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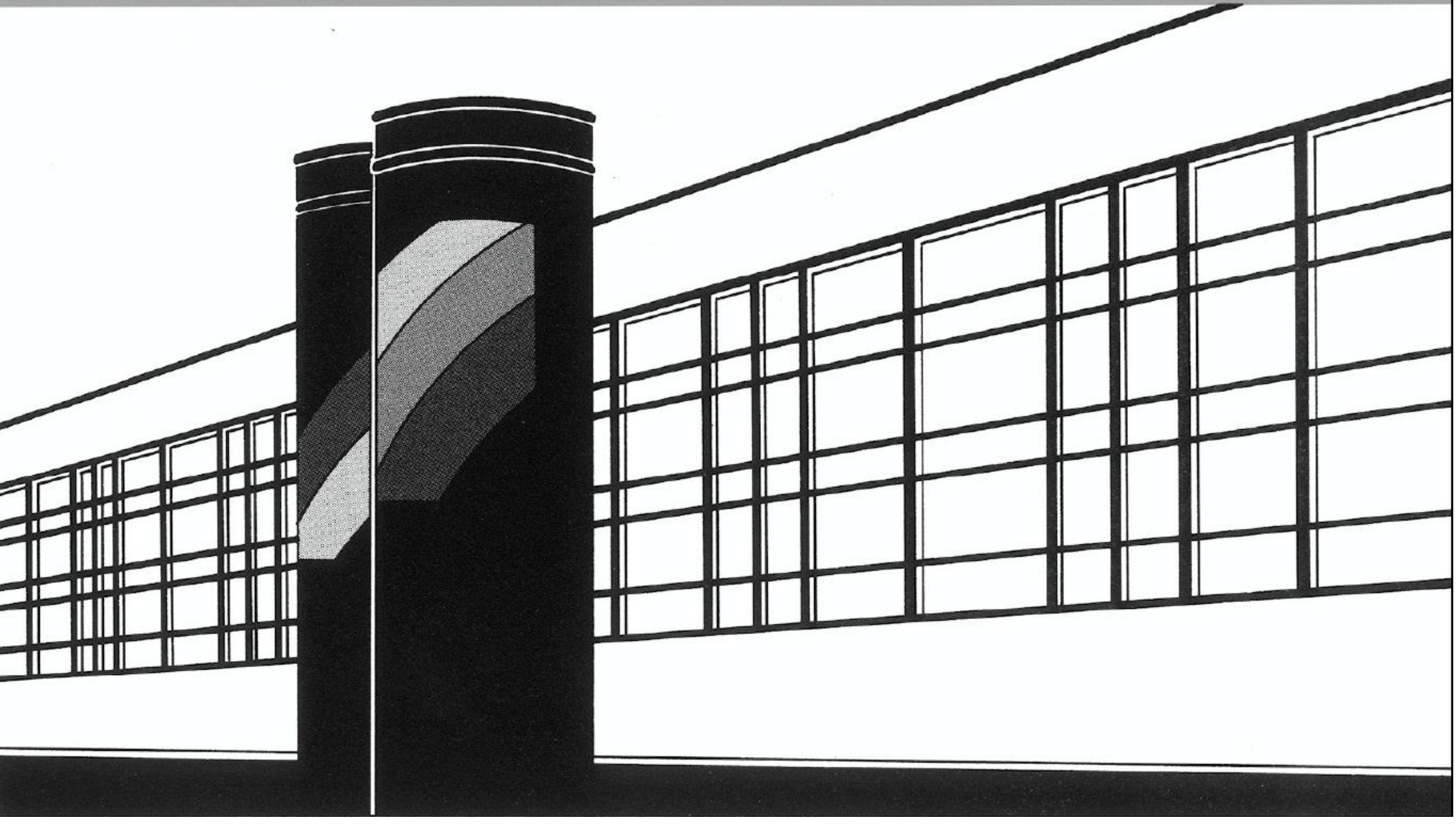

Heft 234 Jin Zhang

Investigations on Urban River Regulation and Ecological Rehabilitation Measures Case of Shenzhen River in China

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Case of Shenzhen River in China

von der Fakultät Bau- und Umweltingenieurwissenschaften der Universität Stuttgart zur Erlangung der Würde eines Doktor-Ingenieurs (Dr.-Ing.) genehmigte Abhandlung

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Dr.-Ing. Jin Zhang

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Jin Zhang

Stuttgart, Germany

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Abbreviations

AFCD	Agriculture, Fisheries and Conservation Department
AHP	Analytical Hierarchy Process
CASiMiR	Computer Aided Simulation Model for Instream flow Requirements
CoG	Centre of Gravity
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DoF	Degree of Fulfilment
EC	European Community
EROS	Earth Resources Observation and Science
GIS	Geographical Information System
GWP	Global Water Partnership
IDW	Inverse Distance Weighting
IFSI	Integrated Fish habitat Suitability Index
IWRM	Integrated Water Resource Management
MoM	Mean of Maximum
RHI	River Health Index
RHS	River Habitat Survey
SI	Suitability Index
SI_LTF	Least Tolerant Fish Species Habitat Suitability Index
SI_MTF	Most Tolerant Fish Species Habitat Suitability Index
TVA	Tennessee Valley Authority
UTM	Universal Transverse Mercator
URHabi	Urban/Rural Habitat
URRCC	Urban-Rural River Continuum Code
URRCI	Urban-Rural River Continuum Index

URRCS	Urban-Rural River Continuum Identification System
URRHI	Urban-Rural River Ecological Health Index
URS	Urban River Survey
USGS	United States Geological Survey
WFD	EU Water Framework Directive 2000/60/EC

Abstract

River systems, as a major component of the water environment, have the most interactions with human beings in many ways, especially along with social development and population growth, as well as the intense utilization of the river systems by humans, a series of major ecological environmental problems have arisen in recent years. Therefore, river system regulation and management has become a crucial focus point of research. Although the integrated river management is the preferred and most commonly accepted method that is applied in water resources management, a significant problem is that there is a shortage of integrated river ecological research which focuses specifically on urban rivers.

Urban river, usually as one section or several sections along the entire river system, has not obtained enough attention or even has been neglected, been treated equal as the natural river sections. But actually, river has been affected seriously due to the process of urbanization and the over utilization by human beings in terms of geomorphology, physical-chemical characteristics, flow regime, ecosystem and water quality.

The current problems governing urban river regulation and ecological status rehabilitation can be summarised into the following points: The definitions of urban and rural rivers are still not clarified; Interactions between urban and rural rivers are neglected; Need for an applicable mapping method for driving the urban river health index; Limited availability of input data sources, especially in the developing world for assessment and management of environmental problems. This research aims to study on the above addressed issues, to clarify the characteristics of urban rivers and to find an applicable method of assessing their health status.

In this PhD research, the identification of urban and rural river reaches is studied as the first main purpose, a generic conceptual model namely the Urban-Rural River Continuum Identification System (URRCI) is developed. Reference of this system is to review the classification of urbanization, in order to distinguish whether the surveyed river section belongs to urban river or rural river, and further to solve the problem of the unclear definition of urban rivers.

In the URRCI system, the urban-rural river continuum codes are set up to describe 5 classes of river systems with respect to the urban and rural characteristics. A set of key parameters which represent geomorphologic, chemical, hydrological and habitat characteristics of the water body and riparian zones are selected based on the literature review. In order to coincide with the urban-rural river continuum codes, information on each of the parameters is transformed into a single dimensionless score, and also has 5 classes corresponding to the urban-rural river continuum codes. The definition of each class for each parameter is given based on the literature review and export knowledge. And the score of each parameter is obtained through field investigation and survey. Then, the prioritization of all the parameters is done by using the method of Analytic Hierarchical Process (AHP). Along with the weights

(W) and scores for all the involved parameters (S), an expression is developed for the integration of the key parameter, and the Urban-Rural River Continuum Index (URRCI) for each surveyed stretch unit is calculated.

The rehabilitation of river systems has become an important objective of many local, state and national governments around the world. The problems of how to restore damaged river ecosystems, how to rebuild healthy river ecosystems, how to maintain river system functions better, and how to coordinate the interaction between human needs and river ecology are attracting more and more international society's attention. Considering the high economic investment in most rehabilitation projects, there is a need for a very effective river ecological health assessment system, which can give decision-makers a clearer direction of which plot of river should be rehabilitated, and which parameter matters to ecological health the most, in order to carry out more effective and economical rehabilitation measurements. Thus the identification of factors which influence urban river ecosystems and potential rehabilitation options is essential in order to determine the ecological health status and carry out a coordinated ecological rehabilitation process.

In the light of this, the second important issue has been addressed in this PhD research is to focus on urban river regulation, aiming to set up an advanced urban river ecological health assessment system which can be applied easily. The case study area of Shenzhen River in China has been selected to build up the database in order to establish and prove this new improved river health assessment system, and simulate effective rehabilitation measurements scenarios. The fuzzy logic approach is integrated into the fish habitat model CASiMiR, which is developed at the University of Stuttgart, Institute for Modelling Hydraulic and Environmental Systems, and is receiving a continuously growing acceptance in Europe and worldwide. The customized tool took advantage of an existing fuzzy inference calculator, which is integrated within the ArcGIS, thereby allowing direct data integration from various geospatial sources as input parameters and the presentation of output in the form of spatial and temporal maps. Indeed, the system of fuzzy rules (rulebase) can contain more than one input and one output parameter.

In this research, two field investigations were carried out in different seasons, one in the wet season and one in the dry season in order to simulate ecological health variations in different statuses of river discharge. For each field survey, the basic parameters of flow velocity, water depth, substrate, and riparian vegetation and bank materials were mapped. But for these two seasons, there was no data which was measured precisely for water temperature and dissolved oxygen. Data sources which can be used in this research are the annual environmental reports from the local Shenzhen government.

Considering the characteristics of the case study area of the Shenzhen River, through the annual environmental report from the local government, it is obvious that fish is a very important factor for indicating the ecological health status of the Shenzhen River. In this research, as it is investigated from government environmental reports and from a local survey of Dasha River, one tributary of Shenzhen river, 3 least tolerant fish species- Parazacco spilurus, Nicholsicypris normalis and Oryzias latipes are selected from the historical survey reports, and the common carp is selected as the least tolerant fish species. In order to integrate all the effects of both groups, another parameter of biodiversity has been introduced into the river ecological health assessment system.

The fuzzy sets and rules are developed for each of the habitat suitability indicators based on the habitat requirements. The key influencing parameters are verified according to different habitat requirements for different fish species, although the three basic parameters - water depth, flow velocity and substrate are suggested to be considered for each of the fish species. The other key influencing parameters can be interpolated into the diagnosis system afterwards.

Considering the calculation capability of the fuzzy logic method, these parameters are combined into the ArcGis based CASiMiR model step by step. For the first step, the three basic parameters of flow velocity, water depth and substrate are combined by making fuzzy rules and sets for each of the selected fish species, considering their different habitat requirements, and other necessary parameters can also be set in reality. The output is the habitat suitability index for each of the fish indicators. The second fuzzy step is to combine the most tolerant fish habitat index with the other three less tolerant fish habitat indexes. The parameter of biodiversity is taken into this system to consider different influences of the four selected fish indicators, in order to generate an integrated fish habitat suitability index (IFSI). The last step, in which riparian vegetation and bank/bed protection can be grouped, is on a larger scale. The final output is the urban-rural river ecological health index (URRHI).

The interaction between the urban river reach and the rural river reach is also identified as the third addressed objective. The integrated health status index is generated for both the urban and rural reaches base on the ArcGis based simulation. One expression is developed to calculate the health index for each of the urban and rural river stretches which are identified by the urban-rural river continuum identification system. The study on the Urban/Rural river interaction helps to find out what the thresholds of these main parameters in the urban river reach are, so that the urban river will not bring any stress onto the whole river system, which will affect the habitat suitability, and the most important is to lead a direction on the specific influenced plot and effective rehabilitation measures.

As the last main objective of this PhD research, several mitigation scenarios are planned for the simulation of river rehabilitation. From the assessment of the urban/rural river ecological health status, bank/bed protection and riparian vegetation are the two parameters which have the most influence. Removal of bank protection and the enhancement of riparian vegetation have been carried out as the river rehabilitation measures individually and combined as well, from a comparison of the enhanced integrated river health index for each urban/rural stretch with different fuzzy membership functions, we can see that when the integrated fish suitability index has more weight in the river's ecological health assessment system, the subsequent river ecological rehabilitation measures have less impact. When the integrated fish suitability index, bank protection and riparian vegetation have equal importance in the river's ecological health assessment system, river enhancement is more effective. On the other hand, parameters related to the water body itself refer more to the stands of hydraulics and hydrology, which are not easy to change. So in this research they are not considered for improvement.

The implementation in Shenzhen River shows that the advanced urban/rural River Ecological Health Assessment System was successfully established. It is easy to use and interpret since it adopts the standard governing parameters of river health that are widely accepted all over the globe. This approach allows rapid scenario analysis for large regions and has the potential to be used as a practical tool for the assessment of urban river ecological health by policy-makers and scientists.

Although there are certain limitations of this modelling approach, the predicted river ecological health index is influenced by the expert knowledge base and the experience of the user. The question of subjectivity is still a concern in such an expert-based modelling approach. The selection of the input parameters that govern the fish habitat suitability processes is specific and limited due to the specific situation of the case study area, influenced parameters could be different according to the specific requirements of the indicating ecological factors.

The proper validation of the urban/rural River Ecological Health Assessment System is still another issue due to a lack of river ecological data on a large regional scale. The model is still open for further assessment and improvement with regard to validation.

Zusammenfassung

Fließgewässersysteme, als ein wesentlicher Bestandteil der Wasserwirtschaft zeichnen sich durch vielseitige Interaktion mit der Menschheit aus. Insbesondere die intensive Nutzung der Fließgewässersysteme sowie die gesellschaftliche Entwicklung und das Bevölkerungswachstum führten in den vergangenen Jahren zu erheblichen ökologischen Beeinträchtigungen. Daher stellt das Fließgewässermanagement ein bedeutendes und zentrales Forschungsthema dar. Obwohl im Rahmen des Wasserressourcen-Management meistens das integrative Flussgebietsmanagement angewendet wird, finden dort ökologische Aspekte häufig zu wenig Beachtung. Dies trifft insbesondere im Bereich der urbanen Fließgewässer zu.

Bisher wurde bei urbanen Fließgewässertypen, die einen oder mehrere Fließgewässerabschnitte eines Fließgewässersystems darstellen können, vorwiegend dieselbe Bewertungsmethode wie für natürliche oder ländliche Fließgewässerabschnitte angewendet, die den urbanen Einfluss nur geringfügig berücksichtigen oder vollständig vernachlässigen. Allerdings sind es insbesondere die Prozesse im Rahmen der Urbanisierung und die Übernutzung der Gewässer, die die Fließgewässer hinsichtlich Ökosystem, Wasserqualität, Geomorphologie und Abflussregime, sowie die damit verbundenen physikalisch-chemischen Prozessen beeinflussen.

Die aktuellen Schwierigkeiten im urbanen Fließgewässermanagements und der entsprechenden ökologische Bewertung können wie folgt zusammengefasst werden: Eine exakte Unterscheidung von urbanen und ländlichen Fließgewässertypen ist bisher nicht explizit definiert, Interaktionen zwischen urbanen und ländlichen Fließgewässertypen werden vernachlässigt, Fehlen einer anwendbaren Kartier-Methode die den ökologischen Zustand vor urbanen Fließgewässern erfasst; begrenzte Verfügbarkeit von Datenquellen in Entwicklungsländern um Umweltprobleme bewerten zu können. Die vorliegende Arbeit befasst sich daher mit oben genannten Aspekten um einerseits urbane Fließgewässer charakterisieren und um andererseits deren ökologischen Zustand bewerten zu können.

Erste Zielstellung dieser Doktorarbeit ist die Entwicklung eines Modellkonzepts zur Unterscheidung von urbanen und ländlichen Fließgewässerabschnitten basierend auf verschiedenen Urbanisierungsklassen (Urban-River Continuum Identification System, URRCI), in dem eine klare Definition für urbane Fließgewässertypen enthalten ist.

Im Rahmen des URRCI-Modellkonzepts werden Fließgwässersysteme durch fünf Klassen beschrieben, die sowohl ländliche als auch urbane Charakteristiken beinhalten. Hierfür werden, basierend auf einer Literaturstudie, geomorphologische, chemische, hydrologische und habitatbezogene Schlüsselfaktoren ausgewählt, die für die Beschreibung der zu untersuchenden Fließgewässersysteme herangezogen werden. Alle verwendeten Variablen werden in dimensionslose Bewertungsgrößen umgewandelt, die weiterhin ebenfalls in fünf Klassen unterteilt werden, wobei sich die jeweilige Klassengröße auf Werte in der wissenschaftlichen Literatur und auf Expertenwissen stützt. Die Bewertungsgrößen der

einzelnen Parameter werden durch Beobachtungen/Kartierungen vor-Ort erfasst und es erfolgt anschließend eine Gewichtung und Priorisierung der Variablen mit Hilfe der AHP-Methode (Analytic Hierarchical Process). Basierend auf dieser Gewichtung (W) und den korrespondierenden Bewertungsgrößen (S) werden die Schlüsselfaktoren zu einem URRCI-Index zusammengefasst, der für jeden einzelnen Fließgewässerabschnitt berechnet werden kann.

Die Renaturierung von Fließgewässersystemen ist weltweit das Ziel vieler lokaler, regionaler und nationaler Regierungen und die damit einhergehenden Schwierigkeiten wie z.B. die Wiederherstellung beeinträchtigter Ökosysteme, Erhaltung relevanter Fließgewässerfunktionen oder die Forderung nach einer nachhaltigen anthropogenen Fließgwässernutzung rücken zunehmend in den gesellschaftlichen Fokus. Bezugnehmend auf die erforderlichen hohen wirtschaftlichen Investitionen für Renaturierungsprojekte, ist der Bedarf an einem effektiven ökologischen Bewertungssystem als sehr hoch zu betrachten. Vorwiegendes Ziel eines solchen Bewertungssystems ist die Unterstützung von Entscheidungsträgern hinsichtlich der Fragen wo und wie eine Renaturierungsmaßnahme umgesetzt werden kann, und welche Parameter diesbezüglich berücksichtigt werden müssen, um somit Ressourcen für Renaturierungsmaßnahmen gezielt und effektiv steuern zu können.

Diese Aspekte werden in einem zweiten Schwerpunkt dieser Promotionsarbeit behandelt und durch die Entwicklung eines urbanen ökologischen Bewertungssystems realisiert. Hierfür wird der Shenzhen River in China als Fallstudie ausgewählt, um dort alle notwendigen Daten zu erheben, das neu entwickelte urbane ökologische Bewertungssystem zu testen und zu verifizieren und um potentielle Renaturierungsszenarien zu simulieren. Ein wesentlicher Bestandteil des ökologischen Bewertungssystems ist das Fischhabitatsimulationsmodell CASiMiR, welches an dem Institut für Wasser- und Umweltsystemmodellierung der Universität Stuttgart entwickelt wurde. CASiMiR wird weltweit eingesetzt und basiert auf einen fuzzy-logischen Ansatz um abiotische Variablen mit Habitatansprüchen von Indikatorarten zu verknüpfen. Eine Neuentwicklung von CASiMiR ist eine ArcGIS-Version, die eine direkte Verarbeitung von georeferenzierten Daten erlaubt und die die Ergebnisse in zeitlicher und räumlicher Variabilität darstellt.

Im Rahmen dieser Studie wurden zwei Messkampagnen zu verschiedenen Jahreszeiten (Nass- und Trockenzeit) im Shenzhen River durchgeführt, um ökologische Veränderungen bei unterschiedlichen hydrologischen Bedingungen simulieren zu können. In jeder Messkampagne wurden folgende Basisparameter kartiert: Fließgeschwindigkeit, Wassertiefe, Substrat, Auenvegetation und Uferbeschaffenheit. Unglücklicherweise sind für beide Messkampagnen keine Informationen über Wassertemperatur und Gehalt an gelösten Sauerstoff verfügbar. Als weitere Datenquellen konnten die jährlichen Umweltberichte der für den Shenzhen River zuständigen regionalen Behörde genutzt werden.

In Bezug auf die Charakteristik des Shenzhen Rivers und aus den jährlichen Berichten der regionalen Behörde wird ersichtlich, dass Fische eine bedeutende Rolle für die ökologische Bewertung des Shenzhen Rivers spielen. In dieser Arbeit werden daher einerseits drei Fischarten ausgewählt, die hohe Ansprüche an die Umweltbedingungen haben (Parazacco spilurus, Nicholsicypris normalis and Oryzias latipes) und andererseits eine sehr tolerante Art (Karpfen), die vergleichsweise geringe Ansprüche an die Umwelt haben. Um die unterschiedlichen Fischarten integrativ in der ökologischen Bewertungsmethode berücksichtigen zu können wird zusätzlich ein Biodiversitäts-Index in die Bewertungsmethode integriert. Die benötigten Fuzzy-Sets und Fuzzy-Regeln für die habitatbeschreibenden Variablen (z.B. die Standardvariablen Wassertiefe, Fließgeschwindigkeit, Substrat) werden entsprechend den Habitatanforderungen der zu untersuchenden Fischarten aufgestellt. Weitere Schlüsselparameter können im Anschluss im Rahmen des Bewertungsverfahrens berücksichtigt werden.

Für das ökologische Bewertungsverfahren wird ein mehrstufiger fuzzy-logischer Ansatz angewendet. In einem ersten Schritt werden die oben genannten Standardvariablen in der GIS-Version von CASiMiR miteinander zu einer Habitateignung kombiniert. Dies wird für jede einzelne Fischart gemäß den in den Fuzzy-Sets und Fuzzy-Regeln berücksichtigen Habitatanforderungen durchgeführt. In einem zweiten Fuzzy-Schritt wird die Habitateignung der toleranten Fischart mit den drei Habitateignungen der Fischarten mit hohen Umweltansprüchen kombiniert. Dieser Schritte zielt darauf ab, die Biodiversität in das Bewertungssystem zu integrieren, um somit einen integrativen Index für Fischhabitateignungen zu entwickeln (integrated fish habitat suitability index, IFSI). In einem letzten Schritt werden die Auenvegetation sowie die Uferbeschaffenheit und eventuell vorhandene Sohlstabilisierungen berücksichtigt. Das finale Endergebnis der ökologischen Bewertungsmethode ist der sogenannte „urban-rural river ecological health index (URRHI)“

Ein dritter Schwerpunkt dieser Arbeit befasst sich mit der Wechselwirkung zwischen urbanen und ländlichen Fließgewässerabschnitten, um Grenzwerte hinsichtlich beeinträchtigender Parameter in urbanen Fließgewässerabschnitten formulieren zu können, die das gesamte Fließgewässersystem beeinträchtigen könnten, sowie Entscheidungsprozesse bezüglich potentieller Renaturierungsmaßnahmen zu unterstützen.

Als letztes Hauptziel dieser Promotionsarbeit werden verschiedene Renaturierungsmaßnahmen geplant und simuliert. Bezugnehmend auf die Ergebnisse der entwickelten ökologischen Bewertungsmethode haben die Uferbeschaffenheiten und die Auenvegetation den größten Einfluss auf den ökologischen Zustand des Shenzhen Rivers. Daher eignen sich der Rückbau von Ufersicherungen und eine Revitalisierung der Auengebiete als potentielle Renaturierungsmaßnahmen, die sowohl einzeln als auch kombiniert simuliert und bewertet werden. Zusätzlich werden die fuzzy-logischen Zugehörigkeitsfunktionen der Eingangsparameter im Rahmen einer Sensitivitätsanalyse variiert mit dem Ergebnis, dass bei einer höheren Gewichtung des integrierten Fischhabitat-Indexes (ISFI), die ökologische Renaturierungsmaßnahme geringere Auswirkungen aufzeigt. Für eine identische Gewichtung des ISFI-Werts, der Ufersicherung und der Auenvegetation zeigen die simulierten Renaturierungsmaßnahmen einen größeren Effekt. Allerdings gilt zu beachten, dass Parameter, die das Fließgewässer selbst betreffen (z. B. Hydaulik und Hydrology) im Rahmen dieser Untersuchung nicht für die Renaturierung verwendet wurden.

Die Anwendung am Beispiel des Shenzen Flusses zeigt, dass das entwickelte ökologische Bewertungssystem für urbane und ländliche Fließgewässerabschnitte (URRHI) erfolgreich eingesetzt werden konnte. Durch die Verwendung von Standardvariablen, die weltweit Akzeptanz finden, ist das Bewertungssystem einfach anzuwenden und zu interpretieren. Mithilfe dieses Ansatzes können für großskalige Fließgewässersysteme rasch Szenarienanalysen durchgeführt werden und zusätzlich kann der Ansatz als ein nützliches Werkzeug für die ökologische Bewertung von Fließgewässern mit urbanen Fließgewässerabschnitten sowohl von Politikern als auch von Wissenschaftlern eingesetzt werden.

Der im Rahmen der ökologischen Bewertungsmethode entwickelte Modellansatz beinhaltet gewisse Einschränkungen und hängt zusätzlich von dem verwendeten Expertenwissen sowie der Erfahrung des Anwenders ab. Insbesondere die Subjektivität kann für expertenbasierte Modellierungsansätze ein Problem darstellen. Des Weiteren hängt die Auswahl der Eingangsparameter für die Fischhabitatmodellierung sowohl von den verfügbaren Daten, als auch von der Fischart ab, die je nach Habitatansprüchen eventuell nicht nur durch die hier angewendeten Standardvariablen beschrieben werden können. Eine belastbare Validierung des URRHI-Systems konnte aufgrund der mangelhaften ökologischen Datengrundlage bisher nicht durchgeführt werden und die ökologische Bewertungsmethode inklusive der Simulationsansätze stehen diesbezüglich für eine Optimierung und Verbesserung zu Verfügung.

1 Introduction

1.1 Background Introduction

Water is an essential resource for all life on the planet. Water bodies provide drinking water for people, and process water for manufacturing goods. They are habitats for many plant and animal species and contribute to preserving biological diversity. It is therefore necessary to reconcile the protection and use of water bodies as far as possible.

River systems, as the major component of the water environment, have the most interactions with human beings in many ways, not only being used more by human beings and having more effect on the development of society and economies, but also being more polluted and causing further environmental problems back onto human beings.

Especially along with social development and population growth, as well as the intense development and utilization of the river system by humans, a series of serious ecological environmental problems have arisen in recent years. Almost all the river systems in the world have been damaged to varying degrees. River no-flow, river siltation and water quality degradation are seriously affecting the stability of river ecosystems and become the major obstacle to social development, even endangering the survival and development of human-kind. Therefore, river system regulation and management has become a crucial focus of research.

In past research, river management has covered almost all aspects, including water pollution treatment, flow regime regulation, river restoration, etc. After decades of research, the awareness and principles of integrated river management have significantly increased and become widely accepted.

The Integrated River Basin Management can be defined as a "process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems." (Global Water Partnership, 2000).The main objective of the Integrated River Basin Management is to establish a balance between the existing natural functions of the river system and the developed aspects of the system. The management activities should fulfill the expectations of society for industrial use, recreation, nature management, and agricultural purposes.

Although river management is the preferred and most commonly accepted method that is applied to integrated river systems, a significant problem is that there is a shortage of integrated water resource management research which focuses specifically on urban rivers.

Urbanization has significant impacts on stream systems (Leopold, 1968; Hammer, 1972; Klein, 1979; Booth, 1991; Schueler, 1994; Booth and Jackson, 1997; Pizzuto et al., 2000; Booth et al., 2002; Hession et al., 2003). Urban watersheds show increased surface runoff, in terms of both magnitude and frequency, and decreased amount of water during low flow periods. As a result, the balance of water and sediment supplied to stream channels changes, resulting in geomorphological alterations.

Urbanization also impacts on aquatic habitat quality. Urban channels tend to be morphologically "simpler," having a less defined pool/riffle structure, more uniform depth, and a bed grain size distribution shift toward smaller particles during watershed level construction due to increased sedimentation. Because urbanization affects the geomorphic, hydrologic, habitat and aquatic biota characteristics of river systems to varying degrees, there is a need for studying the specific health status of urban rivers.

The rehabilitation of river systems has become an important objective of many local, state and national governments around the world. The problems of how to restore damaged river ecosystems, how to rebuild healthy river ecosystems, how to maintain river system functions better, and how to coordinate the interaction between human needs and river ecology are attracting more and more international society's attention.

But considering the high economic investment in most rehabilitation projects, there is a need for a very effective river ecological health assessment system, which can give decision-makers a clearer direction of which plot of river should be rehabilitated, and which parameter matters to ecological health the most, in order to carry out more effective and economical rehabilitation measurements.

Thus the identification of factors which influence urban river ecosystems and potential rehabilitation options is essential in order to determine the ecological health status and carry out a coordinated ecological rehabilitation process.

In the light of this, the purpose of this research is to focus on urban river regulation, aiming to set up an advanced urban river ecological health assessment system which can be applied easily. The case study area of Shenzhen River in China has been selected to build up the database in order to establish and prove this new improved river health assessment system, and simulate effective rehabilitation measurements scenarios.

1.2 Current problems and the need for research

Very few survey methodologies have been developed specifically for urban or heavily engineered rivers. As some research has mentioned, fluvial processes and channel form and structure interact within most river reaches (Newson, 2002). Even so, a particular feature of urban river channels is that they have often been subject to engineering modification. This, in turn, may alter or, rather, constrain the channel size, e.g. by reinforcement of channel boundaries so that process and form can no longer interact freely and longitudinal patterns become disguised by local hydraulic controls. As a result, the physical assessment of urban rivers must put an emphasis on the characteristics of channel engineering, as well as on the physical habitat features, so that subtle distinctions between different reaches of a river can be recognized.

As current river classification systems tend to group urban rivers into a single homogenous category of “bad” or “poor” quality, the urban river may then become undervalued (Pollard and Huxham, 1998). However, the EC Water Framework Directive defines a category of “heavily modified water bodies” and advocates that reference conditions should be developed for such water bodies to establish river restoration aims (European Community, 2000).

The fact that current classification systems cannot readily discriminate between urban rivers, means that if a sustainable rehabilitation of urban rivers is to be achieved, new classification systems are required.

Generally speaking, the current problems governing urban river regulation and ecological status rehabilitation can be summarised into the following points:

1. The definition of urban and rural rivers is still not clarified.

2. Interactions between urban and rural rivers are neglected.

3. Need for an applicable mapping method for driving the urban river health index.

4. Limited availability of input data sources, especially in the developing world for assessment and management of environmental problems.

Therefore, it is important to understand the characteristics of urban rivers and to find an applicable method of assessing their health status.

In this research, the first main purpose is to study the identification of urban and rural river reaches, in order to have a clear vision of what an urban river is and what a rural river is. The ecological attributes of urban and rural rivers vary significantly. Therefore, the measurements which should be taken to rehabilitate the ecological functions on urban rivers and rural rivers are totally different.

Based on the identification of urban and rural river reaches and the diagnosis of elements influencing urban and rural river ecologies, an advanced river ecological health assessment system is intended to be set up from the new angle of focusing on the differences between urban and rural rivers.

2 State-of-the-art of water resources management

2.1 Integrated water resources management - a global trend

Throughout the development of civilization, people have come to the important realization that for water, being the principal element of nature, a comprehensive management policy should be in place. This should take into account the integration of different waters, users, and impacts that determine the sustainability, efficiency, and safety of water availability (Sokolov, 2011).

Traditional models of water management, which approach the issue from only one perspective, have come to be challenged more and more, and integrated water resource management is often seen as the way ahead. Based on the understanding of water resources being an integral component of the ecosystem, a natural resource, and a social and economic good, integrated water resource management is pointed out as a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives.

The basis of integrated water resource management was developed in Europe and elsewhere at the beginning of the 20th century in the process of establishing the frameworks for water resource management. The roots of integrated water resource management can be traced back to the establishment of the Tennessee Valley Authority (TVA) in 1933 (Adams, 2001). The TVA targeted many of the elements included in modern integrated water resource management perceptions, i.e. the planning of natural resource utilization combined with a strategy to balance social, economic and environmental objectives based on the sustainability concept (Shoffner and Royall, 2008).

Integrated Water Resources Management (IWRM) is the practice of making decisions and taking action while considering multiple viewpoints of how water should be managed. IWRM has been defined by the Technical Committee of the Global Water Partnership (GWP) as: "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."

In addition to the definition of IWRM from the Technical Advisory Committee of Global Water Partnership, distinguished authorities in this field have expanded on this definition to include the following points:

- Transition from water management within administrative units towards water management within the limits of drainage basins or catchments (hydrological boundaries).

- Moving from sectoral water management towards an integrated cross-sectoral one.
- Transition from the authoritarian one-way principle of water management “top-down” towards the more democratic two-way principle - “bottom-up” (forming water requirements and participation of water users in decision-making) and “top-down” (establishing water use limits and the support of water users).
- Transition from the command-administrative method of water management towards corporative water management with the participation of water users and other stakeholders in decision-making.
- Moving from water resource management towards water demand management.
- Transition from sectoral water management by water professionals towards public water management with the participation of water users and other stakeholders.

So far, the concept of integrated water resource management has been in existence for almost 80 years. While at a first glance, the concept of IWRM looks attractive, a deeper analysis brings out many problems, both in concept and implementation, especially for meso- to macro-scale projects. The definition of IWRM continues to be amorphous, and there is no agreement on fundamental issues such as what aspects should be integrated, how, by whom, or even if such integration in a wider sense is possible (Biswas, 2004).

Despite increases in the awareness of IWRM, there still exist only a few in-depth scientific studies on the rationale behind the principles and concepts. Moreover, as Gooch and Stålnacke (2006) point out, IWRM definitions and concepts, which focus on and influence thinking about sustainability, do not provide us with much indication of how this proposed co-ordination, balancing and integration is to be achieved in practice (Stålnacke and Gooch, 2010).

There is even still a strong need for strict principles on top, and more effective tools for the implementation of integrated water resource management. Only such an approach can enable us to integrate the requirements of the environment, society, ecosystems and industrial infrastructure. This thesis will endeavour to make some scientific points on the topic of integrated water resource management.

2.2 Overview of urban river health assessment

Previous research shows that there is a shortage of research covering integrated water resource management research specifically on urban rivers. Urban river systems are often heavily degraded, and this is a situation that is not confined to a particular geographic region of the world, but common to all areas subject to urbanization (Morley and Karr, 2002).

Initially, these waters were managed as a resource for human benefit including water supply, flood mitigation, disposal of wastewater and so on (Walsh, 2000). However, this leads to the degradation of stream ecological functioning, an issue that was initially ignored (Paul and Meyer, 2008).

The physical, chemical and ecological integrity of the world's freshwater ecosystems is now an important issue, and supported by many international, national and regional programs and legislation. Tangible socio-economic or biophysical reasons for the rehabilitation of urban streams are often hard to identify, since maintenance of ecological integrity and ecosystem services are not readily achieved or identifiable in urban areas.

Questions relating to social, political and economic issues can be extremely relevant in these urban stream systems, where ecological integrity is compromised for flood mitigation and wastewater control. Frequently the solutions to these questions are specific to individual situations, however collectively they are integral to the overriding question, which is to determine whether or not urban river rehabilitation is justified. Urban stream rehabilitation decisions are usually dominated by conflicting triple bottom line pressures of social (including political), economic and environmental factors. These factors are gaining increasing significance in many fluvial areas, including dam management, and emerging water management policies, such as the European Water Framework Directive (European Commission, 2000).

Urbanization has a great impact on river systems in different aspects, and it is of vital importance to do research on urban rivers. The differences between urban and rural streams regarding hydrological processes, channel morphodynamics and ecosystem functioning have been highlighted by a number of studies in recent decades (Dyer and Thoms, 2006).

Major changes in channel cross-section and other morphological attributes which are associated with urbanization, are also responsible for changes in substrate composition and hydraulic structure. Such changes potentially result in fundamental differences in physical habitats between rural and urban streams (Townsend, Scarsbrook, and Dolédec, 1997). In addition, changes in urban hydrology and stream channel geomorphology may affect the earliest and largest damage to stream ecosystems (Shields, Knight, and Cooper, 1998; Harbor and Doyle, 2000; Newson and Newson, 2000).

Very few survey methodologies have been developed specifically for urban or heavily engineered rivers (Newson, 2002). Notable exceptions include Anderson, 1999; Suren et al., 1998 and RSPB, 1994. Fluvial processes as well as channel form and structure interact within most river reaches, but a particular feature of urban river channels is that they have often been subject to significant engineering alteration, which may have constrained channel size and reinforced channel boundaries so that process and form can no longer interact freely and longitudinal patterns become disguised by local hydraulic controls.

As a result, the physical assessment of urban rivers must place an emphasis on the characteristics of channel engineering and must also record physical habitat features in some detail so that subtle distinctions between different reaches of the river can be highlighted. Indeed, Brooks (RSPB, 1994) suggested that his channelized river morphology survey should be undertaken over a length of uniform channel management in order to emphasize the importance of management in controlling river channel characteristics.

An urban river survey (URS) has been established by Davenport, Gurnell, and Armitage in 2004, which is a modification of the Environment Agency's river habitat survey (RHS) from 1997 (Fox, Naura, and Scarlett, 1998). Davenport et al. (2004) present a survey methodology designed specifically for urban rivers that is applicable to reaches of rivers of a single engineering type. Such a detailed survey can be relatively straightforward, and can usually be applied with good precision when surveying reaches of a single engineering type, because such reaches tend to have a more uniform character than their rural counterparts.

The most effort associated with this method concerns the reach-scale habitat survey of urban rivers, although for effective management, such reaches need to be placed in their catchment and network context. On the reach scale, they describe a) a method of urban river survey; b) some synthetic indices that can be derived from URS survey data to provide a quantitative description of urban river reaches, and c) three different classifications of urban river reaches to reflect the character of their boundary materials, physical habitats and vegetation characteristics.

The fact that current classification systems cannot readily discriminate between urban and rural rivers means that if sustainable rehabilitation of urban rivers is to be achieved, new classification systems will be required especially for this river type.

2.3 Habitat modelling: capabilities and limitations

In the present research, looking into the simulation systems which have been developed for the assessment of integrated water resource management, both physical models and habitat models are mainly used. For the study of river ecological functions, however, habitat models are more suitable and applicable.

In river management there is a clear need for models that are able to quantify species-environment relationships (Guisan et al. 2000). Habitat models allow for such quantification because they predict species habitat conditions based on data describing the abiotic environment. River management and conversation biology can benefit from these predictive models as decision support tools for adaptive management (Mouton et al., 2008).

According to the Water Framework Directive 2000, fish are considered to be one of the most important indicator species to assess the ecological status of rivers due to their varying temporal and spatial habitat requirements in their life-cycle, and have significant dependencies on hydraulic and morphologic river characteristics. Traditionally there are three basic physically based parameters used to simulate fish habitats conditions: water depth, flow velocity, and the substrate condition. In order to gain information about the abiotic conditions in a river, habitat models are coupled to multidimensional hydro- and morphodynamic models which are able to predict flow conditions, suspended and bed load, as well as morphological development in rivers.

Since the late 1970s, aquatic habitat simulation models have been used to analyze fish habitats in water resource management (Bovee, 1982; Jowett, 1997; Parasiewicz and Dunbar, 2001). Physical habitat models are particularly useful for assessing the impact of hydropower projects, analyzing water abstraction on river ecology, and determining the minimum flow requirements of aquatic populations. These models may also be used to simulate and evaluate the impact of restoration projects on surrounding environments (Shuler and Nehring, 1993; Shields, Knight, and Cooper, 1997; Maddock, 1999).

The need to assess ecological impact on rivers has led to the development of different habitat modelling techniques. Generally the bridge between abiotic and biotic components causes the differences in the modelling approach. Bovee and Milhous (1978) used preference functions which are univariate curves describing habitat suitability on a scale from 0 to 1 as a function of local water depth, flow velocity or substrate. Such preference curves describe univariate linkages between abiotics and biotics and lead to separate habitat suitabilities for each parameter. To combine these different habitat suitabilities, simple mathematical operations are used, although they are not adequate for the description of habitat suitability because the calculated result depends strongly on the mathematical method used (Bain 1995). Another critical point for the clear-cut boundary approach is that transition in ecology is not clear-cut but gradual, resulting in ecological gradients (Cadenasso et al., 2003). Another method is a statistical one based on multivariate regression techniques (Schmutz, 1999) to determine the probability of fish occurrence depending on combinations of input-parameters based on multiple logistic regressions. The probability of occurrence can be converted to a habitat suitability index and is preferably applied for typical binary occurrence applications (absence and presence of fish). The last approach incorporates a knowledge-based method (e.g. neural networks, genetic algorithms or fuzzy-logic). Fuzzy-logic means to work with imprecise (fuzzy) information. The most significant advantage is that expert knowledge which is readily available from experienced fish biologists can easily be transferred into preference data sets by setting up check-lists with possible combinations of relevant physical criteria and let experts define if habitat quality is, for example, high, medium or low. This definition coincides well with ecological issues due to the fact that the impact of ecological coherence cannot be described in exact functions or equations, but can be estimated quite well. Fuzzy-logic has proven to be an appropriate modelling technique to deal with these ecological gradients because the boundaries between the classes of the input variables are overlapping and thus reflect these gradual transitions (Salski, 1992; Mouton et al., 2008). Giving these facts the multivariate fuzzy-logical approach provides the state-of-the-art in habitat modelling.

The computer-aided simulation model for instream flow requirements (CASiMiR), developed at the University of Stuttgart, Institute for Modelling Hydraulic and Environmental Systems, is based on fuzzy sets and rules. CASiMiR, a surface water habitat model, is used to investigate fish habitats (Mouton et al., 2007; Jorde, 1996). CASiMiR, which is based on the input of experienced fish biologists and the analysis of monitored data, can adequately predict the habitat conditions for several fish species. It is observed that habitat requirements of species depend on their stage of life and river type (Jungwirth, Muhar, and Schmutz, 2000).

Habitat suitability models are widely used to evaluate the ability of a habitat to support a particular species (Vincenzi, et al., 2006 and Fukuda, 2009). These models ultimately allow the researchers to evaluate the effects of different influencing factors on their surrounding environments (Mouton et al., 2008). One application of the habitat suitability model has been investigated in China. Yi et al. (2010) have studied the ecological effects of dams on the Yangtze River. The lack of attention paid to the effects of artificial embankments and dams on their surrounding habitats have resulted in the widespread disturbance of the ecosystems of several rivers in China.

2.4 Need for fuzzy logic methodology

It was shown previously that classical habitat modelling based on the use of preference curves has a number of disadvantages. A relatively new method, based on a fuzzy logic approach, can help to overcome some of these difficulties.

Fuzzy logic was initiated in 1965 by Lotfi A. Zadeh, professor for computer science at the University of California in Berkeley (Zadeh, 1965). Basically, fuzzy logic is a multivalued logic, which allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Notions like rather tall or very fast can be formulated mathematically and processed by computers in order to apply a more human way of thinking in the programming of computers (Zadeh, 1978).

This method focuses on what the system should do rather than trying to model how it works. One can concentrate on solving the problem rather than trying to model the system mathematically, if that is even possible. On the other hand, the fuzzy approach requires sufficient expert knowledge for the formulation of the rule base, the combination of the sets and the defuzzification. In general, the employment of fuzzy logic might be helpful for very complex processes where there is no simple mathematical model (e.g. ecological problems), for highly nonlinear processes, or if the processing of (linguistically formulated) expert knowledge is to be performed (Adriaenssens et al., 2004).

In river regulation, when we consider ecosystem health within the framework of ecological function, uncertainty is the greatest problem to overcome. In order to solve this problem, the fuzzy logic method can be imported into the assessment process.

Regan (2002) advocates that uncertainty falls broadly into two main groups: epistemic uncertainty (uncertainty about a determinate fact) and linguistic uncertainty (uncertainty that arises because our natural language is vague, ambiguous and context dependent, and because the precise meaning of words can change over time). Most of the data and knowledge concerning aspects of an ecosystem contain uncertainties that comprise either epistemic or linguistic uncertainty, or a combination of both. Epistemic as well as linguistic uncertainty can be present in model predictions (Elith, Burgman, and Regan, 2002). It is important to recognise and distinguish these two types of uncertainty since each type needs to be handled differently (Regan, Colyvan, and Burgman, 2002).

Different approaches exist as to how models are used in ecosystem management when dealing with these uncertainty aspects (Ducey and Larson, 1999; Jgensen, 1999). Rule-based models often deal with the linguistic aspect. The linguistic aspect could be based on two different approaches in ecosystem management: (1) expert knowledge and/or ecological (monitoring) data are available in a linguistic format (Salski, 1992) and because of the imprecision of the natural language, we are dealing with linguistic uncertainty; (2) ecosystem managers want the models developed for decision support to be interpretable and transparent.

Rule-based models can also work with epistemic uncertainty, integrating the imprecision and variability inherent in ecological data (Silvert, 2000). Because of these aspects, approaching ecosystem management by reasoning according to the principles of "fuzzy logic," and in particular by means of fuzzy-rule based models, may be appropriate. A number of ecological models based on fuzzy logic have already been reported. An increase in use of this methodology is expected in the near future.

In fuzzy rule-based systems, knowledge is represented by if-then rules. Fuzzy rules consist of two parts: an antecedent part stating conditions on the input variables; and a consequent part describing the corresponding values of the output variables. Usually, the case of a single output variable is considered. In Mamdani-Assilian type models, both antecedent and consequent parts consist of fuzzy statements concerning the value of the variables involved (Mamdani, 1977), whereas in Takagi–Sugeno type models, the consequent part expresses a (non-)linear relationship between the input variables and the output variables (Takagi and Sugeno, 1985). In this thesis, Mamdani–Assillian type models will be discussed, mainly because they are relevant to ecosystem management for the fuzzy rule-based models. The fuzzy statements mentioned above are usually of a linguistic nature, for example expressing that a certain variable takes a "high" or "low" value. Variables that can be quantified in this way are, therefore, also called linguistic variables. The antecedent parts of the fuzzy rules are evaluated for their degree of fulfilment. In Mamdani–Assilian type models, this degree of fulfilment determines the contribution of the rule to the fuzzy set of possible values of the output variable (Mamdani, 1977). A final precise output value can be obtained by defuzzification.

The main reason for applying the fuzzy modelling approach in the field of decision support in ecosystem management regarding these applications is the ability to integrate expert knowledge, which is mainly structured by means of linguistic expressions. The implementation of these semantic expressions is of vital importance in the field of sustainability due to the fact that sustainability is difficult to define or measure, because it is an inherently vague and complex concept.

