Eco-hydraulics modelling of the ecological water requirement in an Eco-City

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ABSTRACT

An integrated eco-hydraulics model has been developed and applied to simulate the ecological values of water dependent ecosystems in an eco-city, which is designed to be ecologically friendly in water and energy at a low level of risk. The model comprises a two-dimensional hydrodynamic and water quality model and an ecological model Habitat Suitability Index (HSI). The modelling work in this study aims to understand the roles of different flows for different bioperiods of aquatic habitat and keep the quality and quantity of the water flowing through the river in the eco-city within acceptable limits.

Three scenarios were simulated, based on the current flow rates in the supply river for different stages. With the purpose of improving the river habitat, flow augmentation simulations were implemented for the Jiyun River. The modelling results indicated that the optimum ecological water requirement in the study area is between 144 and 192 m^3/s from March to November and between 112 and 144 m^3/s from December to February. However, due to water shortage in the study area, flow augmentation may not be achievable unless significantly more water can be diverted onto the river. The planner should consider other interventions, such as channel modification.

Key words: ecological water requirements, habitat suitability index, 2D numerical simulation

1. Introduction

Due to the over-abstraction and inappropriate regulation of water resources in the past decades, many freshwater ecosystems have been degraded to the point that they can no longer support biodiversity or food production. To protect the ecological functioning of water resources some water must be left in rivers and lakes, and this is known as the ecological reserve, sometimes called Ecological Water Requirements (EWR) (*Acreman, 2004*). Detailed methods for quantifying the ecological in-stream flow requirements of river and lakes have been used to estimate environmental water requirements internationally, such as hydrology-based approaches (Montana method, flow during curve method, 7Q10), hydraulics-based approaches (wetted perimeters method, R-cross method) and habitat simulation-based approaches (in-stream flow incremental methodology, PHABSIM) (*Tennant, 1976; Caissie et al., 1998; Mosely, 1982; Milhous et al., 1984; Jowett, 1997; Reiser et al., 1989a,b).* These methods differ mainly in terms of the data requirements. For example, some methods require only flow data, while others require hydraulic and biological information. Each method has its advantages and disadvantages. Hydrology-based approaches are inexpensive and rapid but they have limited or no ecological information to support them. Hydraulic methodologies provide river-specific data and are relatively inexpensive and simple to apply, but they can fail to indicate the significance of changes in the measured physical conditions for the aquatic biota. Habitat simulation methodologies involve high resolution characterisation of habitat availability for target organisms and are flexible for the assessment of different flow scenarios but they are resource and time intensive and largely confined to target species (*Gippel, 1998; Prewitt, 1980; King, 1998; Thomas, 2002; Jackie, 2003*).

With the advancement of computing simulation power, the use of numerical modelling for conducting environmental flow assessments has become widespread for rivers, lakes, estuaries and coastal regions. For example, one-dimensional (1D) flow models are often used to analyse a river reach by breaking it into discrete cells (or subsections), with each being assigned a single depth and velocity value (*Bovee, 1978*). The HEC-RAS software *(USACE, 1991)* is an example of the type of models used to simulate water surface levels in rivers. However, the inability of 1D models to describe two-dimensional (2D) flow processes favour the use of 2D hydraulic models as predictive tools in environmental flow studies (*Leclerc et al., 1995; Tarbet and Hardy, 1996; Waddle et al., 1996*). *Bovee (1996*) suggests that the most promising aspect of 2D models in environmental flow studies is their potential to accurately and explicitly quantify spatial variations and combinations of flow patterns important to stream flora and fauna.

Recent developments in the fields of stream ecology and geomorphology have provided an opportunity to link ‘biological’ and ‘physical’ definitions of aquatic habitat. Therefore, the major trend in environmental flow assessment over the past few years has been a shift from narrow studies that concentrate on one single method to a holistic approach. Linking physical habitat conditions (flow depth, flow velocity, and sediment calibre) in rivers to their ecological characteristic is now a fundamental requirement in river management and river restoration (*Clifford et al., 2010*). Accurate hydrological and hydraulic data, together with a sound understanding of the ecosystem dynamics based on field surveys over extended periods of time should be able to generate high confidence EWR recommendations (*Hughes, 2010*). Many researchers have used 2D hydraulic models combined with HSI modelling and described their superior performance over traditional 1D river models. For example, the environmental flow requirement of spawning for ayu (*Plecoglossus altivelis*) was predicted with the preference curves of the flow depth, velocity and substrate by making use of a horizontal 2D numerical model (*Takayaki, 2008*). *Yi (2010)* developed a mathematical model to simulate and predict minimum instream flow and suitable daily discharge during the reproduction season for the carp species in the Yangtze River, by coupling the habitat suitability curves and the mathematical model. Combining the suitability criteria curves of various macroinvertbrate species with a hydrodynamic model permitted a better understanding of factors influencing and enhancing ecological diversity and habitat creation (*Bockelmann et al., 2004*). However, little research has been done to simulate the ecological water requirement of the whole bioperiod of a target species. Thus, this study aims to build on the ability to model the roles of different flows for different bioperiods of aquatic habitat using an ecohydraulics model, where the 2D hydrodynamic and water quality model Depth Integrated Velocities and Solute Transport (*DIVAST - Falconer and Lin, 1998*) is linked to an HSI model.

2. Study area and data collection

2.1 Study site

In this paper a case study of water planning in Sino-Singapore Tianjin Eco-City is presented. The 30-sq km Tianjin Eco-city is a strategic cooperation project between China and Singapore to create a resource-conserving and environment-friendly community that will serve as a model of sustainable development for other cities of China. Its proposed location is along the Jiyun River in Hangu District of Tianjin Municipality, as shown in Figure 1.

