Dynamics Model of Eco-Security Surveillance System for River Tamsui in Taipei City

Hsiao-Lin Wang[1]   Yu-Feng Ho[2]   Ching-I Wu[3]
Graduate School of Architecture and Urban Design,
Chaoyang University of Technology, Taichung, Taiwan
1 Email: whl1435@hotmail.com
2 Email: hyfarch@ms32.hinet.net
3 Email:gardenar571@gmail.com

Abstract

Current research on the river ecosystem in Taiwan is mostly focused on the water conservancy, ecology, and afforested viewpoints. There is a lack of integrated strategy on urban river ecosystem management. In this study which aims to examine the river quality based on ecological safety. By means of the systems engineering technology, the related ecological safety operation mechanisms have been analyzed. Also, through the new Fuzzy Delphi expert survey, the index system of urban river ecological safety (IES) has been compiled in order to explore the variables. The key indicators affecting the urban river ecology safety can be fully defined by sensitivity analysis in order to engage in thr evaluation of effectiveness and to create a dynamic simulation model. The study results indicate that the strategic implementation of improved embankment vegetation structure, reduced degree of river channelization, and maintenance of a high degree of longitudinal connectivity of rivers can effectively enhance the urban river ecology risk prevention, strengthen the efficient use of resources, and promote the sound development of the urban river ecology.

Keywords: ecological safety monitoring, Tamsui River, Fuzzy Delphi, system dynamics

1. Introduction

With the overall goal of "building a land of esthetic ecological urban and rural environment" and the vision of a "vibrant city and sustainable Taiwan", the ecological optimization of urban development in Taiwan has become an important indicator for Taiwan's future land development. Taiwan is situated in the sub-tropics with abundant rainfall. In addition, due to the uneven distribution of rainfall in terms of the time and place, coupled with the steep mountains and short river currents, a total of 350 typhoons have struck Taiwan and up to one thousand heavy rains have taken place in the past 101 years. With the rainfall concentrations, short rivers and rapid currents, flooding has been the most serious natural disaster in Taiwan (Water Policy and

Management Research Center, 2010). Therefore, flood management is Taiwan's long-term goal in river management. However, the urban flooding caused by Typhoon Morakot and Typhoon Toraji seems to imply that the urban river ecological system can no longer bear the destruction brought about by the urban development. In recent years, the Taiwan government has actively promoted flood prevention and river remediation programs; however, river management has been implemented under the premises of flood management and maximum economic benefits of lands, of which numerous hydraulic structures have been built in order to protect people's lives and property. By doing so, the original ecological habits have been changed at the same time. Because the ecological functions had often been neglected in the past, the river ecological systems were subject to destruction. This negligence may likely hinder the sustainable urban development while the proper water consumptions of rivers and the self-purifying water quality and biological diversity functions have gradually diminished, thereby threatening the long-term survival and well-being of mankind. Thus, the necessity and value of an effective early warning system have been confirmed. In addition, the effective implementation of the early warning system can also greatly reduce the occurrence of disasters (Tung Ching-Ping, et.al, 2008). For city residents, the early warning system can minimize the risk of living in insecure environments.

At present, environmental safety issues have been developed toward macroscopic and microscopic trends. "Security"is the status of safety and eco-security means the security to maintain human beings' ecosystem upon healthy and sustainable development. The ecology means multiple artificial eco-security system constructed by nature, economy and society(Xie,2007;Wu,2011) . A large number of researches have applied the ecological theories to the economic development considerations. Instead of having fragmented national policies, they have been turned into alliance cooperation, thereby putting a stop to environmental degradation and slowing down the global climate changes through the economic mechanisms. Take the "Kyoto Protocol" signed in 1997 for instance; through the carbon tax system, the goal of restoring the global ecological balance has been achieved. Discussions on the urban ecological development issues are unlike other general ecological system related studies. First of all, the urban ecological system covers the natural, social, and economic system aspects, not a static one-way system; second, the formulation of the urban ecological management strategies must be forward-looking and implementable. Rivers, like human blood, must perform the functions of ecological environment conservation, transportation, and cleaning. The idea of urban river eco-security is to keep urban residents life in safety and to keep nature water resource comes from urban river which people used no longer in risk both(Wu,2011).The rivers and green spaces that demarcate the water from the land are ecological habitats that stabilize the urban biological species and provide the city residents with open spaces for recreation purposes. The review of the river ecological system from the security-based viewpoint, the establishment of a cordon for monitoring the river ecological functions, and the review of the complex relationship between the river ecology and human

development are essential for the ongoing sustainable urban development.