Because of the growing interest in the participatory approach in ecosystem management (Jakeman and Letcher, 2003; Oxley et al., 2002), interpretable (Casillas et al., 2003) and easy-to-adapt modelling structures such as fuzzy rule-based models turn out to be of great interest. As such, the fuzzy rule-based model can serve as an excellent technique for an enhanced involvement of the end-user in the development process.

It was shown previously that classical habitat modelling based on the use of preference curves has a number of disadvantages. A relatively new method, based on a fuzzy logic approach, can help to overcome some of these difficulties. Fuzzy logic appears to be promising in the area of environmental science, as the modelled processes possess many parameters of influence that are not well understood or lack certain discreteness. A relatively new method, based on a fuzzy logic approach, can help to overcome some of these difficulties.

Fuzzy logic can be considered as a problem-solving control system methodology, which provides a simple way to arrive at a definite conclusion based on imprecise, incomplete, noisy input information. This approach mimics the way a human would solve a problem, but – implemented as a computer program – allows a much faster solution.

In general, the fuzzy logic-based approach offers the following advantages in comparison to the classical one based on preference curves (Eisner et al., 2005):

- Interdependency of habitat variables can easily be accounted for.
- Simple enrolment of expert knowledge, formulated in a qualitative or semi-qualitative way; application of precise information for input as well as for the calibration of the model is possible at the same time.
- In theory, no restrictions are imposed on the number of input variables.
- The simplicity of the approach is an advantage when negotiating with stakeholders in a decision-making process.
- It is not a black box; rather it allows analyzing how a result was obtained.

2.5 Definitions of keywords in the study

2.5.1 Urban rivers

The field of research on urban rivers is dogged by confusing definitions, hampering comparisons between studies (McIntyre et al., 2000). For example, the term “urban” has been defined vaguely as “built up” (Erskine, 1992), or more precisely as “an area with more than 2500 people/ (620 individuals/km^2)” (USBC, 2000). Even so, a purely human demographic definition of urbanization may be inappropriate, especially when considering the ecological footprint of these areas. Another definition has also appeared in some scientific research to describe what is meant when the term “urban stream” is used (Findlay, 2000): “A stream where a significant part of the contributing catchment consists of development where the combined area of roofs, roads and paved surfaces results in an impervious surface area characterising greater than 10% of the catchments.” Clearly, urban rivers are often identified as streams which flow through urban areas and equally described as heavily engineered rivers in current research. The above generalization has its limitations and is inappropriate.

In this research, a more comprehensive definition of urban rivers will be given by establishing an urban-rural river continuum identification system (Chapter 5). Consideration of the complex hydrology, simplified geomorphology and reduced ecological functions of urban rivers will be taken. Six key parameters from both aspects of the river body itself and its riparian environment are selected to estimate the degree of urbanization. The river section will only be defined as urban river when the integrated value of key parameters shows a high degree of urbanization (Chapter 5-3).

2.5.2 Rural rivers

In contrast, rural rivers in current research are often defined as river streams which flow through a rural area and are described equally as natural rivers. This definition also has significant limitations and only gives emphasis to the aspect of geomorphologic characteristics.

In this research, the definition of rural rivers will be given by establishing an urban-rural river continuum identification system (Chapter 5). As with urban rivers, six key parameters from both aspects of the river body itself and its riparian environment are selected to estimate the degree of urbanization. The river section will only be defined as rural when the integrated value of key parameters is showing a low degree of urbanization.

2.5.3 Ecological function

The core of rehabilitation means not simply a return of a damaged river to its original condition, but to rehabilitate the damaged functions to an expected ideal condition and to rehabilitate the river ecosystem’s health to a condition in which the river could be self-sustaining, and in parallel meet developing social demands. So, the analysis of river functions and river regulation characteristics, and its influencing factors is very important for determining the special ecological river rehabilitation tasks for each phase.

In the engineering-regulated phase, functions of a river are reduced to parameters which are helpful for anthropogenic uses. Ecological aspects are more or less completely neglected. Thus flood protection, fresh water-supply for irrigation and drinking water, navigation and hydro power is in the focus. At this stage, due to water blocking by dams, reservoirs, reduced water dynamics and changed hydrographs sediment transport decreases and, furthermore, a high impact on landscape recreation occurs. When the ecological function is inadequate, the riverbed landforms undergo detrimental change and biodiversity decreases. The main indicators in this river phase are physical parameters.

In the river pollution-controlled phase, most of the river functions are damaged except the flooding function, navigation function and hydroelectric function due to the deterioration of water. The river ecosystem’s health is then affected severely. The main indicators of the river pollution-controlled phase are physical and chemical indicators.

When a river evolves into the ecological-rehabilitated phase, sediment transport, landscape recreation and ecology are the most important factors to consider. This phase rehabilitates the river as one ecosystem. The main indicators in this river phase are biological indicators.

Generally speaking, river regulation and rehabilitation must be suitable for the corresponding phase. Targets for river pollution-control are lower than those for river ecological rehabilitation. It would not be efficient to implement river ecological rehabilitation measures until the problem of water pollution has not been solved.

2.5.4 River health

There are a range of factors that should be considered by environmental managers when assessing river health status and planning potential rehabilitation projects. In this research, the ecological factor has been selected as the main factor that can represent the ecological health status of a river system.

River health is a term used to describe the ecological condition of a river. Health is more than just plants and animals that live in a river or the quality of its water. It also depends on the diversity of the habitats, the number and diversity of plant and animal species, and the effectiveness of linkages and the maintenance of ecological processes. Therefore, in this research, it is assumed that river system health relies on the ecological function meeting a minimum required level.

An ecologically healthy river is a river that retains its major ecological features and functioning and is able to sustain these characteristics into the future. When a river evolves into the ecological – rehabilitation phase, sediment transport, landscape recreation and ecology are the most important factors to consider. This phase rehabilitates the river as one ecosystem. The main indicators in this river phase are biological indicators. Generally speaking, river regulation and rehabilitation must be suitable for the corresponding phase.

The application of this concept to river health follows the outcome of scientific principles, legal mandates, and changing societal values (Karr, 1999).

2.5.5 Rehabilitation

Rutherfurd et al. (2000) provide a summary of the definitions associated with restoration and rehabilitation. The relationship of rehabilitation to ecosystem structure and function is schematically represented in Figure 2-1. Restoration describes the return of a system to a fully recovered natural ecosystem. In contrast, rehabilitation describes a condition along the same vector as restoration, where elements of the natural biophysical system are returned, but not all. For example, rehabilitation projects may effectively target channel morphology and riparian vegetation, but not the magnitude and frequency of flow, often an essential step for achieving a complete stream restoration (Abernethy and Wansbrough, 2001; Bennett et al., 2001; Brierley and Fryirs, 2001; and Brooks et al., 2001).

The final definition, and probably the most important and pragmatic solution for the majority of urban river systems, is that of remediation. This describes where a river is managed to develop along a different vector of ecosystem improvement. Although this process does not result in total rehabilitation of a system, it promotes improvement in terms of increased ecosystem function and species richness.

In some cases, urban river restoration efforts attempt to reverse decades of physical degradation through reshaping the channel, manipulating habitat heterogeneity and replanting riparian vegetation in order to return the stream ecosystem. This is, however, an extreme situation for river rehabilitation and cannot normally be accomplished.

Firstly, it is often impossible to establish what the initial condition looked like. Secondly, such restoration works would mean modifying the physical and biological character of the reach (channel form, biological communities) so that a replication of the original state is assured. This would involve changing all input and output (water quality and quantity changes, sediment management and resettlement of organisms) from upriver, downriver and the riparian zone, to the original state. Clearly, this will almost never be possible. Even if the attempt was made, the changes that have occurred over the last centuries or decades may have been great enough to alter many rivers irretrievably. On the other hand, river systems rely on a certain level of disturbance by flooding, erosion and variable water quality to maintain their diversity. The natural, original level of stability would again be the ideal state.

So, the goal of urban river rehabilitation should be to restore the essence of the ecological structure and function characterizing rural streams, and to re-establish the natural temporal and spatial variation in these ecological attributes rather than stable conditions. In this research, the most important task in rehabilitating the urban river is to find out the essential parameters for an ecological functioning river system and to repair the specific influencing parameters.

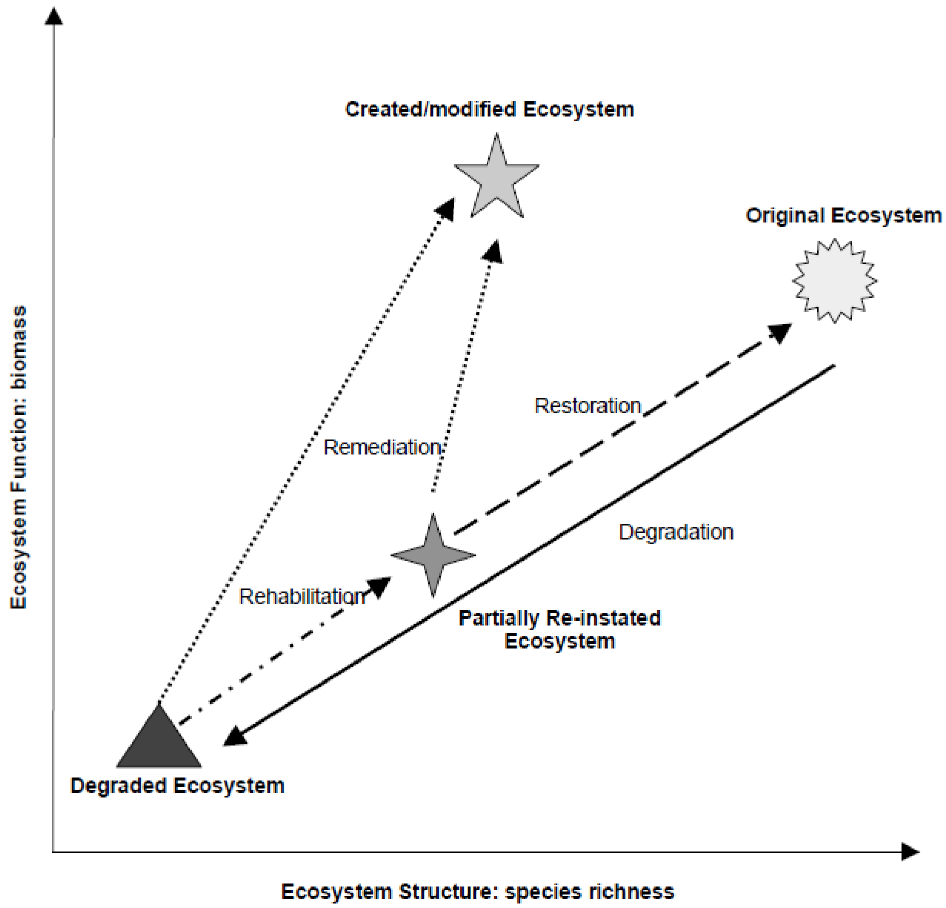


Figure 2-1 A schematic diagram showing the distinction between restoration, rehabilitation and remediation (Rutherfurd et al., 2000)

3 Research conception and framework

3.1 Research objectives and methodologies

In order to make further progress on urban river rehabilitation, this research work is subdivided into four modules according to specific objectives.

- **Objective 1** - Identify urban and rural rivers by establishing an urban-rural river continuum identification system (see Module 1 in Fig. 3-1).

  - **Methodology** - The conception of urban-rural river continuum codes will be brought up to define the different urban or rural river classes. The main influencing parameters will be identified, scaled and normalized into the same classification. The analytical hierarchy process can be used for weighing these key parameters. Through an integration mechanism, the index which is representing an urban or rural river status can be generated and a status map can be developed.

- **Objective 2** - Develop a fuzzy logic-based modelling system for assessing urban river health status (see Module 2 in Fig. 3-1).

  - **Methodology** - Due to the limitations of available input data sources for the management of environmental problems, the fuzzy logic method can be applied to develop a simplified and easily understandable model that incorporates human knowledge and experiences. All the ecologically related factors derived from analysing river functions will be taken into consideration and grouped into the multi-step fuzzy modelling in order to generate the urban river health index.

- **Objective 3** - Estimation of the interactions between urban river reaches and rural river reaches (see Module 3 in Fig. 3-1).

  - **Methodology** - These two, the urban-rural river continuum identification system and the urban river ecological health assessment system will show separately the classification of urbanization and the classification of degradation of urban rivers. Through their comparison the interaction of urban river reaches and rural river reaches can be analyzed. The most degraded spots of the whole river system as well as the most influencing factors can be easily identified.

- **Objective 4 -** Estimation of urban river ecological rehabilitation measures (see Module 4 in Fig. 3-1).

  - **Methodology** - Corresponding to different urban river health levels, proper and effective rehabilitation measures can be carried out. Estimation of the different mitigation scenarios will be done to optimize the most efficient ecological rehabilitation measures. A case study on Shenzhen River is performed for the feasibility of the proposed integrated river management method.

3.2 Research framework

The flowchart regarding the main problems and expected output for each module is shown in figure 3-1.

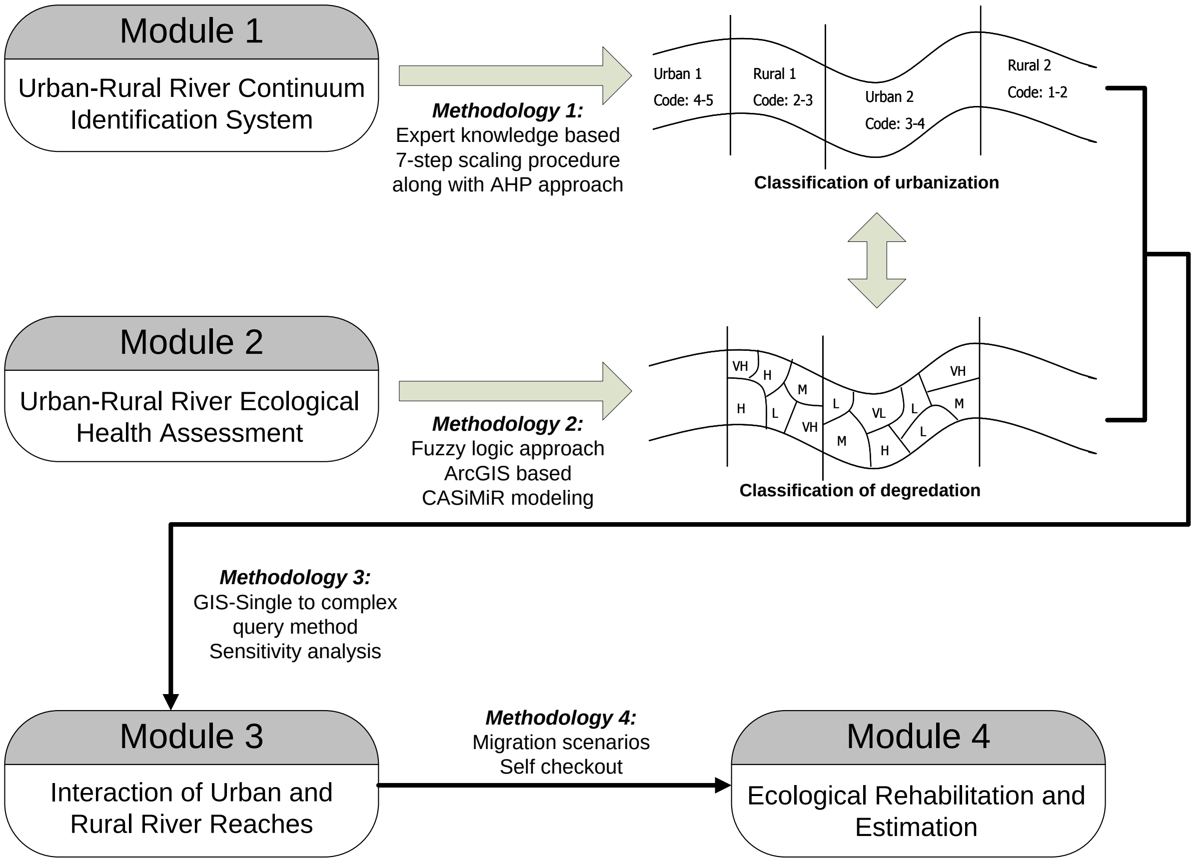


Figure 3-1 Research framework and expected outputs

4 Investigations on case study area and database setup

Shenzhen River in China is chosen as the case study area in this research. Shenzhen River is a typical urban river which can meet the research objective. The river scale is of an adequate size to carry out the mesoscale mapping method.

Shenzhen is a city of sub-provincial administrative status in southern China's Guangdong province, situated immediately north of Hong Kong. It is situated at north latitude 22°27' - 22° 52', and east longitude 113°46' - 114°37'.

Figure 4-1 Location of Shenzhen River Basin in China

4.1 Characteristics of the Shenzhen River Basin

The Shenzhen River basin lies in the North District of Hong Kong, and the city of Shenzhen, Guangdong. Shenzhen River serves as the natural border between Hong Kong and mainland China, together with the Sha Tau Kok River.

The Shenzhen River Basin system mainly consists of Shenzhen River, Shenzhen Bay and its tributaries. Its source is at Wutong Shan, Shenzhen. Its tributaries include Shenzhen River, Liantang River, Shawan River, Buji River, Futian River, Wutong River, Xinzhou River and Dasha River, The Shenzhen Reservoir also flows into the river when it is full. Rivers flow into Shenzhen Bay and Mirs Bay to the east. The Mai Po Marshes lie on its estuary. The status of the main rivers in Shenzhen is shown in table 4-1.

Table 4-1 Basic status of the main rivers in Shenzhen city

River	**Source**	**Length [km]**	**Drainage area [km^2]**	**Annual Discharge [$10^6 m^3/a$]**	**Slope [‰]**	**Flows into**
Shenzhen River	Sanchakou	13.16	297.4	42.92	0.94	Shenzhen Bay
Liantang River	Wutong Maintain	13.24	10.1	5.81	10.06	Shenzhen River
Shawan River	Shenzhen Reservoir	14.08	68.52	39.39	3.4	Shenzhen River
Buji River	Niulingxia	**17.72**	**63.41**	**36.46**	**3.2**	Shenzhen River
Futian River	Meilinao	6.77	14.68	8.44	7.3	Shenzhen River
Wutong River	Wutong Reservoir	**12.54**	**21.1**	**24.95**	**8.13**	Shenzhen Reservoir
Xinzhou River	Meilin Reservoir	11.3	43.4	13.39	5.77	Shenzhen Bay
Dasha River	Changlingpi Reservoir	**18**	**92.3**	**57.48**	**1**	Shenzhen Bay

Efforts have been made to alleviate the flooding and pollution problems of the Shenzhen River Basin. Part of its course was straightened, leading to a shift of boundary. Some square kilometres became annexed by Hong Kong after the restructuring work. The Shenzhen River Regulation Project was completed in November 2007. It will smooth the traffic flow between Hong Kong and Shenzhen, enable infrastructure projects to proceed steadily, and create favourable conditions for economic development.

Regarding the problem of ecological rehabilitation, only minor work has been done. The research of the author of this thesis on the topic of urban river ecological rehabilitation should help the decision-making process for the next steps of the river regulation of Shenzhen City.

For the characteristics of the urban river needed here, three tributaries have been chosen to carry out the field investigation. These are Buji River, Wutong River and Dasha River. The location and the stream system can be seen in the following map (Figure 4-2).

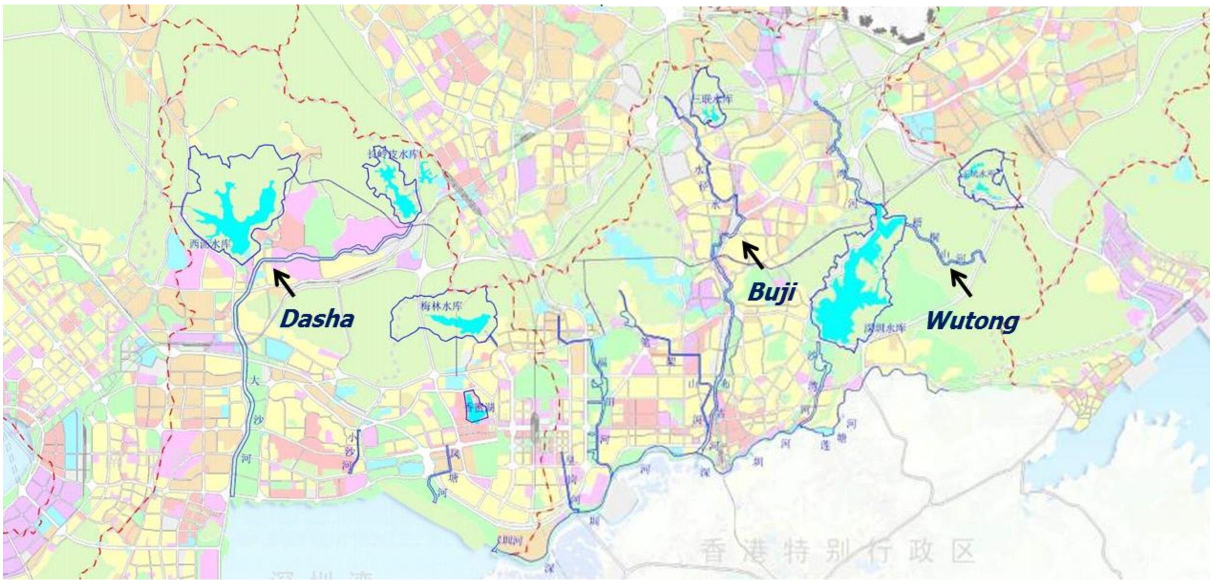


Figure 4-2 of Dasha, Buji and Wutong River in the Shenzhen River Basin

4.2 Field investigations

4.2.1 Introduction of mapping method

The field survey methodology employed in this research is the mapping method for MesoCASiMiR. MesoCASiMiR is an extension of the microscale, fuzzy-logic based model CASiMiR (Jorde, 1996; Schneider et al., 2002; Wieprecht et al., 2007). The main objectives of its development are to produce a) a highly efficient and impartial mapping method, b) a clear and convenient data evaluation and visualization tool based on GIS, and c) habitat simulations for certain scenarios (e.g. changed water allocations, mitigation measures, different intensities of water use) with particular consideration to specific mesoscale habitat needs, such as habitat connectivity and fragmentation.

The challenge in developing a mesohabitat mapping method is that it must be, firstly, detailed enough to be valuable and accurate with regard to the habitat needs of target indicating species (or the focus of foreseen investigation; fish species are chosen as the target indicator in this research, and a further description is in the following chapters). Secondly, it has to provide consistent and reliable results, yet at the same time carry reasonable time and labour costs. This is important as it is to be applied to very long stretches of river. To satisfy these requirements, the developed mapping method for MesoCASiMiR combines descriptive and quantitative investigations to describe the characteristics of mesohabitats.

Mesohabitats in this context are separate sections of rivers that have relatively similar characteristics of flow velocity, water depth, slope, substrate conditions and cover. They may be described as a pool, a riffle, a glide, or a set of rapids, for example. The longitudinal extent of a mesohabitat has to be at least the width of the investigated river being considered.

Two of the basic parameters for the habitat modelling of fish are: flow velocity and water depth. Because mesoscale modelling requires an assessment of these parameters for many river-kilometers, traditional geometric surveys for subsequent hydrodynamic modelling - as is usually done for microscale modelling - are not acceptable. Instead, for MesoCASiMiR these parameters are estimated (mapped). Exact values of water depth and flow velocity are not mapped but instead ranges of these are estimated for representative categories. Other mesohabitat mapping approaches rely on either time-consuming measurement strategies or define exact boundaries between classes, whereas in the MesoCASiMiR mapping method, classes for flow velocity and water depth overlap. During the development of the mapping method, investigations by means of case studies showed that overlapping class boundaries lead to a significant increase in impartiality and repeatability and therewith to more reliable model results. An example of this is: depth classes of “20-40 cm,” “40-70 cm,” and “70-100 cm” are replaced with classes of “20-50 cm,” “40-70 cm,” and “60-120 cm.” In addition to this quantitative classification, the descriptive parameters “range” and “variability” are also required. The parameter “range” describes if the representative value inside the chosen category is high, medium or low, and consequently helps to convert the mapping results to the physical value, which is further used in habitat modelling. The parameter “variability” indicates whether the heterogeneity inside the mesohabitat is high or low, which might be important for certain fish species or life stages of such fish species.

Since flow velocity and water depth are required, substrate information is the third basic parameter that completes the basis for MesoCASiMiR modelling. For the assessment of the spawning and rearing habitats of gravel-spawning fish species, the parameters embeddedness and packing are required as well (see Eastman et al., 2007 and Wieprecht et al., 2007). Depending on the requirements of certain target species, additional parameters like temperature or water quality may be included. This information, however, is not mapped, but can be provided by routine investigations from the case study area or water quality models or monitoring. To be able to assess habitat fragmentation or connectivity, migration barriers have to be mapped as well. For this purpose it has to be observed a) if there is a diverted reach or not, b) if a fish pass, constructed either as a technical or natural bypass, is installed operatively, and c) if a sufficient attraction flow to the fish pass and to the diverted reach is available.

In order to increase the efficiency of mapping, field data collection occurs either with a Tablet-PC or a Pocket-PC so that it is possible to digitalize the data directly in the Geographical Information System (GIS) ArcGIS or ArcPad. The habitats are represented by polygon-shapes and the observed attributes are saved directly into the associated database. This practice enables quick performance, since there is almost no post-processing required. Depending on river size and other characteristics, daily mapping distances of 3 to 7 km are achievable. For certain rivers with inland navigation it is possible to map from a boat. Distances of 20 km a day or more have been achieved by this transportation method. Normally, the main focus of habitat mapping of these river types lies on the long drawn-out habitats on the river-banks. With the aid of GPS signals directly on the touch screen of the Tablet-PC or Pocket-PC and the use of aerial photographs, precise location and definition of the extent of each mesohabitat are possible.

4.2.2 Data collection on three tributaries of Shenzhen River

According to the characteristics of the urban river, three tributaries of Shenzhen River have been chosen to carry out the field investigation, which are Buji River, Wutong River and Dasha River. The following example demonstrates the collected data from the Dasha River.

The detailed field survey and collected materials were composed as a field investigation report. A comparison and status summary of these case study areas are given in the following table.

Table 4-2 Comparison and status summary of three case study areas

Study area	Length/km	Upstream	Middle Stream	Downstream
Buji River	17.72	Artificial banks, good vegetation	Residential area, channelized, artificial banks	Channelized, artificial banks, poor vegetation
Wutong River	12.54	Good vegetation, artificial reservoir	Hydraulic engineering, artificial banks, good vegetation	Residential area, artificial banks
Dasha River	18	Natural banks, good vegetation	Channelized, straight, artificial banks,	Natural ecosystem in Shenzhen Bay

One important research objective in this thesis is to identify the interaction between urban river reach and rural river reach. So, the upstream and downstream of the case study area should have more natural river characteristics. According to this requirement, the Dasha River is more suitable and was finally chosen to be the case study area. Figure 4-3 shows the evolution of the course of the Dasha River over the past few decades.

Dasha River in 1979

Dasha River in 2008

Figure 4-3 River course comparison of Dasha River between 1979 and 2008

Figure 4-4 shows an example of photography of Dasha River in the first field investigation in 2008, which gives a visual impact on the different hydraulic, geomorphological and ecological status of upper, middle and downstream.

Upstream

Middle stream

Downstream

Figure 4-4 An example of photography of Dasha River in the first field investigation

4.2.3 The second field investigation on the Dasha River

After analyzing the field data which was collected in October 2008, and comparing the three tributaries with the initial simulation results, it is found that the Dasha River best meets the requirements, and is finally chosen to be the main case study area. Therefore it is essential to focus even more on the Dasha River and investigate much more deeply into its ecological situation and carry out the assessment.

The second field study on the Dasha River was completed in April 2010. This study measured not only the same parameters of last survey again, but also took into account some other additional parameters which were proven to be the main influencing factors for river ecological health status. The selection of these key parameters is described in detail in Chapter 6.

On the other hand, located on a tropical seafront, the Shenzhen River basin belongs to a south semi-tropical oceanic monsoon climate with the distinct feature of dry and wet seasons. From statistics, the annual mean precipitation is about 1,900 mm and mainly concentrated in the wet season, lasting from April to September. The wet season accounts for up to 90% of the overall rainfall per year, whereas only 10% of precipitation occurs during the dry season (October to March). The results of data analysis from the last field survey indicate that the dynamics of each parameter and the mapped variation of fish habitat suitability along the river sections are very low. Following further analysis, it becomes clear that the main reason behind this is the low discharge during dry season. The discharge situation has a very strong influence on the flow regime. Therefore, the habitat suitability in different flow conditions is going to be different. For calibration purposes of the model, another field study during wet season is necessary. An additional wet season field study will help to complete the database and to support a more reliable analysis dynamic. This will allow us to understand more comprehensively the ecological status of the case study area.

For this field investigation, the MesoCASiMiR mapping method has also been applied along the Dasha River from source to mouth. The range of each significant variable, that is, flow velocity, water depth, substrate, riparian vegetation and bank protection, was measured. Additionally, the information of discharge, turbidity and suspended load was also collected. The digitization of the analysis of this field data is processed after the investigation.

4.3 Database setup and digitizing process

All the data analysis and modelling procedures regarding urban and rural river identification and ecological health assessment in this research has been done using ArcGIS (ESRI; ArcGIS Release 9.3). In order to set up the geospatial database of the Dasha River in the Shenzhen River Basin, further to importing and working with the field survey data, different types of geospatial sources of study area have been discussed and compared in this chapter.

4.3.1 Geospatial data source from the US Geological Survey

The United States Geological Survey (USGS) is a scientific organization that provides impartial information on the health of ecosystems and environments which covers almost the entire world. The Earth Resources Observation and Science (EROS) Centre is a remotely sensed data management, systems development, and research field centre for the US Geological Survey's Geography Discipline. EROS archives remotely sense images of the Earth's land surface. This data is acquired by civilian satellites and aircrafts and is used to study a wide range of natural hazards, global environmental changes, and economic development and conservation issues. To obtain the observed data, we can use the USGS Global Visualization Viewer (GloVis), which is a quick and easy browse-based search and order/download tool of all available satellite and aerial data (Data source: http://glovis.usgs.gov/).

As the first opportunity to set up the database of the Dasha River, the Landsat map and the Digital Elevation Model (DEM) map of the case study area are obtained from the Earth Resources Observation and Science Centre of USGS, and the Dasha stream network shape is generated by two different methods.

First of all, the stream network polygon can be digitized with the ArcGis Editor Toolbar manually.

The second step is to generate the stream network based on the Digital Elevation Model.

After importing the DEM image into the ArcGIS, we use Spatial Analyst Tools/Hydrology to generate the flow accumulation shape, and then Conditional or Extraction Tools, or a Spatial Analyst/Raster Calculator to get the raster which represents flowacc>500 (or >1000) (see Figure 4-5).

After that, we use Conversion Tools/From Raster to features to generate the Dasha_stream_polygon, and the Dasha_stream_polyline. We then convert the polygon data into raster data (we can change cell size here), followed by converting the raster data into the Dasha_stream_point. By this step, the Dasha stream network is digitized as a grid-based image; it has a property which can be loaded with more specific field observation data (see Figure 4-6).

Figure 4-5 (a) Landsat image of the Dasha River downloaded from USGS and (b) the stream network generated based on the DEM image

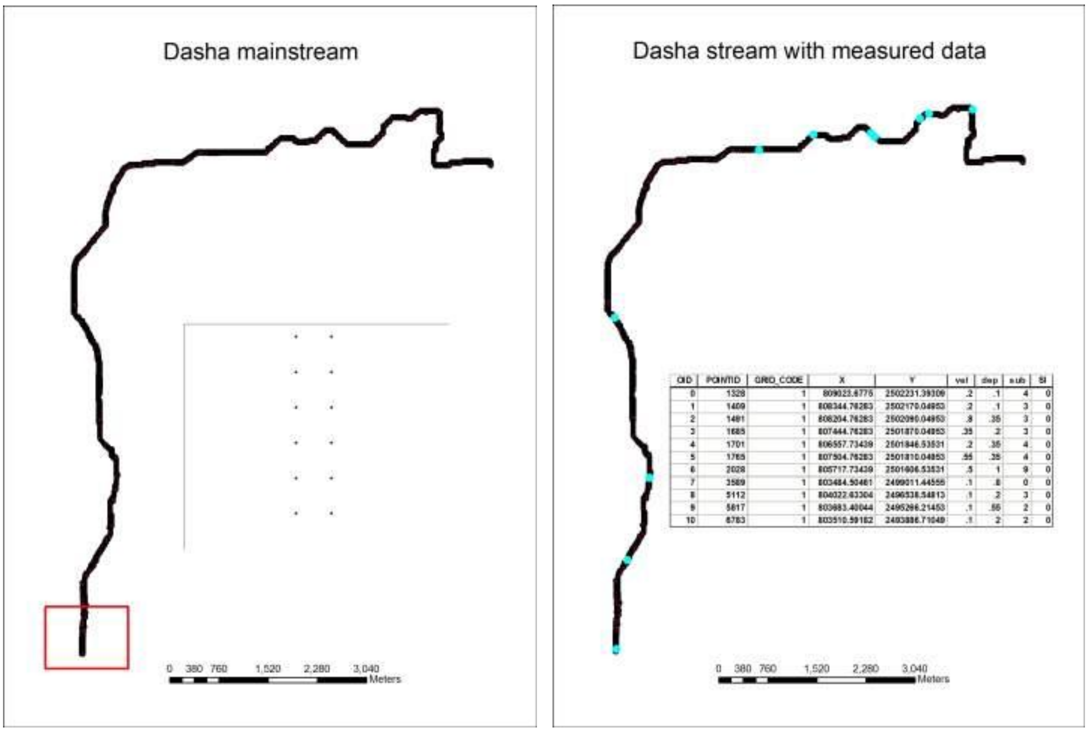


Figure 4-6 (a) Grid-based Dasha main stream and (b) an example of the Dasha main stream displayed with field data

In order to simplify the simulation work, and consider the real Dasha River course, which the field survey follows, the main stream network is generated by using the Editor Toolbar for further digitization. Working with the attribute table of the Dasha main stream point shape, the field survey data of each parameter can be imported and analyzed.

Since the Dasha river course is partly underground, the field investigation does not continually cover all the reaches from the river source to the mouth. Therefore, the method of interpolation is considered in order to achieve a continuous simulation result. Different interpolation methods including Inverse Distance Weighting (IDW), Kriging (Spherical, Exponential, and Gaussian) and Spline have been used and compared, and different grid cell sizes have also been considered (see table 4-3).

Table 4-3 Comparison of different interpolation methods

Interpolation Method		Cell Size	Result (out of 1293)
IDW		10	526
		25	553
Kriging	Spherical	10	525
	Exponential	10	478
	Gaussian	10	548
		25	520
Spline		10	1148
		25	1176
		30	1155

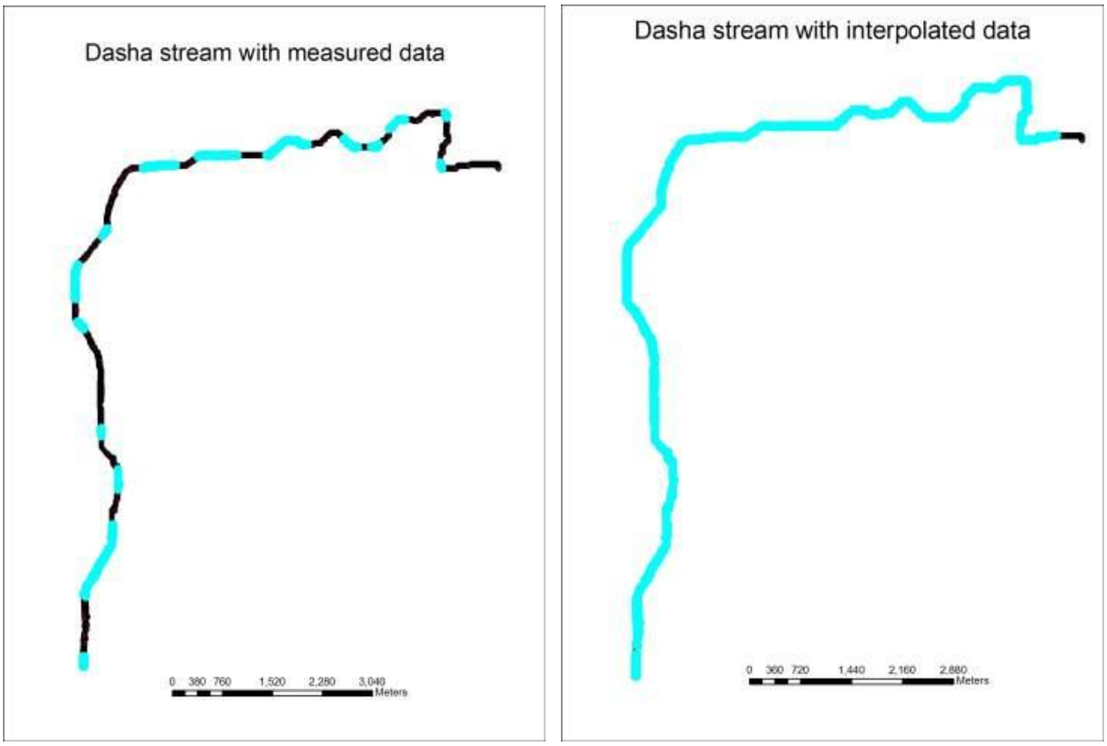


Figure 4-7 Comparison between (a) measured data and (b) interpolated data

Finally, the Spline method with a cell size of 10 has been chosen. Previously the measured data covered 459 out of 1293 points on the Dasha stream, after the procedure of Spline interpolation with the determination of cell size of 10, the covered stream point increased significantly (see Figure 4-7).

One disadvantage is that, the satellite images from the USGS are too blurred; the resolution of Dasha Landsat image is 30m, and the resolution of the DEM is 90m. Because the width of the Dasha River is mostly less than 60m, so the display of input and output images could not precisely express the variance of the river system.

4.3.2 Geospatial database base on Google Earth Images

Google Earth is a virtual globe, map and geographical information program that was originally called EarthViewer 3D, and was created by Keyhole, Inc. a company acquired by Google in 2004. It maps the earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe (Software Download Source: http://www.google.com/intl/en/earth/download/ge/).

GEtScreen – The short name for Get Screen Copy from Google Earth - is a special tool that helps users to capture screenshots of Google Earth and save as local maps. Users can choose individual captured areas and their altitude, and then GEtscreen will calculate all the related data and captured seamless maps automatically. Files can be saved in BMP or JPEG format, and also can be created in OZI format, which could be used for GPS. There is a similar type of software to Google Earth image downloader (Software Download Source: http://bbs.godeyes.cn/showtopic-180196.aspx).

One advantage of this method is that GEtScreen can download satellite images with different resolutions. In the case of the Dasha River, a satellite image with the highest resolution of 7m is captured.

In this research, the satellite image of the Dasha river basin area has been captured by using GEtScreen from Google Earth. Afterwards it is imported into ArcGIS 9.3 to build up the database. Based on this Dasha map, all the data analysis and simulation procedures have been carried out.

Along with this, one big problem is that there is a lack of geo-information on the downloaded image, which means we could not get a clear geo-position of the map and there is a difficulty in importing the image into ArcGIS with a proper location. Therefore, the further step of geo-referencing has to be carried out.

ERDAS IMAGINE is a remote sensing application with raster graphics editor capabilities designed by ERDAS Inc. for geospatial applications. The latest version is 2010, version 10.1. ERDAS IMAGINE is aimed primarily at geospatial raster data processing and allows the user to prepare, display and enhance digital images for mapping use in ArcGIS software. It is a toolbox allowing the user to perform numerous operations on an image and generate an answer to specific geographical questions. By manipulating imagery data values and positions, it is possible to see features that would normally not be visible and to locate geo-positions of features that would otherwise be graphical (Software Download Source: http://www.erdas.com/).

Through the step of re-projection, the image of the Dasha River is geo-referenced with the Universal Transverse Mercator (UTM) geographic coordinate system. It is a grid-based method of specifying locations on the surface of the Earth that is a practical application of a 2-dimensional Cartesian coordinate system. At last, the re-projected satellite image is imported into the ArcGIS to set up the database, and the Dasha River shape is captured by using the Editor Tool, which is shown below (see Figure 4-8).

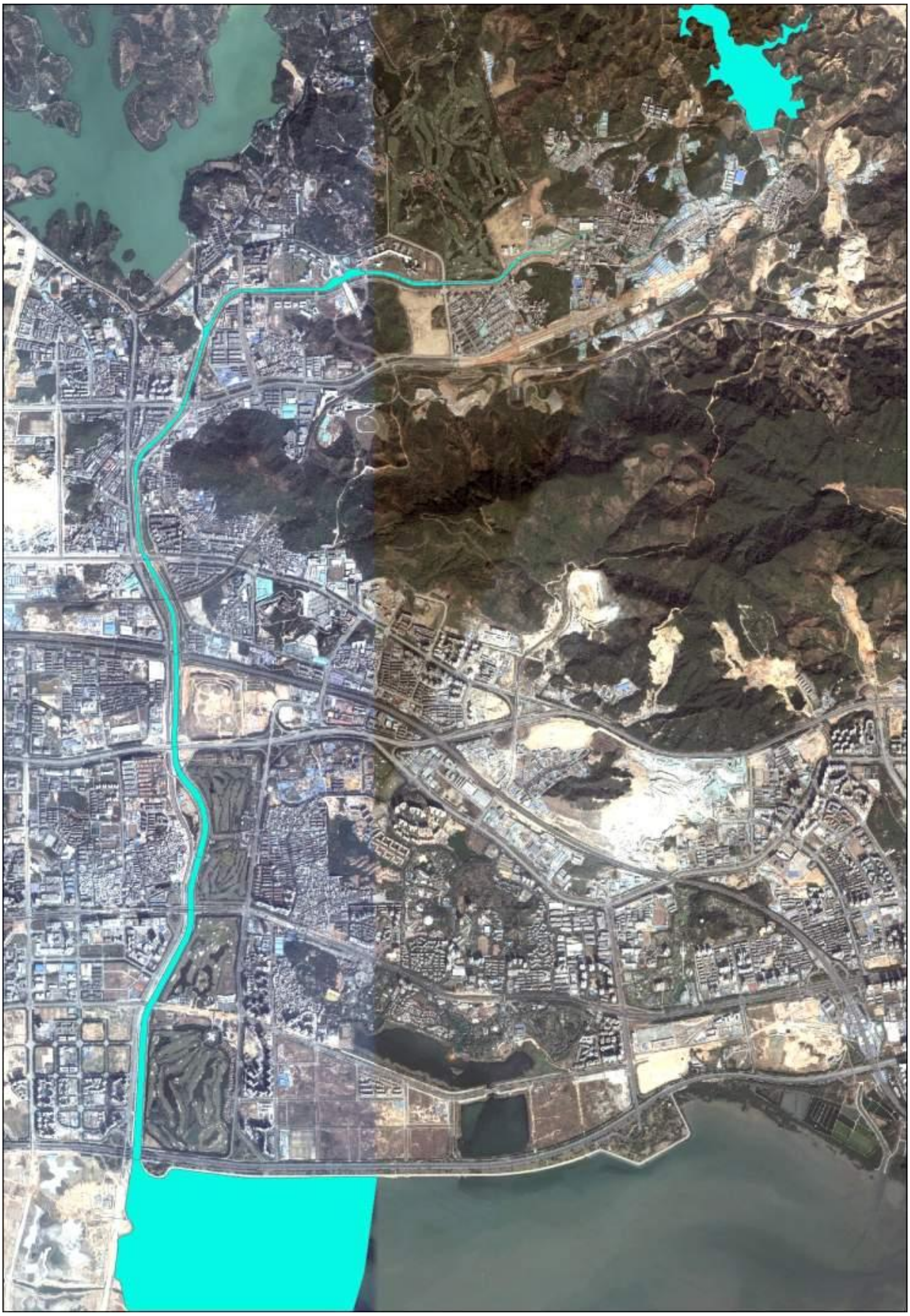


Figure 4-8 Satellite image of the case study area and the Dasha River captured by using the ArcGIS Editor Tool

4.3.3 Other possibilities of data sources and discussion

Depending on the situation of the case study area, other data sources could also be considered to be used. In this research, another two possibilities of geospatial data source have been used.

The third geospatial data source we are working with is the aero photographs from the Shenzhen local government. The resolution of these satellite images is higher; 1:10000. In the case of the Dasha River, there are in total six aero photographs from 2001. In order to import this data source into the ArcGIS, the step of geo-referencing by using ERDAS could be used. Or, we can also use Photoshop to join these 6 aero maps together. But the problem is that the image shrinks significantly, even though it is oriented correctly.

The fourth possibility to obtain geospatial data is to take one entire image from Google Maps online by using MapCap software along with the procedure of re-projection by using ERDAS. But the image we get has a high level of background noise, which could affect the quality of the geospatial database of the Dasha River (Software download: http://www.godeyes.cn/html/2009/01/04/download_3243.html).

In this research, four different geospatial data sources have been used to set up the database for the case study area: 1) Satellite images from the US Geological Survey; 2) Satellite images from Google Earth by using GEtScreen; 3) Aero photographs from local government; 4) Satellite images from Google Maps by using MapCap. Based on the above analysis, we can see that the best data source for the Dasha River is the satellite image downloaded from Google Earth by using GEtScreen. It has a very high resolution of 7m without any background noise, and can be geo-referenced in ArcGIS properly. So, this geospatial data source of the Dasha River (see Fig. 4-9) is used in this research for all modelling processes.

Regarding the raster feature of the Dasha River database in ArcGIS, we prefer to lay it out as grid-based rather than polygon-based, since the resolution of the grid-based raster feature could be defined as very high. The smallest grid size defined in this research is 1m*1m, where usually the grid size could be defined as 30m into 30m. Based on this conception, we were able to import more detailed data from the field investigation, and significant variations along the river system can be expressed.

5 Urban-Rural River Continuum Identification System and Implementation

5.1 Conception of the identification system

This Urban-Rural River Continuum Identification System is developed for the identification of urban and rural rivers based on a longitudinal continuum. Here, we are concerned specifically with the stretch-scale survey of the river system, although for effective management such stretches need to be placed with different definitions in their catchment and network context. On the stretch scale, the following points are described: 1) a method to identify the urban river and rural river; 2) some synthetic indices that can be derived from this Urban-Rural River Continuum Identification System to provide a description of urban river reaches; 3) five different classifications of a river system to reflect the degree of degradation which has to be concerned to establish urban river ecological rehabilitation goals.