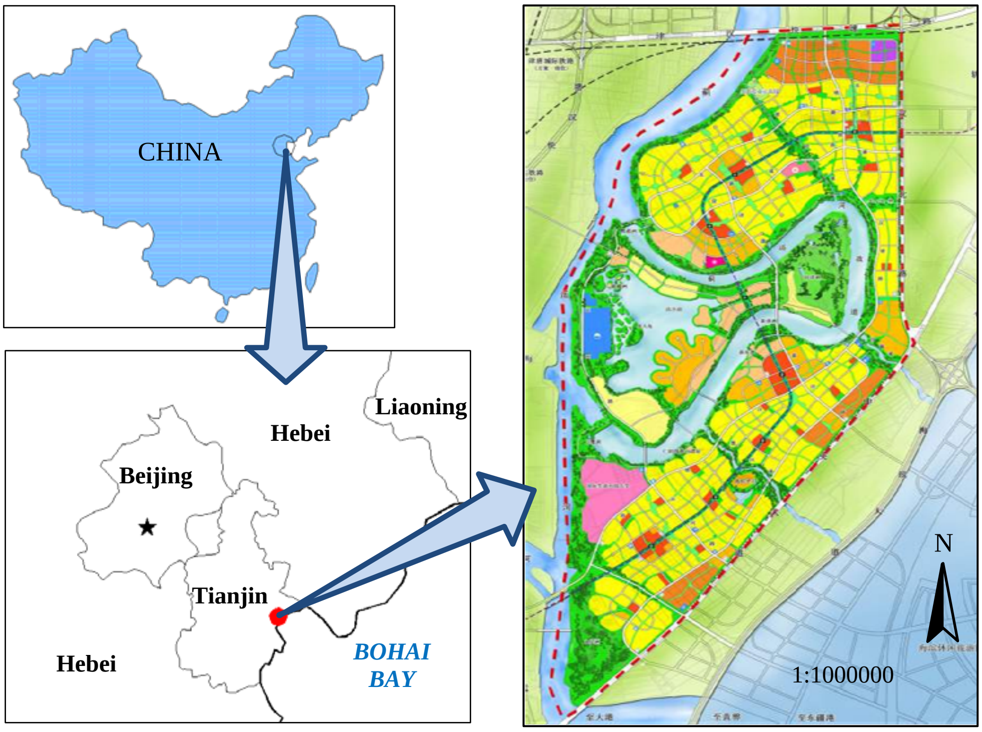


Figure 1 Location of the Eco-City and the water planning diagrammatic sketch (*Yang, 2008*)

As shown in Figure 1, the study area includes a river which is separated into two parts and an artificial lake. Water management is one of the key features of the design of this Eco-City, which will be subjected to a semi-humid continental monsoon climate, generally with low rainfall in the winter and high temperatures in the summer. The mean annual rainfall is 639.2mm, 70-80% of which is concentrated in the period of June to September. The study area includes a 10.7 km reach of the Jiyun River, which is a tributary of the River Hai. In this reach, the river has a mean flow rate of approximately 72 m^3/s in the summer and 19.2 m^3/s in the winter.

2.2 Target species in the Jiyun River

Grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*) and black carp (*Mylopharyngodon piceus*) are known as the "Four Domesticated Fish" in China and these four fish species were selected because they represent the major fish populations of the river Jiyun. These four fish species are in the family Cyprinidae with similar life habitat and could be called carp. The bioperiods (flow/habitat seasons) of carp, during which the management of river flow and habitat condition is of particular importance are selected by evaluating the seasonal needs of the target species. Therefore, life stages must be explicitly defined prior to discussing habitat requirements. The growth pattern of carps could be divided into three stages: spawning stage (March-June), growth stage (July-November), over-wintering stage (December- February). These three stages are summarized below, followed by discussions concerning water depth, velocity, water quality and habitat suitability.

Spawning activity is associated with high spring flows from March to June (*Verigin et al., 1978*). If carp spawn in a river of sufficient length with a current of 0.2 m/s or faster, hatching of eggs theoretically could occur. The optimal velocity for spawning is from 0.4 to 0.8 m/s and water temperature in the range of 18-30°C (*Kolar et al., 200*7). Carp produce eggs that are semi-buoyant and require current to keep them from sinking to the bottom (*Soin and Sukhanova, 1972; Pflieger, 1997*). The sticky eggs are deposited on submerged vegetation and hatch in less than a week. Carp fry feed on plankton.

Eggs are laid among aquatic vegetation and then the growth stage occurs from July to November. The embryonic development of carp takes about 3 days at 20-23°C. Under natural conditions, hatched fry stick to the substrata. After hatching, the fry remain in shallow (< 2 m), warm, fertile, sluggish waters for 2 to 8 weeks (*Sigler, 1958*). About three days after hatching the posterior part of the swim bladder develops, the larvae swim horizontally and start to consume external food with a maximum size of 150-180 μm (mainly rotifers). The young grow quickly in warm plankton rich water (*McCrimmon, 1968).* Dense vegetation is also required by fry and juveniles for cover. In stable streams, water velocity in the plant-free area of the channel appears to control the maximum vegetation abundance in the stream. *Tenna Riis (2003)* calculated the percentage area of stream cross-sections occupied by vegetation along with the mean velocity in the plant-free area across the channel. Juveniles and adults are found in deeper waters feeding predominantly on aquatic plants, algae and small invertebrates near the bottom (*He and Cai, 1998*).

As temperatures drop, the fish move into deeper waters for the winter (*Adams and Hankinson, 1928; Jester et al., 1969*). Winter is commonly regarded as a critical period and a bottleneck for the fish in rivers. To survive low temperatures in combination with declining food resources, fish have adapted and evolved different overwintering strategies, e.g. residency versus migration to alternative habitats. For the overwintering of carp, winter survival is influenced by factors other than food abundance. Depth and dissolved oxygen (DO) are considered to be the crucial parameters (*e.g. Lukowicz and Gerstner, 1998*). Under the conditions of Central European aquaculture, carp lose weight in winter. A weight loss (WL) of 5-10% is considered acceptable for successful overwintering (*Schaperclaus, 1961*).

2.3 Data collection

The base topographic data for the study area was sourced from Tianjin Survey and Design Institute. Monthly stream flow data were available from Xinfangchaozha gauging station, which has been in operation since July 1974. The data were made available by Tianjin Hydrology and Water Resources Centre. Habitat use data has been collected from the literature and expert opinion.