2. Study Methods

From the ecological-based viewpoint, rivers are a dynamic and continuous water ecological system (Wang Ching-Ming, 1992). The environmental makeup of rivers is constituted by water environments and catchment areas. The ecological system structures accommodate a cluster of biological species (such as producers, consumers, decomposers, and other biological components), which are made up of physical and chemical environments that are habitats for biological species (such as air, sunlight, water, soil, chemicals, etc.) (Kuo, Monica, 2001). The combination of geography and landscape ecology also offers another direction of thinking: the biological species migrate along the river, forming a narrow band of "river corridor" (Kuo, Monica, 2001). This band stabilizes the water cycle and acts as a buffer for maintaining ecological balance; it is also a biological habitat that provides biological species with shelter and food and allows them to nurture their young after birth. The creatures in clusters in the rivers are subject to effects of both the external (land) and internal (water) environmental factors; that is, the interaction between nature and humanity related environmental factors possess more complex structures and functional processes. Although the urban rivers are subject to limitations of the riverbank and flood-prevention facilities, the urban river ecological system is not only about water or river areas as are often discussed, but also includes the water resources and network systems of the natural land environment and resources that rely on and maintain the river functions so that the overall river ecological system can be better expressed.

The urban river ecology is a part of the urban ecology. Although the complex ecological system is made up of social, economic, and natural aspects, it is still consistent with the mechanism of urban ecology. The urban river ecology features the following:

1. Integrity: The urban river ecological system is a complex and independent functional unit in the environment.
2. Causality: The urban river ecological system's functions are affected by the internal and external variables of the system, of which the factors affect each other as a unified system.
3. Restorability: The urban river ecological system has stable and feedback-regulating internal mechanisms.

In this study, for the sake of obtaining complete and continuous research quality, the research discussions and purposes in every stage of the paper are independent; yet, they are logically related. It is therefore necessary to adopt cross-disciplinary approaches to engage in integrated research.

2-1. Systems Engineering

Systems engineering takes into consideration system related discussions, as well as the uncertain factors. In addition, the order in rank within the system elements has

been found through logical and organized tools and steps, and the correlation between the system elements and the entire system have been measured in order to explore the entire system organizational structure. In view of the massive and complex urban river ecological system, this study has adopted the systems engineering theories and methods in order to formulate the preliminary index system.

2-2. Fuzzy Delphi

Ishikawa et.al (1993) used the cumulative frequency distribution and fuzzy integral concepts to integrate the expert opinions and transform them into fuzzy numbers. In addition, the geometric mean serves as the basis for the group decision-making screening and evaluation criteria in order to avoid extreme values and ensure better results in the evaluation factor selection, all of which are collectively known as the Fuzzy Delphi Method (FDM). In this study, the amended method of fuzzy number construction proposed by Cheng (2005) has been adopted. That is, the traditional Delphi Method has been adopted to evaluate the indicators using single values. On the other hand, after obtaining the mean, the researcher evaluated the consensus reached among the experts in order to determine the degree of importance of the expert opinions and derive at the triangular fuzzy number graphics. In this study, the FDM has been adopted in order to enhance the objective and sciential urban river ecological system index system. The FDM has advantages such as low investigation frequencies, complete expression of the expert opinions, and inclusion of fuzziness that inevitably appears in the investigation process (Wang, 2007; Wu, K.Y. et al, 2002; Wu Yi-Yen, 2008).