In this research, a generic conceptual model is developed, and the urban-rural river continuum codes are set up to describe 5 classes of river systems with respect to the urban and rural characteristics. A set of key parameters which represent geomorphologic, chemical, hydrological and habitat characteristics of the water body and riparian zones are selected based on the literature review. In order to coincide with the urban-rural river continuum codes, information on each of the parameters is transformed into a single dimensionless score, and also has 5 classes corresponding to the urban-rural river continuum codes. The definition of each class for each parameter is given based on the literature review and export knowledge. And the score of each parameter can be obtained through field investigation and survey. Then, the prioritization of all the parameters is done by using the method of Analytic Hierarchical Process (AHP). After we have got all the weights (W) and scores for all the involved parameters (S), the integration of the key parameters can be completed, and the Urban-Rural River Continuum Index (URRCI) for each surveyed stretch unit can be calculated.

Generally, the developed Urban-Rural River Continuum Identification System is a 7-step screening level assessment for the degree of urbanization:

Step 1: Definition of the basic stretch unit.

Step 2: Description of Urban-Rural River Continuum Codes

Step 3: Selection of key parameters

Step 4: Description of the key parameters used for identifying urban-rural stretch

Step 5: Scaling of each parameter

Step 6: Prioritization of all the key parameters

Step 7: Calculation of the Urban-Rural River Continuum Index and identification of urban or river reaches

The flowchart of this Urban-Rural River Continuum Identification System can be seen below (Figure 5-1), and a more detailed identification process for each step is discussed in the following paragraphs.

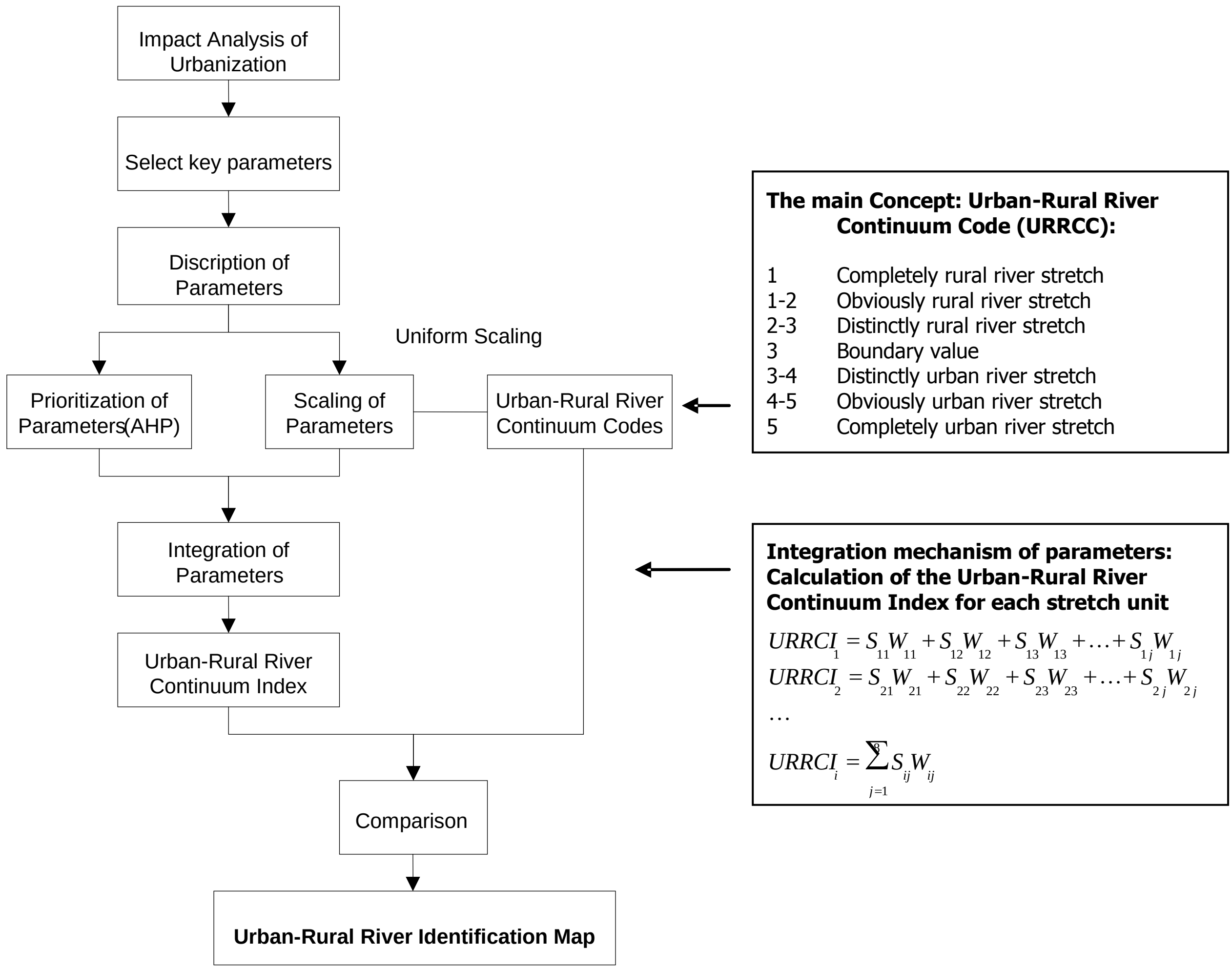


Figure 5-1 The flowchart of the Urban-Rural River Continuum Identification System

5.2 Definition of the basic stretch unit

This urban and rural river classification is based on a longitudinal continuum, the survey and data collection are applied to the unit of stretch for the main parameters involved. Each 1 km length of river is equally divided into 10 stretches, each 100m long. The basic unit of a stretch can also be changed to 50m or 500m of length, according to the different scale of the river system being studied. The method we are using here to define the corresponding watershed of each river stretch unit is to give a certain buffer to the river stream, and divide it equally according to the stretch unit.

One question is: How big should a buffer zone be? One size does not fit all over. It depends on what we want to buffer .An example of buffer zones for the Great Miami River Watershed can be seen in Figure 5-2, which shows different suitable buffer widths according to different purposes. There is not one generic buffer that will keep the water clean, stabilize the bank, protect fish and wildlife, and satisfy human demands on the land. The minimum acceptable width is one that provides acceptable levels of all the needed benefits at an acceptable cost. The basic minimum buffer is 50 feet (15m) from the top of the bank, which is the same length of river width. If the impact of the human land use is considered, the buffer zone should be at least 6 times of river width in general. In this research, considering the river size of Dasha River, we consider using a 500m buffer (riparian zone) on each side of the stream along the entire stream network (6 times the river width).

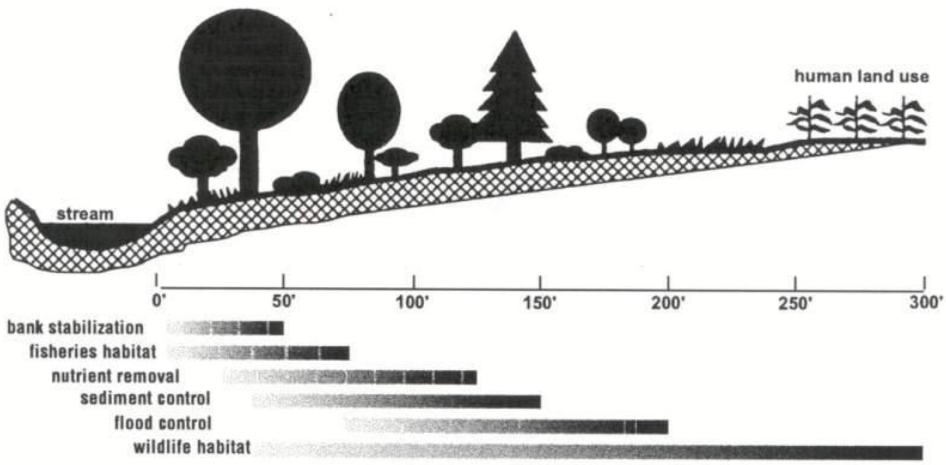


Figure 5-2 Different suitable buffer widths according to different purposes (Figure source: Introduction to Streamside Buffer Zones for the Great Miami River Watershed) as example

In this work, a river stretch which is 100m long and with 500m buffer (6 times the river width) zones on both sides of the river has been chosen as one basic study unit. The Dasha River is 13.6 km long in total, so the field survey has been done along the river 137 single stretches.

5.3 Description of Urban-Rural River Continuum Codes

The United States Department of Agriculture, Economic Research Service has developed several classifications to measure reality and assess the economic and social diversity of rural America. Rural-Urban Continuum Codes form a classification scheme that distinguishes metropolitan (metro) counties by the population size of their metro area, and non-metropolitan (non-metro) counties by the degree of their urbanization and adjacency to a metro area or areas.

Referencing this successfully applied classification scheme, the Urban-Rural River Continuum Codes are established in this research work to identify urban river reaches and rural river reaches by their degree of urbanization (Table 5-1), which can be defined by a number of parameters that respond to describe what is rural and urban. Here we define code 1 as a completely rural river stretch, codes 1 to 3 as a rural river stretch, 3 to 5 as an urban river stretch, 5 as a completely urban river stretch, and 3 as the threshold value between an urban river and rural river stretch.

Table 5-1 Definition of the Urban-Rural River Continuum Codes

Urban-Rural River Continuum Code	Definition
1	Completely rural river stretch
1-2	Obviously rural river stretch
2-3	Distinctly rural river stretch
3	Boundary value
3-4	Distinctly urban river stretch
4-5	Obviously urban river stretch
5	Completely urban river stretch

Obviously in reality it is more difficult to say there is a boundary line between an urban river stretch and a rural river stretch. The threshold is given only because this fuzzy zone of urban river and rural river is not long enough and is not significant enough in the whole mesoscale or even macro scale river system, and it is much easier for the following research where the river lengths of urban and rural rivers are needed.

The main important parameters which can represent the situation of the river system in terms of all its aspects, such as hydraulic, hydrology, geomorphology, ecology and chemical characteristics are playing a key role in getting an Urban-Rural River Continuum Code. For the sake of maintaining uniformity, the collected data for each parameter is also being normalized on the same scale as the classification of the urban-rural river continuum; the scaling of each parameter will be described in detail in the following paragraph 5.4.

For one surveyed stretch unit, the Urban-Rural River Continuum Code will be calculated by the normalized scales of all the involved parameters and the weights of all those parameters. The weight of each parameter can be derived from the prioritization method of the Analytic Hierarchical Process (AHP), which will be described in paragraph 5.5.

5.4 Selection and definition of key influencing parameters

The key aspects to identify urban and rural river reaches should include both the river body itself and the surrounding environment. In this research, 6 parameters from the aspects of watershed geomorphology and the water utilization are used as the key influencing factors, which are listed below.

1. The environment which the river flows through: Watershed geomorphology
    a. Land use type
    b. Degree of Imperviousness of the river area including buffer zone
    c. Population density
    d. Riparian vegetation
2. Utilization and artificial change on the river body: River course modification
    a. Hydraulic constructions
    b. Bank/bed protection

5.4.1 Land use

Both the theory and practice from past research show that land cover and land use are closely related, thus many proposed land use classifications are actually mixing land cover and land use where natural and semi-natural vegetation are described in terms of land cover, and agricultural and urban areas in terms of land use. It is still necessary to develop land use classification separately from land cover classification due to the differences between these two and the importance of land use statistics for related policy analysis and decision-making.

Land use can be considered as reflecting the degree of human activities directly related to the land, and making use of its resources or having an impact (Young 1994). Two key aspects of land use are the products and benefits from the use of the land and the operations applied to the land in order to produce these products and benefits. Field and ground information such as surveys and censuses are usually required.

Remote sensors mainly capture the features of the Earth's surface, i.e., land cover information. Hence, remotely sensed data are more suitable for land cover classification, instead of land use classification. In urban studies, however, land use is more useful than land cover information, because land use is directly related to socio-economic activities. A uniform definition of urban land use categories is not available yet. Most previous research classified urban built-up areas into residential areas and commercial and industrial areas, or their subcategories when high-resolution data were used (Epstein, Payne, and Kramer 2002; Phinn et al. 2002; van der Sande, de Jong, and de Roo 2003; Zha, Gao, and Ni 2003).

The classification approach used in this research is based on expert systems. The dominant land use on the bank top in both buffer zones is subdivided into residential, commercial, industrial, open land, agriculture land and grassland (see Figure 5-3).

Figure 5-3 The dominant land use types on the bank top in buffer zones

Land use is classified into 5 different levels coinciding with the urban-rural river continuum codes (see Table 5-2). 1 corresponds to completely rural; 2 corresponds to rural; 3 corresponds to semi urban-rural; 4 corresponds to distinctly urban; 5 corresponds to completely urban. The specific value of land use categories is obtained from the field survey for each different stretch unit, and a decimal value in between is allowed to be given. The above 6 types of land use are grouped into 5 land use categories according to their characterisers of urbanization.

Table 5-2 Classification and definition of land use

Land use	Classification	Definition
1	Completely rural	Open land or vegetated land like grass land
2	Distinctly rural	Land use for agriculture
3	Semi urban-rural	Commercial/industrial/transportation
4	Distinctly urban	Medium-intensity residential land
5	Completely urban	High-intensity residential land

5.4.2 Impervious surface

Urbanization of a watershed can result in a significant impact on stream health. The impervious area in a drainage basin provides a quantitative measure of this potential impact: it is a measure of the total area where water does not infiltrate into the soil, including roads, rooftops, sidewalks, patios and compacted soil. Imperviousness is an integrative indicator, and can be used to estimate or predict cumulative water resource impact and the degree of urbanization. Research in various regions has consistently shown a strong relation between the imperviousness of a drainage basin and the health of the receiving stream.

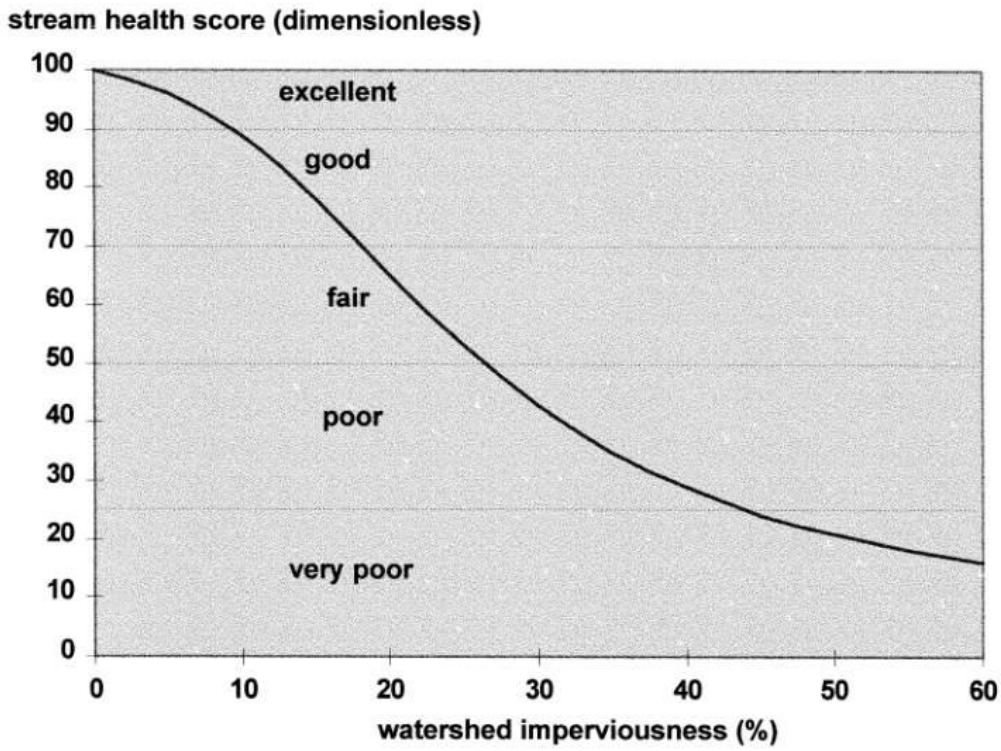


Figure 5-4 Generalized relation between watershed imperviousness and stream health

Here is a generalized description of this relationship, indicating the existence of a threshold at around 10% imperviousness. The effectively impervious area, or the impervious area directly draining into the storm sewer system or streams (and typically significantly lower than the total impervious area in low density residential areas), is the most appropriate measure of the hydrological impact of urbanization, but the total impervious area is the measure used in most studies on the impact of imperviousness on stream health and is considered to be the best indicator to quantify the overall degree of urbanization versus just hydrological changes. For this reason, the total impervious area is used here. Although the use of imperviousness as an integrative indicator has become widely accepted among watershed professionals, it should be emphasized that its use is limited to the sub-basin and watershed level scale (from 5 to 150 km^2). On a larger scale the indicator is not appropriate, because of the topography and land use heterogeneity typical for large river basins.

In this research, imperviousness is classified into 5 different levels coinciding with the urban-rural river continuum codes (see Table 5-3). 1 corresponds to completely rural; 2 corresponds to distinctly rural; 3 corresponds to semi urban-rural; 4 corresponds to distinctly urban; 5 corresponds to completely urban. The specific values of the categories of imperviousness are obtained from the field survey for each different stretch unit, and a decimal value in between is allowed to be given. The definition of each category is mainly based on the percentage of the impervious surface of the river stretch buffer zones being studied.

Table 5-3 Classification and definition of imperviousness

Imperviousness	Classification	Definition
1	Completely rural	Impervious surface is very low, usually less than 10%
2	Distinctly rural	Impervious surface is greater than 10%, but less than 20%
3	Semi urban-rural	Impervious surface is greater than 20%, but less than 40%
4	Distinctly urban	Impervious surface is greater than 40%, but less than 60%
5	Completely urban	Impervious surface is greater than 60%

5.4.3 Population density

Population density is a very important indicator of the urbanization status. It is difficult to compare countries based on the percentage of urban population since many countries have different definitions of what size population is necessary to make a community "urban."

In Sweden and Denmark, a village of 200 people is counted as an "urban" population but it takes a city of 30,000 in Japan. Most other countries fall somewhere in between. Australia and Canada use 1000, Israel and France use 2000 and the United States and Mexico call a town of 2500 residents urban.

Due to these differences, we have a problem with comparisons. Let us assume that in Japan and in Denmark there are 100 villages of 250 people each. In Denmark, all of these 25,000 people are counted as "urban" residents but in Japan, the residents of these 100 villages are all "rural" populations. Similarly, a single city with a population of 25,000 would be an urban area in Denmark but not in Japan. Japan is 78% and Denmark is 85% urbanized. Unless we are aware of what size population makes an area urban we cannot simply compare the two percentages and say "Denmark is more urbanized than Japan."

Because the case study area is the Shenzhen River Basin in China, we therefore used the standard of population density which is released by the Chinese government. In this research, the population density is classified into 5 different levels coinciding with the urban-rural river continuum codes (see Table 5-4). 1 corresponds to completely rural; 2 corresponds to distinctly rural; 3 corresponds to semi urban-rural; 4 corresponds to distinctly urban; 5 corresponds to completely urban. The specific value of population density categories is obtained from a field survey for each different stretch unit, and a decimal value in between is allowed to be given.

Table 5-4 Classification and definition of population density

Population density	Classification	Definition
1	Completely rural	Population density is very low, usually less than 10 persons/km^2
2	Distinctly rural	Population density is greater than 10 persons/km^2, and less than 10 persons/km^2
3	Semi urban-rural	Population density is greater than 500 persons/km^2 and less than 1500 persons/km^2
4	Distinctly urban	Population density is greater than 1500 persons/km^2 and less than 3000 persons/km^2
5	Completely urban	Population density is greater than 3000 persons/km^2

5.4.4 Riparian vegetation

Channel vegetation in the urban environment is important for (i) ecological integrity, (ii) its effect on flow patterns and channel conveyance, and (iii) its impact on dissolved oxygen within the water column (Pitcairn and Hawkes 1973; Kirk 1994). A characteristic of urban channels is the uniformity of the bank in terms of its vegetation, because tall vegetation tends to be pruned or removed to reduce flow resistance. Two indices express the character of the bank vegetation.

The classification of vegetation is based on the research system of the Urban River Survey which was developed by Davenport in 2004. The Urban River Survey (URS) was developed from the River Habitat Survey (RHS) which is applied routinely to UK Rivers (Davenport, Gurnell, and Armitage, 2004). The URS method defined 11 possible categories for measuring channel vegetation.

In this research, the definition of each classification of vegetation will only focus on two aspects, which are the percentage of bank vegetation and the diversity of vegetation types. The vegetation is classified into 5 different levels coinciding with the urban-rural river continuum codes (see Table 5-5). 1 corresponds to completely rural; 2 corresponds to distinctly rural; 3 corresponds to semi urban-rural; 4 corresponds to distinctly urban; 5 corresponds to completely urban. The specific value of vegetation categories is obtained from the field survey for each different stretch unit, and a decimal value in between is allowed to be given.

Table 5-5 Classification and definition of vegetation

Vegetation	Classification	Definition
1	Completely rural	The percentage of bank vegetation is higher than 80%; more than 5 different channel vegetation types
2	Distinctly rural	The percentage of bank vegetation is between 40%~60%; high diversity of channel vegetation types (4–5 types)
3	Semi urban-rural	The percentage of bank vegetation is between 40%~60%; moderate diversity of channel vegetation types (3–4 types)
4	Distinctly urban	The percentage of bank vegetation is between 20%~40%; low diversity of channel vegetation types (2–3 types)
5	Completely urban	The percentage of bank vegetation is less than 20%; uniform bank vegetation type.

5.4.5 Bank/bed protection

Bank/bed protection in this research is defined as the action of building a resistance along a river. The protection is used as a form of preventing soil erosion along the riverbanks. Here we use bank/bed protection to describe the channel construction and the level of channelization, which are the main characters of urban rivers. Therefore, bank/bed protection is an essential parameter to define urban/rural river reaches.

The classification of bank/bed protection is also based on the research system of the Urban River Survey (Davenport, Gurnell, and Armitage 2004). We mainly consider two factors when defining the different classes of the bank/bed protection, which are the percentage of bank/bed protection and the bank/bed materials. Two indices reflect the two components of the channel substrate: immobile materials (concrete, brick, and bedrock) and mobile materials (sand, gravel, etc.).

In this research, the bank/bed protection is classified into 5 different levels coinciding with the urban-rural river continuum codes (see Table 5-6). 1 corresponds to completely rural; 2 corresponds to distinctly rural; 3 corresponds to semi urban-rural; 4 corresponds to distinctly urban; 5 corresponds to completely urban. The specific value of bank/bed protection categories is obtained from the field survey for each different stretch unit, and a decimal value in between are allowed to be given.

Table 5-6 Classification and definition of bank/bed protection

Bank/Bed protection	Classification	Definition
1	Completely rural	No protection, natural bank, mainly mobile bank/bed materials like sand, gravel, etc.
2	Distinctly rural	Lightly modified, low protection with mainly biodegradable materials like reeds, wood piling, willow piling, etc.
3	Semi urban-rural	50% protection with immobile bank/bed materials like concrete, brick and bedrock
4	Distinctly urban	Moderately modified, open matrix
5	Completely urban	Heavily modified, solid bank/bed protection

5.4.6 Hydraulic construction

There has been a lack of attention to the effects of artificial embankments and hydraulic construction. In addition to being a significant migration barrier, these hydraulic constructions such as dams and artificial embankments alter river systems' respective habitats' ecological conditions (depth, flow velocity, width and substrate). Moreover, the effects of dams and artificial embankments are enhanced, causing downstream riverbed erosion, decreasing water quality and losing habitat for some species (Yi, Wang and Yang, 2010). In the present research, the goal of river rehabilitation has been modified to reach an ecological balance, rather than remove all the hydraulic construction which has been popular since 20 years ago when the concept of river restoration was just appearing. One of the reasons is that it is very difficult to find the initial status of the river. Another reason is that one of the most important functions of a river is water supply for human beings. Therefore hydraulic construction should be a parameter to identify whether a river system has been used or impacted by human activities.

In this research, the impact of hydraulic constructions on urban/rural river identification has been defined by the distance away from hydraulic construction.

Table 5-7 Classification and definition of hydraulic construction

Hydraulic construction	**Classification**	**Definition**
1	Completely rural	There are zero hydraulic engineering constructions such as dams, weirs, reservoirs, stream crossing structures, drinking water extraction, or any other construction for public utilities, etc. either in the river reach or upstream and downstream for 3 or more river reaches
2	Distinctly rural	There are zero hydraulic engineering constructions such as dams, weirs, reservoirs, stream crossing structures, drinking water extraction, or any other construction for public utilities, etc. in the river reach, and the distance from the sampling site to the nearest hydraulic construction upstream or downstream is 3-5 times longer than one stretch unit
3	Semi urban-rural	There are zero hydraulic engineering constructions such as dams, weirs, reservoirs, stream crossing structures, drinking water extraction, or any other construction for public utilities, etc. in the river reach, but within 2 river reaches upstream or downstream.
4	Distinctly urban	There are zero hydraulic engineering constructions such as dams, weirs, reservoirs, stream crossing structures, drinking water extraction, or any other construction for public utilities, etc. in the river reach, but within the upstream or downstream river reaches
5	Completely urban	There is 1 or more hydraulic engineering construction such as a dam, weir, reservoir, stream crossing structure, drinking water extraction, or any other construction for public utilities, etc. in the river reaches

In this research, the hydraulic construction is classified into 5 different levels coinciding with the urban-rural river continuum codes (see Table 5-7). 1 corresponds to completely rural; 2 corresponds to distinctly rural; 3 corresponds to semi urban-rural; 4 corresponds to distinctly urban; 5 corresponds to completely urban. The specific value of bank/bed protection categories is obtained from the field survey for each different stretch unit, and a decimal value in between are allowed to be given.

5.5 Prioritization of key parameters

The prioritization of the parameters involved can be done through the method of Analytic Hierarchical Process (AHP), a structured technique for dealing with complex decisions, which was developed by Tomas L. Saaty. The pairwise comparisons for parameters have been used with respect to the goal of how important they are to the degree of urbanization. When the pairwise comparisons are numerous, specialized AHP software can help in making them quickly and efficiently, one choice could be the SuperDecisions Software which was developed by Thomas Saaty and his working group.

Priorities are numbers associated with the nodes of the hierarchy. They represent the relative weights of the nodes in any group. By definition, the priority of the Goal is 1.000. The priorities of the Criteria will always add up to 1.000. The software requires us to express this judgment by entering a number. The fundamental scale for judgments is shown in the following table.

The Fundamental scale for making judgments is from 1 to 9 (RW. Saaty, 2003), 1 stands for the compared two parameters being equally important, and 9 stands for one parameter being much more important than the other. Decimal judgments, such as 3.5, are allowed for fine tuning, and judgments greater than 9 may be entered, though it is suggested that they be avoided.

Table 5-8 The Fundamental Scale for Making Judgments (RW. Saaty, 2003)

1	Equal
2	Between Equal and Moderate
3	Moderate
4	Between Moderate and Strong
5	Strong
6	Between Strong and Very Strong
7	Very Strong
8	Between Very Strong and Extreme
9	Extreme
	Decimal judgments, such as 3.5, are allowed for fine tuning, and judgments greater than 9 may be entered, though it is suggested that they be avoided.

Using pairwise comparisons, the relative importance of one criterion over another can be expressed. To incorporate judgments about the various elements in the hierarchy, one questionnaire on the ranking of important parameters has been prepared and distributed among the professors and PhD students in our department, in order to get general and expert knowledge on making the prioritization of these 6 parameters. Based on the consideration of all these opinions and literature review, the elements are compared two by two as shown below (Table 5-9).

Table 5-9 Pairwise comparisons of selected parameters

	Vegetation	Population density	Land use	Impervious -ness	Bank/Bed protection	Hydraulic construction
Vegetation	**1**	**2/3**	**2/3**	**1/2**	**2/5**	**1/3**
Land use	**1 1/2**	**1**	**1**	**3/4**	**3/5**	**1/2**
Impervious-ness	**1 1/2**	**1**	**1**	**3/4**	**3/5**	**1/2**
Population density	**2**	**1 1/3**	**1 1/3**	**1**	**4/5**	**2/3**
Bank/Bed protection	**2 1/2**	**1 2/3**	**1 2/3**	**1 1/4**	**1**	**5/6**
Hydraulic construction	**3**	**2**	**2**	**1 1/2**	**1 1/5**	**1**

To get a ranking of priorities from the above pairwise matrix, the eigenvector solution approach has been used, which was demonstrated mathematically by Dr. Thomas L. Saaty, the founder of the Analytic Hierarchical Process Method. The stable computed eigenvector gives the relative ranking of the parameters (see Table 5-10), and the weight for each parameter will be used in a further calculation.

Shown here is an example of how to solve the eigenvector; this procedure is done with Excel:

1. A short computational way to obtain this ranking is to raise the pairwise matrix to powers that are successively squared each time.

2. The row sums are then calculated and normalized by dividing the row sum by the row totals.

3. The computer is instructed to stop when the difference between these sums in two consecutive calculations is smaller than a prescribed value.

In this case, we computed four times the eigenvector (to four decimal places) and computed the difference of the previous computed eigenvector to the next one. At the fourth turn, the difference showed as 0, 0000 for all of the criteria.

Table 5-10 Eigenvector calculations and weights for each parameter

	1st Eigenvector	2nd Eigenvector	1st - 2nd	3rd Eigenvector	2nd -3rd	4th Eigenvector	3rd -4th
Vegetation	0,0784	0,0870	0,0085	0,0870	0,0000	**0,0870**	0,0000
Land use	0,0870	0,1304	0,0435	0,1304	0,0000	**0,1304**	0,0000
Imperviousness	0,0870	0,1304	0,0435	0,1304	0,0000	**0,1304**	0,0000
Population density	0,1465	0,1739	0,0274	0,1739	0,0000	**0,1739**	0,0000
Bank/Bed protection	0,2365	0,2174	-0,0192	0,2174	0,0000	**0,2174**	0,0000
Hydraulic construction	0,3646	0,2609	-0,1037	0,2609	0,0000	**0,2609**	0,0000

5.6 Integration mechanism

After we have obtained all the weights (W) and scores (S) for all the involved parameters, the integration of the key parameters can be completed and the Urban-Rural River Continuum Index (URRCI) for each surveyed stretch unit can be calculated through the following expression:

$$URRCI_1 = S_{11}W_{11} + S_{12}W_{12} + S_{13}W_{13} + \cdots + S_{1j}W_{1j}$$
$$URRCI_2 = S_{21}W_{21} + S_{22}W_{22} + S_{23}W_{23} + \cdots + S_{2j}W_{2j}$$
$$\cdots$$
$$URRCI_i = \sum_{j=1}^{8} S_{ij}W_{ij}$$

Where, i stands for the total number of stretches; j stands for the total number of parameters; Sij stands for the score of each involved parameter for stretch i; Wij stands for the weight for each parameter.

Since the scaling of all the parameters coincides with the scale of the Urban-Rural River Continuum code, the URRCI 1, 2, 3…should also be in the range of 1 to 5. Comparing the urban-rural river continuum index to the codes, we can easily know the category of urbanization of each stretch of river.

5.7 Results analysis and Discussion

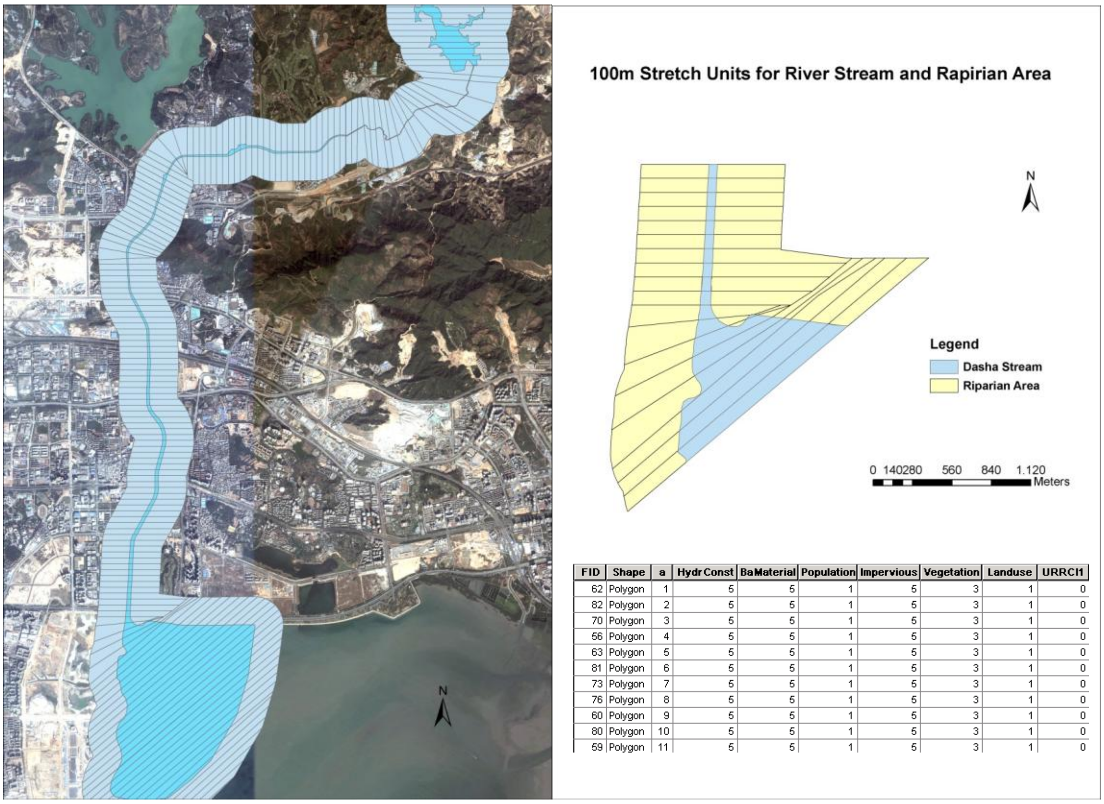
In order to divide the Dasha River into equal stretches of 100m long, first of all, software which called Line Editor Toolbar is introduced into ArcGIS. This set of code contains a toolbar with six commands for the editing of lines, and three additional commands for displaying the characteristics of lines (vertices, dangles, and directions).

The purpose of the toolbar is to provide some additional functionality for the editing of line work. Some of the commands are similar to what can be done with ArcEdit. Some of the functionality will be exposed in the new topology engine currently under development.

Software download source: http://arcscripts.esri.com/details.asp?dbid=13729

After splitting the Dasha stream centreline equally into 100m by using Line Editor Tool in ArcGIS, buffer zones for each specific stretch unit are generated with a 500m width. Based on the attribute table, we can add a field for all the key parameters and import the field data to set up the database, in order to calculate the Urban-Rural River Continuum Index.

Results can be presented as a graph (Figure 5-6) which can show the change of the urban-rural river continuum codes and give us the thresholds of each urban or rural reaches and can also be displayed in hypermedia modules with GIS, which can give us a colourful and vivid map to show the classification of the whole river system (Figure 5-5). In both figures we can see that 1100m at the river source and 400m at the river mouth are identified as rural river reaches, and the main stream has been identified as urban river reaches even where there is variance.



FID	Shape	a	Hydr Const	BaMaterial	Population	Impervious	Vegetation	Landuse	URRCI1
62	Polygon	1	5	5	1	5	3	1	0
82	Polygon	2	5	5	1	5	3	1	0
70	Polygon	3	5	5	1	5	3	1	0
56	Polygon	4	5	5	1	5	3	1	0
63	Polygon	5	5	5	1	5	3	1	0
81	Polygon	6	5	5	1	5	3	1	0
73	Polygon	7	5	5	1	5	3	1	0
76	Polygon	8	5	5	1	5	3	1	0
60	Polygon	9	5	5	1	5	3	1	0
80	Polygon	10	5	5	1	5	3	1	0
59	Polygon	11	5	5	1	5	3	1	0

Figure 5-5 (a) An equally divided Dasha river stretch unit with buffer zones and (b) An example of importing field data with the attribute table

Figure 5-6 shows the variation of the Dasha urban-rural river continuum index. In this figure, the river survey starts from the river mouth, which is stretch unit 0, and goes to the river source. Points with blue colour represent the calculated Urban-Rural River Continuum Index; and points with red colour represent the corresponding categorized Urban-Rural Continuum Code.

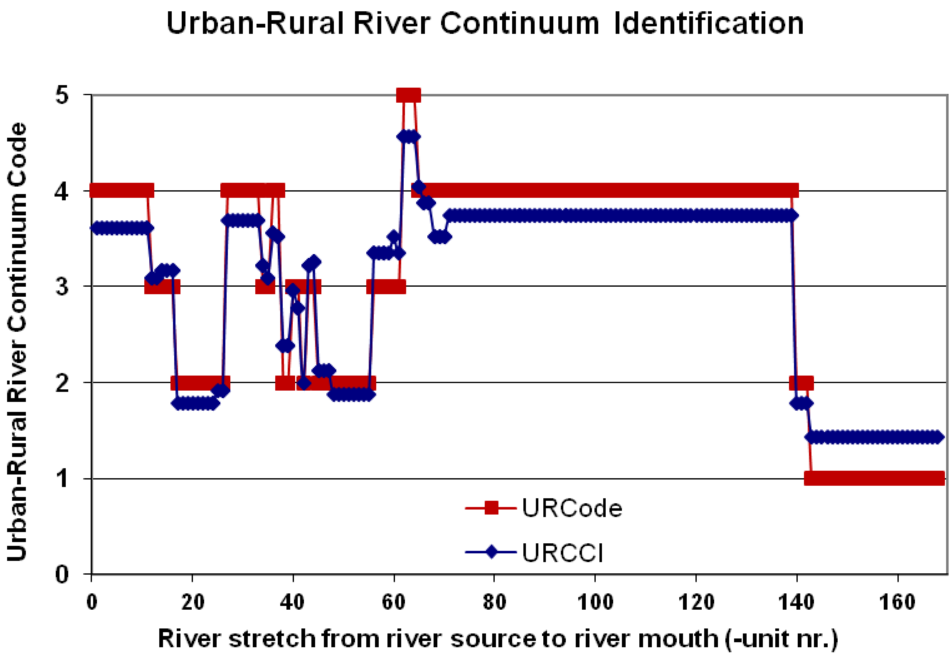


Figure 5-6 Variation graph of the Dasha river urban-rural continuum identification

Here we can see that there are several peaks along the river reach, and although the main middle river falls into the urban river, one peak value of stretch unit 68 has almost reached the URRCI 5, which stands for being completely urban. This is because of the hydraulic construction which is built on the Dasha River (See Figure 5-7 (a)). From paragraph 5-5 we know this parameter has the highest weight, and here we can see its vital influence on the identification of the urban-rural river.

Figure 5-7 Photographs from the field survey on Dasha River
(a) stretch unit 68, (b) River mouth

The stretch of river between units 139 to 168 shows a variation near to the class of obviously rural river stretch. This area is the river mouth where Dasha River flows into Shenzhen Bay, the riparian area is covered by open land with no artificial constructions (See Figure 5-7 (b)).

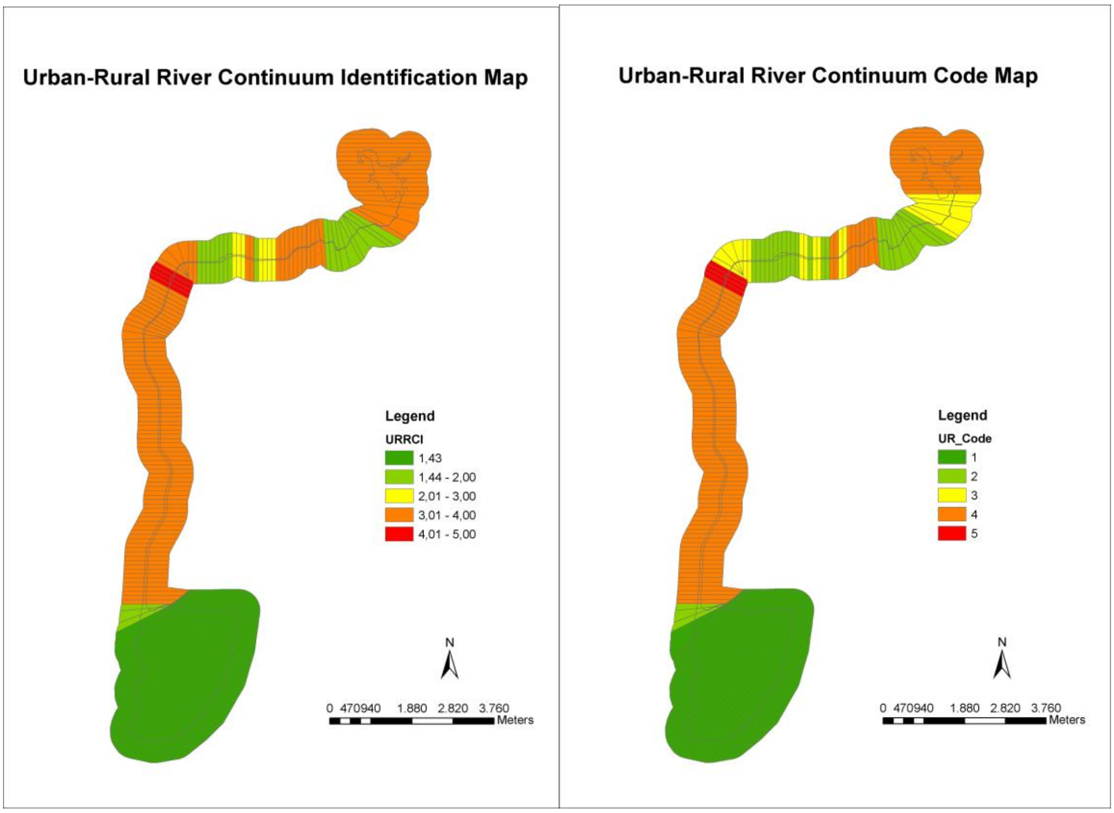


Figure 5-8 Urban-rural river continuum identification map of Dasha River with (a) URRCI and (b) UR-Code

Figure 5-8 shows another possibility to display the result of the urban-rural river continuum identification of Dasha River. The left map (a) shows the variation of calculated Urban-Rural River Continuum Index and the right map (b) shows the variation of calculated Urban-Rural River Continuum Code along the river system. These maps where are resulted from ArcGIS based CASiMiR model can show a much more vivid continuum variation of urban and rural stretches from the red colour of completely urban to green colour of completely rural.

Generally speaking, the developed system of Urban-Rural River Continuum Identification can be implemented very well, which can help researchers to get a quick and clear idea of which is an urban river reach and which is a rural river reach. In the meantime, it can give the users hints about the most influencing factors and the most urbanized river reach, through the above analysis, we can learn that hydraulic construction is the parameter which influences the definition of an urban or rural river the most. Though, the definitions for some parameters in this system need to be adjusted according to the specific situation of the application areas.

6 Fuzzy-based Urban-Rural River Ecological Health Assessment System based on fish habitat indicating the dominant ecological function

6.1 State-of-the-art in ecological assessment of river systems

After decades of research, the awareness of integrated water resource management has significantly increased and its principles are widely accepted. This concept has been applied all over the world, adjusting to the local conditions of water resources and current management methods. One successful example of the application is the European Water Framework Directive (WFD; Commission of the European Community, 2000).

The Water Framework Directive identifies its key purpose as preventing the further deterioration of, and protecting and enhancing the status of, aquatic ecosystems in Europe. The Water Framework Directive together with the recent Marine Strategy Directive (EC 2008) provide the legislative and policy structure for operational integrated water resource management. It is a legally binding document that requires member states to implement water management measures to achieve a good overall quality of European bodies of water by the year 2015.

The WFD is a major step forward in water management, through setting a holistic environmentally sustainable condition with “good ecological status” objectives, and through requiring long-term integrated planning involving not only water managers, but land use planners in the transport and energy sectors. All water usage leaves its mark on aquatic systems. Either water is taken from the system or it is filled with pollutants. Surface waters suffer from morphological changes: Rivers have been straightened and widened to accommodate larger vessels; flood-planes have been drained for housing and agriculture; dams and weirs divert water to generate electricity; and embankments protect houses and human assets from flooding. For the first time all such impacts have to be addressed to achieve a “good chemical and ecological” status.

In particular, in achieving and maintaining a “good water status” the Water Framework Directive emphasizes the ecological importance of reducing chemical pressures. Furthermore, the legislation has several well-defined objectives (Pollard and Huxham, 1998):

- Prevent further deterioration to protect and to enhance the status of water resources.

- Promote sustainable water use.

- Enhance the protection and improvement of the aquatic environment through specific measures for the progressive reduction of pollution discharge.

- Ensure the progressive reduction of the pollution of groundwater and prevent its further pollution.

- Contribute to mitigating the effects of floods and droughts.

The Water Framework Directive could be more important for conservation practice in Europe than previous directives, such as the Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, 1992) - which has explicit conservation targets. This has three reasons: First, it will cover all surface water (not just protected sites). Second, it will require member states to improve the ecological quality of many sites (rather than merely protecting sites). Third, it will require the identification, monitoring and protection of networks of high status sites (Pollard and Huxham, 1998). For the first time, water management is based mainly upon biological and ecological elements (previously, it was mainly based upon physical-chemical elements), with the ecosystem at the centre of the management decisions. This last point constitutes for the WFD a fundamentally new view of water resource management in Europe. Therefore, the key driver – the Water Framework Directive - has been accepted commonly as the state-of-the-art in river ecological assessment.

However, the Water Framework Directive itself is fraught with some weaknesses that are likely to jeopardize the achievement of such goals.

- Insufficient integration among biological, physico-chemical and hydromorphological elements.

- The classification system for assessing the ecological status is not sufficiently integrated.

- Current river classification systems tend to group urban rivers into a single homogenous category of “bad” or “poor” quality.

- The vagueness of the objective “good ecological” status by neglecting hydromorphological elements and by applying methods such as “worst-win logic.”

- Neglecting the role of sediment in assessing good quality.

- Relegate the hydromorphological elements to a very marginal role.

- Expert judgement is considered to be a last resort as an approach to establishing reference conditions.