3. Methodology

3.1 Habitat Suitability Index model

The Habitat Suitability Index (HSI) scoring systems were originally developed by the US Fish and Wildlife Service, as a means of evaluating habitat quality and quantity, and then were proposed by *Oldham et al. (2000)* to evaluate the habitat suitability of great crested newt. The HSI is a numerical index that varies between zero and one, indicating unsuitable and optimal habitat conditions respectively. The HSI for fish incorporates several suitability indices, all of which are factors thought to affect the fish.

The HSI is a geometric mean of all the suitability indices. The geometric mean implies a compensatory mechanism, such that if two of the three variables are in the optimal range then the value of the third variable has little effect, unless it is zero.

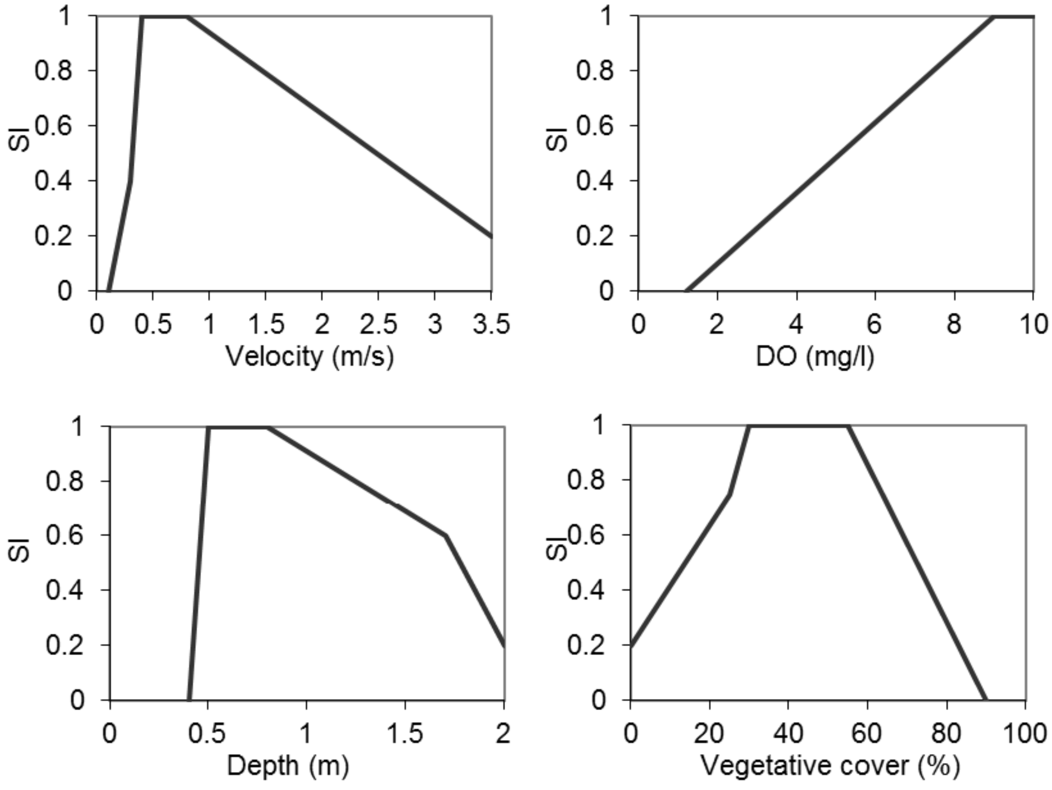
$$HSI = \left(SI1 \times SI2 \times SI3 \times SI4 \ldots SIn\right)^{1/n} \tag{1}$$

In this study, the effective indices for three life stages of carp were selected from several values such as velocity, flow depth, pH, cover, water temperature, biochemical oxygen demand (BOD), dissolved oxygen (DO), chemical oxygen demand (COD), based on field data for the River Jiyun and information found in the scientific literature. As shown previously, carps have different water requirements during their life stages, which should be taken into account when evaluating the water allocation needs to the river and lake. As a result, an HSI system was created based on the literature describing the habitat suitability for three life stages of carps (Table 1). The basic form for the expression of suitability is a habitat suitability curve, as shown in Figure 2. Local expert fish knowledge was also implemented in this system to account for differences between the site-specific situation and the general literature *(Tenna and Biggs, 2003; He and Cai, 1998*).

Table 1 Habitat Suitability Indexes (HSI) for three life stages of carps

Stage	Index	Note
Spawning (March-June)	Velocity	The minimum velocity to support eggs is 0.2 m/s. The optimal velocity is 0.4-0.8 m/s *(Liu and He, 1992).*
	DO	Percentage hatching increases with increasing DO content. At 3 mg/l DO, 40% of the embryos hatched; at 6 mg/l, 65% hatched; and at 9 mg/l, 92% hatched *(Kaur and Toor, 1978*).
	Depth	Preferred spawning areas are over aquatic or inundated terrestrial vegetation, at depths of 0.5-0.8 m *(Edwards and Twomey, 1982*).
	Percentage vegetative cover	The eggs are laid among aquatic vegetation and the young grow quickly in warm and plankton-rich waters (*McCrimmon, 1968*). Water velocity in the plant-free area of the channel appears to control the maximum vegetation abundance in the stream.
Growth (July-Nov)	Velocity	Carp occurred in pools (0.2-0.6 m/s) and in the main channel borders (0.6-1.2 m/s) (*Schmulbach et al., 1975*), but were most abundant in marshes and backwaters (<0.2 m/s) (*Kallemeyn and Novotny, 1977*).
	DO	Optimal DO levels for adults are assumed to be ≥ 6 mg/l (*Edwards, 1982*)
	Depth	The maximum depth for spawning is included because carp primarily frequents shallow waters.
	Percentage marshes and backwater area	This variable quantifies the amount of area available for production of food for the species. The velocity of Marshes and backwaters should be below 0.2 m/s.
Over-wintering stage(Dec-Feb)	DO	Optimal DO levels for this period are assumed to be ≥ 6 mg/l (*Edwards and Twomey, 1982*)
	Depth	As temperatures drop, the fish move into deeper waters for the winter (*Adams and Hankinson, 1928*). Hence, deep water areas are necessary to maintain carps in the winter, with a minimum depth of 0.4m.…