2-3. System Dynamics

System dynamics refers to the application of the causation and information feedback concepts in analyzing the system structure, exploring decision-making that affect system behaviors and the time lag phenomenon during the decision-making process. It is ideal when used to deal with cyclical, long-term, multi-variable, high-ranking, nonlinear, and time lag related issues, making it highly suitable for studying complex problems related to the river ecological system. Moreover, it features strong forecast and back-test functions, which help achieve the purpose of integrating reality and history. In addition, the model simulation operation process reflects the actual operation condition, which shall serve as a reference for policy amendments and project evaluations. The urban river ecological system that involves complex areas such as the overall urban development and ecological operation mechanisms presents the "dynamic complexity" characteristics while the system dynamics applied in the urban ecological system simulation analysis has a unique research advantage.

2-4. Sensitivity analysis

Sensitivity analysis engages in the debugging of the decision-making analysis of the actual system using models. By changing the parameters, structures, model simulation, and comparative model outputs of the models, the extent of effects can be

determined. In the actual system, some parameter data are affected and controlled by multiple factors. Thus, the ultimate purpose of the establishment of models is to pass the debugging and seek more sensitive parameters in the models, which are the leverage points sought in the actual system policy analysis, through which the best policies can be found (Barlas, 1996; Sterman, 2002).

In this study, the systems engineering method has been adopted to analyze the urban river ecological system operation. Through the Fuzzy Delphi expert opinion survey, the index systems affecting Taipei City's Tamsui River ecological system have been compiled. Moreover, through the system dynamics method and using the Vensim DSS 5.9 software, the main causes and causations of the urban river ecological system have been constructed. Through the sensitivity analysis, the key factors affecting the ecological system was grasped to engage in strategy efficiency evaluations, set up the dynamic simulation model of the urban river ecological security monitoring system, enhance the urban river ecological system risk prevention, strengthen the effective use of resources, and promote the comprehensive development of the urban river ecological system.

3. The Setup of the Urban River Ecology Security Evaluation Index system

3-1 The Preliminary Formulation of the Index system for Urban River Ecology Security

In this study, based on the domestic and foreign literatures and in consideration to the urban river management characteristics and experiences, the engineering system technology has been used to find objective, scientific, measurable, and comparable system indicators from the exiting related important research literatures, including 29 variables that are divided into five sub-systems: flood security, water security, purification security, habitat security, and biosecurity. By application of the Delphi Fuzzy Expert Survey Methods (Ho & Wang, 2008) including "group decision-making" and "fuzzy evaluation," the recommended variables were selected from the perspectives of different disciplines and perspectives to output representative viewpoints. In this study, after obtaining the respective indicator evaluations using the Fuzzy Delphi Method, the Fuzzy Partition Method proposed by Zhao,R. and Govind (1991) was applied to obtain the mean after fuzzification (BNP), which serves as the integrated value consistent with the expert opinion. In addition, based on the fuzzy numbers used in the study, the method of fuzzy number construction was applied to analyze the expert values, integrate the urban river ecology security subsystems, and set up the principle for selecting the reference values using single threshold values. This method possesses the objectiveness of indicator selections using fuzzy numbers; at the same time, as the survey content is clear and easy to implement, the writing and numerical computations can be simplified, thereby enhancing the efficiency of the Amalfi survey.

3-2 The Urban River Ecology Security System Index system

This research referenced local and international articles, while taking into consideration the unique characteristics and experiences of Taiwan's urban river

ecosystem. Engineering system techniques established at the initial stage an optimistic, scientific, predictable and comparable variables set. In this study, the questionnaire subjects invited include experts of landscape planning, urban planning, architectural design, water resources engineering, and ecological conservation. A total of 20 questionnaire copies were distributed, and 20 copies were retrieved, thus achieving 100% recovery rate. Of the questionnaires, 20 were valid questionnaires, thus achieving 100% efficiency rate. After obtaining the respective evaluations through the Fuzzy Delphi Method, the respective indicator values in the questionnaires were computed: the BNP value was 3.96, and the standard deviation was 0.57; therefore, 3.3 served as the threshold value selection indicator. Seven evaluation items, including degree of river meandering, horizontal connectivity of the river, human impact, survival rate of protected biological species, ratio of alien species, riverbed sediment types, and environmental awareness have not reached the threshold values and thus they have been eliminated. The indicators were decreased from 29 to 22, which account for 75.86% of the overall ratio.