In this research, it is assumed that river ecological function is the most important function in indicating the status of river health, and that it is also the most important goal of river rehabilitation, so this research is focusing more on the “good ecological” aspect. Since the European Water Framework directive has been commonly accepted as the state-of-the-art in river ecological assessment, this framework can give us some hints on setting up the system of the urban-rural river ecological health assessment in this research.

In the following chapters, I study the Water Framework Directive and analyze the existing assessment system. All the related parameters have been listed and measured within this framework. The above weaknesses have been overcome in order to use a more effective methodology to incorporate the relative parameters, and to establish a more applicable and effective river ecological assessment system, which focuses more on both urban and rural river ecological functions, considers fewer parameters, but generates more reliable results and is simpler to apply to river systems all over the world.

6.2 Controlling factors for the urban-rural river ecosystem health

While the EU Water Framework Directive is commonly accepted and has been applied in many EU member states, part of its indicators could be considered when we study on the river ecological status. In Annex V of WFD, the quality elements for the classification of ecological status have been list out specifically for surface waters. Strictly speaking, to classify the current ecological status, as required by the WFD, only attributes characterizing the state are necessary and sufficient. But furthermore, some key attributes which have listed by WFD capable of incorporating- at least partially, the trends have been included within the hydromorphological elements (figure 6-1).

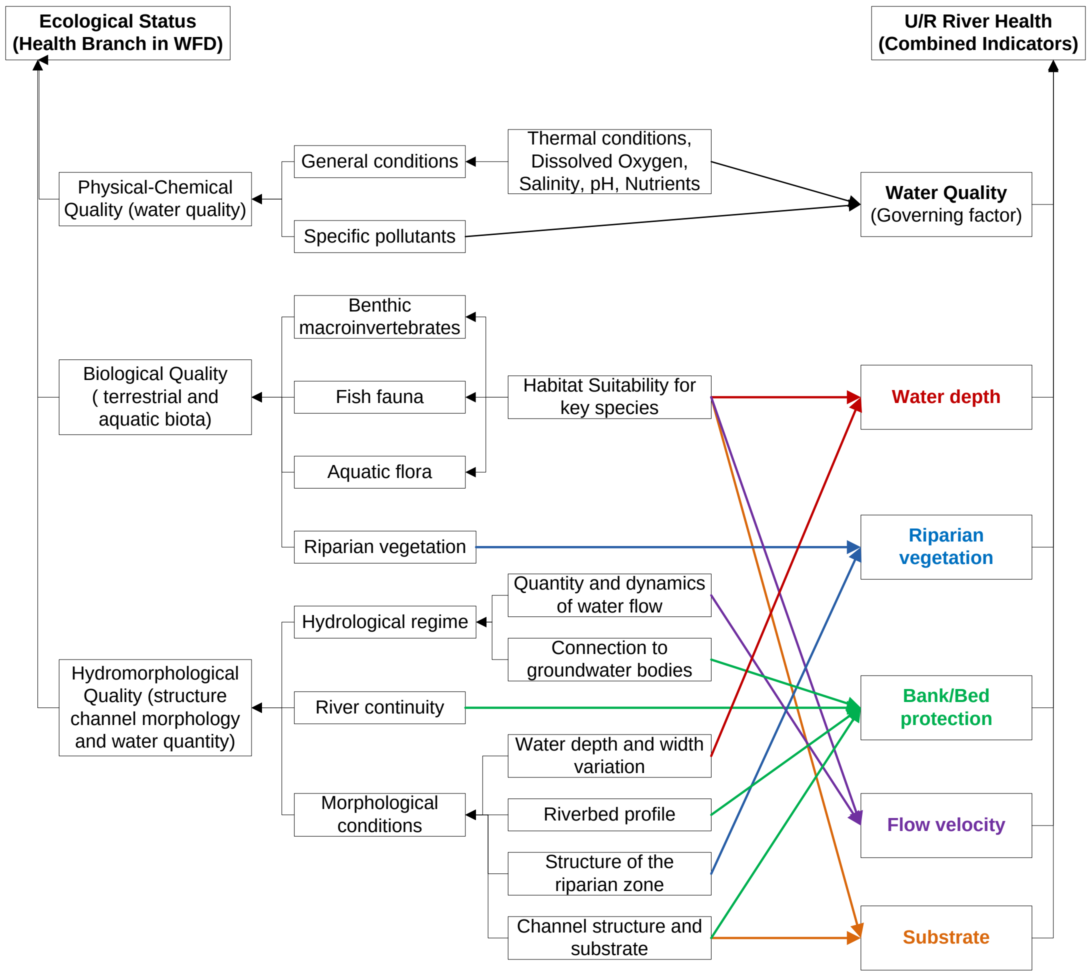


Figure 6-1 The key parameters selected for the U/R Health Diagnosis System

The habitat suitability index has been introduced into this river ecological health assessment system as a complex indicator, and is further represented by another three basic hydromorphological indicators (water depth, flow velocity and substrate). Consider that as the biological elements which are listed in the WFD such as the composition, abundance and biomass of benthic invertebrates, fish fauna, phytoplankton and other aquatic flora cannot be measured easily and precisely, the difficulty of simulating the river ecological health is increased. Instead, the potential for habitat suitability in the river of the key species could be modelled by using hydromorphological parameters and considering the existing biological expert knowledge. Also, the temporal measured data of the biodiversity, abundance, community composition and population structure of the key species we get from the field could be used to validate the output of the river ecological health assessment model.

Riparian vegetation in the WFD is “downgraded” to the role of a hydromorphological element supporting biological elements, whereas it deserves - as an essential biotic component of the river system - full recognition as a biological quality element (like macrophytes and phytobenthos). Suffice it to mention the high species diversity in its ecotonal areas, its productivity, its strategic importance for nature conservation, and its roles of being a source of species distribution; of being fine particulate organic matter and large woody debris, which, in turn, diversify habitats and create local conditions favourable for some fauna; of controlling diffuse pollution conveyed via the surface and sub-surface; and of the regulation of water temperature. Finally, its status can be used as a proxy for many other biological elements that are not directly measured.

Note that the bank/bed protection can serve as a proxy for other attributes as well, particularly those associated with river continuity in vertical, longitudinal and lateral aspects. River continuity, including all vertical, longitudinal and lateral aspects, can be represented by the percentage of bank/bed protection, e.g. when the river bank/bed is all concrete, there will definitely be no water exchange between river body itself and the riparian flow. The connection to groundwater bodies which represent the river hydrological regime could also be indicated by the percentage of bank/bed protection. As well as the channel structure, the level of channelization can be easily described by this type of bank/bed protection.

Therefore, 5 indicators will be considered eventually to assess the river health status, which focus on ecological function.

As the first step of the river ecological health assessment, when considering the river body itself, three basic parameters - water depth, flow velocity and substrate - will be considered to simulate the river habitat suitability status for river ecological indicators. The second step is to combine the external influencing parameters to simulate the final river ecological health status. One of the most important objectives of this advanced river ecological health assessment system is to reduce its involved parameters but to generate similar results with the commonly accepted Water Framework Directive in Europe in order to make the assessment system more effective and applicable. Therefore, we will consider only bank/bed protection and riparian vegetation in the second step, which can represent most of the biological and hydromorphological quality of the ecological status, but are much easier to measure in a field investigation.

Water quality is always a governing parameter, since it influences the river health in every aspect. It is assumed that the studied river basin already reaches a good, basic water quality status, so the research on the river ecological health assessment and further ecological rehabilitation measures can be carried out. Otherwise the first task of river health restoration has to be water quality improvement.

6.3 Fuzzy Inference system and its customization

The customized tool took advantage of an existing fuzzy inference calculator (Schneider, 2001; Kopecki, 2008), which is integrated within ArcGIS, thereby allowing for direct data integration from various sources such as input parameters and the presentation of output in the form of spatial maps. Indeed, the system of fuzzy rules (rulebase) can contain more than one input and one output parameter. Unfortunately, defining the rulebase becomes complex quickly for a growing number of parameters Therefore, it is important to keep the latter to a minimum. The conception and application of fuzzy logic method has been described in Chapter 2; here we make further description of fuzzy logic-based habitat model CASiMiR, regarding its methodology of fuzzy memberships, fuzzification and defuzzification.

This section focuses on the description of the fuzzy inference system and the fuzzy calculator used in this research. A typical fuzzy inference system has the following components: Precise Input, a Fuzzification Interface, a Fuzzy Inference Engine, Defuzzification, Fuzzy Set Data, a Fuzzy Rule Base and Precise Output. The flow chat of a typical fuzzy inference system can be described by following figure (fig. 6-2).

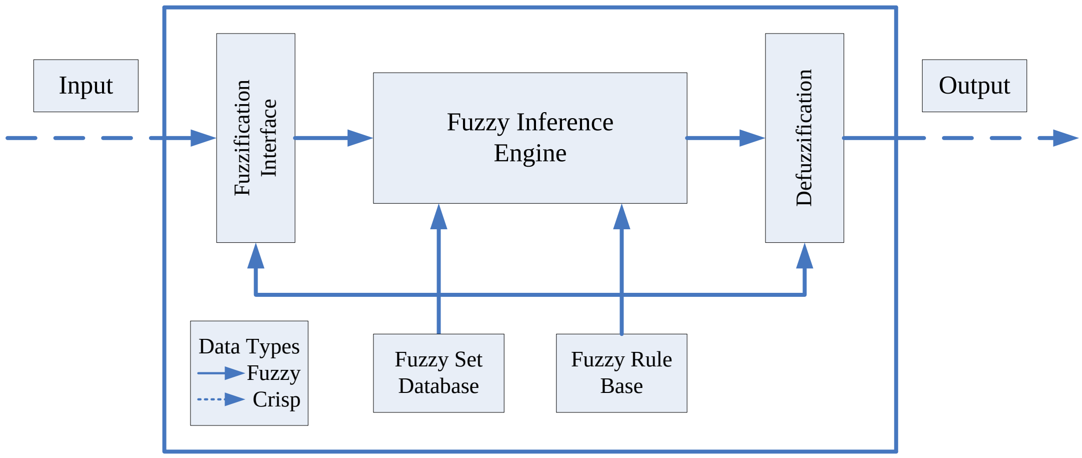


Figure 6-2 Description of a typical fuzzy inference system

Accessing the knowledge base related to the process, and developing the corresponding rule base is a prerequisite for any fuzzy logic system. The knowledge base provides the foundation for setting up fuzzy sets of input variables, i.e. the range of values of the input variables are “fuzzified” into suitable linguistic values which then become labels of fuzzy sets. This initial step of fuzzy logic, which involves the conversion of precise quantities into fuzzy ones, is termed as “fuzzification.” After fuzzification is carried out, the next step of fuzzy inference requires the development of the fuzzy rule base which is characterized by a set of linguistic statements based on expert knowledge and documented literature.

In the inference procedure, various inference methods can be employed to combine fuzzy "IF-THEN" rules from the existing rule base into a mapping from the fuzzy input sets to the fuzzy output sets (Bardossy and Duckstein, 1994; Mendel, 1995; Ross, 2004). The fuzzy calculator usually has a number of pre-defined settings or options for the fuzzy system parameters such as for the selection of the inference method and the combination method.

For the computation of the degree of fulfilment (DOF) of each rule, which depends on the combination of input variables, the user can select the "product inference" or the "min-max inference" method for implementation in the fuzzy calculator. The product inference method uses the standard product, whereas the min-max inference method takes the minimum as the implication operator.

They can be defined mathematically as follows (for the two input parameters having "AND" as logical operator):

Product method: $\eta_i = \mu_A(x_1) \cdot \mu_B(x_2)$

Min-max method: $\eta_i = \min(\mu_A(x_1), \mu_B(x_2))$

where η_i = degree of fulfilment of a rule i,

$\mu_A(x_1)$ = degree of membership of parameter x_1 relating to fuzzy set A,

$\mu_B(x_2)$ = degree of membership of parameter x_2 relating to fuzzy set B

Various studies on fuzzy logic applications show that there is no great difference in the performance of rule systems with respect to the choice of the implication operator for determining the DOF (Bardossy and Duckstein, 1994). Hence, both the product and min-max methods are considered and implemented in the present fuzzy calculator. The product inference method is used as the standard predefined setting for inference, but the user has the flexibility or option to select the min-max method for the computation of the DOF as well.

The next step after calculating the degree of fulfilment for each rule is to combine the DOF's for each of the fired rules to obtain the total consequence output. A number of methods can be applied for obtaining the total consequence, the simplest method is the maximum-product combination:

$$\mu_{tot}(x) = \max_{i=1...N}(\eta_i \cdot \mu_{K_i}(x))$$

where $\mu_{tot}(x)$ = total consequence output

$\mu_{K_i}(x)$ = membership function of the consequence K_i

η_i = degree of fulfilment of a rule i,

N = total number of rules fired,

u = index corresponding to the output fuzzy sets of the rule consequences, e.g. low, medium, high.

In this method, the division by the maximum of the sum is required to ensure that the resulting total consequence output of the membership function is not greater than 1.

However, a precise value may be treated as a fuzzy singleton. Then the firing strengths of the first and second rules may be expressed as where the role of the degree of partial match between the user-supplied data and the data in the rule base is.

The last step in the fuzzy logic modelling process is to obtain a precise output by the way of defuzzification.

Basically, the maximum criterion produces the point at which the possible distribution of the control action reaches a maximum value. The Mean of Maximum strategy (MoM) generates a control action which represents the mean value of all local control actions whose membership functions reach the maximum. The Centre of Gravity strategy (CoG) generates the centre of gravity of the possible distribution of a control yield. Braae and Rutherford presented a detailed analysis of various defuzzification strategies and concluded that the CoG strategy yields superior results (Braae and Rutherford 1978).

The Centre of Gravity method is the most popular defuzzification technique and is widely utilized in actual applications. The method is similar to the formula for calculating the centre of gravity in physics. The weighted average of the membership function or the centre of the gravity of the area bounded by the membership function curve is computed to be the precise value of the fuzzy quantity (Bai and Wang 2006). Mathematically, this is represented as:

$$X_0 = \frac{\int \mu_{total}(x) \cdot x dx}{\int \mu_{total}(x) dx}$$

Where $\int$ denotes an algebraic integration and Xo is the defuzzified output of the system.

In general, this method of defuzzification returns the centre of the area under the curve i.e. the area under the aggregation of the truncated output fuzzy subsets. This CoG method yields a unique number while using all the information of the total output distribution. The output range by the CoG method can approach the boundaries of its interval of definition. These are in fact the CoGs of the two membership functions at the extreme of fuzzy partition.

In the CASiMiR model, the output parameter – the Habitat Suitability Index – is defined in correspondence with other habitat simulation models on a scale between 0 (unsuitable) and 1 (maximum suitability), and also has the corresponding fuzzy sets. In the modelling process, the inference processor runs through the rule base and determines the degree of fulfilment (DOF) of each rule depending on the combination of input variables (Kopecki 2009).

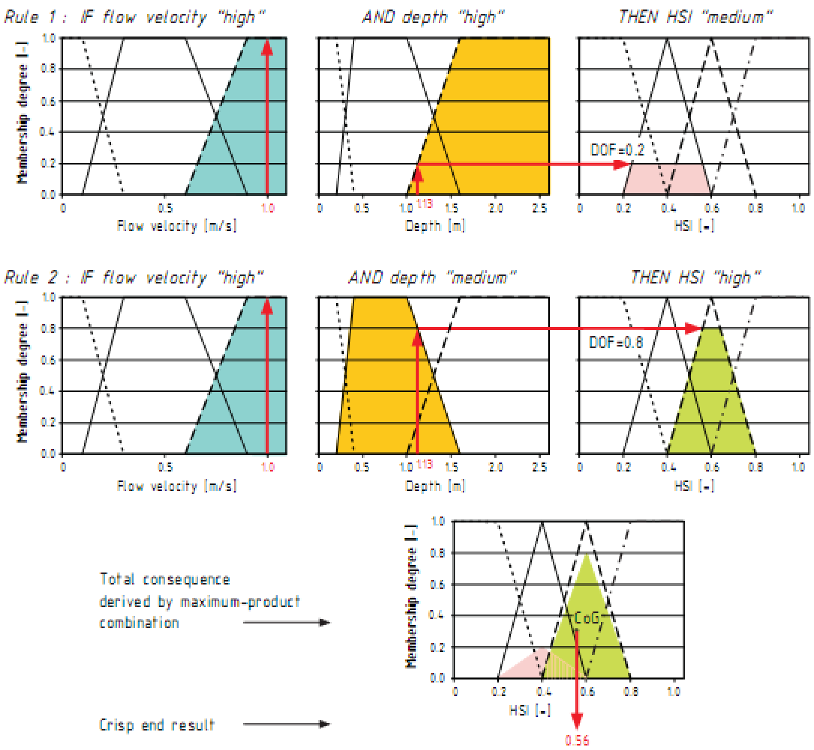


Figure 6-3 Example of a simplified inference process (only two rules and two input parameters, flow velocity 1.0 m/s and water depth 1.13 m) from Schneider and Jorde (2005)

In Figure 6-3, an example of DOF calculation for just two parameters is shown. Here, the maximum-product method is used for the evaluation of total consequence output and the result is defuzzified afterwards to obtain a precise output value of the Habitat Suitability Index.

6.4 Fish species: an important indicator of river health

Traditionally the assessment of river health status has been solely on the measurement of physical, chemical and some biological characteristics. While these measurements may be efficient for regulating effluent discharge and protecting humans, they are not very useful for the large-scale management of catchments or for assessing whether river ecosystems are being protected.

Measurements of aquatic biota, to identify structural or functional integrity of ecosystems, have recently gained acceptance for river assessment. Empirical evidence from studies of river ecosystems under stress suggests that a small group of biological ecosystem-level indicators can assess river conditions (Norris and Thoms, 1999).

As Karr (1981) suggested, fish have numerous advantages as indicator organisms for biological monitoring programs (Karr, 1981). These advantages include:

- Life-history information is extensive for most fish species.
- Fish communities generally include a range of species that represent a variety of trophic levels and include foods of both aquatic and terrestrial origin. Their position at the top of the aquatic food web in relation to diatoms and invertebrates also helps to provide an integrative view of the watershed environment.
- Fish are relatively easy to identify. Indeed, most samples can be sorted and identified at the field site, with the release of the study organisms after processing.
- The general public can relate to statements about the condition of the fish community.
- Both acute toxicity and stress effects (depressed growth and reproductive success) can be evaluated. Careful examination of recruitment and growth dynamics between years can help to pinpoint periods of unusual stress.
- Fish are typically present even in the smallest streams and in all but the most polluted waters.

Considering the characteristics of the case study area of the Shenzhen River, through the annual environmental report from the local government, it is obvious that fish are a very important factor for indicating the ecological health status of the Shenzhen River. We will list all the fish species in the following chapters which can be observed in the present river basin and which were observed in the past by reviewing the literature. All fish species are divided into two groups according to their habitat requirements, from the most tolerant species and to the least tolerant species.

6.5 Methodology and framework for the Urban-Rural River Ecological Health Assessment System of the Dasha River

Considering the calculation capability of the fuzzy logic method, these five parameters will be combined into the CASiMiR model step by step. The flowchart of this modelling is shown below (figure 6-4).

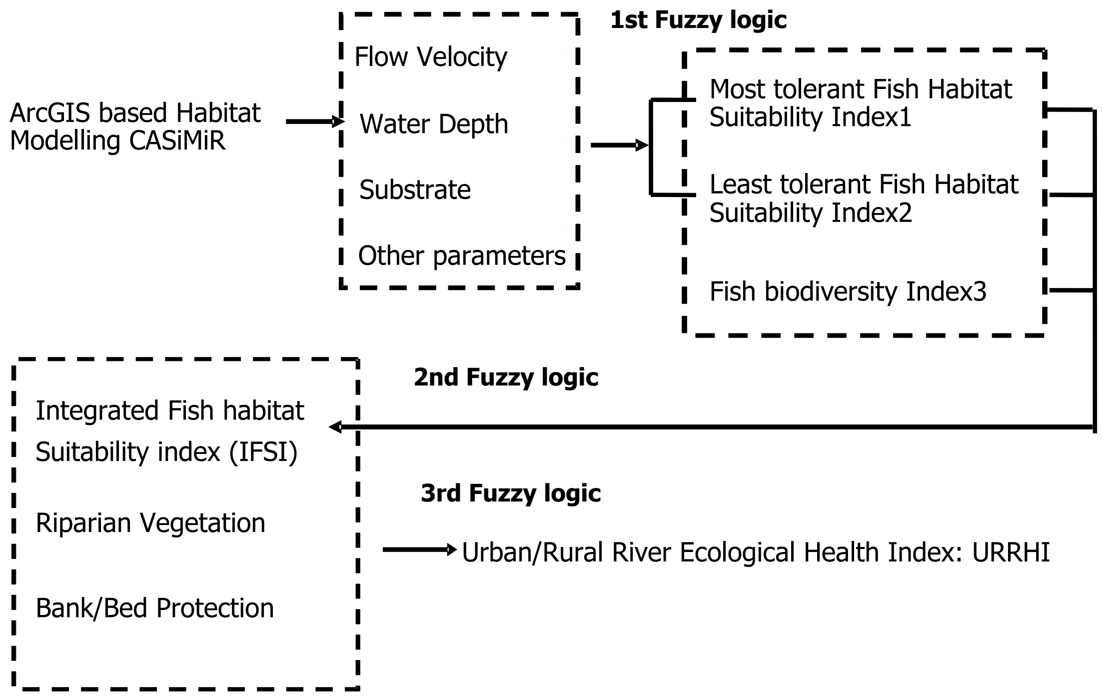


Figure 6-4 The flowchart of the urban-rural river ecological health simulation modelling

For the first step, the three basic parameters of flow velocity, water depth and substrate will be combined by making fuzzy rules and sets for each of the selected fish species, considering their different habitat requirements, and other necessary parameters can also be set in reality. The output is the habitat suitability index for each of the fish indicators.

The second fuzzy step is to combine the most tolerant fish habitat index with the other three less tolerant fish habitat indexes. The parameter of biodiversity is taken into this system to consider different influences of the four selected fish indicators, in order to generate a final fish habitat suitability index.

The last step, in which riparian vegetation and bank/bed protection can be grouped, is on a larger scale. The final output is the urban-rural river ecological health index (URRHI).

6.6 Ecological health indicators of the Dasha River: Indicating fish species

There is a need for understanding the habitat processes and developing mature models for the assessment of the habitats of all different species. The basic principle guiding habitat-modelling is that the majority of water organisms have specific demands for the suitability of their environment. In this research, as discussed earlier, fish have numerous advantages as indicator organisms for ecological monitoring programs. Each species possesses a unique feeding habit, and collectively they occupy different ecological niches within the pond ecosystem. In the Dasha River, as we investigated from government environmental reports and from a local survey, fish species can represent the majority of water organisms of the Dasha River. Therefore, it has been chosen as the main indicator of river ecological health in this research. And the selection of the indicator fish species in the studied stream habitat is important.

The Shenzhen government publishes an annual report based on an environmental survey, and as an example we can see below that most fish species which can be observed in the Shenzhen river basin, including the Dasha River, consist of the culture of common carp (Zhou and Wang, 2004). Most of the fish ponds in the Pearl River Delta are devoted to the culture of grass carp (Ctenopharyngodon idellus), silver carp (hypophthalmichthys molitrix), big head (Aristichthy nobilis), common carp (Cyprinus carpia), mud carp (Cirrhinus molitorells), snail carp (Mylopharynagodon piceus) and tilapia (Tilapia mossambicus ×O. nilotica) (Ruddle and Zhang, 1988).

Table 6-1 Survey on fish species in the Shenzhen River Basin March 2007 (Environmental Quality Communique of Shenzhen City in 2007)

Fish species	Number of Adult	Number of Juvenile
Cyprinus carpio (Common Carp)	12	5
Carassius auratus (goldfish)	5	2
Cirrhinus molitorella (Mud Carp)	6	6
Cichlidae (Tilapia)	4	3
Catfish	6	2
Hypophthalmichthysmolitrix (Chub)	7	1

Even though they have very low habitat requirements and can exist in almost all habitat environments, the common carp has been chosen as one indicator of the river ecological status of the case study area, because it can be defined as the most tolerant fish species to represent the current habitat of the Dasha River.But the main purpose of establishing a river ecological health assessment model based on the fish habitat suitability in this research, is to find out the most effective ecological rehabilitation measures. Therefore, other less tolerant fish species, which are very rarely observed in the Dasha River currently or were investigated in the past as a typical local species but no longer exist in the Shenzhen River Basin, should definitely be taken into the assessment system. From a habitat simulation of these less tolerant fish species, a much higher status of river ecological health may be revealed, which is an important background for carrying out further effective ecological rehabilitation measures.

From reviewing the literature, we collected all the possible less tolerant fish species in the Dasha River itself and the river basins in the Shenzhen area.

In 2002 Kadoorie Farm and Botanical Gardens, in collaboration with Shenzhen Fairy Lake Botanical Gardens and the National Forest Park Office of the Shenzhen Special Economic Zone Government, published a report of a rapid biodiversity assessment at Wutongshan National Forest Park, which listed the observed fish species in Shenzhen. Ten fish species were recorded from Wutongshan (Table 6-2), including three non-native species (i.e. Tanichthys albonubes, Xiphophorus helleri, and Hyphessobrycon herbertaxelrodi). Five species were recorded in Taishan Stream, Dawutongshan (320-475 m), and seven species including exotics were recorded in the stream draining Xiaowutongshan.

Table 6-2 Fish recorded in the Shenzhen Wutongshan National Forest Park on 16 and 17 May 2001 (Abundance: "+" = rare, "++" = average, "+++" = abundant). The sequence follows Nelson (1994).

<table>
<tr><th>Fish species</th><th>Remarks</th></tr>
<tr><td>Xiphophorus helleri (red form)</td><td>Exotic fish species from Central America.</td></tr>
<tr><td>Hyphessobrycon herbertaxelrodi</td><td>Exotic fish species from South America.</td></tr>
<tr><td>Tanichthys albonubes</td><td>Native to Guangdong but no record in decades.</td></tr>
<tr><td>Pseudogastromyzon myersi</td><td rowspan="2">Restricted to eastern Guangdong</td></tr>
<tr><td>Glyptothorax pallozonum</td></tr>
<tr><td>Pterocryptis sp.</td><td>Awaiting identification.</td></tr>
<tr><td>Liniparhomaloptera disparis disparis</td><td rowspan="4">Common in south China including Hong Kong.</td></tr>
<tr><td>Oreonectes platycephalus</td></tr>
<tr><td>Zacco platypus</td></tr>
<tr><td>Rhinogobius duospilus</td></tr>
</table>

The torrent loach Pseudogastromyzon myersi and torrent catfish Glyptothorax pallozonum are globally restricted to eastern Guangdong. The stream catfish Pterocryptis sp. is awaiting specialist identification. All other native species recorded are widespread and common in South China including Hong Kong.

Xiphophorus helleri and Hyphessobrycon herbertaxelrodi are exotic species from Central and South America respectively. Tanichthys albonubes is native to

Guangdong but there has been no confirmed record of wild fish in the last couple of decades. The population encountered here is believed to derive from escaped stock from the nearby tropical fish farm.

Oreonectes platycephalus was the most frequently encountered and generally the most abundant species in the surveyed streams. The torrent loach Pseudogastromyzon myersi and torrent catfish Glyptothorax pallozonum are globally restricted to eastern Guangdong. The stream catfish Pterocryptis sp. is awaiting specialist identification. Another data source for collecting the ecological indicating fish species of the Dasha River is the records of fish species in Hong Kong's river basin, while the river streams in Shenzhen and Hong Kong belong to the same river basin and have similar geographical situations.

Table 6-3 List of freshwater fish threatened with local extinction in Hong Kong, based on Dudgen (1993), and the present survey conducted by Bosco Chan (*=Species recorded during the present survey)

Fish species	**Remarks**
Plecoglossus altivilis	
Rasbora steineri*	Recorded in present survey
Tanichthys albonubes	
Aphyocypris lini	
Rasborinus formosae	
Rhodeus sp. * (see Note below)	Recorded in present survey
Acanthorhodeus macropterus	
Acrossocheilus wenchowensis beijiangensis*	Recorded in present survey
Pseudorasbora parva	
Cobitis sinensis	
Oryzias Iatipes*	Recorded in present survey
Awaous meIanocephalus*	Recorded in present survey
Ctenogobius cervicosquamus*	Recorded in present survey
Stiphodon sp*	Recorded in present survey
Channa asiatica*	Recorded in present survey
Channa gachua*	Recorded in present survey
Macropodus concolor	
Mastacembelus armatus*	Recorded in present survey

While new records of freshwater fishes are still being made locally, there is no room for complacency. The overall prospect for flora and fauna associated with lowland streams looks extremely bleak indeed; the rate of channelization, a by-product of rural development, has never been higher. It is particularly disturbing because the engineering designs of flood channels in Hong Kong have rarely, if ever, considered the ecological consequences of replacing a natural stream with a homogeneous concrete ditch.

Dudgeon (1993) listed 11 native freshwater fishes as threatened with extinction or possibly locally extinct already; only 4 species listed were recorded during the present survey (Rasbora steineri, Acrossocheilus wenchowensis beijiangensis, Rhodeus sp., and Oryzias latipes). Sadly, all were found in and around development sites. In addition, five of the recently recorded species were found in only one location. Considering the rate of urbanization and the alarming appetite for channelization shown by the local government, these five fish could be considered as threatened with extinction in Hong Kong. All are freshwater or amphidromous species mainly confined to lowland watercourses (see above).

Based on the above literature study, in this research we selected 3 less tolerant fish species from the historical survey reports, and we also selected the common carp as the least tolerant fish species.

Most tolerant fish species: common carp

Least tolerant fish species:

- Parazacco spilurus, found in the Shenzhen river basin, Hong Kong
- Nicholsicypris normalis, found in the Shenzhen river basin, Hong Kong
- Oryzias latipes, found in Guangdong Province, 2007 September

In this research, both the most tolerant fish species and the least tolerant fish species are important indicators for assessing the river ecological health status of the Dasha River. We selected 4 species as examples to run the model. In order to integrate all the effects of both groups, another parameter of biodiversity has been introduced into the river ecological health assessment system.

6.7 Ecological factors affecting fish habitat

It is clear that many factors regulate the occurrence and detailed distribution of fish species. Many ecological and, to a lesser extent, physiological studies have provided some insight into the factors which control the occurrence of running water fish, their inter-specific relationships, their numbers, and their growth rates.

Surface hydraulics (water depth, flow velocity) is the first important factor. Its major role is the influence on the exchange rates between surface and groundwater and consequently on the biogeochemical processes in the hyporhetic zone (Chapman, 1988).

And many other climatic or abiotic factors such as the oxygen content of the water, temperature, and substratum interacting with one another are also involved in the occurrence of fish species.

Generally speaking, the most important of these influencing factors are water depth, flow velocity, the substratum including vegetation and dissolved substances, and temperature, including the effects of altitude and season. Water depth relates to sufficient manoeuvrability for the spawning process, and flow velocity matters in that fish need a maximum velocity to hold a position over reeds, and a minimum velocity for the downstream transport of fine materials during digging, and to the substrate, which is also the particle size distribution, portion of suitable grain sizes and portion of unsuitable grain sizes.

Fish which live in running water apparently maintain their position by reference to fixed objects, which may be one reason why most downstream migration occurs at night. Experts figured out that fish are easily fatigued, so even streamlined species which are well adapted to fast-flowing water cannot swim rapidly for long periods.

As we know from the European Water Framework Directive, a zonal classification of European running water is based very largely on the relationship between the current and the common species of fish. In other parts of the world it is also well established that the various species are distributed according to the current.

Studies in central Germany have indicated that brown trout grow better in slower flowing streams than in very swift ones, and better in natural streams with varying depths and shelter than in straightened artificial channels. Their growth rate is also decreased by spate (Tesch and Albrecht, 1961). Even this very streamlined fish expends a lot of energy in fighting the current. It is not surprising, therefore, to find that different species are characteristic in waters of different velocities, and that flattened species are absent from fast water.

A few fish, particularly small behthic species, are more or less confined to rocky or stony substrata. Many others are also fairly definitely associated with a defined type of substratum, e.g. the gudgeon Gobio gobio, and a number of small cyprinids in North America with sand (Hubbs and Walker, 1942; Metcalf, 1959), and the mudfish, Umbra limi, with thick marginal vegetation (Peckham and Dineen, 1957). But for the great majority of species the nature of the substratum is apparently of little consequence except at times of breeding; the current velocity and the depth of the water seem to be more important (Cleary and Greenbank, 1954). In rivers and streams the greatest numbers of specimens and species are usually associated with beds of gravel or sand, as was shown by Allen and Clark (1943) in their analysis of a large number of collections from Kentucky. This is, however, hardly surprising, as these two types of substratum are by far the commonest in running water.

Shelter is also important; even swift-water fish such as trout occur more abundantly where there are more hiding places (Saunders and Smith, 1962, Hartmann, 1963). In larger rivers where the bed is relatively smooth this becomes increasingly clear, and fish of many species congregate near obstructions, in bays and along the banks, or anywhere else that offers some shelter.

Although substrate entrainment and regular bed alterations by flood events are required to maintain the productivity of spawning habitats, intense and frequent bed disturbance during the incubation period can have detrimental impacts on reproduction by destroying eggs and larvae (Lapointe et al., 2004). As the eggs and larvae are nearly immobile they are extremely vulnerable to any disturbances of the stream bed and this may led to mechanical shocks, destruction or displacement (Schuett-Hames et al., 1996). Furthermore, the downstream drifting eggs and larvae suffer mortality rates of up to 50% due to mechanical shocks, starvation and predation (Crisp and Carling, 1989). Another aspect to consider is the high amount of fine material that can enter the interstitials of a gravel river bed and reduce the permeability progressively. This clogging process can result in a nearly impermeable layer blocking the infiltration of oxygen-rich surface water, thus affecting the oxygen supply of embryos and larvae.

For the most tolerant fish species, such as common carp, the water temperature and dissolved oxygen significantly influence their growth, survival and feeding. They are also important water quality variables that can affect embryo survival and development. Temperature is also a primary stimulus for spawning, so its effects should be factored into a simulation of the fish habitat index.

Winberg (1956) published a major work on the use of oxygen by fish. He pointed out that there is no reason to expect fish from different environments to show differences in their basal rates of oxygen consumption, but suggested that one would anticipate that the amounts used in active life would vary from environment to environment.

As we have seen, running water is usually well-oxygenated and only rarely are low levels of saturation encountered. Normally, therefore, oxygen is no problem, except for species in which the rate of metabolism rises very rapidly with temperature. A severe lack of oxygen occurs in only one other type of environment in running water -the upper reaches of streams fed by de-oxygenated ground water. This lack does not, of course, persist far downstream because of rapid solution from the air, but it can often be seen that the upper parts of string streams are devoid of fish, probably for this reason.

Temperature is always an obvious ecological factor, and for stream fish it is an important one, which limits both broad geographical distribution and local occurrences within a single watercourse. Some species can tolerate remarkably warm water. Many species are, however, more limited in their tolerance of high water temperature, but most fish species can only exist in suitable water temperature.

In temperate climates, most running water fish are annually exposed to water at 0 ℃, and some at least remain active at these low temperatures. However, despite the fact that the fish in temperate rivers and streams can endure a fairly wide range of temperature, they need to adjust themselves and they cannot withstand sudden changes (Davis et al., 1963; Fry et al., 1946).

Although, when taking the field data into the simulation system, there was no information on these two parameters all along the Dasha River; only several plots were there for routine measurements. It depends on the specific situation of the river, and for some stretches these two parameters are very important, but for others they could be neglected.

Such observations are fairly general, and super-imposed on this complexity of stony or rocky substratum, current speed, depth, and the need for local shelter is the inability of some species to tolerate continuously turbid water or heavy siltation. Doubtless the same applies in many parts of the world.

In this research, two field investigations were carried out in different seasons, one in the wet season and one in the dry season in order to simulate ecological health variations in different statuses of river discharge. For each field survey, the basic parameters of flow velocity, water depth, substrate, and riparian vegetation and bank materials were mapped. But for these two seasons, there was no data which was measured precisely for water temperature and dissolved oxygen. Data sources which can be used in this research are the annual environmental reports from the local Shenzhen government. The latest version is the report for 2007. These variables are important for water quality; if possible, they should be taken into the mapping list of parameters and should be used for identifying the habitat suitability status for fish species.

7 Implementation of Assessment Stage 1 in the Dasha River: Simulation of the Integrated Fish Habitat Suitability Index (IFHSI)

7.1 Habitat simulation for the least tolerant fish species 1: Parazacco spilurus (Parazacco Chub)

7.1.1 Habitat requirements for PS

Previous records of Hong Kong's freshwater fish have included Plecoglossus altivelis, Rasborinus formosae, Tanichthys albonubes and Aphyocypris lini, referring to them as endangered or possibly extinct. According to the China Red Data Book of Endangered Animals-Pisces (fish), which was published in 1998, Parazacco spilurus is listed as “vulnerable.” This minnow is widespread and abundant in Hong Kong hill streams but has a limited distribution elsewhere in the Shenzhen River Basin in China where it seems to be declining.

The distribution of parazacco spilurus is recorded in Asian inland waters; Eastern China; Vietnam; and the Xi Jiang River. Parazacco spilurus has been proved as one of the local fish species in Guangdong Province.

In the project of River Improvement Works in the Upper Lam Tsuen She Shan River and the Upper Tai Po River-Ecological Impact Monitoring Programme, which was implemented by the Drainage Service Department of Hong Kong in 2007, Predaceous Chub was chosen as one of the target species of the fish community. It was monitored by live trapping, hand nets and direct observation methods. Sampling was conducted at two proposed sampling locations, i.e. upper and lower sections of the river and covered the major types of stream habitats, e.g. stream pool and riffle. The number of captured or observed fish was estimated and recorded. Nomenclature and the protection status of the species followed those documented on the Agriculture, Fisheries and Conservation Department (AFCD) website (www.hkbiodiversity.net) and Virginia et al. (2004).

In the Environmental Monitoring and Audit (EM&A) Report in 2010, the status of the Predaceous Chub was recorded in the following table. As we can see from this three-year survey, the Predaceous Chub is a common species in Hong Kong and exists in the present survey sites.

Table 7-1 Fish species recorded at the Upper Tai Po River (the T1-Upper stream sampling site and T2-Lower stream sampling site) (Data was referred from the Environmental Monitoring and Audit Report in 2010)

				aseline surve		Impact monitoring			Impact monitoring			Impact monitoring			Impact monitoring		
				Oct-07		Jan-09			Jul-09			Jan-10			Jul-10		
Species		Status	Commonness	T1	T2	Reference	T1	T2	Reference	T1	T2	Reference	T1	T2	Reference	T1	T2
Xiphophorus hellerii	劍尾魚	NP	C	++		+			+	+	++	+	+	++	+	+	+++
Puntius semifasciolatus	七星魚	NP	C	+		+	+		+	+	+	+	+	++	+	+	++
Poecilia reticulata	孔雀花魚將	NP	C	++	+			++			+		+	+++		+	++
Pseudogastromyzon myersi	麥氏擬腹吸鰍	NP	C	+		+			+			+			+	+	
Gambusia affinis	食蚊魚	NP	VC	+	++			+		+	+		+	++		+	+++
Xiphophorus variatus	雜色劍尾魚	NP	C	+													++
Parazacco spilurus	異鱲	V and NP	C	++		+	+		+			+			+	+	
Rhinogobius spp.	鰕虎魚	NP	C	+		+	+		+			+	++	+	+	++	+
Schistura fasciolata	橫紋南鰍	NP	C	+		+			+	+		+			+	+	
Oreochromis niloticus	尼羅口孵非鯽	NP	C	+													+
Misgurnus anguillicaudatus	泥鰍	NP				+			+			+			+		
Cyprinus carpio var. viridiviolaceus	錦鯉															+	
		2x2m fish number		70	60	15	8	25	10	20	100	10	2	8	10	7	100

Note: NP – Not protected in Hong Kong
"VC" – Very Common; "UC" – Uncommon; "C" - Common
"+" – Species exists in the survey site
"++" – Species common in the survey site
"+++" – Species abundance in the survey site
V – Listed as vulnerable in China Fish Red Data Book
- Reference point was the sampling location outside the works area used to compare with the data within works area.

Parazacco spilurus (Günther, 1868) belongs to the family of Cyprinidae It has a common name of Predaceous Chub; its maximum size can reach 150mm, and it usually has a long, streamlined and laterally compressed body and a protrusible lower jaw. A distinctive dark mid-lateral band runs from the operculum to the caudal peduncle, and ends with a black spot on the caudal fin base. The black band and spot become less prominent in adults. A picture of Parazacco spilurus is shown below. They prefer to live in hill and lowland streams with clear water. Their physical tolerance for living in terms of temperature is 14-30^{o}C; their tolerance range of pH is 5.7-8.7l; and their tolerance for dissolved oxygen is 2.8-11.6 mg/L. Their diet is usually Zooplankton, aquatic insects, small crustaceans and small fishes.

Figure 7-1 Picture of Parazacco spilurus Taken by CAFS (source: http://eol.org/pages/208094/overview)

7.1.2 Fuzzy rules and sets for each of the influencing parameters

The fuzzy rules and sets are developed for each of the habitat suitability indicators based on the habitat requirements of parazacco spilurus in order to simulate its habitat suitability status in Dasha River.

In this study, a relative scale from 0-1 (0 being “very low” suitability and 1 being “very high” suitability) for the lower and upper threshold, has been used to map the Habitat Suitability Index (SI). Three categories of habitat suitability status are defined at the outset and then the defined classes are transformed into 3 linguistic fuzzy sets as L (Low), M (Medium), H (High). This forms the output fuzzy sets to map SI in the study area (Figure 7-2, d)).

The key influencing parameters could be verified according to different habitat requirements for different fish species. Base on the above analysis on the characteristics of parazacco spilurus, water depth, flow velocity and substrate are considered as the input parameters. For each of the parameters, three categories have been specified and the whole range is categorized into three linguistic sets, taking the same descriptors, i.e. L (Low), M (Medium), H (High). The support crisp values for each fuzzy set are based on expert knowledge and are converted to linguistic variables by assigning an appropriate membership function. The fuzzy sets are shown in Figure 7-2.

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets for each of 3 parameters which make 27 rules in total to define the model output. The associated rules used to map SI for parazacco spilurus are shown in Table 7-2. It is to be noted here that by increasing the number of parameters, the formulation of rules becomes quite complex and less transparent. It is seen that there is always a trade-off between the increasing complexity of fuzzy rules and the resolution of the model output.

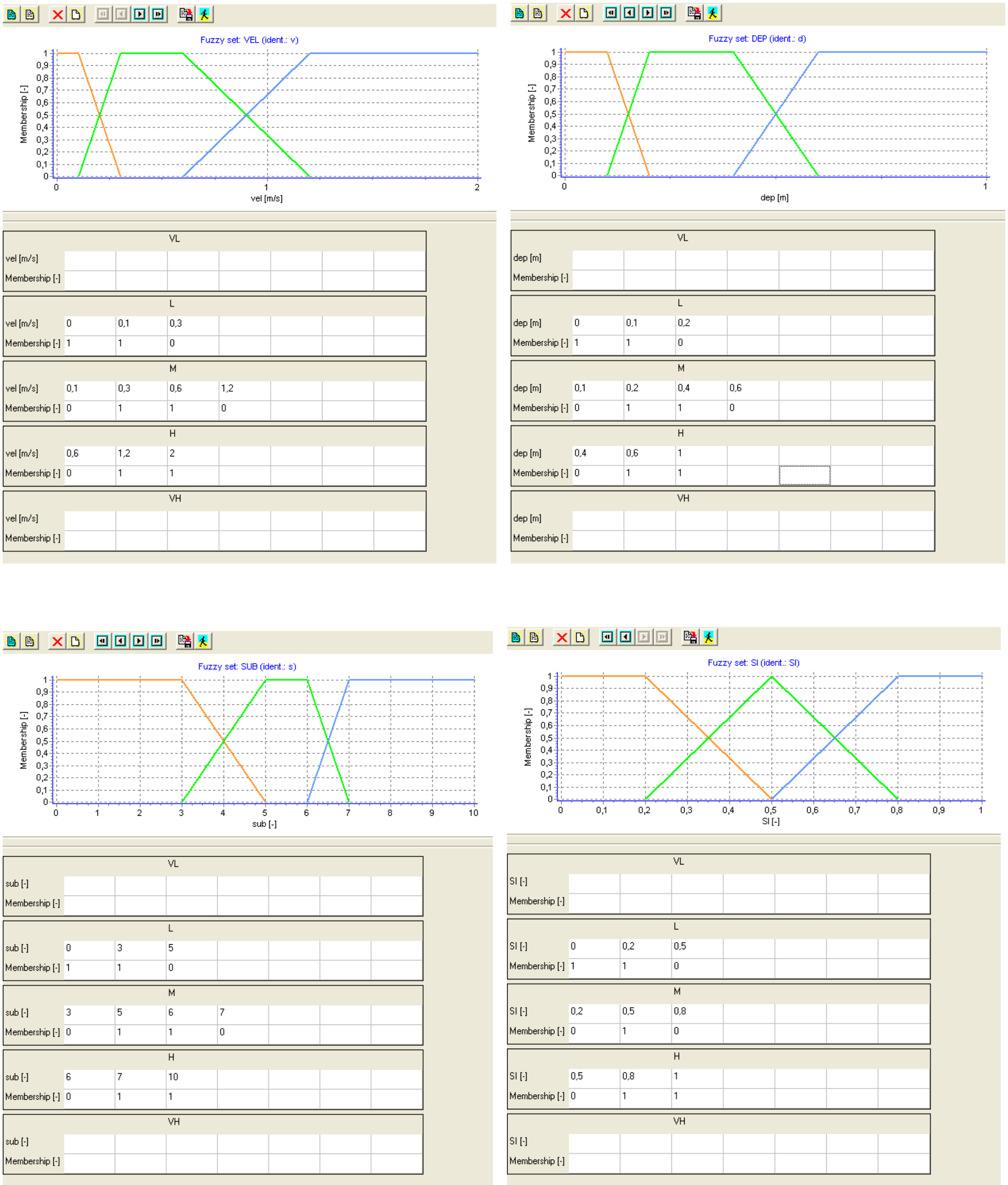


Figure 7-2 Membership functions for Parazacco spilurus a) Velocity; b) Water depth; c) Substrate; d) Habitat suitability index

Table 7-2 Fuzzy rules for PS habitat suitability based on the If-then logic system

Velocity	Water Depth	Substrate	Suitability Index
H	H	H	L
H	H	M	M
H	H	L	L
H	M	H	L
H	M	M	M

H	M	L	L
H	L	H	L
H	L	M	L
H	L	L	L
M	H	H	M
M	H	M	H
M	H	L	M
M	M	H	M
M	M	M	H
M	M	L	H
M	L	H	L
M	L	M	H
M	L	L	M
L	H	H	L
L	H	M	M
L	H	L	M
L	M	H	L
L	M	M	M
L	M	L	M
L	L	H	L
L	L	M	L
L	L	L	L

7.1.3 Results analysis

All the simulation and analysis processes have been done based on the attribute table of the Dasha River map, working with the CASiMiR tool in Arcgis. Three input parameters of flow velocity, water depth, and substrate and the output SI are added as columns of the attribute table, and then the surveyed data are fulfilled in, in order to set up the working table for the habitat suitability simulation of parazacco spilurus. The fuzzy rules and sets which are generated by the fuzzy calculator can be combined together by using notepad, and then further saved as the input fuzzy files for the next fuzzification step.