(a)



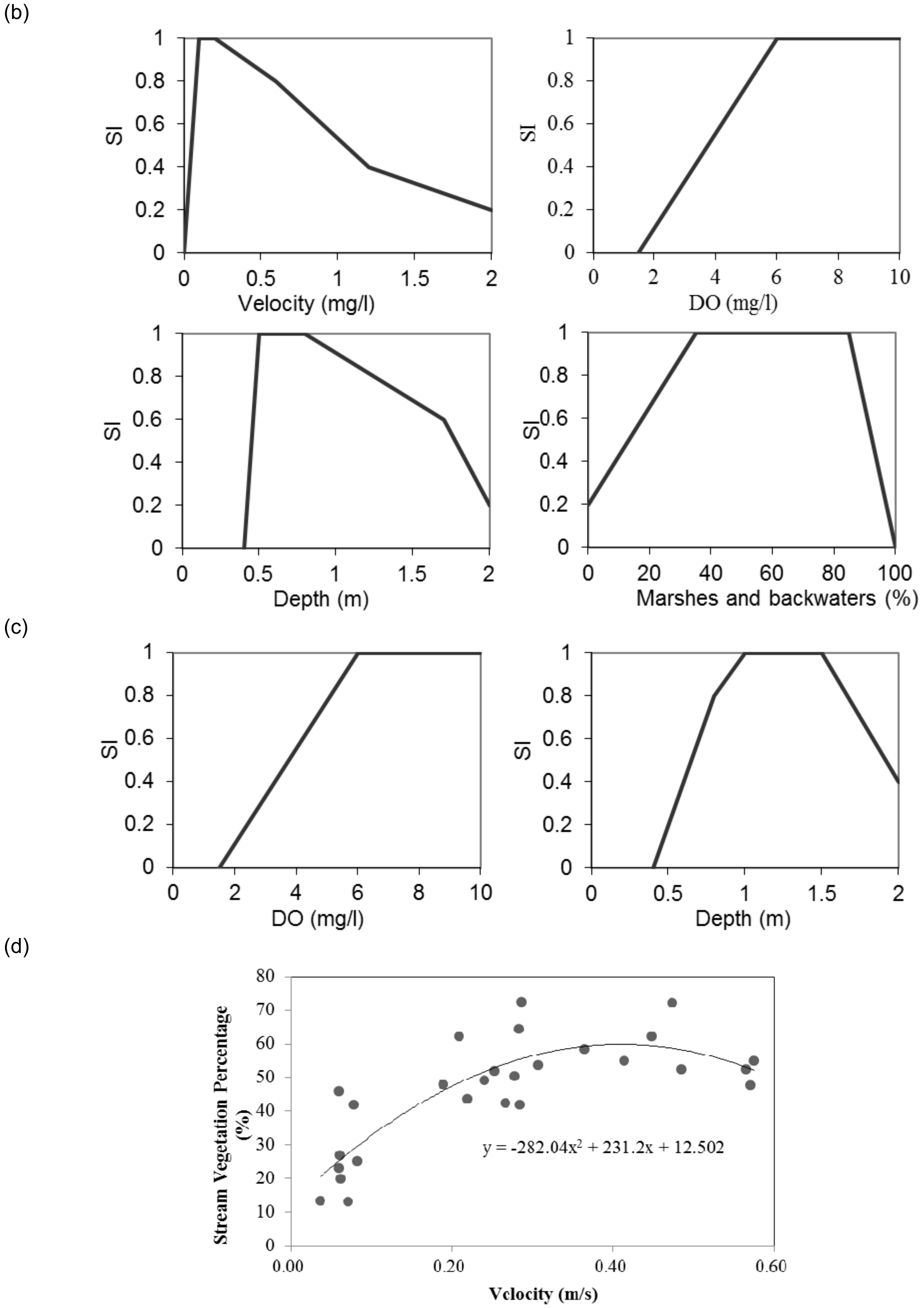


Figure 2 Suitability Index (SI) curves for three life stages of carps, for (a) spawning, March-June; (b) growth, July-November; and (c) over-wintering, December-February; and (d) variation of the vegetated cover area in relation to the mean stream velocity (*Tenna and Biggs, 2003*)

As shown on Fig 2(a), the spawning stage is represented by four indices: velocity, DO, depth and percentage vegetative cover. Taking the suitability curve for velocity as an example, it can be seen that the minimum velocity to support eggs is 0.2 m/s, the optimal velocity is 0.4-0.8 m/s and the suitability index then decreases with the further increase of the velocity. The ranges of velocity, DO, depth and cover that can be associated with carp growth are illustrated in Figure 2b. In the river, carps were most abundant in marshes and backwaters (velocity < 0.2 m/s) and therefore the suitability curve for marshes and backwaters is an important variable. Very little documentation exists on actual overwintering habitat of carps, but fish farming proved that adults prefer to spend the winter in deeper water with optimum depth ranging from 1-1.5 m. Dissolved Oxygen is important because it affects growth, survival and feeding. Herein, depth and DO are considered to be the crucial parameters (*e.g. Lukowicz and Gerstner, 1998*). Figure 2d shows the quantified relationship between vegetation cover and velocity. Vegetation abundance increases with increasing velocity up to 0.4 m/s, after which vegetation abundance decreased with increasing velocities. *Tenna and Riis (2003)* found that the upper limit of mean velocity in the plant-free area in a cross-section is 0.8 m/s.

3.2 Numerical model

Two dimensional (2D) hydrodynamic models have been successfully used to study ecological water flow and river management in recent years (*e.g. Bockelmann et al., 2004; Papanicolaou et al., 2011; Takayaki, 2008; Zhang, 2008*). An appropriate 2D hydrodynamic model for studying the ecological water flow should quantify the in-stream water demand and quality requirements. The model should also simulate flow processes under different flow patterns and different habitat seasons. DIVAST (Depth Integrated Velocities and Solute Transport), developed by *Falconer (1976)* was used herein to estimate the amount of water that should be reserved for environmental purposes in the river or water management units of the study area.