Among the index systems, the discharge security sub-systems including the amount of discharge (four indicators), purification security sub-system (four indicators), water security sub-system (five indicators), habitat security sub-system (five indicators), and biosecurity sub-system (four items). The respective expert evaluation is intended for experts' degree of consensus regarding the importance of the indicators on the systems and respective sub-systems. The survey results indicate that the top nine in overall ranking are: per capita water consumption (4.72), riverbed sediment stability(4.69), livelihood sewage and wastewater emissions(4.67), riverbank stability(4.64), industrial sewage and wastewater emissions(4.64), embankment vegetation structure(4.57), surface runoff(4.55), heavy metals in water(4.55), and number of biological species(4.48). In general, the indicator items related to water consumption, water quality, riverbank type, and vegetation condition have been attached importance. This being said, the urban river ecological water quality and discharge capacity remain the primary targets for maintaining the ecological security system while the maintenance of the river structure types are secondary in the construction of the Fuzzy Delphi index system for urban river ecology security (Table 1).

4. The Dynamic Simulation Model of the Urban River Ecological System

4-1. The Causal Feedback Diagram

The urban river ecological system is a complex organic body that belongs to the decision-making model of a multi-factor decision-making model with considerable complexity and uncertainty. The changes that affect the urban river ecological system condition are quite extensive in scope. In this study, the purification security and biosecurity serve as the core in identifying the five sub-systems that overlap in feedbacks and affect one another. Through the causal feedback diagram, the various feedbacks loops and causations have been expressed.

1. The Discharge Security Sub-system

Table 1 Index system for urban river eco-security evaluations

Sub-system	Evaluation factors	Central value distance of the expert evaluation d_i				Fuzzy number				Total ranking
		Minimum value min	Maximum value max	Mean gi	Variance S^2	Lower limit a	Upper limit b	Σwigi	Expert consensus value BNP	
Discharge security sub-system	Degree of river meandering	0.6316	1.7895	0.9368	0.6410	1.1684	4.7095	3.7821	3.2200	25
	Longitudinal connectivity of rivers	0.7368	1.3684	0.8632	0.5008	2.0186	5.4678	3.5678	3.6847	16
	Horizontal connectivity of rivers	0.4737	2.7895	0.8053	1.6511	-0.5389	4.2229	3.9007	2.5282	28
	River discharge	0.3158	1.7895	0.4947	0.5474	2.3417	5.1736	4.8889	4.1347	13
	Surface runoff	0.5789	1.3158	0.7737	0.3979	3.2010	6.1805	4.2809	4.5541	7
	Bio-based flow	0.3158	1.7895	0.4977	0.5557	2.3577	5.1966	4.8967	4.1942	12
Purification security sub-system	Degree of Water Quality	0.7368	3.4737	0.9158	0.4480	2.7253	5.9960	4.4763	4.3992	10
	Heavy metal concentrations in water	0.4211	2.3158	0.6421	0.3957	3.6794	6.1805	4.2809	4.5541	7
	Land use	0.4211	1.2632	0.6316	0.4074	1.7667	4.3606	3.8511	3.3237	20
	Human impact	0.6842	1.6316	0.8895	0.5091	1.2665	4.8744	3.5596	3.2902	21
	Embankment vegetation structure	0.6316	1.1579	0.8737	0.5490	3.1020	6.4797	4.1260	4.5692	6
Water security sub-system	Total population of the city	0.7368	3.4737	0.9158	0.4480	2.7253	5.9960	4.4763	4.3992	9
	Sewage treatment rate	0.5789	1.5263	0.7105	0.3788	2.7570	5.6861	4.5792	4.3408	11
	Per capita water consumption	0.4211	3.5789	0.7789	0.4092	3.7110	6.3162	4.1427	4.7233	1
	Environmental awareness	0.8421	1.5789	1.1684	0.9798	0.5149	5.0872	3.6085	3.0702	27
	Industrial sewage and wastewater emissions	0.4737	1.3158	0.6684	0.3733	3.5045	6.2111	4.2186	4.6448	5
	Livelihood sewage and wastewater emissions	0.6316	2.1053	0.9684	0.5804	3.3099	6.6126	4.0921	4.6715	3
Habitat security sub-system	Riverbank (embankment) stability	0.5263	2.3158	0.7684	0.3994	3.4493	6.2699	4.2212	4.6468	4
	Riverbed sediment stability	0.4211	3.5789	0.7895	0.4043	3.6144	6.2924	4.1578	4.6882	2
	Riverbed sediment types	0.4211	1.2632	0.6316	0.4074	1.4995	4.3606	3.8511	3.2737	23
	Degree of river channelization	0.6316	2.6316	0.8211	0.4006	1.7788	4.8257	3.5898	3.3981	19
	Water depth	0.5789	2.3684	0.7947	0.3800	2.2707	5.1713	3.3009	3.5810	17
	Water connectivity	0.4737	1.3158	0.6684	0.3733	1.7889	4.4955	3.7814	3.3552	20
Biosecurity sub-system	Number of biological species	0.5789	3.5789	0.7763	0.2901	3.1700	5.8083	4.4737	4.4840	8
	Survival rate of protected biological species	0.5789	1.9474	0.8789	0.6336	1.2323	4.6093	3.8956	3.2457	24
	Ratio of alien species)	0.6316	1.4737	0.7895	0.4648	2.2510	5.4816	3.4426	3.1265	26
	Ratio of water to green area	0.6842	1.2105	0.9000	0.5394	1.6339	5.1382	3.7936	3.5219	18
	River course cross-section area	0.7368	1.3884	0.8782	0.5013	2.2357	5.4678	3.6678	3.7326	15
	Degree of vegetation cover	0.7895	1.7368	1.0158	0.7282	1.9879	6.0460	3.5149	3.8496	14