After running the ArcGIS based CASiMiR model, the habitat suitability map of parazacco spilurus is obtained by applying the sets of fuzzy rules to all input variables. The export map of the SI is shown below (see Figure 7-3).

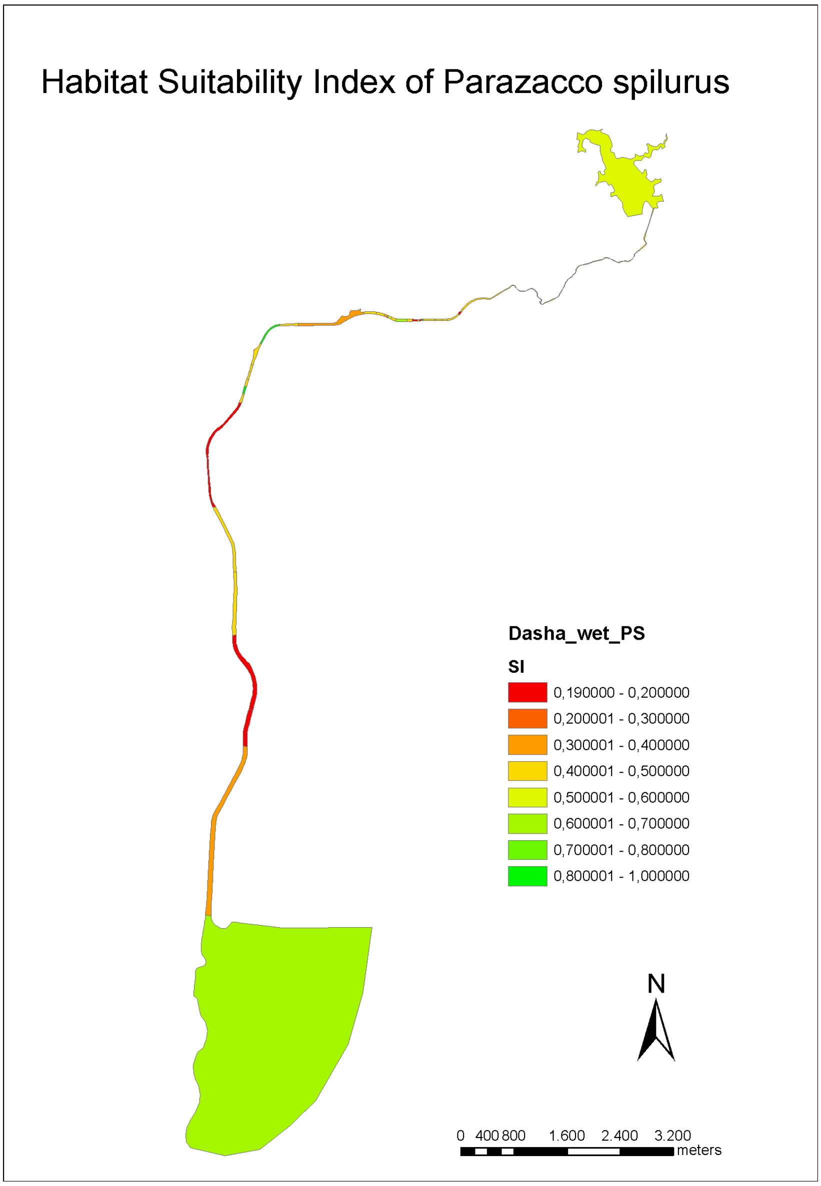


Figure 7-3 Habitat Suitability index simulation of Parazacco spilurus

As we can see, the Suitability Index of Parazacco Spilurus is normalized and classified into different levels (Figure 7-3). The red colour stands for class 1 (value 0~ 0.2), which implied the lowest suitability index, and the green colour stands for class 5 (value 0.8~1), which implied the highest suitability index. From this figure we can learn that the upstream and downstream have a better habitat suitability status for the fish species Parazacco Spilurus. The middle stream shows a worse habitat status mostly caused by the shallow water depth and fine substrate.

7.2 Habitat simulation for the least tolerant fish species 2: Oryzias Latipes (Japanese Medaka)

7.2.1 Habitat requirements for OL

Oryzias latipes (Temminck & Schlegel, 1846) is the second target fish for indicating the ecological health of the Dasha River. Oryzias latipes, also known as the Medaka and Japanese killifish, is a member of genus Oryzias, the only genus in the subfamily Oryziinae. This rather small (2-4 cm long) native fish of Southeast Asia is a common denizen of rice paddies in Japan, Korea, China, Vietnam, and other areas of south-east coastal Asia.

The name Oryzias latipes reflects the preferred habitat of medaka – the rice (Oryzasativa) fields. This habitat also gave rise to the common English name of medaka - ricefish

For decades, Oryzias latipes (Medaka) was an important test system for environmental research. The fish has been considered as one of the symbols of rural environmental conservation and restoration because of its familiarity to people and its vulnerability to environmental changes. It is widely used for carcinogenesis studies and for testing endocrine disruptors in ecotoxicology. Medaka has many attributes that make it a model laboratory organism, among them the clarity of its eggs, hardiness, and lack of aggression.

Sampling fish with trap nets showed that Medaka lived in dense populations in the cattail and reed beds, while the other three fish species, wild goldfish (Carassius auratus), topmouth gudgeon (Pseudorasbora parva), and mud loach (Misgurnus bipartitus), occupied the open water areas in marsh.

For instance, Oryzias latipes generally grow up to approximately 2 cm in length and thus are vulnerable to fast-flowing water. The fish mature in about 3 months when they are in good conditions of water temperature, day length, food, etc. From the previous studies (Yoshioka, 1963; Iwamatsu, 1997), the spawning season of the fish is assumed to be from April to October.

The special distribution of Oryzias latipes and the physical habitat characteristics of water depth, flow velocity and substrate, along with riparian vegetation and bank protection were surveyed. The five physical environments are found to be the primary factors affecting the habitat suitability of Oryzias latipes. The observation was done visually from the bank, with the observer moving slowly from the river mouth to the river source.

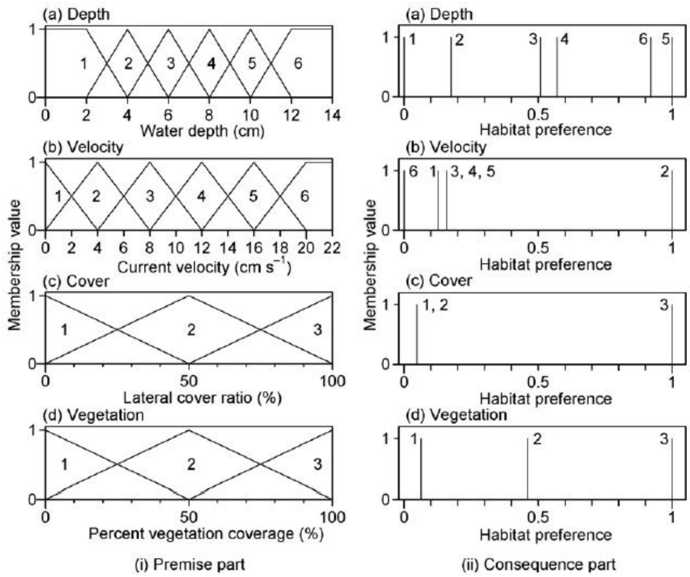


Figure 7-4 Schematics showing the premise and consequence parts of the fuzzy rule-based habitat preference model (Fukuda et al. 2006b)

Fukuda et al. (2008) compared the prediction ability, transferability and sensitivity of the three artificial intelligence-based models of a fuzzy neural network, fuzzy habitat preference model, and patterns of preference level, and one conventional model of a habitat suitability index in predicting the spatial distribution of Japanese Medaka (Oryzias latipes) dwelling in agricultural canals in Japan. From the viewpoint of fish abundance, it seems that Japanese Medaka prefer the areas deeper than 12cm, slower than 10 cm/s in velocity, with greater lateral cover, and relatively little vegetation coverage.

7.2.2 Fuzzy rules and sets for each of the influencing parameters

Fuzzy membership functions are defined for the purpose of reflecting the ecology of Oryzias latipes. For instance, since the body length of the adult Medaka is approximately 2 cm, the critical requirements for Oryzias latipes with regard to water depth and velocity would thus be shallower and slower flowing water due to its swimming ability. The singletons in consequence of this are part determined by using a genetic algorithm so as to minimize the mean square error between the predicted and observed fish population density.

The fuzzy sets and rules are developed for each of the habitat suitability indicators based on the habitat requirements of Oryzias latipes in order to simulate its habitat suitability status in Dasha River.

In this study, a relative scale from 0-1 (0 being “very low” suitability and 1 being “very high” suitability) for the lower and upper threshold, has been used to map the

Habitat Suitability Index (SI). Three categories of habitat suitability status are defined at the outset and then the defined classes are transformed into 3 linguistic fuzzy sets as L (Low), M (Medium), H (High). This forms the output fuzzy sets to map SI in the study area (Figure 7-5, d)).

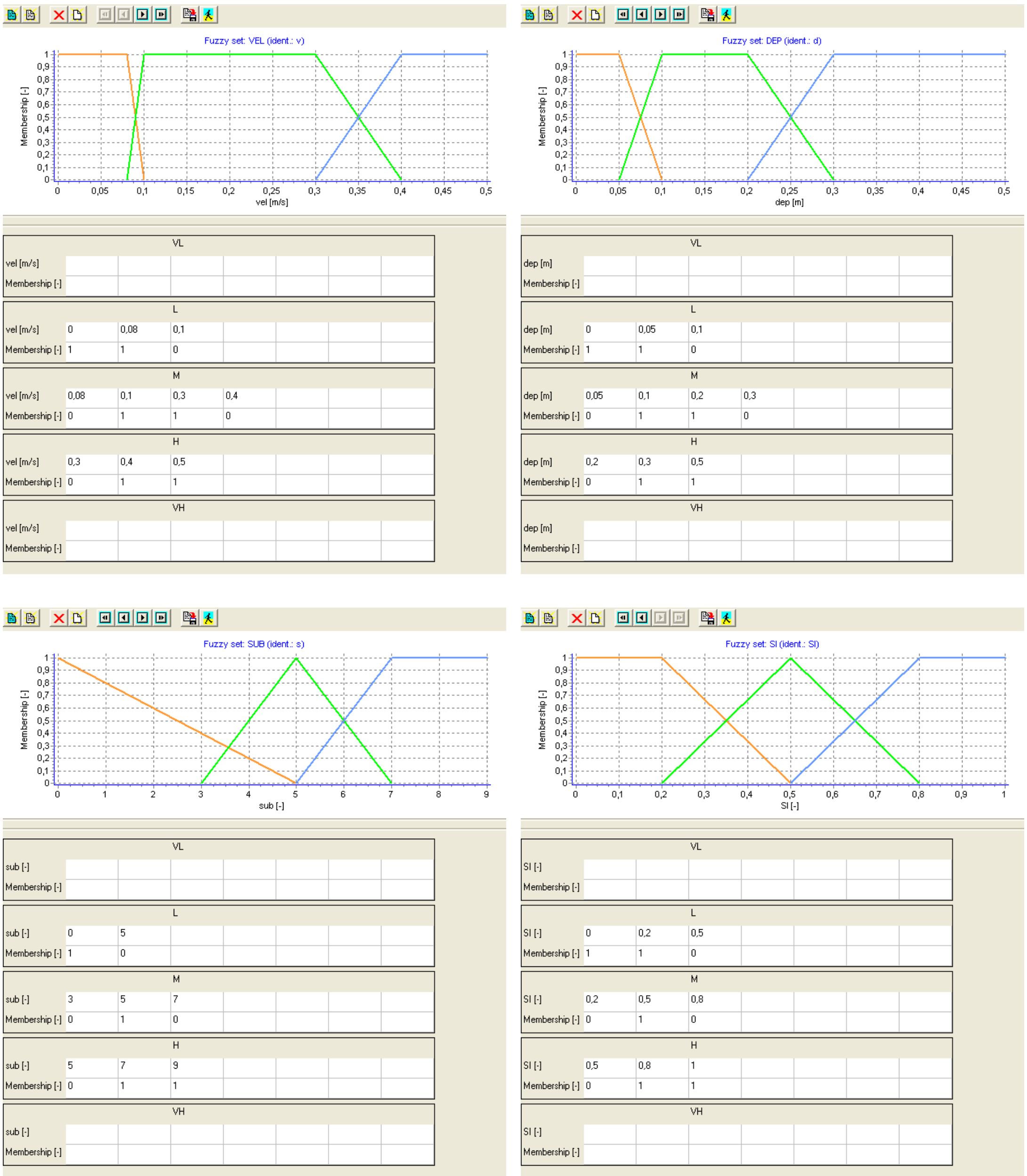


Figure 7-5 Membership functions for Oryzias latipes: a) Velocity; b) Water depth; c) Substrate; d) Habitat suitability index

The key influencing parameters could be verified according to different habitat requirements for different fish species. Base on the above analysis on the characteristics of Oryzias latipes, water depth, flow velocity and substrate are considered as the input parameters. For each of the parameters, three categories have been specified and the whole range is categorized into three linguistic sets, taking the same descriptors, i.e. L (Low), M (Medium), H (High). The support crisp values for each fuzzy set are based on expert knowledge and are converted to linguistic variables by assigning an appropriate membership function. The fuzzy sets are shown in Figure 7-5.

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets for each of 3 parameters which make 27 rules in total to define the model output. The associated rules used to map SI for Oryzias latipes are shown in Table 7-3.

Table 7-3 Fuzzy rules for the Oryzias latipes habitat suitability based on the If-then logic system

Velocity	Depth	Substrate	SI
H	H	H	M
H	H	M	M
H	H	L	L
H	M	H	M
H	M	M	H
H	M	L	L
H	L	H	L
H	L	M	L
H	L	L	L
M	H	H	M
M	H	M	H
M	H	L	M
M	M	H	H
M	M	M	H
M	M	L	M
M	L	H	L
M	L	M	H
M	L	L	M
L	H	H	L
L	H	M	M
L	H	L	M
L	M	H	M
L	M	M	H
L	M	L	M
L	L	H	L
L	L	M	L
L	L	L	L

7.2.3 Results analysis

All the simulation and analysis processes have been done based on the attribute table of the Dasha River map, working with the CASiMiR tool in Arcgis. Three input parameters of flow velocity, water depth, and substrate and the output SI are added as columns of the attribute table, and then the surveyed data are fulfilled in, in order to set up the working table for the habitat suitability simulation of Oryzias Latipes. The fuzzy rules and sets which are generated by the fuzzy calculator can be combined together by using notepad, and then further saved as the input fuzzy files for the next fuzzification step.

After running the ArcGIS based CASiMiR model, the habitat suitability map of Oryzias Latipes is obtained by applying the sets of fuzzy rules to all input variables. The export map of the SI is shown below (see Figure 7-6).

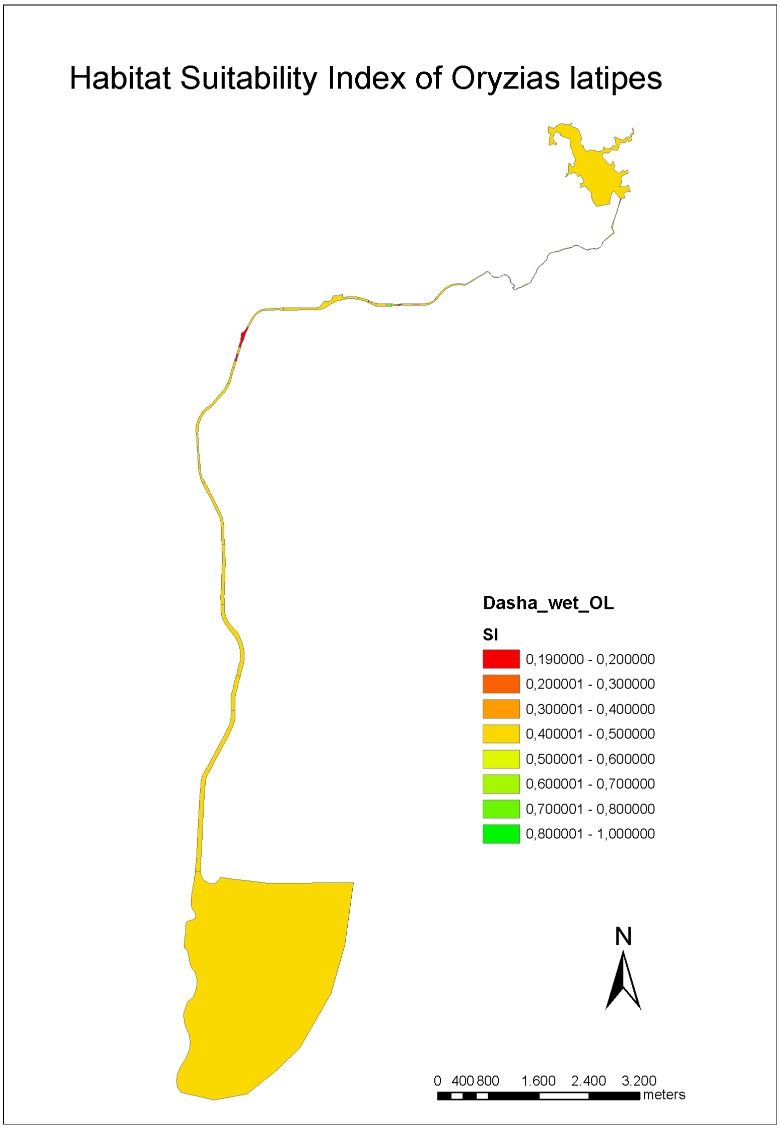


Figure 7-6 Suitability index simulation of the Oryzias latipes

As we can see, the Suitability Index of Oryzias Latipes is normalized and classified into different levels (Figure 7-6). The red colour stands for class 1 (value 0.19~ 0.2), which implies the lowest suitability index, and the green colour stands for class 5 (value 0.8~1), which implies the highest suitability index. From the figure we can learn that over 90% Dasha River shows a medium habitat suitability status for Oryzias Latipes. One short river reaches which located in upper stream with green colour is categorized into High habitat suitability status, mostly due to the proper water depth and suitable substrate. Another river stretch with red colour is categorized into Low habitat suitability status, mainly because there is a small dam established over the Dasha River, and the habitat type is recognized as fall and rapid, which is extremely not a suitable area for Oryzias Latipes.

7.3 Habitat simulation for the least tolerant fish species 3: Nicholsicypris normalis

7.3.1 Habitat requirements for NN

Nicholsicypris normalis (Nichols and Pope, 1927) is widespread in Guangdong, southern Guangxi, and Hainan, while Yaoshanicus arcus is endemic to the Yaoshan area in Ouangxi. In Hong Kong, the fish has only previously been found in the Sai Kung area and Sha Lo Tung. Recently it was found to be quite common in two locations near Sha Tau Kok in the northeast New Territories, and a stream in northern Lantau. The Lantau record represents a rather dramatic local range extension, being the first record from the western side of the Territories.

7.3.2 Fuzzy rules and sets for each of the influencing parameters

The fuzzy rules and sets are developed for each of the habitat suitability indicators based on the habitat requirements of Nicholsicypris normalis in order to simulate its habitat suitability status in Dasha River.

In this study, a relative scale from 0-1 (0 being “very low” suitability and 1 being “very high” suitability) for the lower and upper threshold, has been used to map the Habitat Suitability Index (SI). Three categories of habitat suitability status are defined at the outset and then the defined classes are transformed into 3 linguistic fuzzy sets as L (Low), M (Medium), H (High). This forms the output fuzzy sets to map SI in the study area (Figure 7-7, d)).

The key influencing parameters could be verified according to different habitat requirements for different fish species. Base on the above analysis on the characteristics of Nicholsicypris normalis, water depth, flow velocity and substrate are considered as the input parameters. For each of the parameters, three categories have been specified and the whole range is categorized into three linguistic sets, taking the same descriptors, i.e. L (Low), M (Medium), H (High). The support crisp values for each fuzzy set are based on expert knowledge and are converted to linguistic variables by assigning an appropriate membership function. The fuzzy sets are shown in Figure 7-7.

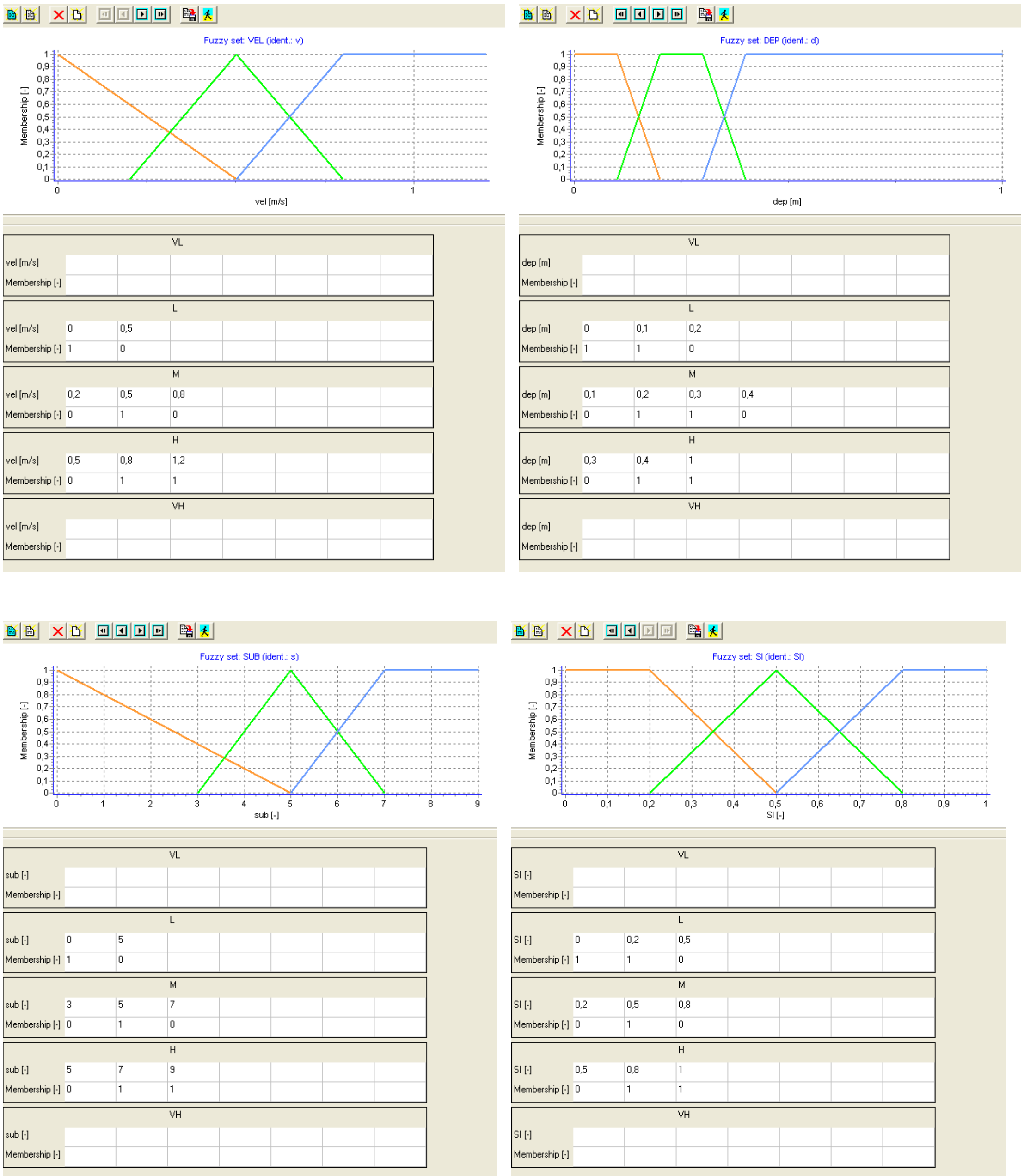


Figure 7-7 Membership functions for Nicholsicypris normalis: a) Velocity; b) Water depth; c) Substrate; d) Habitat suitability index

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets for each of 3 parameters which make 27 rules in total to define the model output. The associated rules used to map SI for Nicholsicypris normalis are shown in Table 7-4. It is to be noted here that by increasing the number of parameters, the formulation of rules becomes quite complex and less transparent. It is seen that there is always a trade-off between the increasing complexity of fuzzy rules and the resolution of the model output.

Table 7-4 Fuzzy rules for Nicholsicypris normalis habitat suitability based on the If-then logic system

Velocity	**Depth**	**Substrate**	**SI**
H	H	H	M
H	H	M	M
H	H	L	L
H	M	H	M
H	M	M	H
H	M	L	L
H	L	H	L
H	L	M	L
H	L	L	L
M	H	H	M
M	H	M	H
M	H	L	M
M	M	H	H
M	M	M	H
M	M	L	M
M	L	H	L
M	L	M	H
M	L	L	M
L	H	H	L
L	H	M	M
L	H	L	M
L	M	H	M
L	M	M	H
L	M	L	M
L	L	H	L
L	L	M	L
L	L	L	L

7.3.3 Results analysis

All the simulation and analysis processes have been done based on the attribute table of the Dasha River map, working with the CASiMiR tool in Arcgis. Three input parameters of flow velocity, water depth, and substrate and the output SI are added as columns of the attribute table, and then the surveyed data are fulfilled in, in order to set up the working table for the habitat suitability simulation of Nicholsicypris normalis.

After running the ArcGIS based CASiMiR model, the habitat suitability map of Nicholsicypris normalis is obtained by applying the sets of fuzzy rules to all input variables. The export map of the SI is shown below (see Figure 7-8).

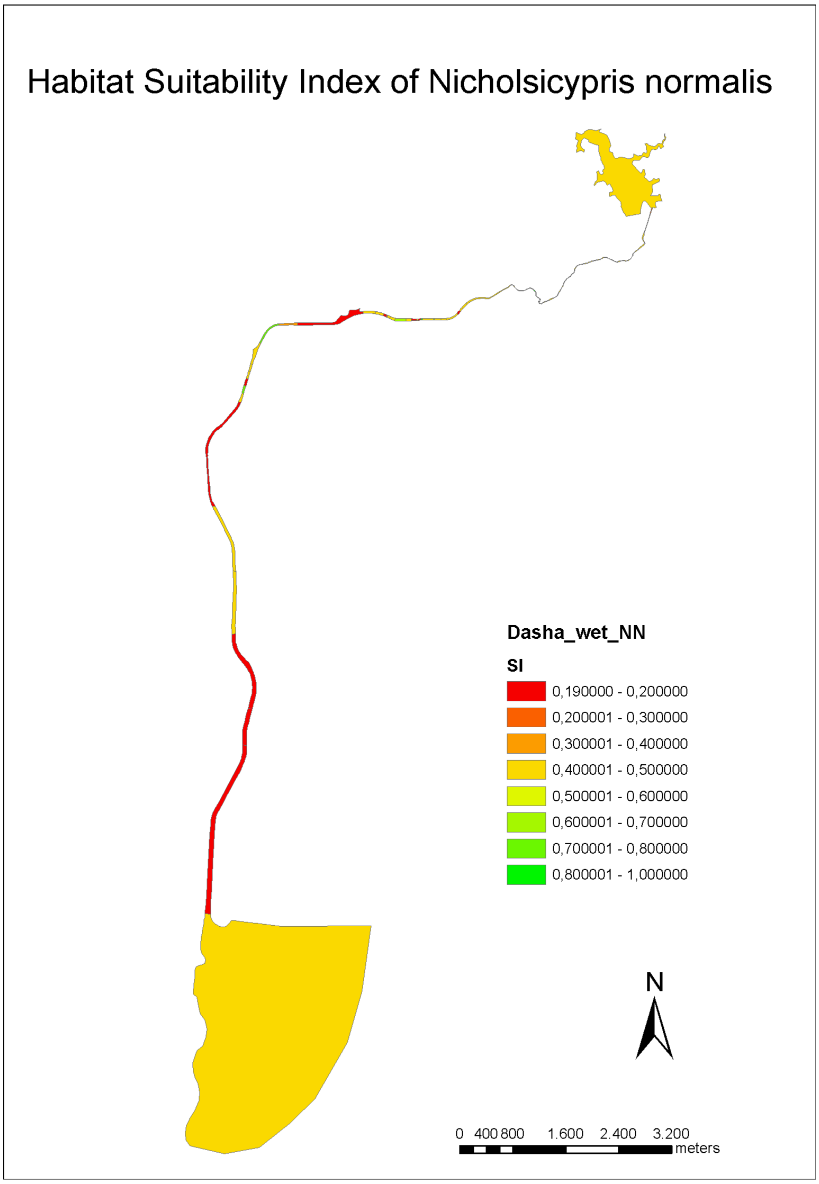


Figure 7-8 Suitability index simulation of Nicholsicypris normalis

As we can see, the Suitability Index of Nicholsicypris normalis is normalized and classified into different levels (Figure 7-6). The red colour stands for class 1 (value 0.19~ 0.2), which implies the lowest suitability index, and the green colour stands for class 5 (value 0.8~1), which implies the highest suitability index. From the figure we can learn that most stretch of Dasha River is recognized as Medium to Low habitat suitability status for Nicholsicypris normalis. Even the upstream and downstream does not have a better habitat status.

7.4 Habitat Suitability Index for the least tolerant fish species

For the least tolerant fish species habitat SI, we consider three fish species as indicators. Regarding the frequency of their appearance, equal weights have been given to the three species when generating the least tolerant fish species habitat Suitability Index (SI_LTF).

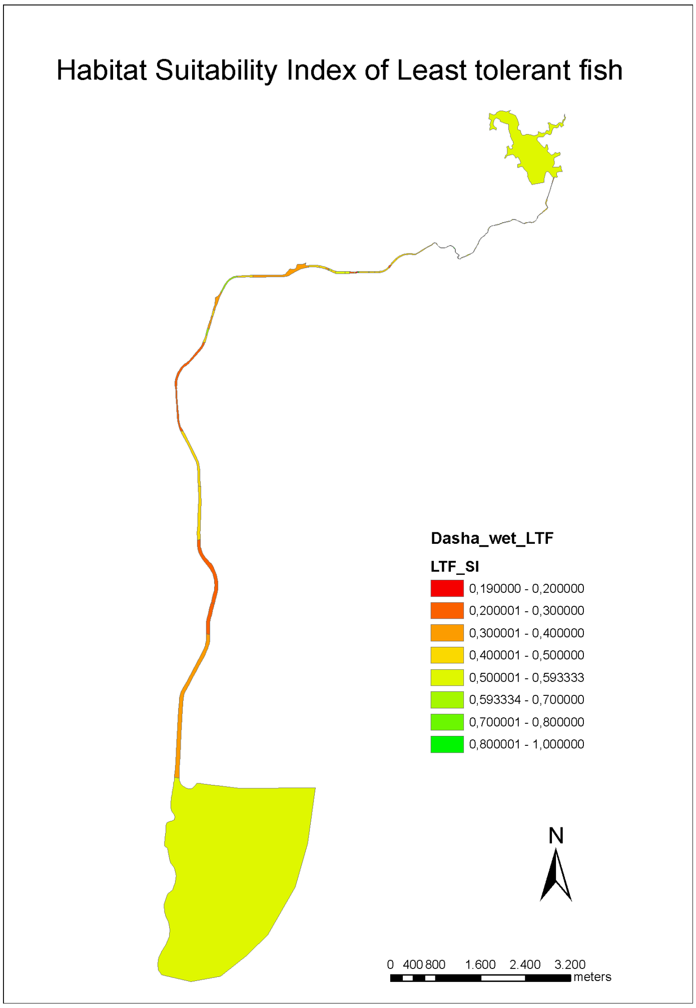


Figure 7-9 Simulation of the least tolerant fish species SI_LTF

The above ArcGIS maps show the simulation results of each individual least tolerant fish species habitat SI and the integrated SI. As we can see, part of the river reaches show good conditions for the habitat suitability of Parazacco spilurus, such as the river source Changlingpi Reservoir and the river mouth Shenzhen Bay indicating a high class of SI, but the downstream reaches which are fully channelized indicate a bad habitat suitability status with a very low value of 0.19 (Fig. 7-3). The suitability status of Oryzias Latipes is shown as quite even, with a habitat SI of 0.5 (Fig. 7-6). The SI of Nicholsicypris normalis is shown as the worst situation beyond all three selected fish indicators, and almost all the river reaches have a low habitat suitability status which is under the value of 0.5 (Fig. 7-8).

After integrating all three fish species with the same weight, the least tolerant fish species suitability is degraded in total (Fig. 7-9). From this figure we can learn that the upstream and downstream have better a habitat status for the fish species. The middle stream shows a worse habitat status, mostly caused by the shallow water depth. The downstream part is remains with a bad habitat suitability status with a very low value of 0.19, mainly due to the concreted river channel.

7.5 Habitat Suitability Index for the most tolerant fish species: Cyprinus Carpio (Common Carp)

7.5.1 Habitat requirements for CC

Cyprinus Carpio, which is well-known as the common carp, has been selected as the indicator of the most tolerant fish species for the Dasha River.

The natural conditions that suit the carp are lowland lakes and rivers where there is abundant vegetation to provide food and shelter.

Its preferred spawning areas have a flow velocity of 0.2 – 0.9 m/s. A velocity increase of 0.25 – 0.50 m/s is better for spawning (Yih and Liang 1964). The eggs and fries will not sink when the velocity is >0.2 m/s (Cao et al., 1987). The eggs begin sinking when the water velocity is <0.27 m/s; most of the eggs sink if the velocity is <0.18 – 0.25 m/s; and all the eggs sink if the velocity is ≤0.1 m/s (Tang and Yu et al., 1996).

The carp generally spawns in spring, but in warmer, southern climates, spawning can occur from March to June, and in cooler, northern climates, from May to June (McCrimmon, 1968). Females with recently spent ovaries have been observed from March to October (Jester, 1974), and ripe males have been observed during most of the summer months in the temperate zone (Swee and McCrimmon, 1966; Sanchez, 1970; Mauck and Summerfelt, 1971; Padilla, 1972). This indicates that the species may spawn over a prolonged period of time in warmer environments (McCrimmon, 1968).

Adults congregate and deposit their adhesive eggs on aquatic or submerged terrestrial vegetation or any other object the eggs will adhere to (Sigler, 1958; McCrimmon, 1968). Spawning over areas of dense vegetation will increase reproductive success (June, 1977).

In both riverine and lacustrine habitats, carp prefer enriched, relatively shallow, warm, sluggish, and well-vegetated waters with a mud or silt substrate (Harlan and Speaker, 1956; Sigler, 1958; Swee and McCrimmon, 1966; McCrimmon, 1968; Pflieger, 1975). Adults spend summer and early autumn in shallow areas of dense vegetation (May and Gloss, 1979) and, as temperatures drop, the fish move into deeper waters for the winter (Adams and Hankinson, 1928; Huntington and Hill, 1956; Jester et al., 1969; Sanchez, 1970; Jester, 1974).

The species prefers areas of slow current. In the Missouri River, common carp occur in pools and chutes (≤ 60 cm/sec) and in the main channel borders (60-120 cm/sec) (Schmulbach et al., 1975), but are most abundant in marshes and backwaters (≤ 20 cm/sec) (Kallemeyn and Novotny, 1977). Deep pools with abundant cover, including logs, brush, and other objects, provide feeding and resting areas in swift rivers (Pflieger, 1975). Although occasionally found in high gradient streams, the species is more common in low to moderate gradient streams. In high gradient streams, carp occur in warm backwaters and in organically polluted sections (Sigler, 1958; Pflieger, 1975).

Adults are very tolerant of low dissolved oxygen (DO) levels, a condition common in warm, fertile waters (Sigler, 1955, 1958; McCrimmon, 1968). Adults will also feed in the oxygen-depleted hypolimnion (< 2 mg/l D.O.) (Hover, 1976). Adults can gulp surface air when the DO is ≤ 0.5 mg/l (Yashouv, 1956). Respiration is elevated at 3-5 mg/l DO (13-23° C) (Itazawa, 1971; Davis, 1975). The DO should remain at least 6-7 mg/l for good growth (Huet, 1970).

Juveniles are most common in the same habitat as the fry (Sigler, 1958). Optimum growth of juveniles occurs from 28-30° C (Adelman, 1977). Temperature preferences of juveniles in the laboratory and in thermal effluents have been reported to be between 27° C and 33.5° C (Pitt et al.,1956; Nei and Magnuson, 1974; Askerov, 1975; Coutant, 1977). Dai1y food consumption is greatest at 23-27° C (Backiel and Stegman, 1968). Temperatures of ≥38° C are lethal for juveniles (Meuwis and Huet, 1957).

The lowest lethal oxygen level for juveniles is < 1.0 mg/l (<20° C) (Privolnev, 1954; Downing and Merkens, 1957; Doudoroff and Shumway, 1970). The growth rate of juveniles begins to decrease at approximately 2.1 mg/l at 20-23° C (Chiba, 1965).

Optimal DO levels are assumed to be ≥ 6 mg/l, as with adults. Salinities greater than 6 ppt were reported to be lethal to juveniles (Askerov, 1975).

The percentage of vegetative cover should be considered because areas with abundant vegetation provide habitats for various food organisms. In addition, the amount of vegetation reflects the general productivity of the habitat, and carp are opportunistic feeders on vegetation and detritus, as well as animal matter. Dense vegetation is also required by fry and juveniles for cover. The percentage of vegetative cover is important because the preferred spawning substrate is vegetation.

7.5.2 Fuzzy rules and sets for each of the influencing parameters

The fuzzy rules and sets are developed for each of the habitat suitability indicators based on the habitat requirements of Cyprinus Carpio separately for spawning and adults in order to simulate their habitat suitability status in Dasha River.

Spawning

In this study, a relative scale from 0-1 (0 being “very low” suitability and 1 being “very high” suitability) for the lower and upper threshold, has been used to map the Habitat Suitability Index (SI). Three categories of habitat suitability status are defined at the outset and then the defined classes are transformed into 3 linguistic fuzzy sets as L (Low), M (Medium), H (High). This forms the output fuzzy sets to map SI in the study area (Figure 7-10, d)).

The key influencing parameters could be verified according to different habitat requirements for different fish species. Base on the above analysis on the characteristics of spawning Common Carp, water depth, flow velocity and substrate are considered as the input parameters. For each of the parameters, three categories have been specified and the whole range is categorized into three linguistic sets, taking the same descriptors, i.e. L (Low), M (Medium), H (High). The support crisp values for each fuzzy set are based on expert knowledge and are converted to linguistic variables by assigning an appropriate membership function. The fuzzy sets are shown in Figure 7-10.

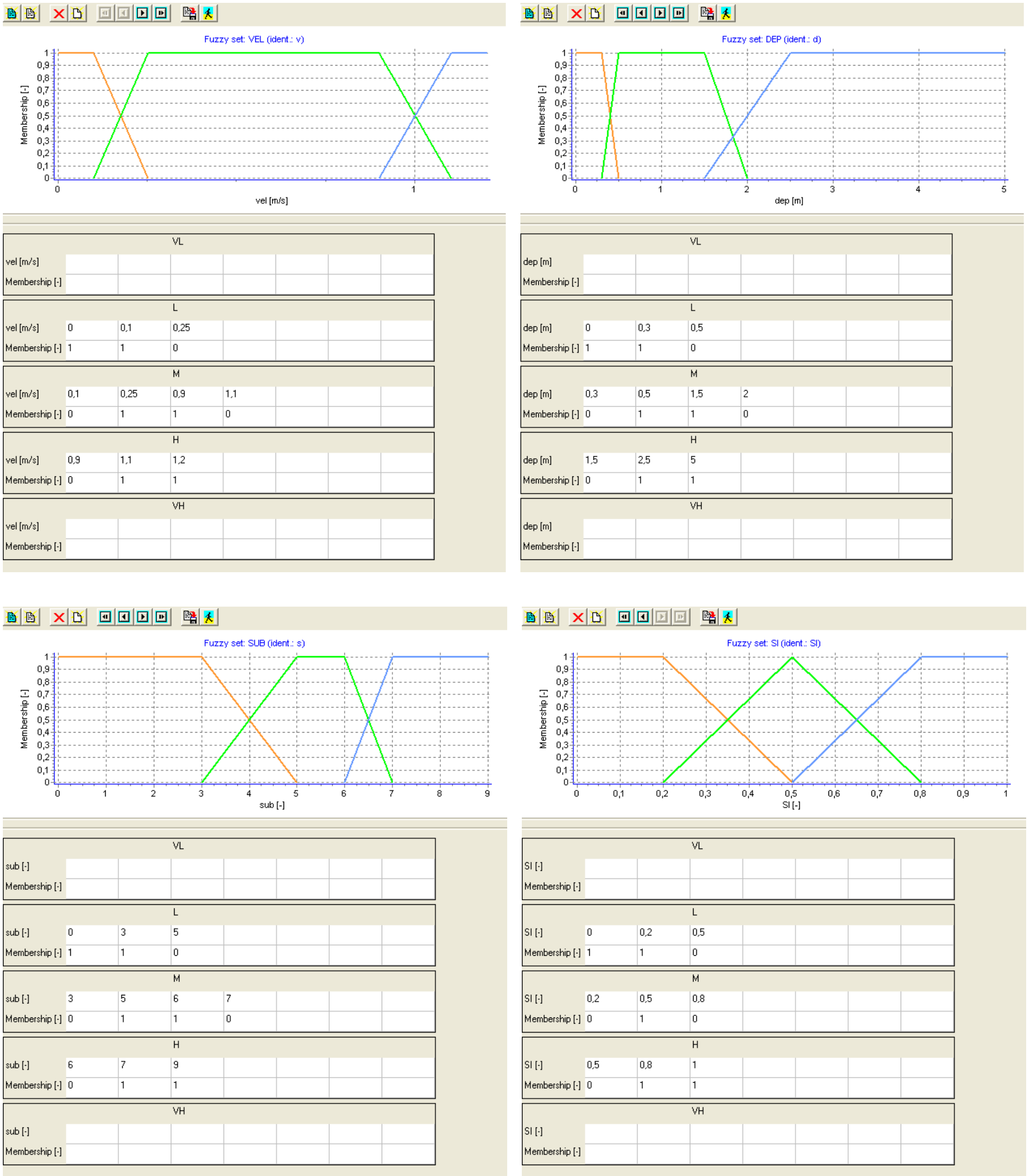


Figure 7-10 Membership functions for spawning Common Carp: a) Velocity; b) Water depth; c) Substrate; d) Habitat Suitability Index

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets for each of 3 parameters which make 27 rules in total to define the model output. The associated rules used to map SI for spawning Common Carp are shown in Table 7-5.

It is to be noted here that by increasing the number of parameters, the formulation of rules becomes quite complex and less transparent. It is seen that there is always a trade-off between the increasing complexity of fuzzy rules and the resolution of the model output.

Table 7-5 Fuzzy rules for spawning Common Carp habitat suitability based on the If-then logic system

Velocity	Depth	Substrate	SI
H	H	H	M
H	H	M	M
H	H	L	M
H	M	H	M
H	M	M	M
H	M	L	H
H	L	H	L
H	L	M	M
H	L	L	M
M	H	H	M
M	H	M	H
M	H	L	H
M	M	H	H
M	M	M	H
M	M	L	H
M	L	H	L
M	L	M	M
M	L	L	H
L	H	H	L
L	H	M	L
L	H	L	L
L	M	H	L
L	M	M	L
L	M	L	M
L	L	H	L
L	L	M	L
L	L	L	L

Adults

Similarly, the fuzzy rules and sets are developed for each of the habitat suitability indicators based on the habitat requirements of adults Common Carp.

For three input parameters of water depth, flow velocity and substrate, and one output parameter of SI, three categories have been specified and the whole range is categorized into three linguistic sets, taking the same descriptors, i.e. L (Low), M (Medium), H (High). The support crisp values for each fuzzy set are based on expert knowledge and are converted to linguistic variables by assigning an appropriate membership function. The fuzzy sets are shown in Figure 7-10.

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets for each of 3 parameters which make 27 rules in total to define the model output. The associated rules used to map SI for adults Common Carp are shown in Table 7-6.