DIVAST is a 2D depth-integrated, time-variant model, which has been developed for simulating the hydrodynamic, solute and sediment transport processes in rivers, estuaries and coastal waters. The hydrodynamic module solves the depth integrated Navier–Stokes equations and can calculate flow velocities and the water depth. The DIVAST solute module is used to simulate solute transport, including salinity, BOD, DO, the nitrogen and phosphorous cycles and algal growth. DIVAST has been refined and validated against many laboratory and field studies data over more than 30 years of research.

The governing equation for solute transport processes can be written as:

$$\frac{\partial HS}{\partial t}+\frac{\partial HUS}{\partial t}+\frac{\partial HVS}{\partial t}=\frac{\partial}{\partial x}\left[D_{xx}H\frac{\partial S}{\partial x}+D_{xy}H\frac{\partial S}{\partial y}\right]+\frac{\partial}{\partial y}\left[D_{yx}H\frac{\partial S}{\partial x}+D_{yy}H\frac{\partial S}{\partial y}\right]+\Phi_z \qquad (2)$$

where

S = depth averaged solute concentration (unit/volume) or temperature

D_{xx} , D_{xy} , D_{xy} , D_{yy} = depth averaged dispersion-diffusion coefficients in the x and y directions respectively (m^2/s) and Φ_z summarises all other sources and sinks of solute, apart from advective and dispersive transport. Sources and sinks include discharge from outfalls and rivers as well as chemical and biological transformations.

The calculation domain measures 10,510 m in length by 3,510 m in width and is shown in Figure 3. The upstream boundary condition was a measured flow rate with a DO concentration of 7.4 mg/l, while the downstream boundary condition was given in the form of water elevation in the range of -1.5 to -3 m. The model was used to predict flow velocities and water depths under different flow rates. The size of the computational mesh was 10 m in both directions and the time step was 2 s. The simulation time for the model was typically 82 hours for each scenario.

The DIVAST model was combined with the Habitat Suitability Index model (HSI) based on the output from the hydrodynamic simulation program. Grid values of each of the indexes were combined with the suitability curve information and thus the overall HSI from the linked eco-hydraulic model was obtained for each scenario. Model calibration could not be performed for the exact flow conditions at the study site due to lack of available data.

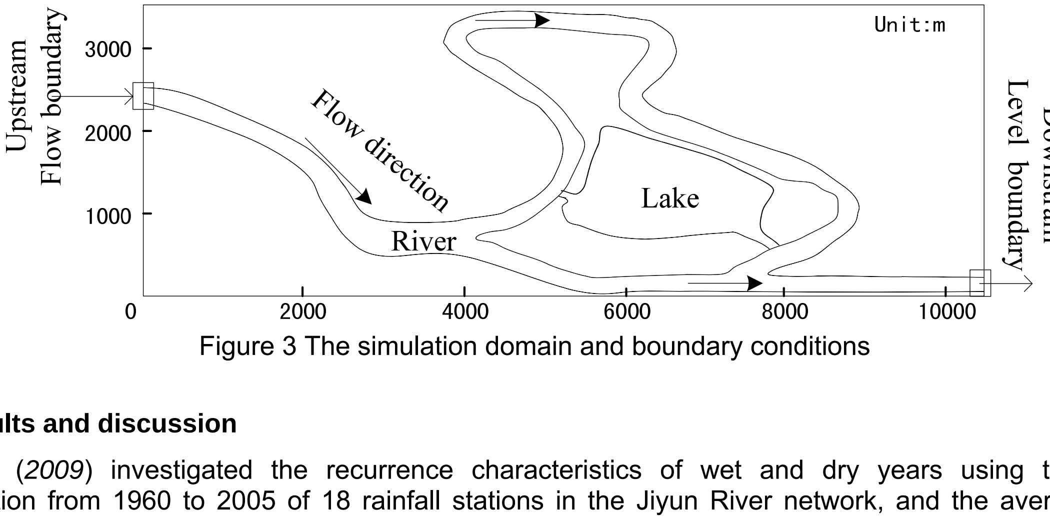


Figure 3 The simulation domain and boundary conditions

4. Results and discussion

Mao (*2009*) investigated the recurrence characteristics of wet and dry years using the annual precipitation from 1960 to 2005 of 18 rainfall stations in the Jiyun River network, and the average return periods were derived using the corresponding stationary probabilities. It was found that the longer lasting normal years were more frequent than the wet and dry years. Thus, here we use the normal flow conditions during each of the three stages of the carp life cycle, of 72 m^3/s, 48 m^3/s and 19.2 m^3/s for spawning, growth and overwintering respectively as the upstream boundary condition.

The HSI in the study area was determined by combining the different suitability index values for the depth, flow velocity, cover and DO using equation 1. Grid values of each of the parameters are combined with preference curve information. The water depth, flow velocities and DO concentration were obtained from the 2D simulations, while the grid values of the cover index were obtained using Figure 2d relative to the predicted flow velocities. The suitable area was then estimated grid by grid and summed for the whole reach. The HSI scoring system shown in Table 2 was adopted herein to define the habitat suitability for carps on a categorical scale.

Table2 Categorisation of HSI scores

HSI		Suitability
< 0.5	=	Poor
0.5 – 0.8	=	Potential
> 0.8	=	Ideal

The suitable areas were then obtained using the eco-hydraulics model for the spawning, growth and overwintering stages, as shown in Figure 4.