The purpose of this system is to evaluate the river flood-prevention capacity and clarify the indicators that affect the river detention and discharge capacity in order to explore the effects of the river environment and structure pattern and the landscape changes on the system changes. The flood-prevention is not one of the capacities of rivers; however, from the perspective of urban ecological security or for the purpose of developing an urban river ecology security evaluation system, it is an important target in ecological security to ensure human survival and reduce the potential risks of disasters.

Landscape changes affect the urban land's water retention capacity and facilitate large quantities of surface runoff water to flow into channelized rivers. They also increase the instant peak flow. In order to reduce the frequency of urban flooding, two directions are essential: one is to increase the river courses' detention capacity, and the other is to increase the urban land's water retention capacity in order to reduce the surface runoff. Therefore, the river ecological security and flood-prevention sub-systems must exceed the scope of rivers or water, thereby linking the effects of the system and urban development and presenting the detailed and realistic face of the flood-prevention sub-systems.

This system uses river discharge as the main stock in constructing casual loop relationships. Longitudinal connectivity means that the rate percentage of permeable surface area of the river construction (Ladson et al，1999；Yong-sheng Gao et al，2007；E-nuo Wu et al，2007). The connectivity between the longitudinal river and surface affect the seepage of the river course flow (Landson,A.R. et al,1999；Kao Yung-Shen et. al, 2007). The higher the seepage, the lower the water consumption that needs to be transported by rivers. Similarly, the higher the permeability of the land surface, the lower the load of river discharge; the lower the risks of floods, the higher the river's ecological security and number of biological species, thus a positive relationsh
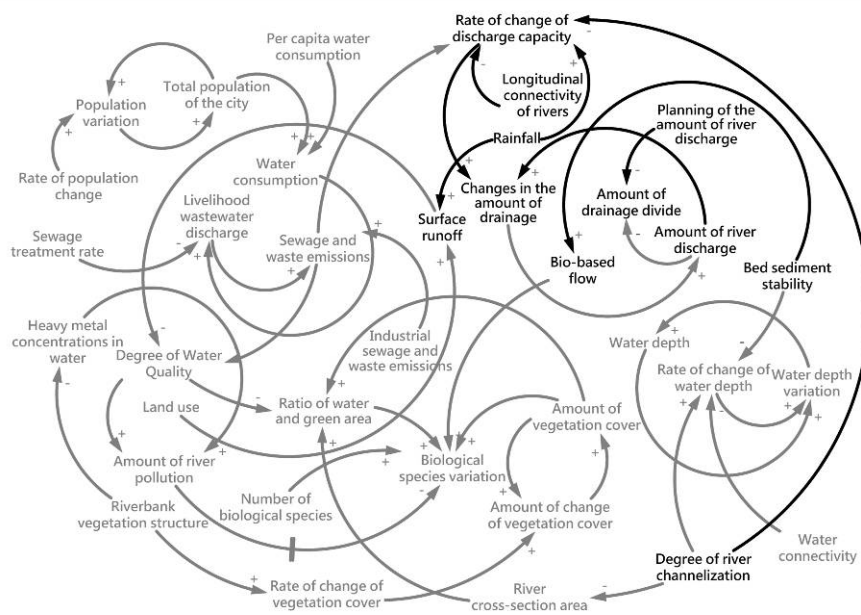