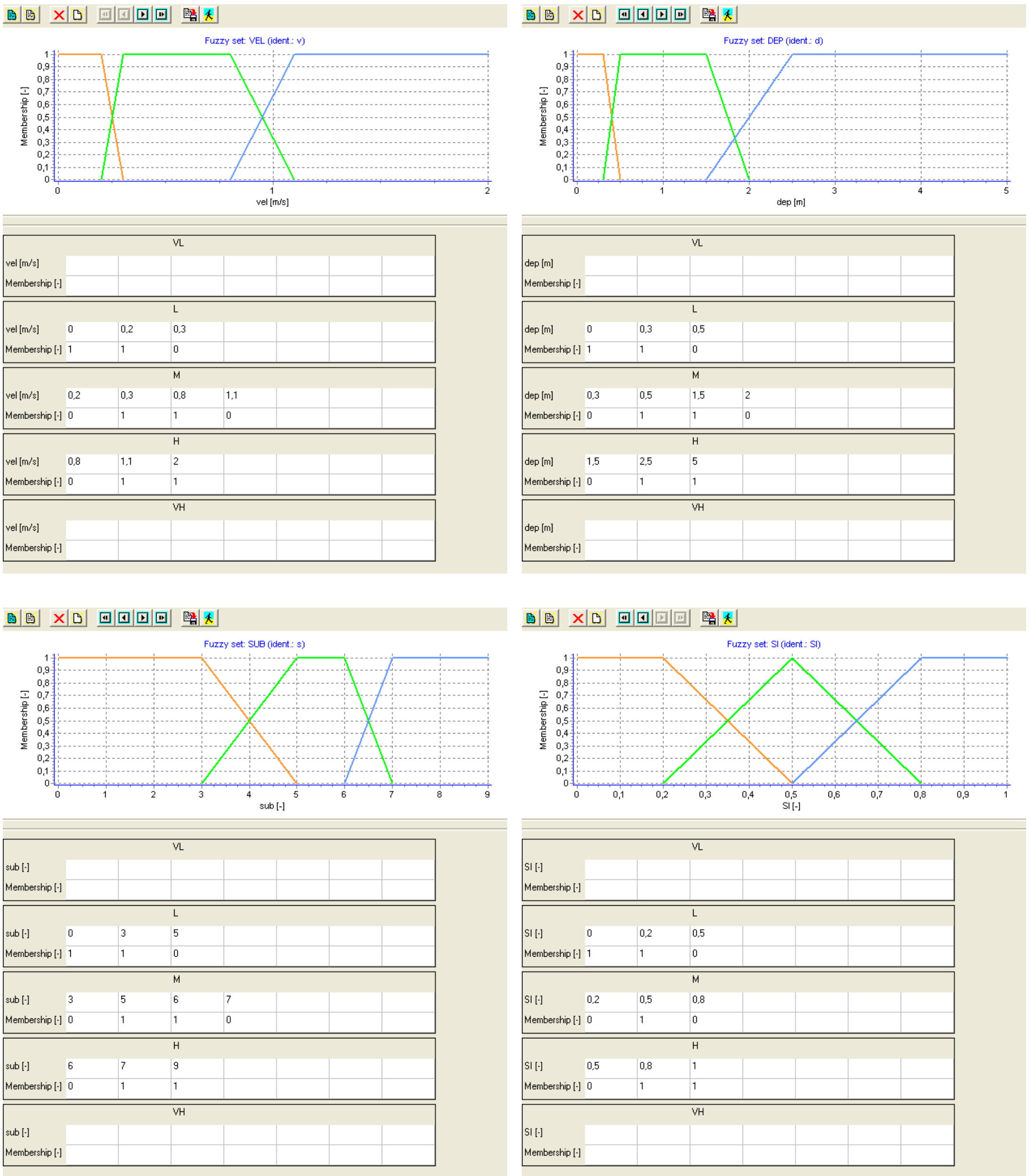


Figure 7-11 Membership functions for adult Common Carp: a) Velocity; b) Water depth; c) Substrate; d) Habitat Suitability Index

Table 7-6 Fuzzy rules for adult Common Carp habitat suitability based on the If-then logic system

Velocity	Depth	Substrate	SI
H	H	H	L
H	H	M	M
H	H	L	M
H	M	H	L
H	M	M	H
H	M	L	M
H	L	H	L
H	L	M	L
H	L	L	L
M	H	H	M
M	H	M	H
M	H	L	M
M	M	H	H
M	M	M	H
M	M	L	H
M	L	H	L
M	L	M	M
M	L	L	L
L	H	H	M
L	H	M	M
L	H	L	M
L	M	H	M
L	M	M	H
L	M	L	M
L	L	H	L
L	L	M	M
L	L	L	L

7.5.3 Results analysis

All the simulation and analysis processes have been done based on the attribute table of the Dasha River map, working with the CASiMiR tool in Arcgis. Three input parameters of flow velocity, water depth, and substrate and the output SI are added as columns of the attribute table, and then the surveyed data are fulfilled in, in order to set up the working table for the habitat suitability simulation of Common Carp. The fuzzy rules and sets which are generated by the fuzzy calculator can be combined together by using notepad, and then further saved as the input fuzzy files for the next fuzzification step.

After running the ArcGIS based CASiMiR model, the habitat suitability map of Common Carp is obtained by applying the sets of fuzzy rules to all input variables. The export maps of the SI are shown below (see Figure 7-12).

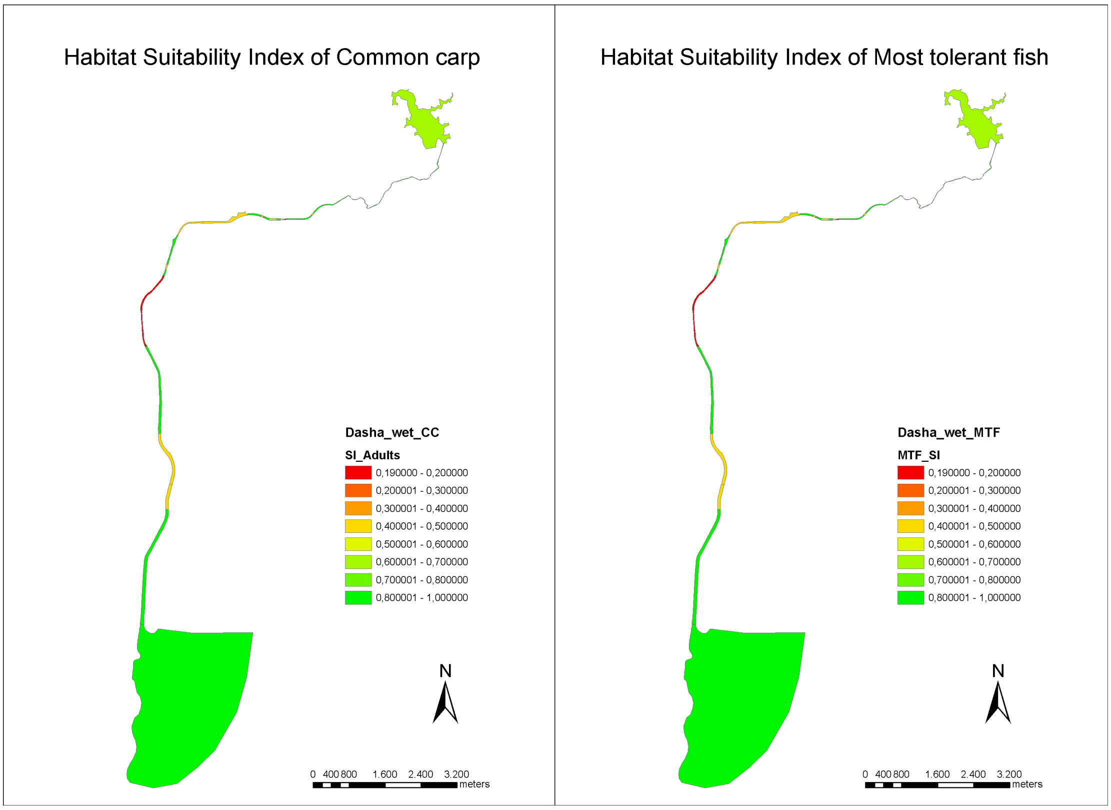


Figure 7-12 Suitability status simulation of a) common carp and b)most tolerant fish species

Due to the limitation of field data, here is only showing the habitat suitability simulation of adult Common Carp. As we can see, the SI of the adult common carp has been normalized and classified into 5 different levels (Fig. 7-12,a)). Since we consider Common Carp as the indicator of the most tolerant fish species, the suitability index of the most tolerant fish species for Dasha River (SI_MTF) is representing the same as the Common Carp (Fig. 7-12, b)).

The red colour stands for class 1 (value 0.19~ 0.29), which implies the lowest SI, and the green colour stands for class 5 (value 0.72~0.81), which implies the highest SI. From this figure we can learn that the SI of the common carp shows a relatively better situation compared to the other three tolerant fish indicators. Almost all the river reaches have a high habitat suitability status for the most tolerant fish species, which is over the value of 0.5.

7.6 Fuzzification for fish diversity

Considering the parameter of biodiversity, it is not easily identifiable for each of the habitat areas by using Simpson's diversity index formula to calculate the value of each with field data. Instead, we can classify the different levels of biodiversity as the other parameters such as bank protection and riparian vegetation. We classify biodiversity into five groups, 1-5; 1 stands for a very good standard of biodiversity, which means the populations of each fish species are mostly equal, and both the most tolerant fish species and the least tolerant fish species can be observed, and 5 stands for the lowest standard of biodiversity, which means the population of the most tolerant fish and the least tolerant fish are extremely different; or even that the least tolerant fish species are missing.

Definition of biodiversity:

- species richness
- species evenness or equitability

Simpson's diversity index:

$$D = 1 - \sum_{i-1}^{S} P_i^2$$

The Shannon-Weiner index:

$$H = -\sum_{i-1}^{S} P_i \log_2 P_i$$

The fuzzy rules and sets are developed to combine biodiversity with SI_LTF and SI_MTF in order to simulate the integrated fish habitat suitability index (IFSI) in Dasha River.

A relative scale from 0-1 (0 being “very low” suitability and 1 being “very high” suitability) for the lower and upper threshold, has been used to map the IFSI. Five categories of integrated fish habitat suitability status are defined at the outset and then the defined classes are transformed into 5 linguistic fuzzy sets as VL (Very Low), L (Low), M (Medium), H (High), VH (Very High). This forms the output fuzzy sets to map IFSI in the study area (Figure 7-13, d)).

Biodiversity classes are categorical variables and do not manifest numerically. Each category is represented as a fuzzy singleton, resulting into 5 linguistic sets from VL (Very Low) to VH (Very High). These linguistic sets correspond to the Biodiversity level in the study area. VL (Very Low), L (Low), M (Medium), H (High), VH (Very High) (Figure 7-13, c)).

For another two input parameters of SI_LTF and SI_MTF, three categories have been specified and the whole range is categorized into three linguistic sets, taking the same descriptors, i.e. L (Low), M (Medium), H (High). The support crisp values for each fuzzy set are based on expert knowledge and are converted to linguistic variables with an appropriate membership function. The fuzzy sets are shown in Figure 7-13.

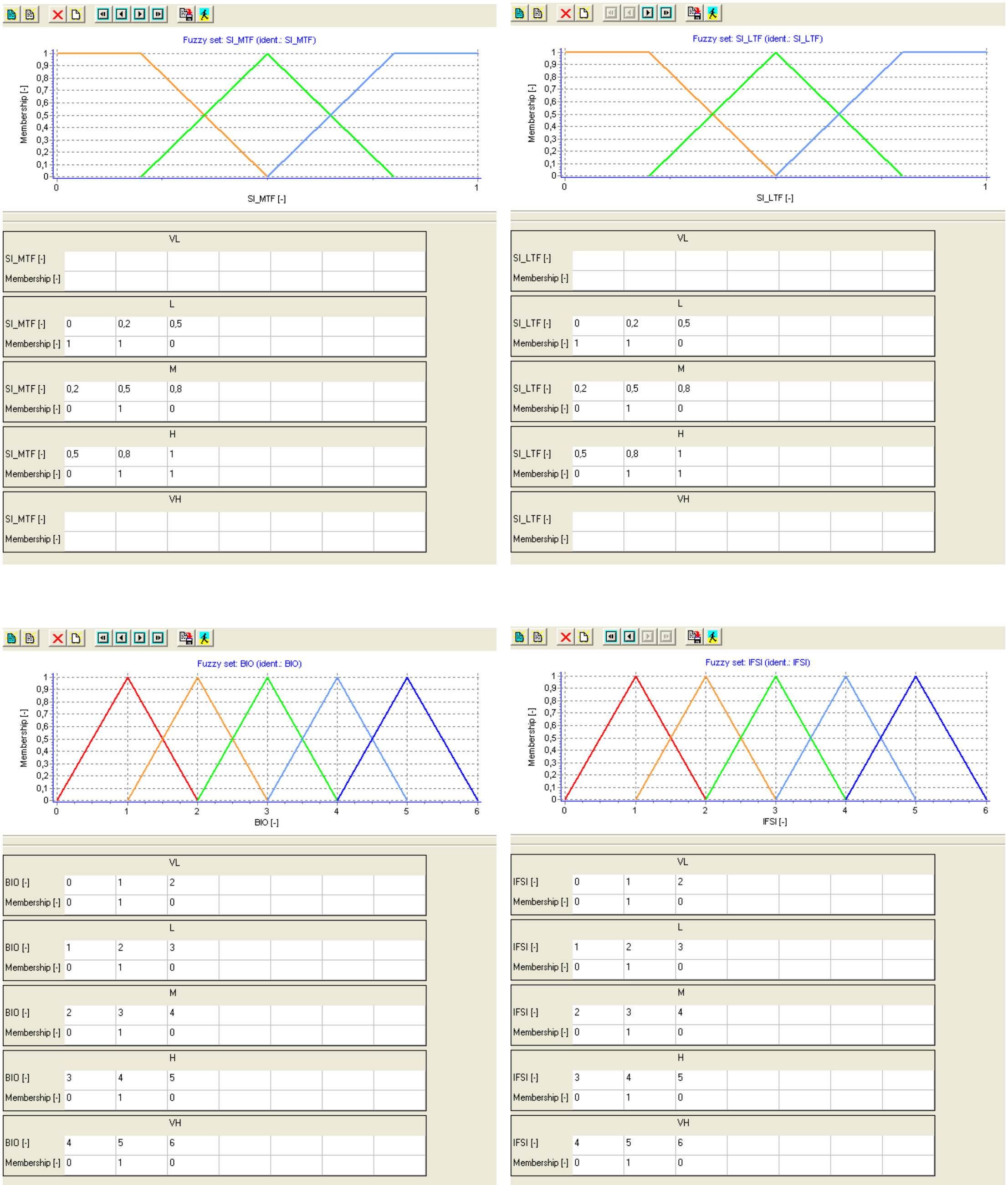


Figure 7-13 Membership functions associated with biodiversity a) SI_LTF; b) SI_MTF; c) biodiversity; d) integrated fish habitat suitability index

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets* 3 sets* 5 sets which make 45 rules in total to define the model output. The associated rules used to map SI for adults Common Carp are shown in Table 7-7.

Table 7-7 Fuzzy rules associated with biodiversity based on the If-then logic system

SI_LTF	**SI_MTF**	**Biodiversity**	**IFSI**
H	H	VH	VH
H	H	H	VH
H	H	M	VH
H	H	L	VH
H	H	VL	VH
H	M	VH	VH
H	M	H	VH
H	M	M	VH
H	M	L	H
H	M	VL	H
H	L	VH	VH
H	L	H	H
H	L	M	H
H	L	L	H
H	L	VL	H
M	H	VH	H
M	H	H	H
M	H	M	H
M	H	L	M
M	H	VL	M
M	M	VH	H
M	M	H	M
M	M	M	M
M	M	L	M
M	M	VL	M
M	L	VH	M
M	L	H	M
M	L	M	M
M	L	L	L
M	L	VL	L
L	H	VH	M
L	H	H	L
L	H	M	L

L	H	L	L
L	H	VL	L
L	M	VH	L
L	M	H	L
L	M	M	L
L	M	L	VL
L	M	VL	VL
L	L	VH	L
L	L	H	VL
L	L	M	VL
L	L	L	VL
L	L	VL	VL

7.7 Simulation of the integrated fish habitat suitability index

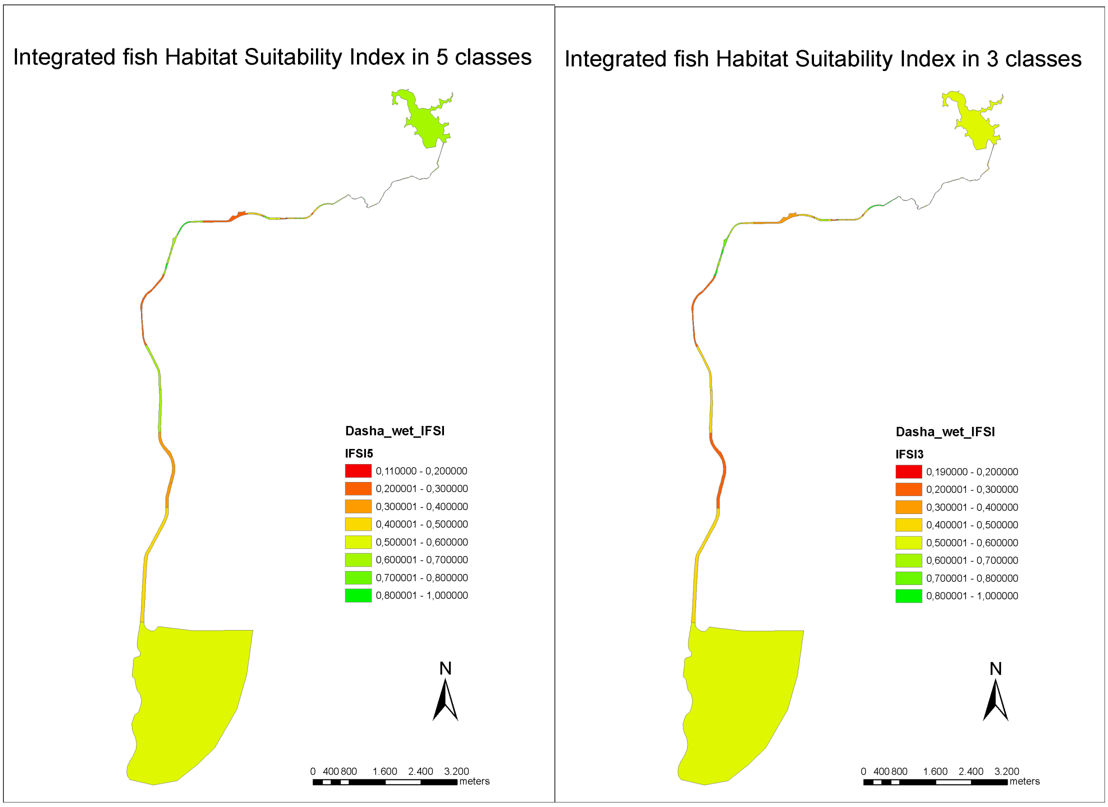


Figure 7-14 Simulation of the integrated fish species suitability index IFSI with a) 5 classes and b) 3 classes

For calculating the integrated fish habitat suitability index, another indicator of biodiversity is taken into the simulation system, and among the three input parameters - the least tolerant fish habitat suitability index, the most tolerant fish habitat suitability index and biodiversity - the least tolerant fish habitat suitability index is the governing parameter, and its highest weights should also be taken into consideration when we generate the fuzzy rules based on biological expert knowledge.

The integrated fish habitat suitability index, which is shown in figure 7-14, is the result of the fuzzy logic-based fish suitability assessment model for the Dasha River.

Fuzzy sets of IFSI with 3 categories is also developed and used in this model, in order to have an impact study on changing fuzzy membership functions. From the comparison, it shows slight differences with the suitability status, only the river stretches in Chanlingpi Reservaior and part of the middle stream have shown a higher class of habitat suitability status by using IFSI5.

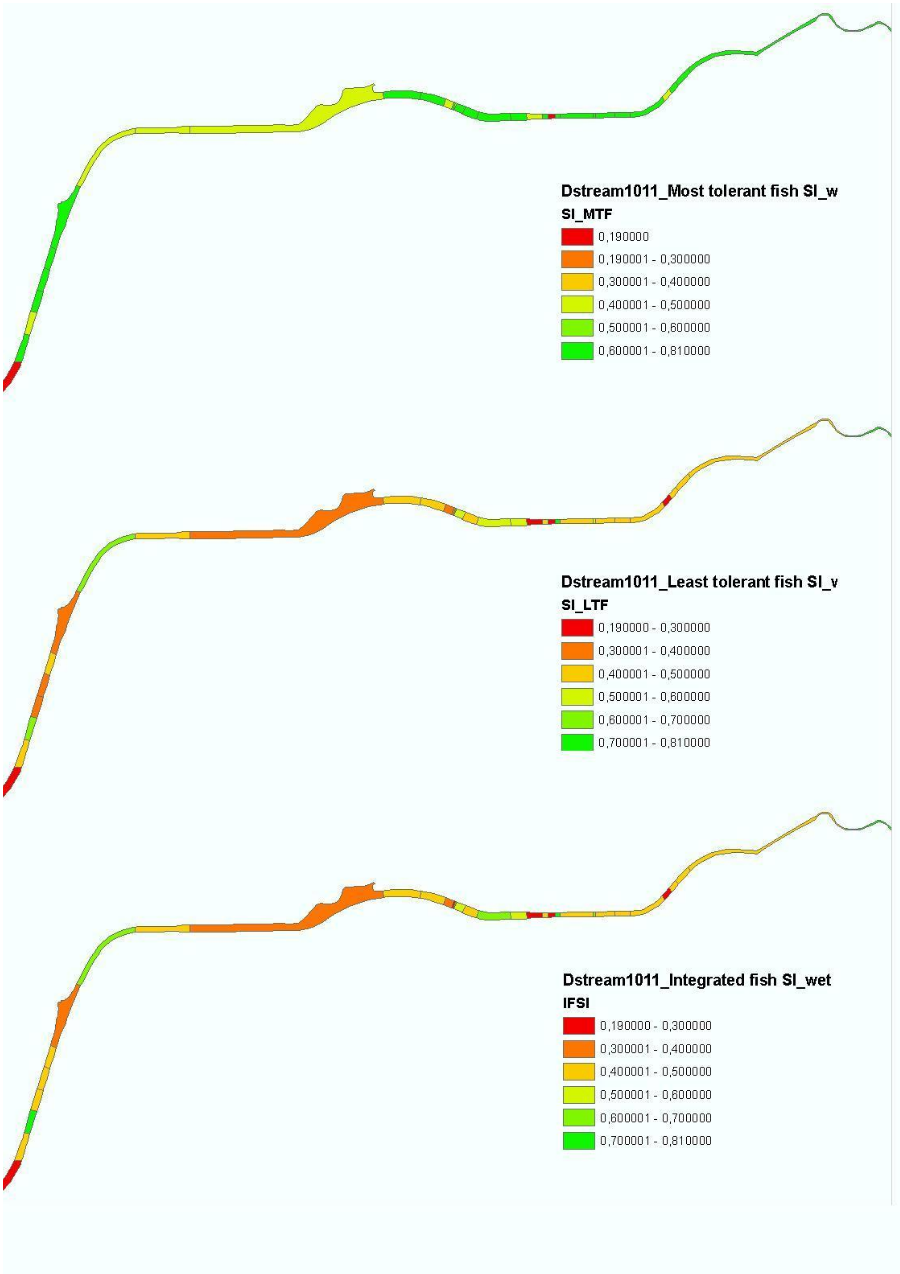


Figure 7-15 A comparison between the most tolerant fish habitat suitability index, the least tolerant fish habitat suitability index and the integrated fish habitat suitability index

We selected a river stretch consisting of half of the upstream to half of the middle stream, which has frequent habitat variation. From comparing the maps we can see the pattern clearly changes. For the most tolerant fish species, the level of habitat suitability status is very high, although for the least tolerant fish species, the habitat is extremely unsuitable (Fig. 7-15). Therefore, the least tolerant fish habitat suitability index is the governing parameter, and its highest weights should also be taken in to consideration.

8 Implementation of assessment stage 2 in the Dasha River: Simulation of the Urban-Rural River Ecological Health Index (URRHI)

8.1 Fuzzy rules and sets in stage 2

The second stage of setting up the urban-rural river ecological health assessment system is to consider the other influencing parameters from the river riparian area. As we discussed in Chapter 8, riparian vegetation and bank/bed protection are two parameters vitally influencing the river's ecological health. They have been chosen as the input factors in stage 2 for simulating the urban-rural river ecological health index in this research. Compared with the influencing parameters concerning the river body itself, the parameters concerning the river riparian area are more related to land use and land cover.

Riparian vegetation, which in the WFD is "downgraded" to the role of a hydro-morphological element supporting biological elements, deserves - as an essential biotic component of the river system - full recognition as a biological quality element (like macrophytes and phytobenthos). It is worth mentioning the high species diversity in the ecotonal areas, its productivity, the strategic importance for nature conservation and its roles as a source of dispersal of species; as fine particulate organic matter and large woody debris, which, in turn, diversify habitats and create local conditions favourable for some fauna; as a control of diffusing pollution conveyed by the surface and sub-surface; and as a regulator of water temperature. Finally, its status can be used as a proxy for many other biological elements that are not directly measured (for example riparian fauna).

The riparian zone can perform a variety of functions that can be managed to protect the water quality of streams and rivers and to protect the habitat of aquatic and terrestrial fauna. These zones are often needed to buffer the effects of land use on streams. However, their biophysical roles and human uses vary both with type of landform and position within the catchment.

Riparian vegetation provides a number of important functions including: 1, nutrients for streams from litter fall; 2, root masses for stream bank stability; 3, shade to control water temperature; 4, large woody debris for stream channel development.

Variability within the riparian zone has been recognized and catalogued by classifying its vegetation. Each vegetation unit has its own characteristics and contributes in its own way to maintaining a healthy riparian and stream ecosystem. Classification of riparian vegetation in relation to fluvial surfaces in a particular watershed will give targets for rehabilitation or mitigation projects.

A reach system is defined as a length of a stream segment lying between breaks in channel slopes, local side slopes, valley floor width, riparian vegetation, and bank material. The reach typically possesses a characteristic range of channel bed materials.

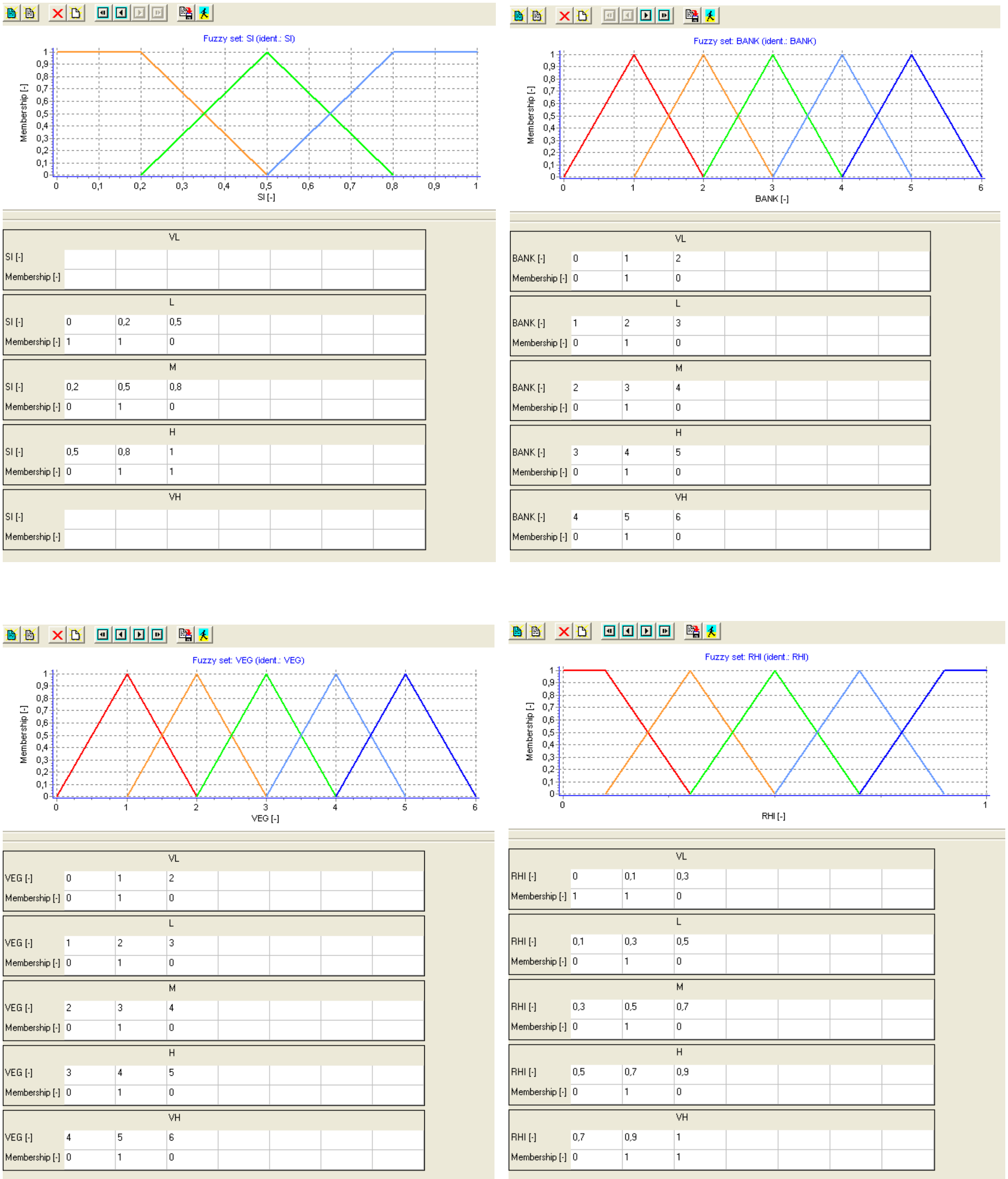
Note that the bank/bed protection can also serve as a proxy for other attributes, particularly those associated with river continuity in vertical, longitudinal and lateral aspects. The connection to groundwater bodies, which represent a river's hydrological regime, can also be indicated by bank/bed protection. As well as the channel structure, the level of channelization can be easily described by the type of bank/bed protection. In this research, according to the level of channelization, we have divided bank/bed protection into 5 different categories as the same classification method which was defined in the first module of the urban-rural river continuum identification system.

For the fuzzy membership functions of riparian vegetation and bank/bed protection, the best way of describing it is a singleton fuzzy membership. Linguistically we divide riparian vegetation and bank/bed protection into 5 categories with a clear definition for each one. In order to translate linguistic value into fuzzy membership, which can be in accordance with other parameters and their fuzzy memberships together into the fuzzy logic based assessment system, the singleton membership function is a proper method. Only at the point of 1, 2, 3, 4, 5, are the values of riparian vegetation and bank/bed protection 1, which means only at the point of 1, 2, 3, 4, 5 will the fuzzy sets get fired.

A relative scale from 0-1 (0 being "very low" suitability and 1 being "very high" suitability) for the lower and upper threshold, has been used to map the Urban/Rural River Ecological Health Index (URRHI). Five categories of river health status are defined at the outset and then the defined classes are transformed into 5 linguistic fuzzy sets as VL (Very Low), L (Low), M (Medium), H (High), VH (Very High). This forms the output fuzzy sets to map URRHI in the study area (Figure 8-1, d)).

Fuzzy rules for SI are developed base on the expert knowledge and literature reviews. The total number of fuzzy rules equals all possible permutations of model inputs, there are 3 sets* 5 sets* 5 sets which make 75 rules in total to define the model output. The associated rules used to map SI for adults Common Carp are shown in Table 8-1.

It is to be noted here that by increasing the number of parameters, the formulation of rules becomes quite complex and less transparent. It is seen that there is always a trade-off between the increasing complexity of fuzzy rules and the resolution of the model output.



VL	SI [-]			
	Membership [-]			
L	SI [-]	0	0,2	0,5
	Membership [-]	1	1	0
M	SI [-]	0,2	0,5	0,8
	Membership [-]	0	1	0
H	SI [-]	0,5	0,8	1
	Membership [-]	0	1	1
VH	SI [-]			
	Membership [-]			

VL	BANK [-]	0	1	2
	Membership [-]	0	1	0
L	BANK [-]	1	2	3
	Membership [-]	0	1	0
M	BANK [-]	2	3	4
	Membership [-]	0	1	0
H	BANK [-]	3	4	5
	Membership [-]	0	1	0
VH	BANK [-]	4	5	6
	Membership [-]	0	1	0

VL	VEG [-]	0	1	2
	Membership [-]	0	1	0
L	VEG [-]	1	2	3
	Membership [-]	0	1	0
M	VEG [-]	2	3	4
	Membership [-]	0	1	0
H	VEG [-]	3	4	5
	Membership [-]	0	1	0
VH	VEG [-]	4	5	6
	Membership [-]	0	1	0

VL	RHI [-]	0	0,1	0,3
	Membership [-]	1	1	0
L	RHI [-]	0,1	0,3	0,5
	Membership [-]	0	1	0
M	RHI [-]	0,3	0,5	0,7
	Membership [-]	0	1	0
H	RHI [-]	0,5	0,7	0,9
	Membership [-]	0	1	0
VH	RHI [-]	0,7	0,9	1
	Membership [-]	0	1	1

Figure 8-1 Membership functions associated with the river health index a) IFSI; b) bank material; c) vegetation; d) urban-rural river ecological health index

Table 8-1 Fuzzy rules associated with the river health index based on the If-then logic system

IFSI	Bank	Vegetation	RHI 2	RHI 3	RHI 4
H	VH	VH	L	M	M
H	VH	H	M	H	M
H	VH	M	M	H	M
H	VH	L	H	H	M
H	VH	VL	M	H	M
H	H	VH	M	H	M
H	H	H	M	H	M
H	H	M	H	H	H
H	H	L	H	H	H
H	H	VL	M	H	M
H	M	VH	M	H	M
H	M	H	M	H	H
H	M	M	H	H	H
H	M	L	H	VH	H
H	M	VL	H	H	H
H	L	VH	M	H	H
H	L	H	H	H	H
H	L	M	H	VH	H
H	L	L	VH	VH	VH
H	L	VL	H	H	H
H	VL	VH	H	H	H
H	VL	H	H	H	H
H	VL	M	VH	VH	VH
H	VL	L	VH	VH	VH
H	VL	VL	H	VH	VH
M	VH	VH	L	L	L
M	VH	H	L	L	L
M	VH	M	M	M	L
M	VH	L	M	M	M
M	VH	VL	L	M	L
M	H	VH	L	L	L
M	H	H	L	M	L
M	H	M	M	M	M
M	H	L	M	M	M
M	H	VL	M	M	M
M	M	VH	L	M	M
M	M	H	M	M	M
M	M	M	M	M	M

M	M	L	H	M	M
M	M	VL	M	M	M
M	L	VH	M	M	M
M	L	H	M	M	M
M	L	M	H	M	H
M	L	L	H	H	H
M	L	VL	M	M	M
M	VL	VH	M	M	M
M	VL	H	M	M	H
M	VL	M	H	H	H
M	VL	L	H	H	H
M	VL	VL	H	M	H
L	VH	VH	VL	VL	VL
L	VH	H	VL	VL	VL
L	VH	M	L	L	L
L	VH	L	L	L	L
L	VH	VL	L	VL	VL
L	H	VH	VL	VL	VL
L	H	H	L	VL	L
L	H	M	L	L	L
L	H	L	M	L	L
L	H	VL	L	L	L
L	M	VH	L	VL	L
L	M	H	L	L	L
L	M	M	M	L	L
L	M	L	M	L	M
L	M	VL	L	L	L
L	L	VH	L	L	L
L	L	H	L	L	L
L	L	M	M	L	M
L	L	L	M	L	M
L	L	VL	M	L	M
L	VL	VH	L	L	M
L	VL	H	M	L	M
L	VL	M	M	L	M
L	VL	L	H	M	M
L	VL	VL	M	L	M

8.2 Results analysis and discussion

All the simulation and analysis processes have been done based on the attribute table of the Dasha River map, working with the CASiMiR tool in Arcgis. Three input parameters of integrated fish habitat suitability index, bank/bed protection, and riparian vegetation and the output urban/rural river ecological health index (URRHI) are added as columns of the attribute table, and then the surveyed data are fulfilled in, in order to set up the working table for the river ecological health simulation of Dasha River. The fuzzy rules and sets which are generated by the fuzzy calculator can be combined together by using notepad, and then further saved as the input fuzzy files for the next fuzzification step.

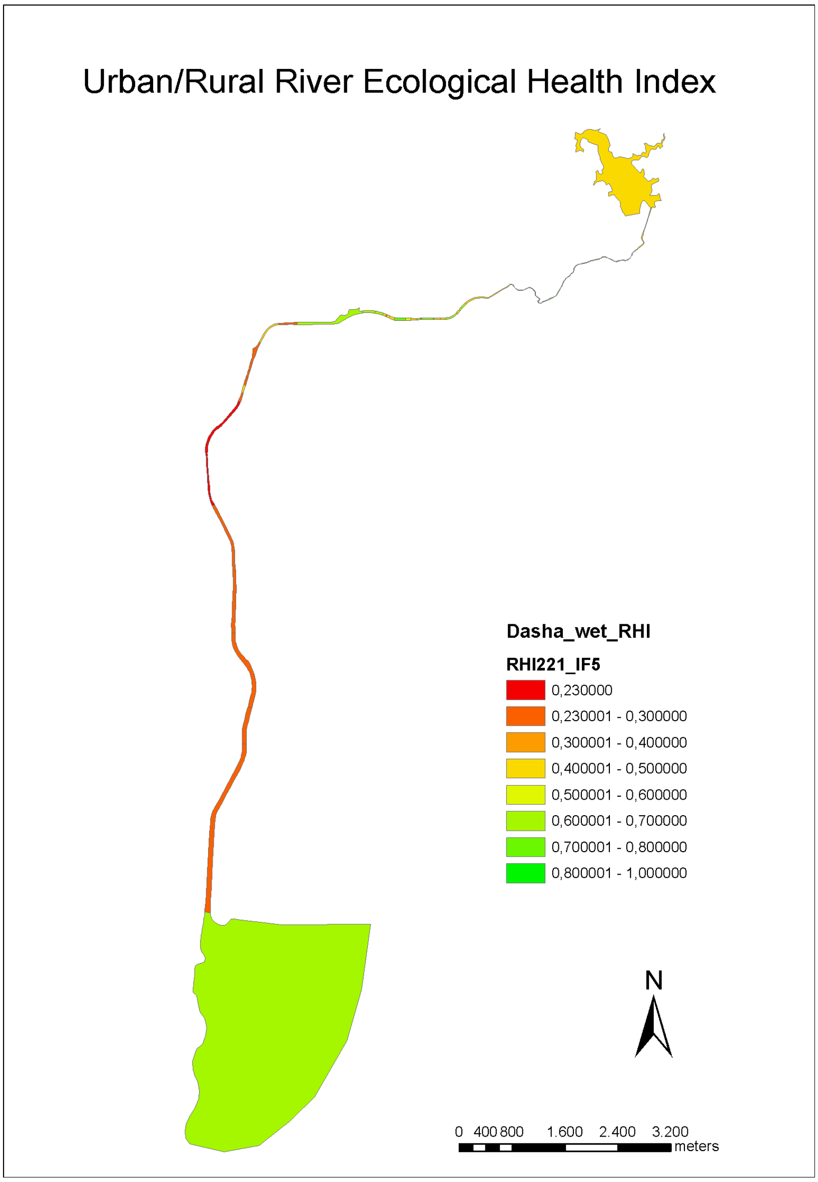


Figure 8-2 Simulation of the urban/rural river ecological health index with IFSI 5

After running the ArcGIS based CASiMiR model, the urban/rural river ecological health map is obtained by applying the sets of fuzzy rules to all input variables. The export map of the URRHI is shown in Figure 8-2.

As we can see, the Urban-Rural River Health Index is normalized and classified into 5 different levels. The red colour stands for class 1, which implies the lowest river health index; the green colour stands for class 5, which implies the highest river health index. From the figure we can learn that upstream and downstream have a better river ecological health status for the fish species, mainly due to the good condition of riparian vegetation and natural river bed form, this can be clearly seen in the picture from the field investigation (Figure 8-3, a)). The middle stream is showing a worse river ecological health status, mostly caused by the poor riparian vegetation, and most importantly, the river bank and bed is almost 100 percent artificial, which has a great impact on the river's ecological health status (Figure 8-3, a)).

Figure 8-3 Photographs from the field survey on Dasha River
(a) upstream, (b) middle stream

8.3 Influence of membership functions and fuzzy rules

In this research, the impact of different fuzzy membership functions is also evaluated. Different weights have been given to the following three parameters: the integrated fish suitability index (IFSI), the bank/bed protection and the riparian vegetation.

1) Set 1: URRHI1, Classes: 5
    a. Input: IFSI5(1) Bank5(1) Veg5(1)
    b. Output: RHI111_IFSI3
2) Set 2: URRHI2, Classes: 5

a. Input: IFSI5(3) Bank5(1) Veg5(1)

b. Output: RHI311_ IFSI3

3) Set 3: URRHI3, Classes: 5

a. Input: IFSI5(1) Bank5(2) Veg5(2)

b. Output: RHI221_ IFSI3

4) Set 4: URRHI4, Classes: 5

a. Input: IFSI3(1) Bank5(1) Veg5(1)

b. Output: RHI111_IFSI3

5) Set 5: URRHI5, Classes: 5

a. Input: IFSI3(3) Bank5(1) Veg5(1)

b. Output: RHI311_ IFSI3

6) Set 6: URRHI6, Classes: 5

a. Input: IFSI3(1) Bank5(2) Veg5(2)

b. Output: RHI221_ IFSI3

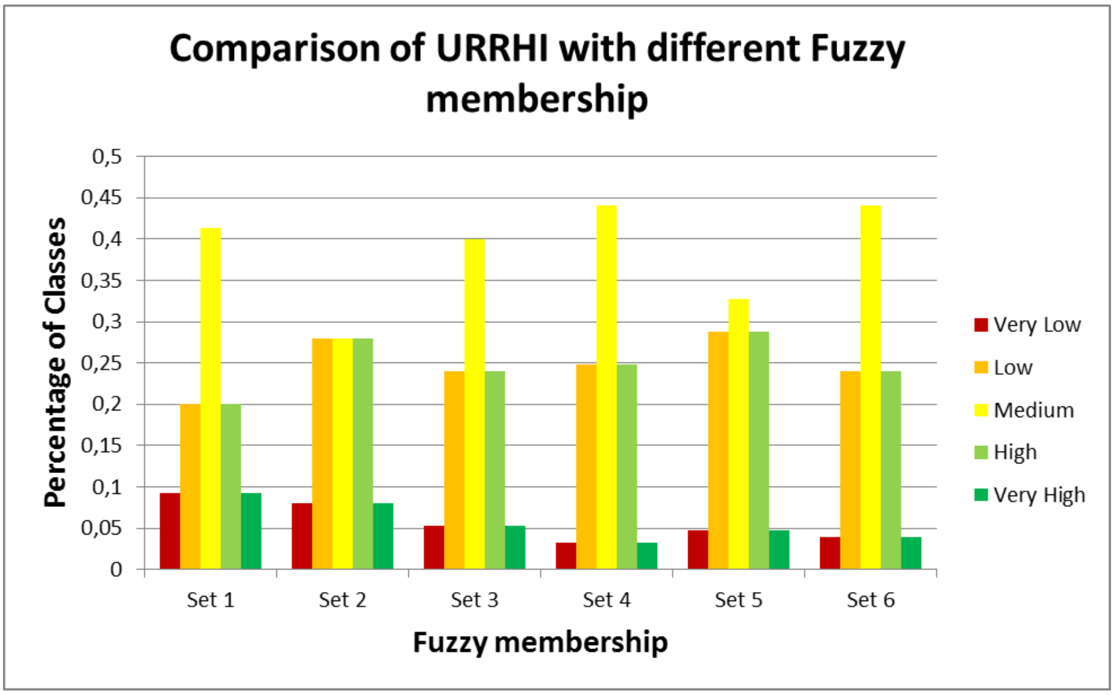


Figure 8-4 Comparison of URRHI in different fuzzy membership conditions

As shown in Figure 8-4, when decreasing the weights of bank/bed protection and vegetation in set 2 and set 5, applying the fuzzy membership functions with IFSI:Bank:Veg=3:1:1, the river health status becomes much better in general, this indicates the great impact of the riparian parameters beyond the river body itself.

9 Interaction between urban and rural river reaches

9.1 Integrated river health index for both urban and rural river reaches

After the process of interaction between urban and rural river reaches, two main goals can be achieved. First of all, the integrated health status index can be generated for both the urban and rural reaches.

The interaction between the urban river reach and the rural river reach has also to be identified. Suppose each urban river is only a section of the whole river system, but the parameters of this section have been changed hugely because of the urbanization and utilization by human beings. We want to find out what the thresholds of these main parameters in the urban river reach are, so that the urban river will not bring any stress onto the whole river system, which will affect the habitat suitability. If the values are beyond these thresholds, and even if the habitat suitability in the rural river reaches (upstream and downstream) are good, the fish species could not survive because, for example, the water quality of the urban river section is so bad, or the channel is very narrow, or there is no way that the fish could avoid the urban river section to reach a suitable spawning place.

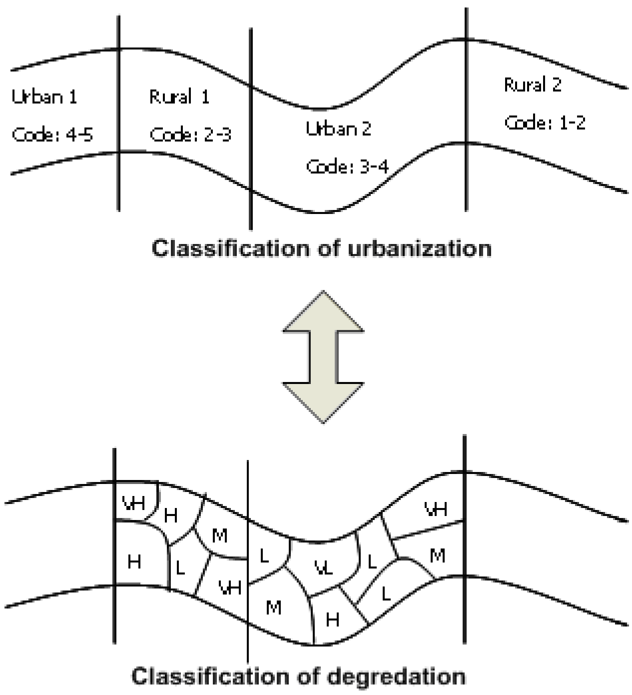


Figure 9-1 Comparison of two different classification systems

9.2 Integration mechanism

The following expression is used for calculating the health index for each of the urban and rural river stretches which are identified by the urban-rural river continuum identification system.

Here we can see that the ratio between the length of the mapped habitat and the urban or rural river stretches is very important. It helps to identify the proportion of each habitat's suitability polygon in order to get the weight of each one, and we can finally add up all the weighted habitat suitability indexes to calculate the integrated urban/rural health index for each of the urban or rural river stretches.

$$URHabi_j = \sum_{i_j=1}^{n_j} \left(RHI_i \times \frac{HabiLength_i}{URLength_i} \right)$$

j=1，2，3，4，5

n1=5, n2=19, n3=3, n4=11, n5=1

$URHabi_j$ is the integrated river health index for both the urban and rural stretches.

RHI_i is the urban/rural river ecological health index based on fish habitats.

$HabiLength_i$ is the length of each of the fish habitats.

$URLength_i$ is the total length of the urban/rural stretches.