4.1 Fluvial region

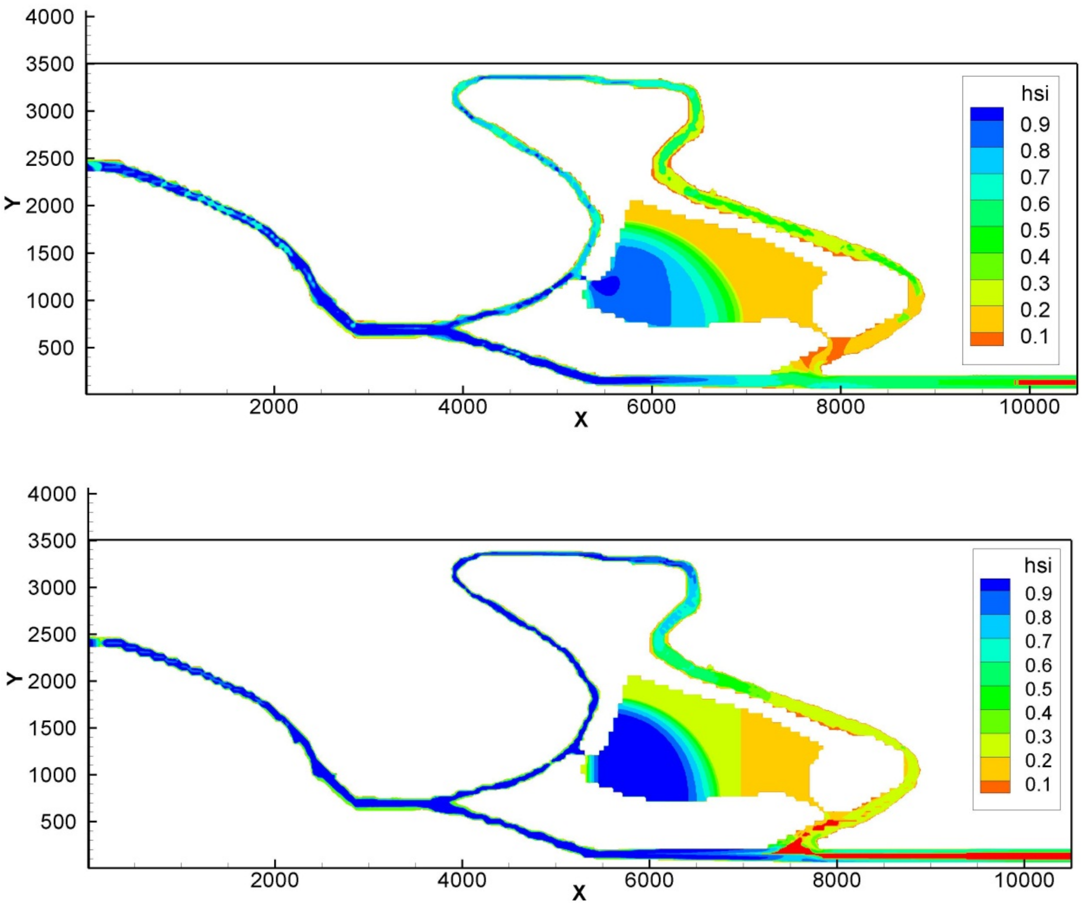
The numerical modelling results showed that, for the spawning stage (Q = 72 m^3/s), 34% the fluvial area would have the ideal conditions in the current river state, while an additional 17% would have the potential for fish habitat development and 49% would be poorly suited (Figure 4a).

For the growth stage (Q = 48m^3/s), 39% of the area would have the ideal conditions, an additional 9.0% would have the potential for fish habitat development and 52% would be poorly suited (Figure 4b).

For the overwintering stage (Q = 19 m^3/s), the area with ideal habitat conditions would cover 6% of the total area, while 8% would have the potential for development and 86% would be poorly suited (Figure 4c).

The numerical simulations suggested that the HSI of a large part of the study area would be too low for carps to settle, with the overwintering being the most critical stage. The upstream river reach of the study area was found to be generally more suitable for the carp life cycle.

(a)



(c)

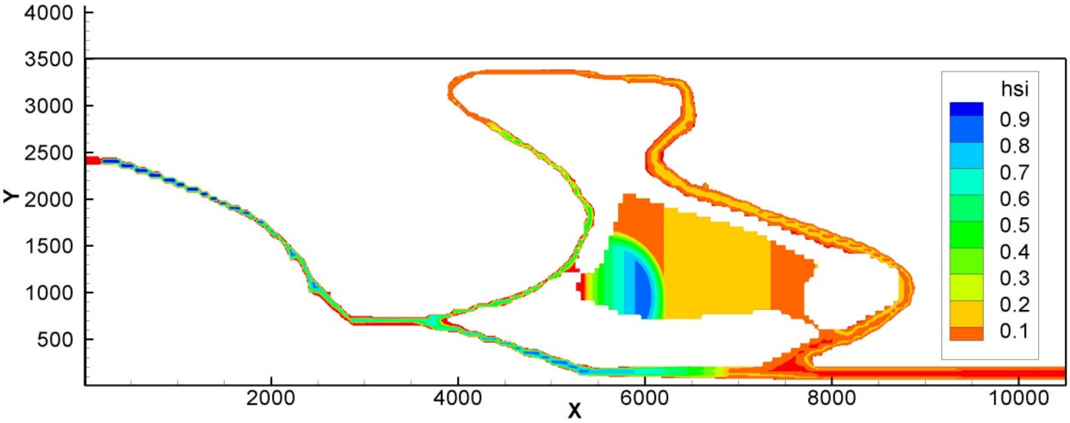


Figure 4 HSI for carps under the current flow conditions for the three life cycle stages of (a) spawning, (b) growth and (c) overwintering

With the overall purpose of improving the HSI in the study area, the numerical model simulations were extended to include the effect of flow augmentation on the habitat conditions. Flow augmentation generally consists of promoting the addition water to the river system from reservoir storage or flow diversion, aiming at maintaining water quality in the river during extreme low flow periods.

The flow augmentation simulations were implemented for the Jiyun River firstly without consideration of whether the required water would be available, but to investigate the ecological water requirement associated with this option. The model was run for a variety of discharge values, ranging from 72 to 432 m^3/s, 48 to 432 m^3/s and 19.2 to 432 m^3/s, for spawning, growth and overwintering stages respectively. The modelling results indicated that the suitability of habitat is highly dependent upon the discharge, as expected, due both to direct (velocity, depth) and indirect (DO, cover) effects. As the discharge and water surface elevation increased, the total area inundated increased. The area of ideally suited habitats increased with the flow rate for the growth and spawning stage and peak between144 and 192 m^3/s, which were found to provide the best ecological conditions in the Jiyun River (see Figure 5). The ideally suited area could reach to 41% and 63% of the study area for the spawning and growth stage respectively. For overwintering stage, the ideally suited area in this reach of the river increased rapidly with the discharge and the best flow for the river habitat is between 112 and 144 m^3/s.