Fig. 1 The causal feedback diagram of the discharge security sub-system

2. The Purification Security Sub-system

This system is used to evaluate the urban rivers' internal water purification capacity, measure the event of environmental pollution, and understand the effects of land use, vegetation green belt, and human intervention on the system. In the city, livelihood and industrial wastewater flow into rivers through pipes while the surrounding land pollutants flow into streams and rivers through the surface runoff or groundwater. The city is burdened with the major task of sewage discharge. The urban river water has become the carrier of pollutant transport while the rivers and surrounding lands have become the concentration site of filth. The width of the river's surrounding green belt and vegetation types affect the quantity of surface pollutants, the vegetation has the ability to metabolize pollutants, and the plants and biological species in the river can break down a part of the pollutants and reduce the extent of river pollution. The water quality was measured to reflect the extent of river pollution. More seriously polluted rivers signify more insecure river ecological systems. When the width of the green belt increases, the quantity of pollutants that flow into the river decreases. The increased vegetation quantity and types enhance the river's self-purification capacity when in the face of water pollution, which in turn improves the ecological system security.

This system has adopted the quantity of urban river pollution as the observation value in order to construct the causal relationship. The river water quality pollutants are constituted by the River Pollution Index and the Water Heavy Metal Index, which jointly reflect the river water conditions and are important indicators for the ecological security of rivers. A higher pollution index indicates lower water quality for biological species and worse ecological security conditions, thus the negative causation. It is characterized by an increase of the "index of the characteristic plants along riverbanks completely cover the embankment vegetation structures" and thus the ratio of water to green area will also increase. More biological habitats are then provided while the increase of vegetation will enhance the heavy metal breakdown capacity of rivers. The land use affects the land's run off in which the common action will improve the water quality, thus the positive cyclic relationship (An, K.-G. et al, 2002；Collins, K. et al,2007；Wang Lin, 2007) (Fig. 2)

3. The water security sub-system

This system evaluates the urban system factors that affect river water quality, including the preservation of river water, the introduced and discharged water quality, the pollutants affecting the water quality, and the effect of the urban environmental policy on the sub-system. Before the issue of sustainability of resources of environment are discussed, it had always been thought that the water supply for urban residents was endless. However, people now understand that in order to retain sufficient clean water for use, the convergence of the river water must be treasured in order to lessen the burden of water purification. The re-use of recycled
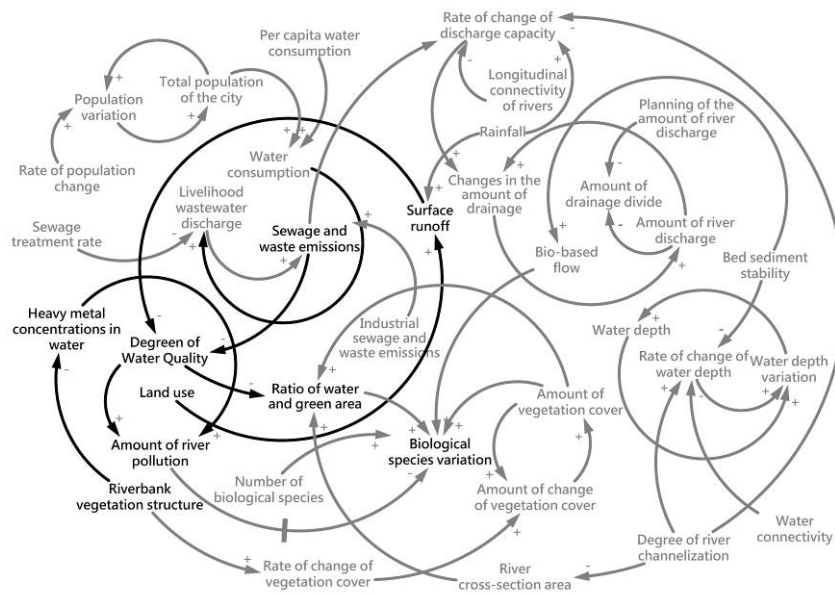
Fig. 2 The causal feedback diagram of the purification security sub-system