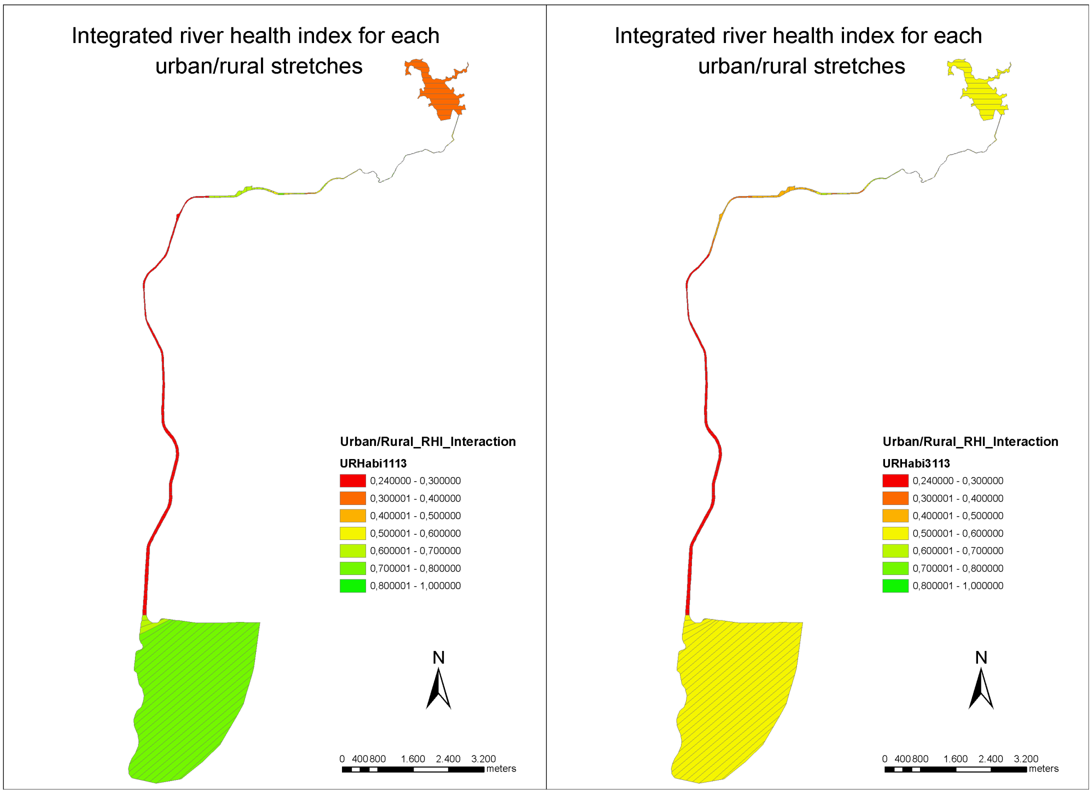
9.3 Interaction between urban and rural river reaches

Using above equation, the interaction between urban and rural river reaches is calculated in ArcGIS (Figure 9-2). As we can see from the results, the overlapping parts from the urban/rurual river continuum identification map and the urban/rural river ecological health assessment map are significant. There are 168 polygons from the urban and rural river continuum identification system and 43 polygons from the urban/rural river ecological health assessment mapping. After this interaction, we find there are 215 polygons in total. Our objective for the interaction is to identify the individual river ecological health value for each of the urban or rural river stretches.

a	URRCI1	FID_Dstr_1	Id	Habitat_ty	RHI311	HabiLength	RHI311_Len	Lengthper	URCode	a_1	URLength	URHabi
1	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
2	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
3	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
4	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
5	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
6	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
7	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
8	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
9	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
10	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
11	1,5652	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
11	1,5652	42	42	Fall	0,46	350	161	0,019337	1	2	4100	0,5924
12	1,5218	7	43	Ponded	0,56	1050	588	0,058011	1	1	4100	0,5924
12	1,5218	42	42	Fall	0,46	350	161	0,019337	1	2	4100	0,5924
13	1,5218	42	42	Fall	0,46	350	161	0,019337	1	2	4100	0,5924
14	3,174	41	41	Glide	0,5	600	300	0,033149	1	3	4100	0,5924
14	3,174	42	42	Fall	0,46	350	161	0,019337	1	2	4100	0,5924
15	3,174	41	41	Glide	0,5	600	300	0,033149	1	3	4100	0,5924
16	3,174	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
16	3,174	41	41	Glide	0,5	600	300	0,033149	1	3	4100	0,5924
17	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
18	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
19	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
20	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
21	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
22	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
23	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
24	1,7825	39	39	Glide	0,89	200	178	0,01105	1	5	4100	0,5924
24	1,7825	40	40	Glide	0,64	1800	1152	0,099448	1	4	4100	0,5924
25	1,913	39	39	Glide	0,89	200	178	0,01105	1	5	4100	0,5924
26	1,913	38	38	Glide	0,5	700	350	0,038674	1	6	4100	0,5924

Figure 9-2 Data examples from the attribute table of interaction

After running model in ArcGIS, the interaction between urban/rural river reaches is processed. The export maps of the Urban/Rural Habitat (URHabi) in different river health conditions are shown in Figure 9-3.



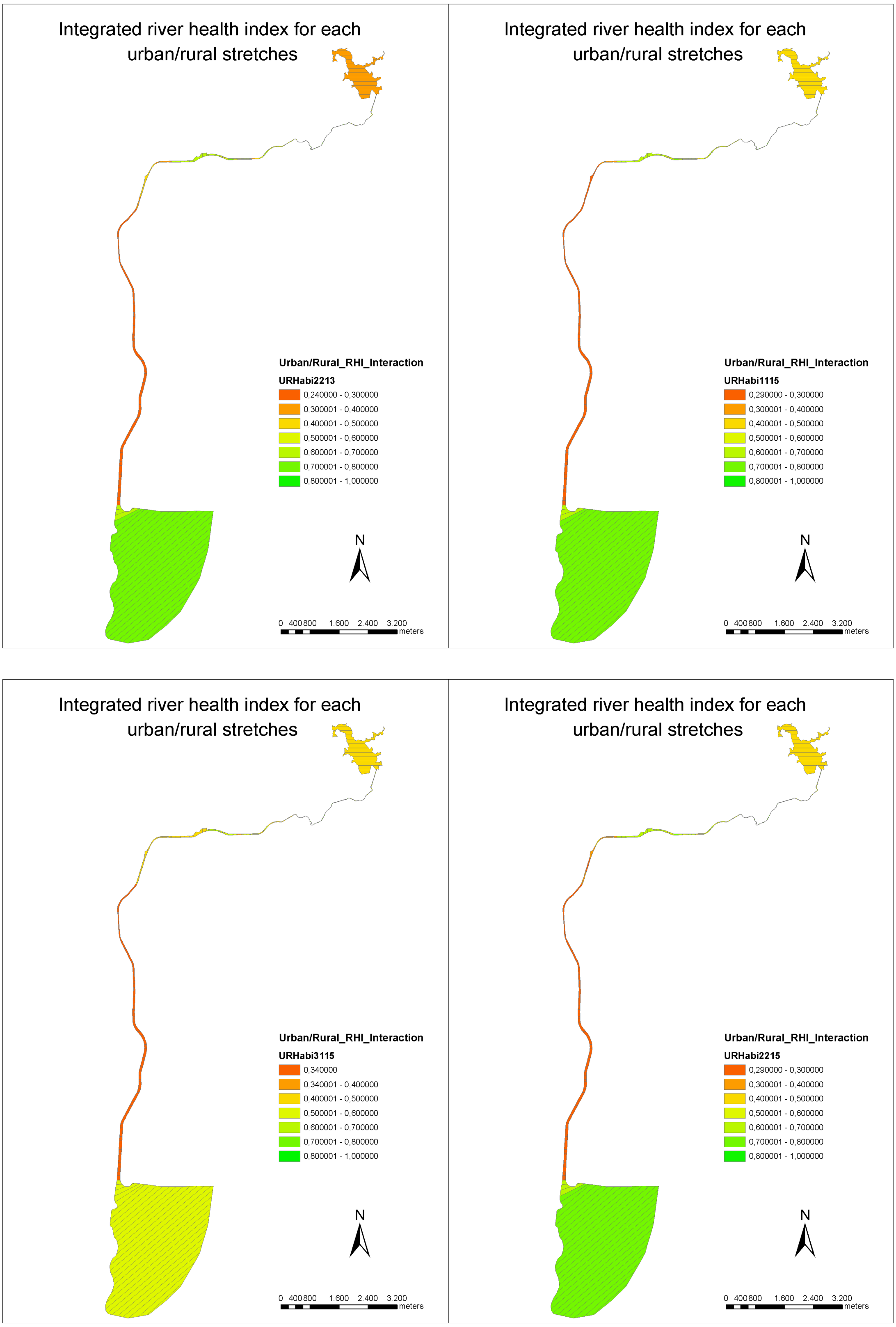


Figure 9-3 Simulation of the integrated river health index in different fuzzy membership conditions

Taking river upstream to see more specific classifications, here we can see clearly the differences between the results from each of the simulation steps (Fig. 9-4). The first map demonstrates the variation of the urban/rural river ecological health index based on fish habitats; the second map shows the identification of the urban/rural reaches; and the last map shows the variation of integrated river health index for both the urban and rural stretches.

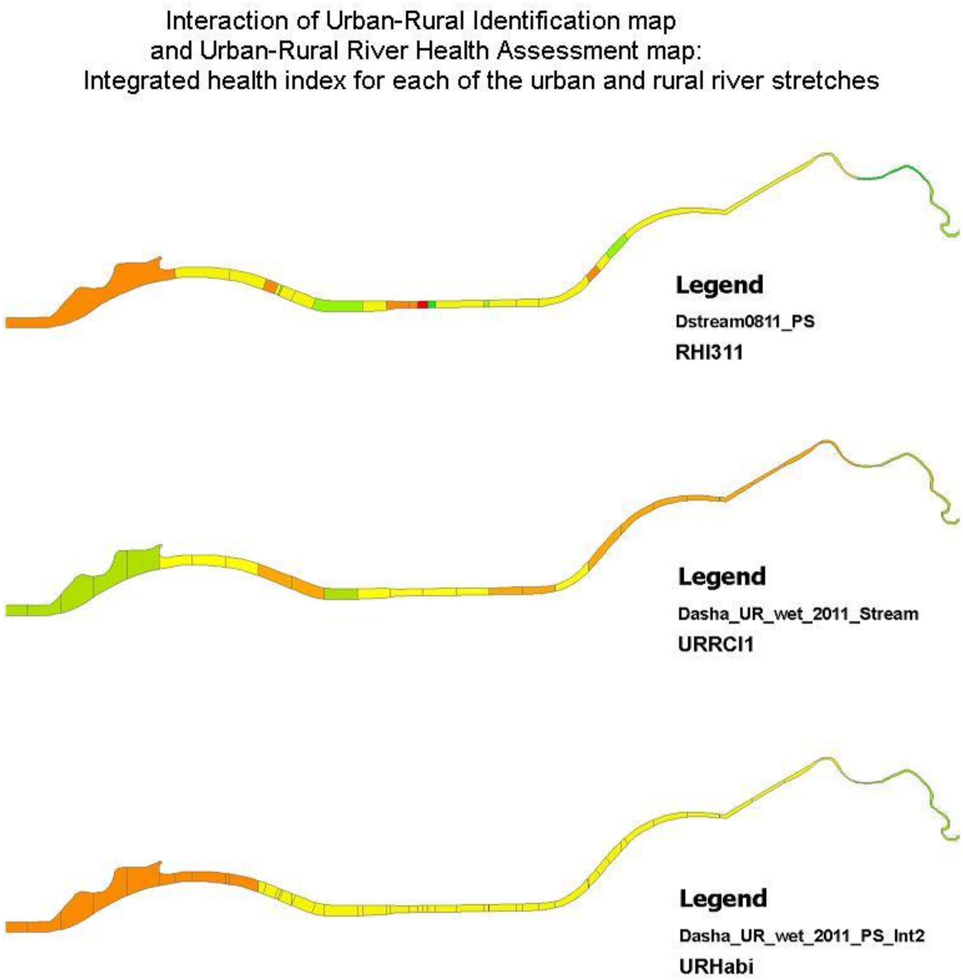


Figure 9-4 Comparison of the different assessment systems: a) river health index; b) urban/rural river continuum index; c) integrated urban/rural health index

The river reach of a Beijing University college graduate is taken as an example, it was identified as a rural river due to its low population density and high imperviousness, although the river's health status was classified as low, mainly caused by poor vegetation and strong bank protection. After calculation, the integrated river health index for this stretch was low. Rehabilitation measures, including degrading the bank protection and improving vegetation cover, can be used as different scenarios to check the improvement of the river's health status.

9.4 Influence of different river ecological health conditions

In this research, the impact of different fuzzy membership functions is evaluated. Different weights have been given to the following three parameters: the integrated fish suitability index (IFSI), bank/bed protection and riparian vegetation in order to simulate different urban/rural river ecological health indexes, the results of which are listed in Chapter 8-3.

1) Value: URHabi1113, Normalization: none, Classes: 5
    a. RHI111_IF3
    b. IFSI3(1) Bank5(1) Veg5(1) RHI5
2) Value: URHabi3113, Normalization: none, Classes: 5
    a. RHI311_IF3
    b. IFSI3(3) Bank5(1) Veg5(1) RHI5
3) Value: URHabi2213, Normalization: none, Classes:5
    a. RHI221_IF3
    b. IFSI3(1) Bank5(2) Veg5(2) RHI5
4) Value: URHabi1115, Normalization: none, Classes: 5
    a. RHI111_IF5
    b. IFSI3(1) Bank5(1) Veg5(1) RHI5
5) Value: URHabi1113, Normalization: none, Classes: 5
    a. RHI311_IF5
    b. IFSI3(3) Bank5(1) Veg5(1) RHI5
6) Value: URHabi1113, Normalization: none, Classes: 5
    a. RHI221_IF5
    b. IFSI3(1) Bank5(2) Veg5(2) RHI5

As discussed previously, when decreasing the weights of bank protection and vegetation, the river's health status becomes much better in general, this indicates the great impact of the riparian parameters beyond the river body itself.

The following graph shows the variation of the URHabitat in different river ecological health conditions in a different way (Fig. 9-6). From the graph, we can see more clearly that, the upstream reach of the Dasha River has a more complex reflection of the URHabitat. This is mainly due to the frequent variation of influencing parameters. For example, due to the construction of the Dasha River, the hydrological and geomorphological conditions vary very often.

Taking the river reach of a Beijing University college graduate as an example, it was identified as a rural river due to its low population density and high imperviousness, although the river's health status was classified as low, mainly caused by poor vegetation and strong bank protection. After calculation, the integrated river health index for this stretch was low. Rehabilitation measures, including degrading the bank protection and improving vegetation cover, can be used as different scenarios to check the improvement of the river's health status.

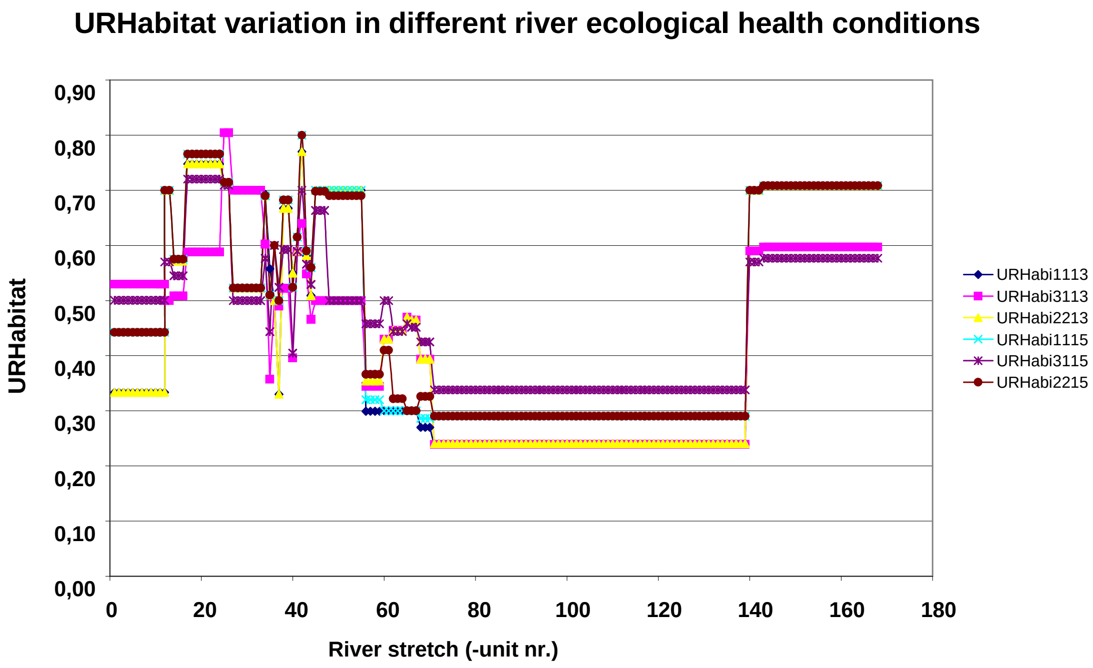


Figure 9-5 Variation of the URHabitat in different river ecological health conditions

10 Estimation of urban river ecological rehabilitation measures

10.1 Estimating the procedure for ecological rehabilitation measures

The urbanization of catchment areas leads to changes to streams along three axes: (i) geomorphic simplification in that the habitat's heterogeneity and floodplain connectivity is reduced; (ii) diminished societal value in that the stream channels become increasingly unattractive and are avoided for recreational purposes; and (iii) ecological simplification in that the stream's biodiversity declines and its ecosystem functioning is impaired resulting, for example, in a reduced capacity of the streams to reduce downstream nutrient losses. The rehabilitation of urban stream channels is highly constrained, so it is unlikely that an urban stream will ever be restored to its pre-urbanization state. Instead, the goal of effective rehabilitation should be to move the stream as far back along the three axes as possible given existing constraints. Currently, rehabilitation efforts focus on restoring channel form and maintaining channel stability (often artificially), making progress along axes 1 and 2, but not necessarily along the third axis of improving biological communities or ecosystem functioning.

A key question for managers, scientists and practitioners is "when are the constraints too severe to warrant rehabilitation of urban streams?" When they are, investment of money and effort towards improving catchment conditions or less impacted streams will be more effective. Site selection and project design in urban settings should be guided by a fundamental understanding of the operating constraints that may preclude success. A great deal more ecological, geomorphic and hydrologic research and evaluation of unrestored and restored urban streams is necessary for guiding the critical decisions about when restoration can have a positive impact on urban stream ecosystems, and when it is merely gardening around urban infrastructure.

The main purpose of the above procedure in this research is to find out the river reach with the worst ecological status, in order to carry out the most effective rehabilitation measures. While considering the economic aspects of river basin management, for decision-makers, it is always a serious problem to look into the financial budget. River rehabilitation always takes a very long period, and requires a lot of efforts, including expensive engineering projects, for example removing the river banks for a highly channelized river basin. If this restoration measurement is carried out on the whole river channel, the project will have high costs and will be very time-consuming. If the plot with the worst river ecological health status is studied, and the main influencing parameters are identified, then specific rehabilitation measures such as the removal of bank protection or the riparian vegetation enhancement can only be carried out on the plot identified as having the worst ecological status.

In this chapter, several mitigation scenarios are planned for the simulation of river rehabilitation (Figure 10-1). From the assessment of the urban/rural river ecological health status, bank/bed protection and riparian vegetation are the two parameters which have the most influence. Therefore, the mitigation scenarios will mainly focus on the removal of bank protection and the enhancement of riparian vegetation.

Parameters related to the water body itself refer more to the stands of hydraulics and hydrology, which are not easy to change. So in this chapter they are not considered for improvement.

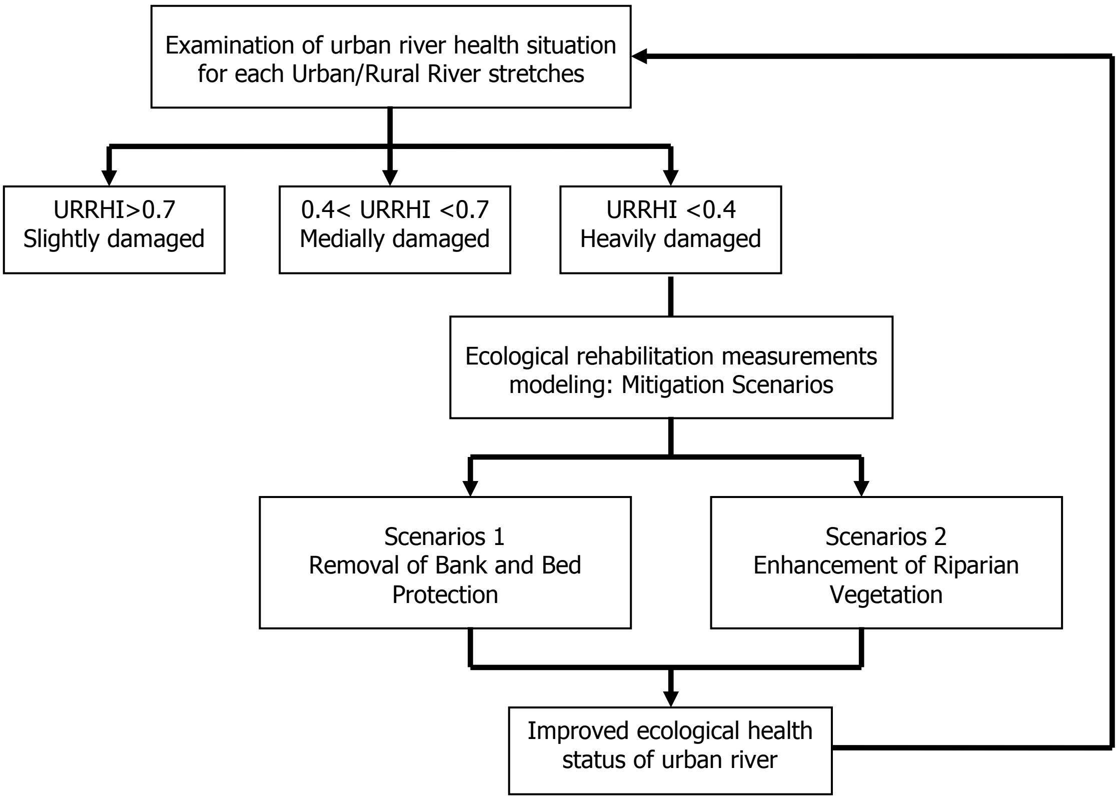


Figure 10-1 Flowchart of river rehabilitation measures

10.2 Mitigation scenario 1: Removal of bank protection

Riverbank naturalization can take different forms, but generally involves the removal of some, or all of the steep concrete channel banks and creating a more gently sloping bank. This is stabilized with native plants, trees and rocks. Naturalization creates a softer landscape feel and can greatly improve the riverbank habitat for fish species, native birds and other animals.

Wetlands can also be established as part of the naturalization process. Wetlands have a significant role in improving the river's ecology and health by treating storm water runoff from streets and industrial areas, before it enters the river.

Dams are built on rivers primarily to store water for human use, generate hydroelectric power, and/or control flooding. Natural ecosystems upstream of dams can be destroyed when newly created reservoirs inundate the riparian habitat. Dams can also cause substantial changes in downstream riparian communities by altering the magnitude, frequency, and timing of flood events and reducing the amount of sediment and nutrients delivered from upstream. Diverting water from stream channels for agricultural, industrial, and human use reduces the volume of water flowing downstream, and can have similar effects.

Stream channelization is the process of engineering straighter, wider, and deeper stream channels, usually for improved navigation, wetland drainage, and/or faster transport of floodwaters downstream. Levees are often constructed in conjunction with channelization to protect human development and agricultural fields from flooding. Riparian vegetation can be directly removed or damaged during and after the channelization process. In addition, channelization and levee construction modify the natural hydrology of a stream system. As water flows through a natural stream, meanders are created when faster flowing water erodes outer banks, and slower flowing water deposits sediment on inner banks. Many riparian plant species depend on these areas of new sediment deposition for the germination and establishment of seedlings. Channel straightening and levee construction eliminate these areas of deposition, creating unfavourable conditions for riparian vegetation recruitment.

By preventing overbank flooding, levees reduce the amount of water available to riparian vegetation in the floodplain, which alters the types of vegetation that can persist in these conditions. A lack of flooding has been shown to decrease the amount of habitat heterogeneity in riparian ecosystems as wetland depressions in the floodplain no longer fill and hold water. Because habitat heterogeneity is correlated with species diversity, levees can cause reductions in the overall biodiversity of riparian ecosystems.

In this chapter, the mitigation scenario of removing bank protection is done in two different conditions. The simulation results are shown below (Fig. 10-2). Different weights have been given to the following three parameters: the integrated fish suitability index (IFSI), bank/bed protection and riparian vegetation.

1) Value: River health index_1, Normalization: none, Classes: 5

   IFSI3(1) Bank3(1) Veg3(1) RHI5

2) Value: River health index_3, Normalization: none, Classes: 6

   IFSI5(3) Bank5(1) Veg5(1) RHI5

As we can see, if the class of bank protection is very high, the rehabilitated river ecological health shows a good status in both conditions.

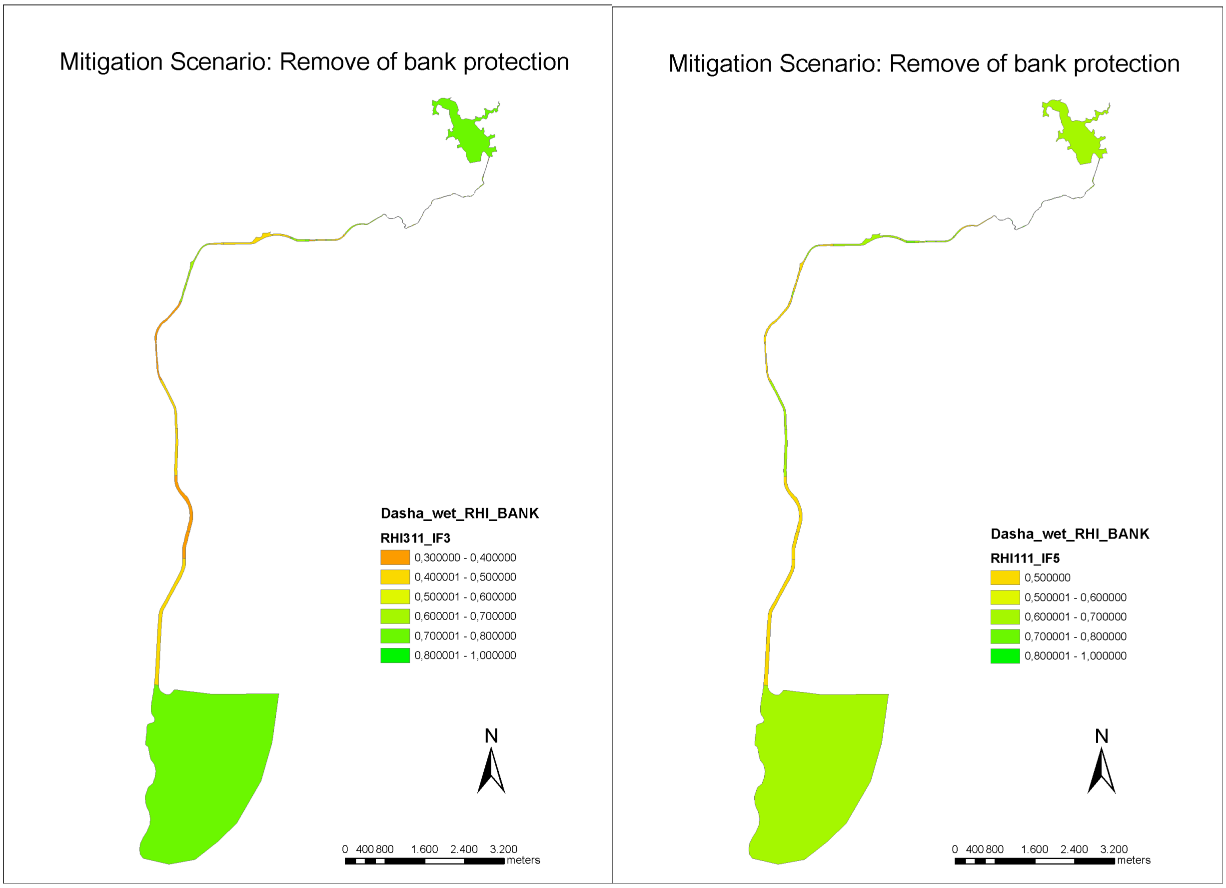


Figure 10-2 Simulation of the enhanced integrated river health index for both urban and rural stretches with different mitigation scenarios

From the above ArcGIS maps we can clearly see that there is a great enhancement of the river's ecological health status when removing part of the bank protection of the river body. The comparison shows the impacts of the different fuzzy membership functions of the influencing parameters. The left map is the result of 3 classes of each parameter with equal weights, and the right map is the result of 5 classes of each parameter with high weights of the integrated fish habitat suitability index.

10.3 Mitigation scenario 2: Riparian vegetation enhancement

Stream ecologists, fishermen, and wildlife managers have long advocated the preservation of buffer strips of riparian vegetation along streams. Riparian or bankside vegetation is important because it shades a stream, stabilizes its banks, and improves water quality. Elevated water temperatures associated with the removal of riparian vegetation are one of the problems plaguing streams in urban and agricultural settings. High water temperatures contribute directly to poor water quality by stimulating the growth of algae and bacteria, and by lowering concentrations of dissolved oxygen.

The re-establishment of shade trees along a river’s bank is the first step. In addition to providing shade, the vegetation and organic soil in a 10-30 metre wide buffer strip of vegetation will trap eroding soil and sediment carried in surface runoff from adjacent farmland, and will also help filter out fertilizers and chemicals. Riparian vegetation can also provide an important role in stabilizing stream banks and preventing erosion, since the roots of riparian trees, shrubs and groundcover literally hold stream banks together. Roots and fallen logs make excellent in-stream cover for fish.

The importance of managing and restoring riparian vegetation is now well recognized, and remedial work is being undertaken at local, regional, state and national levels worldwide. Catchment and Landcare groups, for example, recognize that environmental and agricultural objectives can be achieved simultaneously. Riparian revegetation is widely accepted as an affordable and effective means of erosion control and bank stabilization in many catchments.

For many river reaches globally, such as those in urban areas, natural riverine processes cannot be restored because the economic costs are too high or the social and political will are not present. In many cities, such as Shenzhen, the case study area in this research, the floodplains of rivers have been converted to housing or industrial areas, restricting the river bed to a small channel. Although the levees can be set back to some degree, the historic floodplains cannot realistically be reclaimed by the river. Large human settlements are sustained in arid regions by massive and extensive dam and reservoir systems and water distribution structures. Although the flow pattern of below-dam rivers can be naturalized to some degree (Rood et al., 2003), many dams are a permanent feature of the present landscape.

Rivers by their nature reflect their watershed, and urbanized rivers are often vegetated by a mixture of historically dominant species and a wide variety of introduced species, including agricultural and horticultural plants and other cultivars. In such highly modified rivers, it is perhaps advisable to let plant communities “self assemble” with species (alien or native) that are adapted to these unique conditions. The removal of alien plants from rivers in urban landscapes and other situations with pervasive human influence is, in almost every case, futile and potentially counter-productive with respect to maintaining ecosystem function. Efforts to remove the imprint of humans from the landscape also may be counter-productive with respect to human–nature interactions.

Riparian systems have an intimate connection with in-stream systems and appear to be sensitive indicators of environmental change (Werren and Arthington, 2003). The riparian zone is the link between terrestrial and aquatic systems (Auble et al., 1994). Tabacchi et al. (1998) argued that this zone is now well integrated into conceptual models of stream ecosystem functioning. A review of existing methods for quantifying riparian vegetation as an indicator of stream health by Werren and Arthington (2002) found that most methods measured structure and failed to consider activity (metabolism or primary productivity), while few considered resilience [i.e. the three system attributes that define health, according to Karr (1999)].

In this chapter, the mitigation scenario of riparian vegetation enhancement has been done in two different conditions. The simulation results are shown below (Fig. 10-3). Different weights have been given to the following three parameters: the integrated fish suitability index (IFSI), bank/bed protection and riparian vegetation.

1) Value: River health index_1, Normalization: none, Classes: 5

   IFSI3(1) Bank3(1) Veg3(1)

2) Value: River health index_3, Normalization: none, Classes: 5

   IFSI5(3) Bank5(1) Veg5(1) RHI5

As we can see, if the class of bank protection is very high, the rehabilitated river's ecological health shows a good status in both conditions.

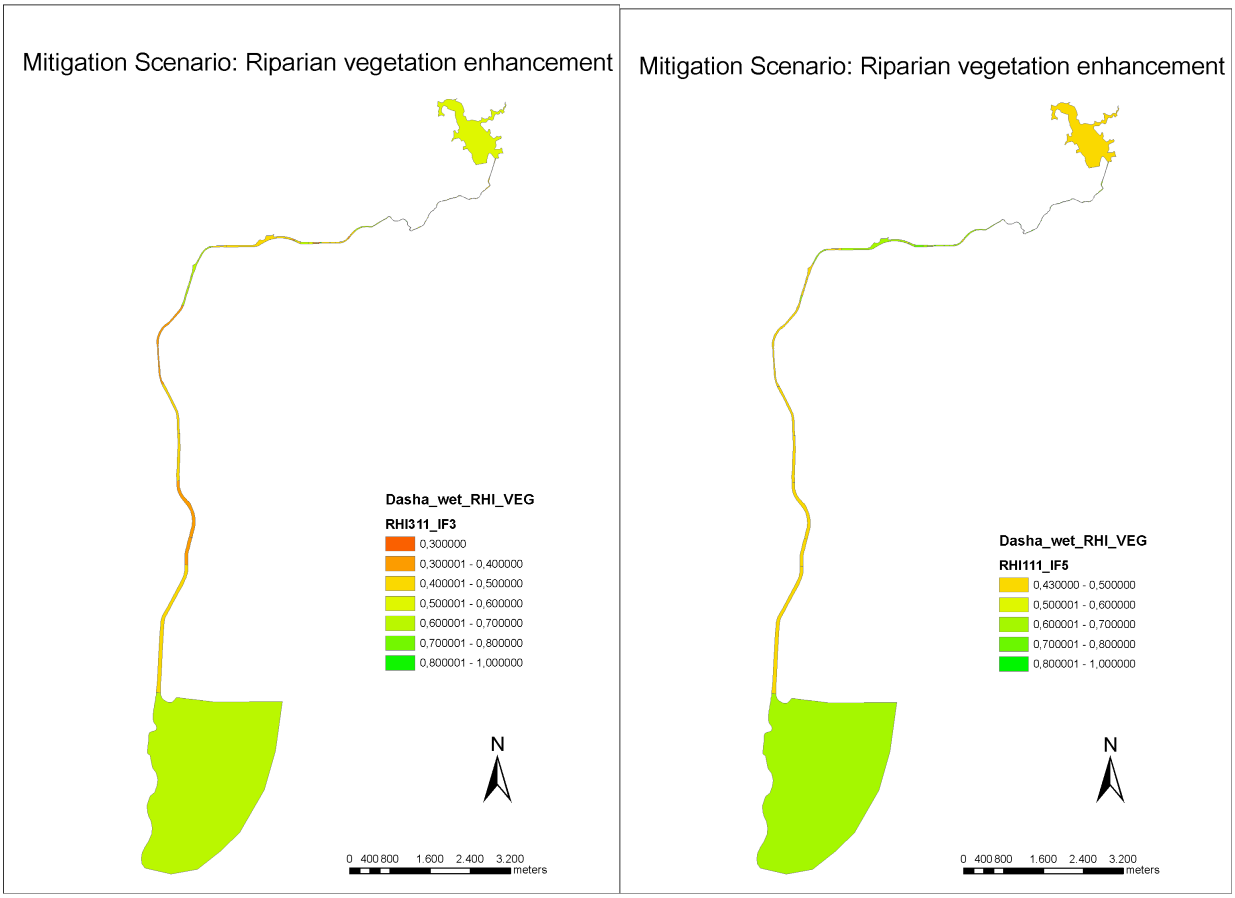


Figure 10-3 Simulation of the enhanced integrated river health index for both urban and rural stretches with different mitigation scenarios

From the above ArcGIS maps we can clearly see that there is a great enhancement of the river's ecological health status when removing part of the bank protection of the river body. The comparison shows the impacts of the different fuzzy membership functions of the influencing parameters. The left map is the result of 3 classes of each parameter with equal weights, and the right map is the result of 5 classes of each parameter with high weights of the integrated fish habitat suitability index.

When the integrated fish species play a more important role in the simulation, the impact from riparian vegetation is becomes less.

10.4 Comparison with the maximum ecological quality of urban rivers

Further study on the maximum ecological quality of river health has also been done, by considering carrying out both the removal of the river-bank, and riparian vegetation enhancement. We assumed that both the river-bank and riparian vegetation were in very good condition in the simulation scenario, so we set both the river-bank and riparian vegetation as class 1 with a health index of 1.

The export ArcGIS maps below (Fig. 10-4) show a clear enhancement of the river’s ecological health status.

In this research, the impact of different fuzzy membership functions is also evaluated. Different weights have been given to the following three parameters: the integrated fish suitability index (IFSI), the bank/bed protection and the riparian vegetation.

1) Value: River health index_1, Normalization: none, Classes: 5

   IFSI3(1) Bank3(1) Veg3(1)

2) Value: River health index_3, Normalization: none, Classes: 5

   IFSI5(3) Bank5(1) Veg5(1) RHI5

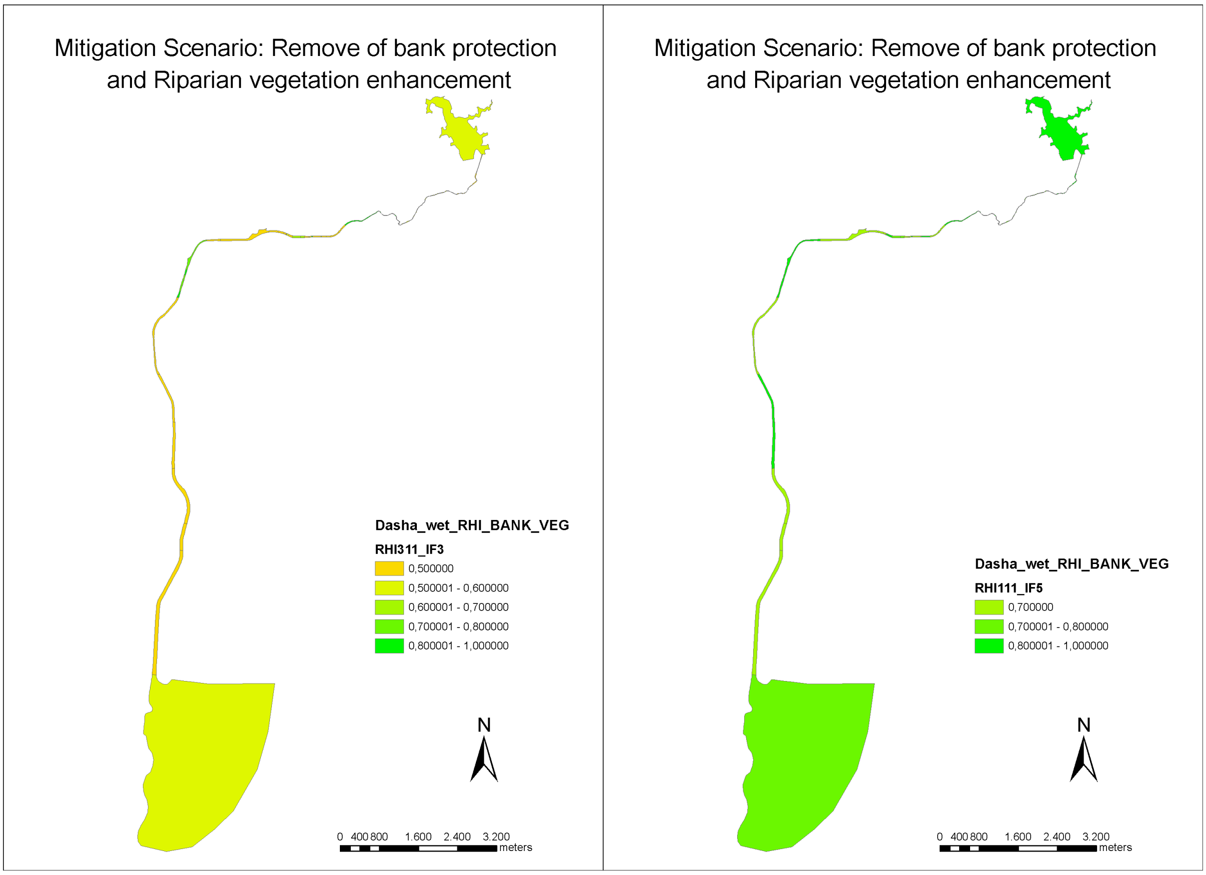


Figure 10-4 Comparison of the enhanced integrated river health index for each urban/rural stretch with different fuzzy membership functions

From a comparison of the enhanced integrated river health index for each urban/rural stretch with different fuzzy membership functions (Fig. 10-4), we can see that when the integrated fish suitability index has more weight in the river’s ecological health assessment system, the subsequent river ecological rehabilitation measures have less impact. When the integrated fish suitability index, bank protection and riparian vegetation have equal importance in the river’s ecological health assessment system, river enhancement is more effective.

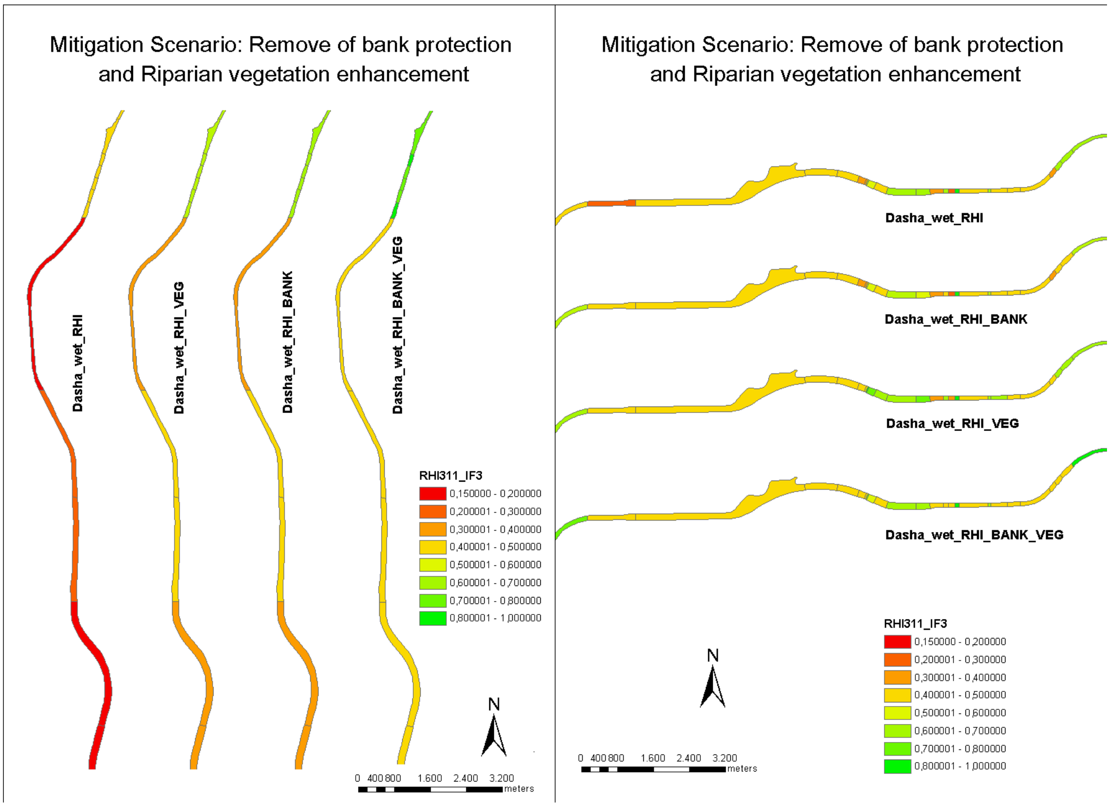


Figure 10-5 Comparison of the enhanced integrated river health index for each urban/rural stretch with different mitigation scenarios (IF3)

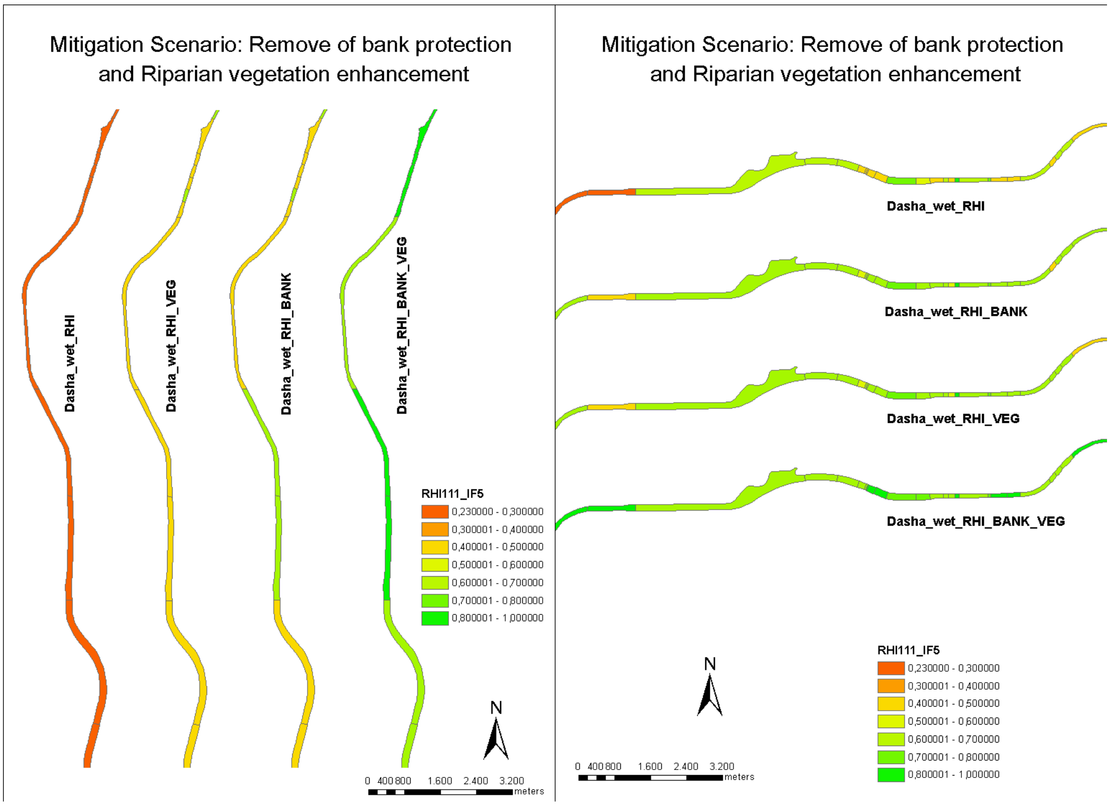


Figure 10-6 Comparison of the enhanced integrated river health index for each urban/rural stretch with different mitigation scenarios (IF5)

The above comparisons show the simulation results in more detail (Fig. 10-5 and Fig. 10-6). We selected two river reaches of the Dasha River. One is an upstream section which has a more complex reflection of the URHabitat. This is mainly due to the frequent variation of influencing parameters, for example, due to the formation of the Dasha River, the hydrological and geomorphological conditions vary very often. This river reach is identified as a rural river due to lower population density and high imperviousness, although the river's health status is classified as low, mainly caused by poor vegetation and strong bank protection, and the integrated river health index for this stretch is calculated as being low. After taking different rehabilitation measures, including the degradation of the bank protection and improving riparian vegetation, the river's ecological health status gradually got better, but no significant enhancement occurred (Fig. 10-5a and Fig. 10-6a). The main reason was the high impact of low flow velocity and low water depth on its suitability as a fish habitat.