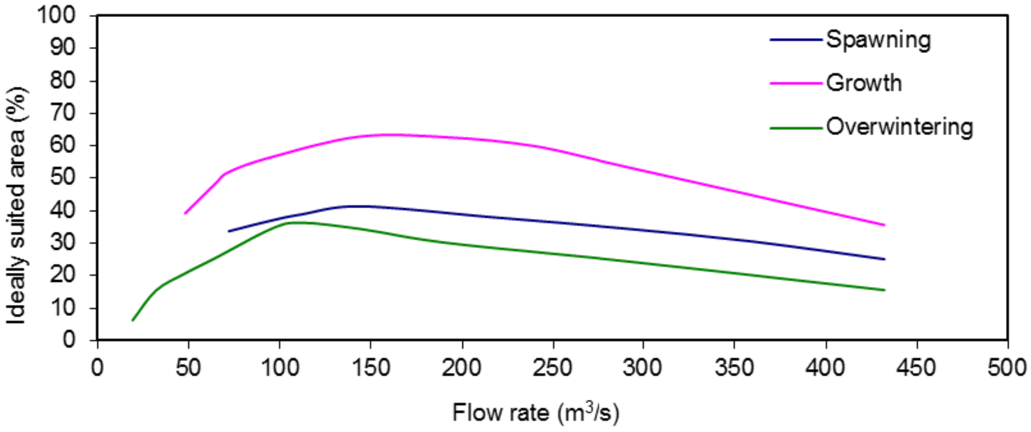


Figure 5 Relationships between the ideally suited habitat areas and flow rate in the three life stages, for whole study area

Figure 6 shows that the HSI results obtained for the study area significantly improved after flow rate increased to 144 m^3/s, 144 m^3/s, and 112 m^3/s for the spawning, growth and overwintering stages respectively. A comparison of the predicted HSI after the flow augmentation is presented on Table 3. Ideal suitable area for carps was significantly increased from 39% to 63% for the growth stage and from 6% to 36% for the overwintering stage, while the ideally suited area increased from 34% to 42% for the spawning stage.

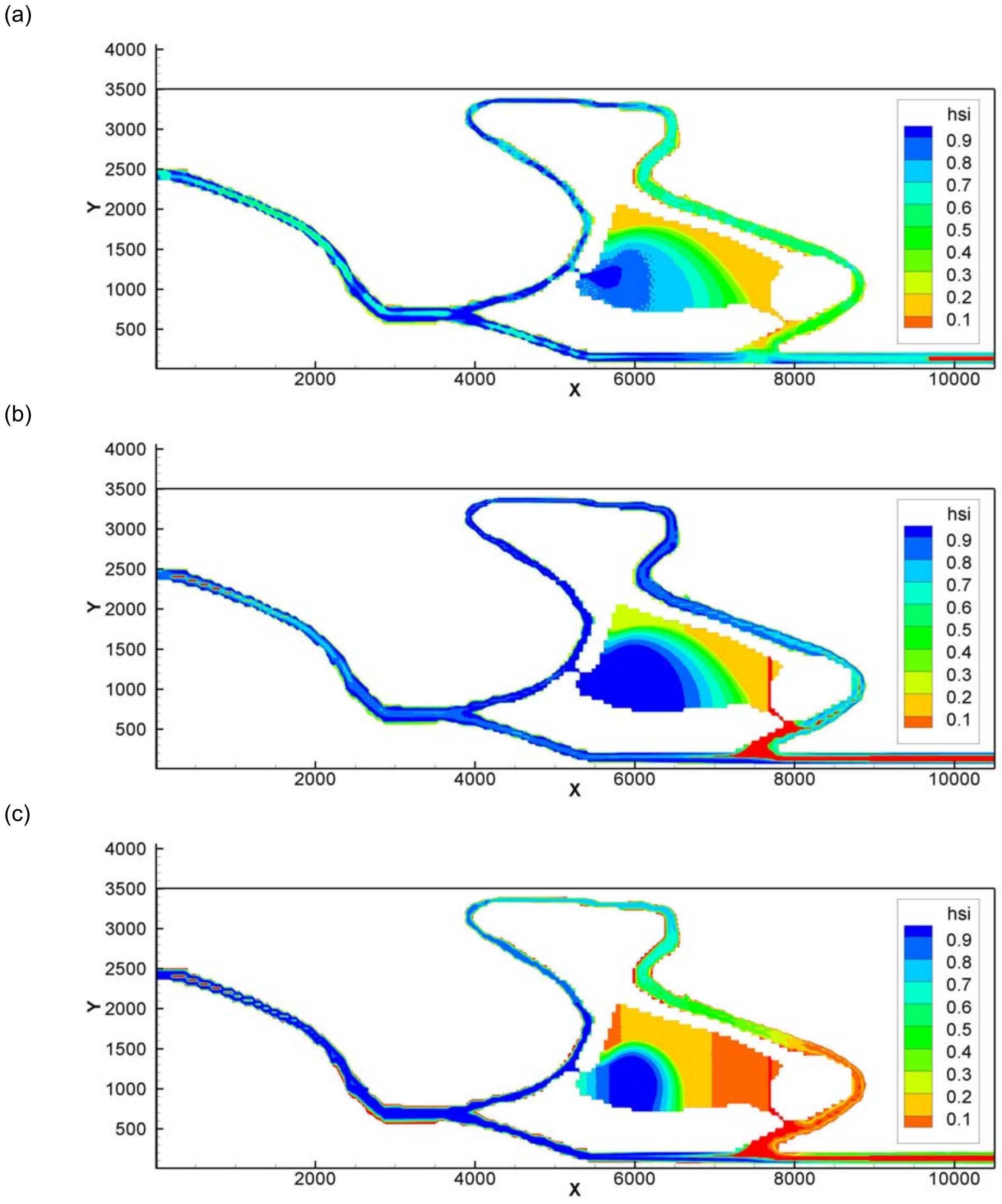


Figure 6 Predicted HSI for carps after flow augmentation, for the three life cycle stages of (a) spawning, (b) growth and (c) overwintering

