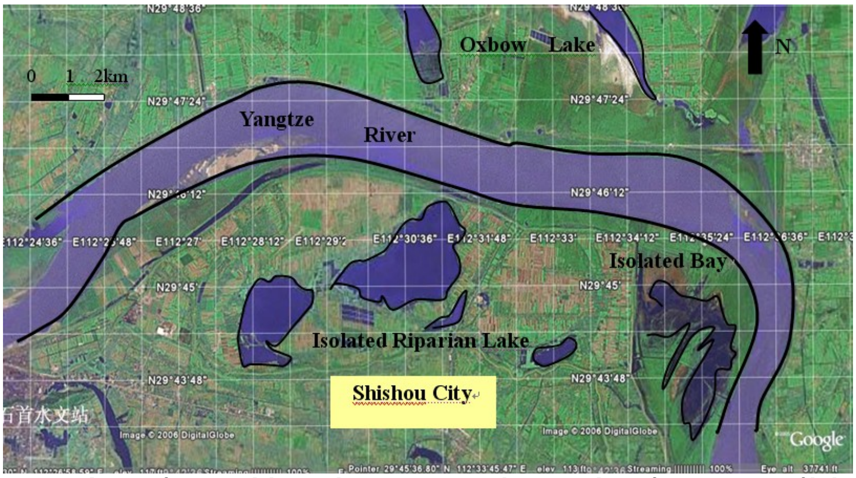


Fig. 9 Isolation of riparian lakes in the Yangtze River basin results in fragmentation of habitat (Satellite image from the web http://earth.google.com)

6 PRINCIPLE IV - RESTORING NATURAL LANDSCAPES

River flows through the continent and shapes all landscapes. Indeed, rivers are such an integral part of the land that in many places it would be as appropriate to talk of riverscapes as it would be of landscapes. Various river uses have changed the riverscapes. Beautiful meanders have been changed into straight channels with hardened banks, waterfalls have been replaced by power stations, and the riparian forests have been changed into grand levees. Recently, people have realized that the riverscapes are a wealth of nature presenting to humans. Riverscape (or landscape) restoration has become a public concern and projects have been performed to restore riverscapes.

Cheongyechon in Seoul in South Korea was a beautiful stream in the past. Following quickly urbanization in the drainage area the river was congested with rubbish and was reshaped into a subdrainage culvert. To restore the riverscapes the government invested 360 million dollars to reconstruct the urban stream. As shown in Fig. 10 (a), now Cheongyechon has become a resort of urban residents, with clean water, a beautiful artificial step-pool system, bridges, riparian vegetation and pedestrian path, making the city more charming (Kyung and Zeng, 2007).

The Jiuzhaigou Creek in southwest China was a debris flow gully in the past. Landscape protection and restoration projects have been carried out. Check dams have been constructed to control debris flows but not affect the landscapes. The ecosystem in the creek has a high ecological resilience, which has been considered as an important element in the projects (Cui et al., 2003). Figure 10 (b) shows the beautiful water

(a) (b)

Fig. 10 (a) Restoration of riverscapes of Cheongyechon in Seoul in South Korea; (b) Beautiful Jiuzhaigou Creek in the Sichuan Province in southwest China has become a tourist attraction because of its protected landscapes falls in the Jiuzhaigou Creek, The landscapes in the creek attract 1.5 millions tourists every year. Economically the Jiuzhaigou Creek with the preserved landscapes is more money-making than hydro-power development. The annual tourism income is more than 200 million dollars, which is about 7 times of the hydro-power income from the great Sanmenxia Dam on the Yellow River.

7 CONCLUSIONS

The integrated river management comprises: 1) taking the watershed, upper stream basin including the tributaries, middle and lower reaches and the estuary as an integrated entity in the planning, design and management; and 2) mitigating or controlling the negative impacts on hydrology, erosion and sedimentation, fluvial processes, land use and river use, environment and ecology while in achieving economic benefit from water resources development, flood safety management and hydropower exploitation. River training and management should be in accordance with the four principles: 1) extending the duration of river water flowing on the continent, which may be achieved by extending the river course or reducing the flow velocity; 2) controlling various patterns of erosions and reducing the sediment transportation in the rivers; 3) increasing the diversity of habitat and enhancing the connectivity between the river and riparian waters; and 4) restoring natural landscapes. The study also demonstrates that the suitability index for most of the aquatic creatures reaches one in a range of velocity below 2 m/s. If the velocity is higher than 3 m/s, fishes will suffer and die. Therefore, river flow velocity should be kept below 3 m/s. Ecology restoration and landscape restoration are focal points in river training and management projects.

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