The other section was a downstream part of the Dasha River which is mainly channelized, and it has uniform bank protection and riparian vegetation conditions. After taking different rehabilitation measures including the degradation of the bank protection and improving riparian vegetation, the river's ecological health status underwent a significant enhancement (Fig. 10-5b and Fig. 10-6b). This was because the flow velocity and water depth were supplying a suitable habitat for fish species. The main reasons for this influence on the river's ecological health were the concreted river bank and poor riparian vegetation. Therefore, the rehabilitation measures of removing the river-bank and enhancing riparian vegetation for this downstream part of the Dasha River should have the highest priority.

Two different fuzzy membership functions of the influencing parameters were also taken into consideration. Figure 10-5 is the result of the condition of 5 categories of each parameter with a high weight of the integrated fish habitat suitability index, and Figure 10-6 is the result of the condition of 3 categories of each parameter with equal weights. When the integrated fish species play a more important role in the simulation, the impact from riparian vegetation becomes less.

10.5 Summary and suggestions

Rehabilitation failures may occur when appropriate ecosystem conditions are not re-established, such as soil characteristics (e.g., salinity, pH, beneficial soil biota, etc.), surface water and groundwater levels, and flow regimes. Therefore, successful restoration may be dependent on taking a number of both biotic and abiotic factors into account. For example, the restoration of soil biota, including symbiotic myccorhizae, invertebrates, and microorganisms may improve nutrient cycling dynamics. The restoration of physical processes may be a prerequisite to the reestablishment of healthy riparian communities. Ultimately, a combination of approaches taking into account causes for degradation and targeting both hydrology and the reestablishment of vegetation and other life forms may be most effective in riparian zone restoration.

When rehabilitation efforts target key species, consideration for individual species needs are important for ensuring restoration occurs when appropriate ecosystem conditions are not re-established, such as soil characteristics, surface water and groundwater levels, and flow regimes. Therefore, successful restoration may be dependent on taking a number of both biotic and abiotic factors into account.

Methods for river ecological rehabilitation are often determined by the cause of degradation. Two main approaches are used: restoring hydrologic processes and geomorphic features, and re-establishing native riparian vegetation.

When altered flow regimes have impacted riparian zone health, re-establishing the natural stream flow may be the best solution to effectively restore riparian ecosystems. The complete removal of dams and flow-altering structures may be required to fully restore historic conditions, but this is not always realistic or feasible. An alternative to dam removal is for periodic flood pulses consistent with historical magnitude and timing to be simulated by releasing large amounts of water at once instead of maintaining more consistent flows throughout the year. This would allow overbank flooding, which is vital for maintaining the health of many riparian ecosystems. However, simply restoring a more natural flow regime also has logistical constraints, as legally appropriated water rights may not include the maintenance of such ecologically important factors.

The negative effects of channelization on stream and riparian health can be lessened through the physical restoration of the stream channel. This can be accomplished by restoring flow to historic channels, or through the creation of new channels. In order for restoration to be successful, particularly for the creation of entirely new channels, restoration plans must take into account the geomorphic potential of the individual stream and tailor restoration methods accordingly. This is typically done through the examination of reference streams (physically and ecologically similar streams in a stable, natural condition) and by methods of stream classification based on morphological features. Stream channels are typically designed to be narrow enough to overflow onto the floodplain on a 1.5 to 2-year timescale. The goal of geomorphic restoration is to eventually restore hydrologic processes important to riparian and instream ecosystems. However, this type of restoration can be logistically difficult: in many cases, the initial straightening or modification of the channel has resulted in humans encroaching into the former floodplain through development, agriculture, etc. In addition, stream channel modification can be extremely costly.

Stream channels will often recover from channelization without human intervention, provided that humans do not continue to maintain or modify the channel. Gradually, channel beds and stream banks will begin to accumulate sediment, meanders will form, and woody vegetation will take hold, stabilizing the banks. However, this process may take decades: a study found stream channel regeneration took approximately 65 years in channelized streams in West Tennessee. More active methods of restoration may speed the process along.

The restoration of riparian vegetation

The re-vegetation of degraded riparian zones is a common practice in riparian restoration. Re-vegetation can be accomplished through active or passive means, or a combination of the two.

Active vegetation restoration

A lack of naturally available propagules can be a major limiting factor in restoration success. Therefore, actively planting native vegetation is often crucial for the successful establishment of riparian species. Common methods for actively restoring vegetation include sowing seeds and directly planting seeds, plugs, or seedlings. Re-establishing clonal species such as willows can often be accomplished by simply putting cuttings directly into the ground. To increase survival rates, young plants may need to be protected from herbivory with fencing or tree shelters.

Preliminary research suggests that direct-seeding woody species may be more cost-effective than planting container stock.

Reference sites are often used to determine appropriate species to plant and may be used as sources for seeds or cuttings. Reference communities serve as models for what restoration sites should ideally look like after restoration is complete. Concerns about using reference sites have been raised however, as conditions at the restored and reference sites may not be similar enough to support the same species. Also, restored riparian zones may be able to support a variety of possible species combinations, therefore the Society for Ecological Restoration recommends using multiple reference sites to formulate restoration goals.

Passive vegetation restoration

The active planting of riparian vegetation may be the fastest way to re-establish riparian ecosystems, but methods may be prohibitively resource-intensive. Riparian vegetation may come back on its own if human-induced disturbances are stopped and/or hydrologic processes are restored. For example, many studies show that preventing cattle grazing in riparian zones through exclusion fencing can allow riparian vegetation to rapidly increase in robustness and cover, and also shift to a more natural community composition. By simply restoring hydrologic processes such as periodic flooding that favour riparian vegetation, native communities may regenerate on their own (e.g., the Cosumnes River floodplain). The successful recruitment of native species will depend on whether local or upstream seed sources can successfully disperse propagules to the restoration site, or whether a native seed bank is present. One potential hindrance to passive vegetation restoration is that exotic species may preferentially colonize the riparian zone. Active weeding may improve the chances that the desired native plant community will re-establish.

Restoring animal life

Restoration often focuses on re-establishing plant communities, probably because plants form the foundation for other organisms within the community. Restoration of faunal communities often follows the “Field of Dreams” hypothesis: “if you build it, they will come.” Many animal species have been found to naturally recolonize areas where habitat has been restored. For example, abundances of several bird species showed marked increases after riparian vegetation had been reestablished in a riparian corridor in Iowa. Some riparian restoration efforts may be aimed at conserving particular animal species of concern, such as the Valley elderberry longhorn beetle in central California, which is dependent on a riparian tree species (blue elderberry, Sambucus mexicana) as its sole host plant. When restoration efforts target key species, consideration for individual species’ needs (e.g., minimum width or extent of riparian vegetation) is important for ensuring restoration success.

11 Conclusions and outlooks

11.1 Overview of the answered research questions

The purpose of this research is to focus on urban river regulation, aiming to set up an advanced urban river ecological health assessment system which can be applied easily. The case study area of the Shenzhen River in China has been selected to build up the database in order to establish and prove this new and improved river health assessment system, and simulate effective rehabilitation measurement scenarios.

In this research, two field investigations were done in different seasons. One was in the wet season and one was in the dry season, in order to simulate ecological health variations during different statuses of river discharge. For each field survey, the basic parameters of flow velocity, water depth, substrate, and riparian vegetation and bank materials were mapped. However, for these two seasons, there is no data which exactly measures the water temperature and dissolved oxygen. Data sources which can be used in this research are the annual environmental reports from the local Shenzhen government, and the latest version is the report for 2007. These variables are important for water quality; if possible, they should be taken into the mapping list of parameters and should be used when identifying the suitability of habitat status for fish species.

A generic conceptual model was developed, and the urban-rural river continuum codes were set up to describe 5 categories of river system with respect to urban and rural characteristics. A set of key parameters which represent geomorphologic, chemical, hydrological and habitat characteristics of the water body and riparian zones were selected based on a review of the literature. In order to coincide with the urban-rural river continuum codes, information on each of the parameters was converted into a single dimensionless score, and also had 5 categories corresponding to the urban-rural river continuum codes. The definition of each category for each parameter was given based on the literature and expert knowledge. The score for each parameter was obtained though field investigation and survey. Then, the prioritization of all the parameters was done by using the Analytic Hierarchical Process (AHP). After we had obtained all the weights (W) and scores for all the involved parameters (S), the integration of the key parameters could be completed and the Urban-Rural River Continuum Index (URRCI) for each surveyed stretch unit could be calculated.

Through the above research, we can learn that hydraulic construction is the parameter which influences the definition of an urban or rural river the most. So, a simulation process was carried out for the urban-rural river continuum identification when we had removed all hydraulic construction. This clearly shows that, with hydraulic construction the URRCI value reduces significantly, and the main urban stretches fall into the class of distinctly urban.

Generally speaking, the developed system of Urban-Rural River Continuum Identification can be implemented very well, which can help research to get a quick and clear idea of which river reach is urban, and which is rural. Meanwhile, it can give users hints of the most influencing factors and the most urbanized river reaches. Although, the definitions for some parameters in this system need to be adjusted according to the specific situation of the application areas.

Considering the characteristics of the case study area of the Shenzhen River, through the annual environmental report from the local government, we chose fish as a very important factor for indicating the ecological health status of this river. We listed all the fish species which could be observed in the present river basin and which were once observed in history by reviewing literature. All fish species are divided into two groups according to their habitat requirements; the most tolerant species and the least tolerant species.

The fuzzy logic approach is integrated into the fish habitat model CASiMiR, which is receiving a continuously growing acceptance in Europe and worldwide. The customized tool took advantage of an existing fuzzy inference calculator, which is integrated within the ArcGIS, thereby allowing direct data integration from various geospatial sources as input parameters and the presentation of output in the form of spatial and temporal maps.

Considering the calculation capability of the fuzzy logic method, these five parameters will be combined into the CASiMiR model step by step.

For the first step, the three basic parameters of flow velocity, water depth and substrate will be combined by making fuzzy rules and sets for each of the selected fish species, considering their different habitat requirements, and other necessary parameters could also be used. The output is the habitat suitability index for each of the fish indicators.

The second fuzzy step is to combine the most tolerant fish habitat index with the other least tolerant fish habitat index. The parameter of biodiversity is taken into this system to consider the different influences of the four selected fish indicators, in order to generate the final fish habitat suitability index.

The last step, riparian vegetation and bank/bed protection, can be included since they are on a much larger scale. The final output is the urban-rural river ecological health index (URRHI).

In this research, this advanced urban/rural River Ecological Health Assessment System was successfully established, using a more effective methodology to incorporate the relative parameters, and establishing a more applicable and effective river ecological assessment system, which focuses more on both urban and rural river ecological functions, considering fewer parameters but generating more reliable results, and being simpler to apply to river systems all over the world.

This assessment system can give decision-makers a more straightforward direction on which plot of river should be rehabilitated, and which parameter matters to ecological health the most, in order to carry out more effective and economical rehabilitation measures.

11.2 Limitations of the urban/rural River Ecological Health Assessment System

The achievements and limitations of a model can be assessed by examining whether the model serves its intended purpose and goal. The fuzzy-based urban/rural River Ecological Health Assessment System is based on fish habitat, indicating the dominant ecological function is unique as it is Arc-GIS based, and adopts the underlying principle of fuzzy logic for river ecological health assessment and analysis in a multi-stage approach. From this research, the main strengths and weaknesses of the urban/rural River Ecological Health Assessment System can be discussed as below.

Achievements of the urban/rural River Ecological Health Assessment System

- Among the research on river resource management, it is very rare to study specifically urban river systems. The urban/rural River Ecological Health Assessment System has reached the objective of the classification of urban rivers and rural rivers, the assessment of river ecological health considering both urban and rural river conditions, and the interaction between urban and rural rivers in order to carry out more effective rehabilitation measures.

- The urban/rural River Ecological Health Assessment System effectively handles the problem of uncertainty and imprecision by representing each of the identified model parameters as fuzzy parameters. This modelling approach handles variables effectively in the form of linguistic sets, defined by using membership functions.

- The multi-stage modelling framework allows handling the problem of dimensionality when formulating the fuzzy rule bases. Less input of fuzzy parameters at each stage means simpler rules, and the evaluation of the model at each intermediate stage is possible. For instance, for mapping the fish habitat suitability index, the fuzzy rule base consists of only 27 rules, and for the urban/rural river health index the rule base consists of only 27 or 45 rules which depend on different fuzzy membership functions.

- Lower input data requirements and capabilities to incorporate additional expert knowledge in the form of fuzzy rules allow this modelling framework to be tested and applied in other parts of the world. Here, the urban/rural River Ecological Health Assessment System involves only 5 parameters instead of taking into consideration a long list of parameters in the European Water Framework Directive.

- Implementation of the framework within the GIS allows the handling of both spatial and non-spatial data with ease and it allows for efficient decision-making through spatial analysis. In addition, fuzzy modelling within the GIS provides a spatial dimension to the nature of the results, thereby providing the spatial variability of the outcomes visually and statistically. This research shows the spatial analysis of the urban/rural River Ecological

Health Assessment System output in the GIS to understand urban and rural river classification and the variation of a river's ecological health.

- Overall, the urban/rural River Ecological Health Assessment System is easy to use and interpret since it adopts the standard governing parameters of river health that are widely accepted all over the globe. This approach allows rapid scenario analysis for large regions and has the potential to be used as a practical tool for the assessment of urban river ecological health by policy-makers and scientists.

Weaknesses of the urban/rural River Ecological Health Assessment System

- The model's results are more or less dependent on the design of the fuzzy sets and the fuzzy rule base adopted. In another words, the predicted river ecological health status is influenced by the expert knowledge base and the experience of the user. Hence, the question of subjectivity is still a concern in such an expert-based modelling approach.

- The proper validation of the urban/rural River Ecological Health Assessment System is still another issue due to a lack of river ecological data on a large regional scale. The model is still open for further assessment and improvement with regard to validation.

- The selection of the input parameters that govern the fish habitat suitability processes is specific and limited due to the specific situation of the case study area, which is the Dasha River in this research. Input parameters could be different according to the specific requirements of the indicating ecological factors, and an increasing amount of input parameters results into a complex fuzzy rule base.

- The urban/rural River Ecological Health Assessment System is only used for the decision-making support of river ecological rehabilitation. Since river regulation projects are time-consuming and long-term planning projects, it is difficult to check the simulation results with the final real project output, which results in slow feedback on making improvements to the assessment system.

11.3 Outlooks and suggestions

Some of the future prospects and recommendations to enhance and improve the urban/rural River Ecological Health Assessment System are listed below:

- Data driven for fuzzy rules
- Other parameters
- Other river ecological indicators
- Validation

One of the advantages of the urban/rural River Ecological Health Assessment System is the implementation of the fuzzy logic method. Fuzzy rules were mainly derived from literature reviews, expert knowledge and questionnaire results in this research, which were too objective and led to a lower accuracy compared to the simulation results. The possibility of generating fuzzy rules from numerical data should be investigated as an extension of this research. Specifically, the possibility of applying data-driven fuzzy rule optimization techniques is recommended. Sufficient ground data for formulating the rules is one of the pre-conditions for applying such algorithms. Additional efforts should be undertaken to evaluate the multi-step habitat modelling framework regarding the specifications of fuzzy-modelling.

A sensitivity analysis investigating aspects such as the variations in single membership functions (e.g. trapezoidal, triangular), the degree of overlapping membership functions, the number of membership functions for each habitat variable, as well as the influence of different expert knowledge (specification of fuzzy rules from independent fish biologists) would increase the resilience of the results of the modelling framework.

Additional stages of fuzzy modelling can be implemented into the developed framework by introducing relevant input parameters. Factors regarding water quality, such as temperature and oxygen density turbidity, can be considered as potential fuzzy parameters which account for the influence on habitat suitability of ecological indicators. Another important development can be undertaken in the direction of large-scale modelling. On larger scales, the incorporation of other parameters like water quality appears to be important for species. Considering the complexity of fuzzy membership functions when increasing input parameters, the incorporation of additional parameters using the fuzzy logic approach should be implemented step-by-step, controlling limited fuzzy rules in each of the simulation phases.

Fish were selected as the only river ecological health indicator due to the limitations of the field investigation and the research of biologists. Since the habitat requirements of adult and juvenile fish can be different, for example the common carp, one of the ecological indicators of the Dasha River has totally different flow velocity requirements for spawning and hatching, and the spawning areas have a flow velocity of 0.2 – 0.9 m/s. A velocity increase of 0.25 – 0.50 m/s is better for spawning (Yih & Liang 1964). The eggs and fries do not sink when the velocity is >0.2 m/s (Cao et al. 1987). The eggs begin sinking when the water velocity is <0.27 m/s, most of the eggs sink if the velocity is <0.18 – 0.25 m/s, and all the eggs deposit if the velocity is ≤0.1 m/s (Tang, & Yu et al., 1996). Therefore, further habitat suitability simulations should be taken separately for adults and juveniles, and take into consideration the different demands of the environment.

Other ecological indicators can also be taken into consideration, such as benthos, when applying this assessment system in larger river basins. Benthos refers to the benthic invertebrate community, which is a group of animals that live on or in the bottom sediments. The benthic community includes a wide variety of organisms including clams, oysters, small shrimp-like crustaceans, and the blood and clam worms often used as bait. In a polluted environment, these species would be replaced by species more tolerant of pollution. Most degraded communities would also tend to have fewer species, fewer large organisms deep in the sediment, and a lower total mass of organisms. Oysters, mussels, sponges, and barnacles are other examples of benthic organisms which attach to hard surfaces such as rocks and reefs. Therefore the habitat requirement of benthos can also be taken into consideration in future research.

There is an urgent need to test the performance of the advanced urban/rural River Ecological Health Assessment System together with validation via local river health reports and biological sampling. Since river regulation projects are time-consuming and long-term planning projects, follow-ups from local government environmental reports and fish surveys should be taken; then river ecological function enhancement measures should be continually adjusted according to the current feedback. Validation is always an important but difficult task. Application of the assessment system in other river basins which have similar geomorphological and topographic conditions can be taken as one method. Further research could also import models for the purpose of validation.

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13 Appendices

Appendix 1: Mesohabitat-Classification MesoCASiMiR (1st August 2005)

Mesohabitat		Turbulence	Brief description
Fall (Fa)	9	Turbulent & Very Fast	Vertical drops of water over a full span of the channel, commonly found in bedrock and steep-pool stream reaches
Cascade (Ca)	8	Turbulent & Very Fast	Highly turbulent series of short falls and small scour basins, frequently characterized by very large substrate sizes and a stepped profile; prominent features of bedrock and upland streams
Chute (Ch)	7	Turbulent & Very Fast	Narrow steep slots or slides in bedrock
Rapid (Ra)	6	Turbulent & Fast	Moderately steep channel units with coarse substrate, but unlike cascades possess a planar rather than stepped profile
Riffle (Ri)	5	Turbulent & Moderately Fast	The most common type of turbulent fast water mesohabitats in low gradient alluvial channels. Substrate is finer (usually gravel) than other fast turbulent mesohabitats, and there is less white water, with some substrate breaking the surface
Run (Ru)	4	Non-Turbulent & Moderately Fast	Moderately fast and shallow gradient with ripples on the surface of the water. Deeper than riffles with little if any substrate breaking the surface
Glide (Gl)	3	Non-Turbulent & Moderately Slow	Smooth ‘glass-like’ surface with visible flow movement along the surface, relatively shallow (compared to pools) depths
Pool (Pl)	2	Non-Turbulent & Slow	Relatively deep and slow flowing, with fine substrate. Usually little surface water movement visible. Can be bounded by shallows (riffles, runs) at the upstream and downstream ends
Ponded (Pd)	1	Non-Turbulent & Slow	Water is ponded back upstream by an obstruction (weir, dam, sluice gate, etc.)
Other (O)	0		To be used in unusual circumstances where the feature does not fit any of the recognized types

Appendix 2: Datasheet of the MesoCASiMiR mapping method

MesoCASiMiR, Oktober 2005 (Florian)

Name: ____________ Page ____________

Reach Nr.:

Start
x coord y coord
End
x coord y coord

Water Use
Navigation
Hydro Power
Flood protection
Urban Area
None
Water extraction
Q-Estimation % MNQ l/s

Attraction flow
None
Limited
Good

Date
Time Start Time End

River Location
Developed Landscape
Undeveloped Landscape

Discharge
Extremely Low
Low
Low to middle
Middle
Middle to high
High
No comment
Gauging station
Name:
Measure [cm]

Hinderance to Connectivity
x coord
y coord
None:

Fish Pass
Technical Fish Pass
Naturelike Bypass.
None
Heigth[cm]

Connectivity
Yes
Mostly
Selective
No

Sketch / Notes / Pictures:

Width
Bankfull [m]
MQ [m]
Actual wet [m]

Ufer, links

Ufertyp:
U1: Harter Uferverbau
U2: Alter, aufgelöster Block-Verbau
U3: Neuer Blockwurf
U4: Raubaumverbau/Totholz
U5: Flaches Schotter-/Kiesufer (mit Strömungsgradient)
U6: Rauigkeitselemente aus Blöcken
U7: Steinbuhnen
U8: Holz-Kastenbuhnen (mit dazwischen liegendem Raubaumverbau)
U9: "Naturufer" (unbefestigt, geprägt durch Bewuchs)
U10: Hinterwasser (Totwasser mit Anschluss ans Gerinne) und geschützte Buchten
U11: Mündungsbereiche von Zubringern

Gleithang/Prallhang:
Weder noch; gerader Verlauf
Gleithang
Prallhang

Uferneigung:
Flach
Mittel
Steil

Wassertiefe:
0-20, 10-30, 20-50, 40-70, 60-120, 100-200, > 200 cm
Range: Low, Middle, High
Variance: Low, High

Strömung:
0-10, 10-30, 20-50, 40-70, > 70 cm/s
Range: Low, Middle, High
Variance: Low, High

Substrate:
1 Clay, silt and loam, <0.063 mm
2 Sand, 0.063-2.0 mm
3 Fine gravel, 2.0-6.0 mm
4 Medium gravel, 6.0-20-0 mm
5 Coarse gravel, 2.0-6.0 cm
6 Small cobbles, 6.0-12.0 cm
7 Large cobbles, 12.0-20 cm
8 Boulders, >20.0 cm
9 Rock
Dom
Sub

Deckungstyp:
0 Ufervegetation, überhängend
1 Ufervegetation, ins Wasser ragend (auch Wurzeln)
2 Makrophyten
3 Totholz
4 Steine/Blöcke
5 Unterspültes Ufer
6 Turbulente Oberfläche

Deckungsqualität:
Gering
Mäßig
Gut
Sehr Gut

Packing
1, 1-2, 2-3, 3-4, 4

Pore space
1, 1-2, 2-3, 3-4, 4

Embeddedness Level
1 2 3 4 5

Ufer, rechts

Ufertyp:
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11

Uferneigung:
Flach
Mittel
Steil

Strömung:
0-10, 10-30, 20-50, 40-70, >70 cm/s
Range: Low, Middle, High
Variance: Low, High

Wassertiefe:
0-20, 10-30, 20-50, 40-70, 60-120, 100-200, > 200 cm
Range: Low, Middle, High
Variance: Low, High

Deckungsqualität:
Gering
Mäßig
Gut
Sehr Gut

Gleithang/Prallhang:
Weder noch; gerader Verlauf
Gleithang
Prallhang

Deckungstyp:
0 Ufervegetation, überhängend
1 Ufervegetation, ins Wasser ragend (auch Wurzeln)
2 Makrophyten
3 Totholz
4 Steine/Blöcke
5 Unterspültes Ufer
6 Turbulente Oberfläche

Substrate:
1 Clay, silt and loam, <0.063 mm
2 Sand, 0.063-2.0 mm
3 Fine gravel, 2.0-6.0 mm
4 Medium gravel, 6.0-20-0 mm
5 Coarse gravel, 2.0-6.0 cm
6 Small cobbles, 6.0-12.0 cm
7 Large cobbles, 12.0-20 cm
8 Boulders, >20.0 cm
9 Rock
Dom
Sub

Packing
1, 1-2, 2-3, 3-4, 4

Pore space
1, 1-2, 2-3, 3-4, 4

Embeddedness Level
1 2 3 4 5

Extra Pool 1:

Wassertiefe:
< 1m tief
1m bis 1,5 m tief
Tiefer als 1,5 m

Strömung:
0-10, 10-30, 20-50, 40-70 cm/s

Größe:
Wasserfläche < 5m²
Wasserfläche 5m² bis 15m²
Wasserfläche > 5m²

Habitat-type

Typ-Nr.: ____________________

Substrate

	1	2	3	4	5	6	7	8	9
Dom									
Sub									

Flow velocity [cm/s]	0-10	10-30	20-50	40-70	60-100	>100	
Waterdepth [cm]	0-20	10-30	20-50	40-70	60-120	100-200	>200

	Flow velocity	Waterdepth
Range	Low / Middle / High	Low / Middle / High
Variance	Low / High	Low / High

k s -Wert ***k st -Wert***

Embeddedness Level 1 2 3 4 5

Pictures

Cover 0 1 2 3 4 5 6 7 8 9 10

<5 %
5-20 %
>20 %

Packing 1 1-2 2-3 3-4 4

Pore space 1 1-2 2-3 3-4 4

Depth to Embeddedness

1. [cm]
2. [cm]
3. [cm]
4. [cm]
5. [cm]

Habitat-type

Typ-Nr.: ____________________

Substrate

	1	2	3	4	5	6	7	8	9
Dom									
Sub									

Flow velocity [cm/s]	0-10	10-30	20-50	40-70	60-100	>100	
Waterdepth [cm]	0-20	10-30	20-50	40-70	60-120	100-200	>200

	Flow velocity	Waterdepth
Range	Low / Middle / High	Low / Middle / High
Variance	Low / High	Low / High

k s -Wert ***k st -Wert***

Embeddedness Level 1 2 3 4 5

Pictures

Cover 0 1 2 3 4 5 6 7 8 9 10

<5 %
5-20 %
>20 %

Packing 1 1-2 2-3 3-4 4

Pore space 1 1-2 2-3 3-4 4

Depth to Embeddedness

1. [cm]
2. [cm]
3. [cm]
4. [cm]
5. [cm]

Habitat-type

Typ-Nr.: ____________________

Substrate

	1	2	3	4	5	6	7	8	9
Dom									
Sub									

Flow velocity [cm/s]	0-10	10-30	20-50	40-70	60-100	>100	
Waterdepth [cm]	0-20	10-30	20-50	40-70	60-120	100-200	>200

	Flow velocity	Waterdepth
Range	Low / Middle / High	Low / Middle / High
Variance	Low / High	Low / High

k s -Wert ***k st -Wert***

Embeddedness Level 1 2 3 4 5

Pictures

Cover 0 1 2 3 4 5 6 7 8 9 10

<5 %
5-20 %
>20 %

Packing 1 1-2 2-3 3-4 4

Pore space 1 1-2 2-3 3-4 4

Depth to Embeddedness

1. [cm]
2. [cm]
3. [cm]
4. [cm]
5. [cm]

Habitat-type

Typ-Nr.: ____________________

Substrate

	1	2	3	4	5	6	7	8	9
Dom									
Sub									

Flow velocity [cm/s]	0-10	10-30	20-50	40-70	60-100	>100	
Waterdepth [cm]	0-20	10-30	20-50	40-70	60-120	100-200	>200

	Flow velocity	Waterdepth
Range	Low / Middle / High	Low / Middle / High
Variance	Low / High	Low / High

k s -Wert ***k st -Wert***

Embeddedness Level 1 2 3 4 5

Pictures

Cover 0 1 2 3 4 5 6 7 8 9 10

<5 %
5-20 %
>20 %

Packing 1 1-2 2-3 3-4 4

Pore space 1 1-2 2-3 3-4 4

Depth to Embeddedness

1. [cm]
2. [cm]
3. [cm]
4. [cm]
5. [cm]

Habitat-type

Typ-Nr.: ____________________

Substrate

	1	2	3	4	5	6	7	8	9
Dom									
Sub									

Flow velocity [cm/s]	0-10	10-30	20-50	40-70	60-100	>100	
Waterdepth [cm]	0-20	10-30	20-50	40-70	60-120	100-200	>200

	Flow velocity	Waterdepth
Range	Low / Middle / High	**Low / Middle / High**
Variance	Low / High	**Low / High**

k s -Wert ***k st -Wert***

Embeddedness Level 1 2 3 4 5

Pictures

Cover 0 1 2 3 4 5 6 7 8 9 10

<5 %
5-20 %
>20 %

Packing 1 1-2 2-3 3-4 4

Pore space 1 1-2 2-3 3-4 4

Depth to Embeddedness

1. [cm]
2. [cm]
3. [cm]
4. [cm]
5. [cm]

Appendix 3: Materials Collection of Shenzhen River Basin

1 Environmental Quality Report of Shenzhen City in Guangdong Province (1986-1990)

2 Environmental Quality Report of Shenzhen City in Guangdong Province (1996)

3 Environmental Quality Report of Shenzhen City in Guangdong Province (1997)

4 Environmental Quality Report of Shenzhen City in Guangdong Province (1998)

5 Environmental Quality Report of Shenzhen City in Guangdong Province (1999)

6 Environmental Quality Report of Shenzhen City in Guangdong Province (1996-2000)

7 Environmental Quality Report of Shenzhen City in Guangdong Province (2001)

8 Environmental Quality Report of Shenzhen City in Guangdong Province (2002)

9 Environmental Quality Report of Shenzhen City in Guangdong Province (2003)

10 Environmental Quality Report of Shenzhen City in Guangdong Province (2004)

11 Environmental Quality Report of Shenzhen City in Guangdong Province (2001-2005)

12 Environmental Quality Report of Shenzhen City in Guangdong Province (2006)

13 System of reporting the Environmental Protection and Planning Framework of Shenzhen City (2007-2020)

14 The Water Pollution Control Programme of Shenzhen River Band

15 The Theme of Ecological City Building and Environmental Protection

16 The Surface Water Resource Protection Distinct for municipal water

17 Environmental Quality Communique of Shenzhen City (2007)

18 Ecological Water Requirements Research of Shenzhen City

19 Shenzhen Map Series

20 The Water Environmental Integrated Regulation Project of Guanlan River Basin in Shenzhen City (2004)

21 The Water Environmental Integrated Regulation Project of Longgang River Basin in Shenzhen City

22 The Water Environmental Integrated Regulation Project of Dasha River in Shenzhen City

23 The Water Environmental Integrated Regulation and Sewage Intercepting Project of Futian River (Supplementary Specification to the Preliminary Design)

24 The 10th Five-Year Plan on the Ecological Environmental Protection and Building Shenzhen

25 The Environmental Impact Assessment Report on Caofu Wastewater Treatment Plant in Buji of Shenzhen Longgang Distinct

26 The Water Environmental Integrated Regulation Project of Pinshan River Basin in Shenzhen City

27 The Planning and Design on the Ecological Environment of Buji Town

28 The 10th Five-Year Plan on the Environmental Protection of Longgang Distinct in Shenzhen

29 The Hydrological Survey Data of Surface Water in Shenzhen City (Flood Season in 2005)

30 The Hydrological Survey Data of Surface Water in Shenzhen City (Flood Season)

31 Environmental Simulation of Surface Water in Shenzhen City

32 Discharge of Shenzhen River

33 The Integrated Regulation Project of Futian River, Xinzhou River and Dasha River in Shenzhen City

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JIN ZHANG

SUMMARY

Female

13.05.1982, China

EDUCATION

Dr. -Ing., Hydraulic Engineering, 2014

International Doctoral Program, ENWAT

Department of Hydraulic Engineering and Water Resources Management

Institute for Modelling Hydraulic and Environmental Systems

University of Stuttgart, Germany

M.Sc., Environmental Engineering, 2006

College of Environmental Sciences and Engineering

Peking University

B.Sc., Environmental Engineering, 2003

Department of Environment Science and Engineering

Shandong University

RESEARCH

2013 [Sustainable Rubber Cultivation in the Mekong Region Project founded by BMBF of Germany]

2010 [Yunnan Living Landscapes China founded by BMBF of Germany]

2007 [Research Assistant in the institute of Environmental Engineering, Peking university]

2006 [UN-Habitat Sustainable City Program (the Second Phase of China)]

2005 [National Key Technology Support Program "Integrated exploitation and utilization of Dioscorea aingiberensis project", one patent published]

2004 [Participated in the EU-China Environment Management Cooperation Project, data collection and analysis for book compilation "River basin management and institutional building at home and aboard”]

2004 [Participated in the project of the wastewater treatment design for a water treatment Corporation, 2 patents published]

LANGUAGE

[CHINESE] Native Speaker

[ENGLISH] Fluent speaking, reading and writing

[GERMAN] Fluent speaking, good in reading and writing

AWARDS

2007-2011 [DAAD Scholarship for undergoing PhD Program ‘ENWAT’ (Environment and Water) at University of Stuttgart, Germany]

Dec.2005 [“Special Contribution Award for Postgraduate” (1st Grade) by the Institute of Environmental Engineering]

Jun.2003 [“Excellent Graduate of Shandong province” (Only three students in Environmental Department)]

Jun.2003 [Recommended to enter graduate school at Peking University as the top 1 student in Environmental Department of Shandong University]

PUBLICATION

Investigations on Urban River Regulation and Ecological Rehabilitation measures, Case Study of Shenzhen River in China, 2014 (ISBN: 978-3-942036-38-2).

Jin Zhang, Wen Huang, Zhenshan Li. Optimizing extraction of lycopene from tomato skin. Chinese Journal of Food and Fermentation Industries, 2006.

Jinren Ni, Wen Huang, Jin Zhang, Wei Liu. Physical and biologic methods for producing of cellulose and glucose from Dioscorea aingiberensis (patent), 2006.

Jin Zhang, Qiang Jin, Mingfeng Wang, Yunwei Li. Degradation of volatile compound in water by two frequencies’ ultrasonic (Published patent, CN1597542), 2004.

Qiang Jin, Zheng Zheng, Quanxing Zhang, Weili Jiang, Jin Zhang. Degradation of organic compound in water by ultrasonic cooperate with magnetism (Published patent, CN1344685), 2004.

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Verzeichnis der Mitteilungshefte

1 Röhnisch, Arthur: *Die Bemühungen um eine Wasserbauliche Versuchsanstalt an der Technischen Hochschule Stuttgart*, und
Fattah Abouleid, Abdel: *Beitrag zur Berechnung einer in lockeren Sand gerammten, zweifach verankerten Spundwand*, 1963

2 Marotz, Günter: *Beitrag zur Frage der Standfestigkeit von dichten Asphaltbelägen im Großwasserbau*, 1964

3 Gurr, Siegfried: *Beitrag zur Berechnung zusammengesetzter ebener Flächentragwerke unter besonderer Berücksichtigung ebener Stauwände, mit Hilfe von Randwert- und Lastwertmatrizen*, 1965

4 Plica, Peter: *Ein Beitrag zur Anwendung von Schalenkonstruktionen im Stahlwasserbau*, und Petrikat, Kurt: *Möglichkeiten und Grenzen des wasserbaulichen Versuchswesens*, 1966

5 Plate, Erich: *Beitrag zur Bestimmung der Windgeschwindigkeitsverteilung in der durch eine Wand gestörten bodennahen Luftschicht*,
und
Röhnisch, Arthur; Marotz, Günter: *Neue Baustoffe und Bauausführungen für den Schutz der Böschungen und der Sohle von Kanälen, Flüssen und Häfen; Gestehungskosten und jeweilige Vorteile*, sowie Unny, T.E.: *Schwingungsuntersuchungen am Kegelstrahlschieber*, 1967

6 Seiler, Erich: *Die Ermittlung des Anlagenwertes der bundeseigenen Binnenschiffahrtsstraßen und Talsperren und des Anteils der Binnenschiffahrt an diesem Wert*, 1967

7 *Sonderheft anläßlich des 65. Geburtstages von Prof. Arthur Röhnisch mit Beiträgen von* Benk, Dieter; Breitling, J.; Gurr, Siegfried; Haberhauer, Robert; Honekamp, Hermann; Kuz, Klaus Dieter; Marotz, Günter; Mayer-Vorfelder, Hans-Jörg; Miller, Rudolf; Plate, Erich J.; Radomski, Helge; Schwarz, Helmut; Vollmer, Ernst; Wildenhahn, Eberhard; 1967

8 Jumikis, Alfred: *Beitrag zur experimentellen Untersuchung des Wassernachschubs in einem gefrierenden Boden und die Beurteilung der Ergebnisse*, 1968

9 Marotz, Günter: *Technische Grundlagen einer Wasserspeicherung im natürlichen Untergrund*, 1968

10 Radomski, Helge: *Untersuchungen über den Einfluß der Querschnittsform wellenförmiger Spundwände auf die statischen und rammtechnischen Eigenschaften*, 1968

11 Schwarz, Helmut: *Die Grenztragfähigkeit des Baugrundes bei Einwirkung vertikal gezogener Ankerplatten als zweidimensionales Bruchproblem*, 1969

12 Erbel, Klaus: *Ein Beitrag zur Untersuchung der Metamorphose von Mittelgebirgsschneedecken unter besonderer Berücksichtigung eines Verfahrens zur Bestimmung der thermischen Schneequalität*, 1969

13 Westhaus, Karl-Heinz: *Der Strukturwandel in der Binnenschiffahrt und sein Einfluß auf den Ausbau der Binnenschiffskanäle*, 1969

14 Mayer-Vorfelder, Hans-Jörg: *Ein Beitrag zur Berechnung des Erdwiderstandes unter Ansatz der logarithmischen Spirale als Gleitflächenfunktion*, 1970

15 Schulz, Manfred: *Berechnung des räumlichen Erddruckes auf die Wandung kreiszylindrischer Körper*, 1970

16 Mobasseri, Manoutschehr: *Die Rippenstützmauer. Konstruktion und Grenzen ihrer Standsicherheit*, 1970

17 Benk, Dieter: *Ein Beitrag zum Betrieb und zur Bemessung von Hochwasserrückhaltebecken*, 1970

18 Gàl, Attila: *Bestimmung der mitschwingenden Wassermasse bei überströmten Fischbauchklappen mit kreiszylindrischem Staublech*, 1971, vergriffen

19 Kuz, Klaus Dieter: *Ein Beitrag zur Frage des Einsetzens von Kavitationserscheinungen in einer Düsenströmung bei Berücksichtigung der im Wasser gelösten Gase*, 1971, vergriffen

20 Schaak, Hartmut: *Verteilleitungen von Wasserkraftanlagen*, 1971

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22 Wang, Chung-su: *Ein Beitrag zur Berechnung der Schwingungen an Kegelstrahlschiebern*, 1972

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27 Steinlein, Helmut: *Die Eliminierung der Schwebstoffe aus Flußwasser zum Zweck der unterirdischen Wasserspeicherung, gezeigt am Beispiel der Iller*, 1972

28 Holthoff, Franz Josef: *Die Überwindung großer Hubhöhen in der Binnenschiffahrt durch Schwimmerhebewerke*, 1973

29 Röder, Karl: *Einwirkungen aus Baugrundbewegungen auf trog- und kastenförmige Konstruktionen des Wasser- und Tunnelbaues*, 1973

30 Kretschmer, Heinz: *Die Bemessung von Bogenstaumauern in Abhängigkeit von der Talform*, 1973

31 Honekamp, Hermann: *Beitrag zur Berechnung der Montage von Unterwasserpipelines*, 1973

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33 Rueff, Helge: *Untersuchung der schwingungserregenden Kräfte an zwei hintereinander angeordneten Tiefschützen unter besonderer Berücksichtigung von Kavitation*, 1974

34 Röhnisch, Arthur: *Einpreßversuche mit Zementmörtel für Spannbeton - Vergleich der Ergebnisse von Modellversuchen mit Ausführungen in Hüllwellrohren*, 1975

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36 Berger, Jochum: *Beitrag zur Berechnung des Spannungszustandes in rotationssymmetrisch belasteten Kugelschalen veränderlicher Wandstärke unter Gas- und Flüssigkeitsdruck durch Integration schwach singulärer Differentialgleichungen*, 1975

37 Dirksen, Wolfram: *Berechnung instationärer Abflußvorgänge in gestauten Gerinnen mittels Differenzenverfahren und die Anwendung auf Hochwasserrückhaltebecken*, 1976

38 Horlacher, Hans-Burkhard: *Berechnung instationärer Temperatur- und Wärmespannungsfelder in langen mehrschichtigen Hohlzylindern*, 1976

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40 Ruppert, Jürgen: *Über den Axialwirbelkammerverstärker für den Einsatz im Wasserbau*, 1977, ISBN 3-921694-40-X

41 Hutarew, Andreas: *Beitrag zur Beeinflußbarkeit des Sauerstoffgehalts in Fließgewässern an Abstürzen und Wehren*, 1977, ISBN 3-921694-41-8, vergriffen

42 Miller, Christoph: *Ein Beitrag zur Bestimmung der schwingungserregenden Kräfte an unterströmten Wehren*, 1977, ISBN 3-921694-42-6

43 Schwarz, Wolfgang: *Druckstoßberechnung unter Berücksichtigung der Radial- und Längsverschiebungen der Rohrwandung*, 1978, ISBN 3-921694-43-4

44 Kinzelbach, Wolfgang: *Numerische Untersuchungen über den optimalen Einsatz variabler Kühlsysteme einer Kraftwerkskette am Beispiel Oberrhein*, 1978, ISBN 3-921694-44-2

45 Barczewski, Baldur: *Neue Meßmethoden für Wasser-Luftgemische und deren Anwendung auf zweiphasige Auftriebsstrahlen*, 1979, ISBN 3-921694-45-0

46 Neumayer, Hans: *Untersuchung der Strömungsvorgänge in radialen Wirbelkammerverstärkern*, 1979, ISBN 3-921694-46-9

47 Elalfy, Youssef-Elhassan: *Untersuchung der Strömungsvorgänge in Wirbelkammerdioden und -drosseln*, 1979, ISBN 3-921694-47-7

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51 Hafner, Edzard: *Rohrleitungen und Behälter im Meer*, 1983, ISBN 3-921694-51-5

52 Rinnert, Bernd: *Hydrodynamische Dispersion in porösen Medien: Einfluß von Dichteunterschieden auf die Vertikalvermischung in horizontaler Strömung*, 1983, ISBN 3-921694-52-3, vergriffen

53 Lindner, Wulf: *Steuerung von Grundwasserentnahmen unter Einhaltung ökologischer Kriterien*, 1983, ISBN 3-921694-53-1, vergriffen

54 Herr, Michael; Herzer, Jörg; Kinzelbach, Wolfgang; Kobus, Helmut; Rinnert, Bernd: *Methoden zur rechnerischen Erfassung und hydraulischen Sanierung von Grundwasserkontaminationen*, 1983, ISBN 3-921694-54-X

55 Schmitt, Paul: *Wege zur Automatisierung der Niederschlagsermittlung*, 1984, ISBN 3-921694-55-8, vergriffen

56 Müller, Peter: *Transport und selektive Sedimentation von Schwebstoffen bei gestautem Abfluß*, 1985, ISBN 3-921694-56-6

57 El-Qawasmeh, Fuad: *Möglichkeiten und Grenzen der Tropfbewässerung unter besonderer Berücksichtigung der Verstopfungsanfälligkeit der Tropfelemente*, 1985, ISBN 3-921694-57-4, vergriffen

58 Kirchenbaur, Klaus: *Mikroprozessorgesteuerte Erfassung instationärer Druckfelder am Beispiel seegangsbelasteter Baukörper*, 1985, ISBN 3-921694-58-2

59 Kobus, Helmut (Hrsg.): *Modellierung des großräumigen Wärme- und Schadstofftransports im Grundwasser*, Tätigkeitsbericht 1984/85 (DFG-Forschergruppe an den Universitäten Hohenheim, Karlsruhe und Stuttgart), 1985, ISBN 3-921694-59-0, vergriffen

60 Spitz, Karlheinz: *Dispersion in porösen Medien: Einfluß von Inhomogenitäten und Dichteunterschieden*, 1985, ISBN 3-921694-60-4, vergriffen

61 Kobus, Helmut: *An Introduction to Air-Water Flows in Hydraulics*, 1985, ISBN 3-921694-61-2

62 Kaleris, Vassilios: *Erfassung des Austausches von Oberflächen- und Grundwasser in horizontalebenen Grundwassermodellen*, 1986, ISBN 3-921694-62-0

63 Herr, Michael: *Grundlagen der hydraulischen Sanierung verunreinigter Porengrundwasserleiter*, 1987, ISBN 3-921694-63-9

64 Marx, Walter: *Berechnung von Temperatur und Spannung in Massenbeton infolge Hydratation*, 1987, ISBN 3-921694-64-7

65 Koschitzky, Hans-Peter: *Dimensionierungskonzept für Sohlbelüfter in Schußrinnen zur Vermeidung von Kavitationsschäden*, 1987, ISBN 3-921694-65-5

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