Table 3 Suitable habitat areas in the river before and after flow augmentation

	Spawning		Growth		Overwintering	
	Before (Q=72 m^3/s)	After (Q=144 m^3/s)	Before (Q=48 m^3/s)	After (Q=144 m^3/s)	Before (Q=19.2 m^3/s)	After (Q=112 m^3/s)
Ideal	34%	42%	39%	63%	6%	36%
Potential	17%	21%	9%	10%	8%	9%
Poor	49%	37%	52%	27%	86%	55%

4.2 Lacustrine region

Although the model is applicable to both the riverine and lacustrine habitats, the suitability indices for the lake could not be the same due to physical habitat differences between river and lake, such as…. In this model, the suitability index for velocity was neglected for the lacustrine habitat, as the flow velocities in the lake were generally quite low, which also led to a low level of DO in the lake. In this case, a simulated aeration system was set up at the inlet to the lake to increase dissolved oxygen by circulating the water within the impoundment for surface reaeration of the water body and the boundary conditions comprised a flow rate of 5 m^3/s with a DO concentration of 30 mg/l. As shown on Figure 7, the area of ideally suited habitats peaked between 144 and 192 m^3/s for the growth and spawning stages, while for the overwintering stage, the ideally suited area in the lake peaked between 112 and 144 m^3/s. The results obtained for the conditions before and after flow augmentation are shown in Table 4. It can be seen from these results that the ideal and potential suitable areas for carps in the lake increased for all life stages and, correspondingly, the poorly suited areas decreased.

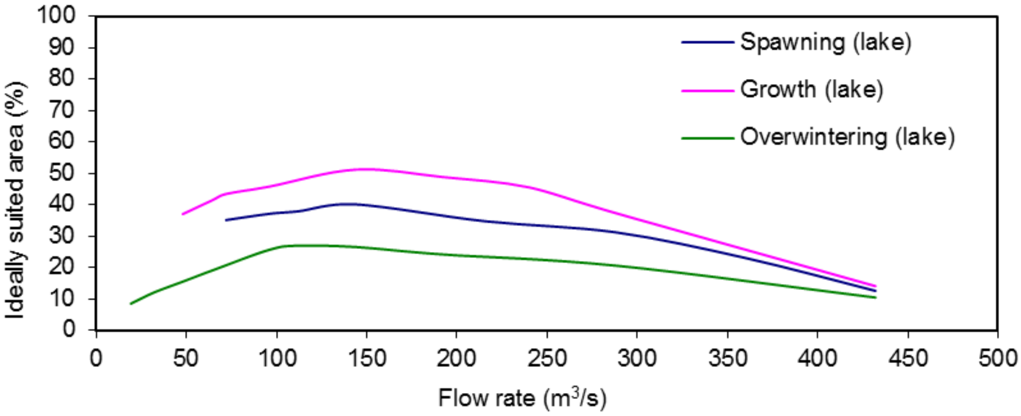


Figure 7 Relationships between the ideally suited habitat areas and flow rate in the three life stages for lacustrine area

Table 4 Suitable habitat areas in the lake before and after flow augmentation

	Spawning		Growth		Overwintering	
	Before (Q=72 m^3/s)	After (Q=144 m^3/s)	Before (Q=48 m^3/s)	After (Q=144 m^3/s)	Before (Q=19.2 m^3/s)	After (Q=112 m^3/s)
Ideal	35%	40%	37%	46 %	9 %	27%
Potential	12%	12 %	6%	7 %	9 %	9 %
Poor	53%	48 %	57%	47 %	82%	64%

The modelling results indicated that the optimum ecological water requirement in the study area is between 144 and 192 m^3/s from March to November and between 112 and 144 m^3/s from December to February. However, as the Jiyun River is located in a low rainfall area and has relied on external water sources for many years, namely the Water Diversion Project from Luanhe River to Tianjin City, the optimum ecological water requirements are not usually reached in normal years, especially from December to February. This suggests that the extent of overwintering grounds for carps would be very limited. Hence, although flow augmentation is an effective proposal to improve suitable habitat area, it should be noted that a continuous high flow for the growth stage is not easily achievable. In terms of river habitat improvements, more could be achieved by other means, such as channel modification, than by continuous augmentation in river flows.

Channel modification for the Jiyun River is one of the core works for local officials of the eco-city to carry out, due to the deposition of sediment in the natural stream channel. Previous investigations on the effects of channel modification on fish habitat for other streams have shown that the fish population could have equal or higher abundances in modified main channel habitats, compared to unmodified main channel habitats (*Bowen, 2003; Mohammed-Aslam, 2010; Horsa, 2009)*. River channel modification may include channel shape, cross-section and channel profile, which have an impact on stream velocity and turbulence, sediment volume and size distribution, scour and water surface elevations, among other characteristics (*WDFW, 2004*). Channel modifications may yield improved habitat for wildlife and plants in a stream corridor, but can also result in flooding, excessive erosion or other damage, if not carefully planned (*Bowen, 2003*). Therefore, modelling studies can be extended to investigate the impacts of different channel modification strategies on the HSI results, which could inform interventions aimed at river restoration and water planning of the Eco-City.

5. Conclusion

In this study, the DIVAST model was coupled with a Habitat Suitability Index Model (HSI) to produce a variety of relationships between flow rate and ideally suited habitat area. Three Scenarios were simulated based on the flow rates in the supply river for different stages. These simulations could help planners to evaluate the effectiveness of actions intended to prevent ecological deterioration before they are actually implemented. Our study suggested that a significant augmentation of the river flows would be required to maintain ecological values of water dependent ecosystems in the Jiyun River. However, due to the high flow requirements, this solution may not be achievable unless significantly more water can be diverted onto the river. The planner should also consider other interventions, such as channel modification.

This study considered the habitat suitability for carp based on depth, velocity, covers and DO values. These variables were selected because they are assumed to be the most important ones to explain habitat selection of carp. Further research could take into account other variables that can also influence the ecological water requirement assessment, such as temperature and substrate.

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