water and reduced water inputs can reduce the burden of the river ecological services and provide the river ecological system sufficient buffer and nurture. In terms of the river ecological security system, not only the water consumption and water quality issues, but also urban development policies, particularly the environmental protection policies and extension of the environmental protection related facilities, ought to be included in the sub-system in order to explore the effects and interaction of the urban river ecology security sub-system on the respective environmental protection policy standards.

In this system, with the total population of the city as the main stock, which is the characterization of the water needs, the causal loop relationship has been constructed. The human use of river water resources involves the discharge of wastewater after use into rivers; therefore, population increases will lead to increased livelihood wastewater as well. The industrial wastewater is characterized by the economic pressure on the river ecology; therefore, the higher the industrial sewage and wastewater emissions, the worse the ecological security will be. Through sewage treatment rate control, the river water security can be improved. Therefore, higher sewage treatment rates and increased recycled water consumption will lead reduce the river water supply load. Thus, reduced wastewater discharged into rivers will improve the river water security (Fig. 3).
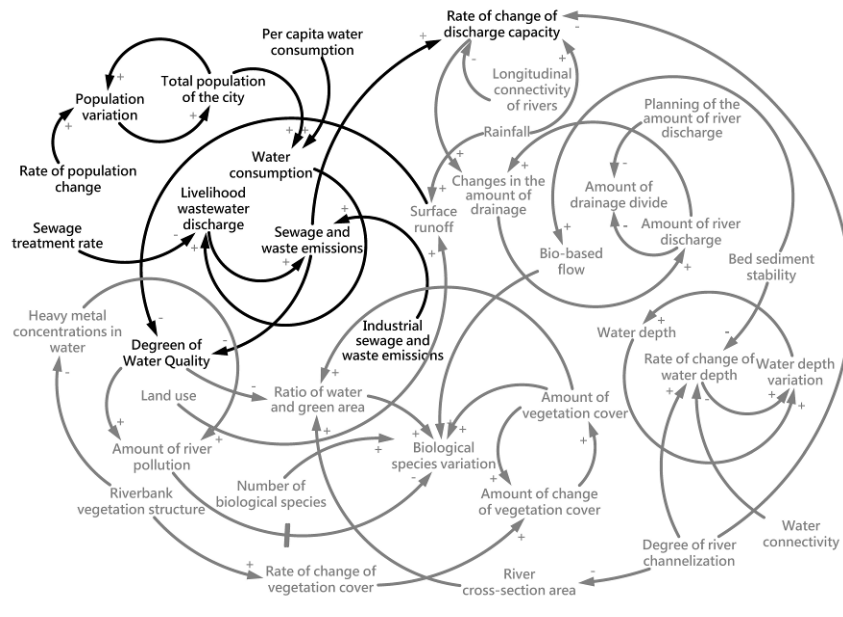
Fig. 3 The causal feedback diagram of the water security sub-system

4. The Habitat Security Sub-system

This system examines the effects of the substantial changes of rivers in urban development on the natural ecologies. In addition, by gaining an insight into the biological habitat changes, the trend of the living environment changes was obtained. The concept of "to conduct oneself virtuously" in terms of resource utilization has jeopardized the foundation of human survival. We must not compromise the ecologies of the species in rivers for our own survival, the significance of which is far beyond the ideal of sustainable development. In fact, the ecological networks of river species reflect the desirability of the environment for human survival. That is if all living creatures die out, we cannot possibly survive. We have achieved the expected discharge at rapid rates at the expense of the river vegetation's natural detention capacity, which have in turn altered the riverbank habitats and reduced the biodiversity. Enhanced urban river ecology security can improve the habitats of species, restore natural forms of the riverbank environment, and maintain the environmental quality and stability in the long-run.

This system has adopted the urban river habitat water depths as the main stock. In consideration to the factors affecting the environmental quality of the biological habitats provided by rivers, the trend of river ecological habitat security development has been analyzed. Rivers and pools function as habitats and breeding sites for organisms in the water and stabilize the rivers' physical forms to improve the habitat

quality, thus forming a positive causation. Channelization is the characterization of the degree of human-level river course changes. The higher the degree of channelization, the faster the flow of rivers and the more drastic the fluctuation ranges will be. Single and straight rivers decrease the likelihood of biological survival and decrease the river ecological habitat security, thus the negative causation of the two. Moreover, rivers with water connectivity not only provide stable habitat water depths for organisms, but also buffer the water consumption during flood peaks and enhance the habitat security and discharge capacities, thus a positive correlation (Fig. 4).
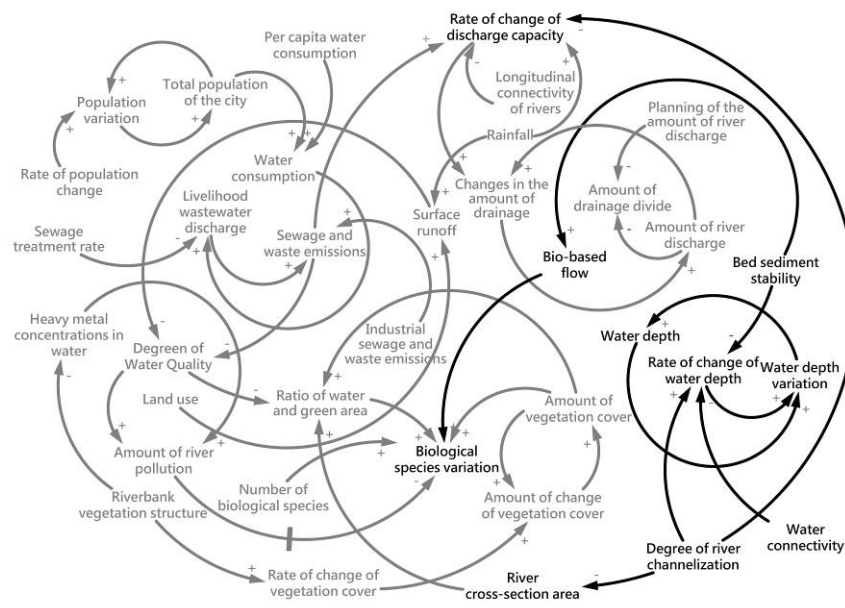

Fig. 4 The causal feedback diagram of the habitat security sub-system

5. The biosecurity sub-system

The urban river biological composition and quantity have been evaluated, and the effects of the alien species and environmental changes have been explored in order to explore the trend of the river ecological system security changes. The quantity and types of river organisms reflect the environmental quality of rivers, which include the nutrient levels and the quantity of the dependent loads. If greater vegetation cover areas can be provided, the biological habitat areas and river ecological quality can be enhanced, thus bringing positive benefits to river biodiversity and more secure river ecologies.

The number of biological species is the characterization of the internal and external changes on the physical environment and biological habitats. This system has adopted the number of biological species as the stock of the security sub-system in order to explore the interaction of the important factors in the system that affect the biological survival. The higher the biodiversity, the more closely related and stable the ecological system and nutrient levels, thus the positive correlation. By increasing the

degree of vegetation cover, more secure habitat spaces can be provided for organisms while more green plants can improve their water purification capacities. As the coverage ratio increases, the biosecurity condition will improve as well, thus the positive causal relationship between the two. At the same time, the degree of vegetation cover affects the ratio of water to green area, thus the positive correlation for the environmental security sub-system (Fig. 5).
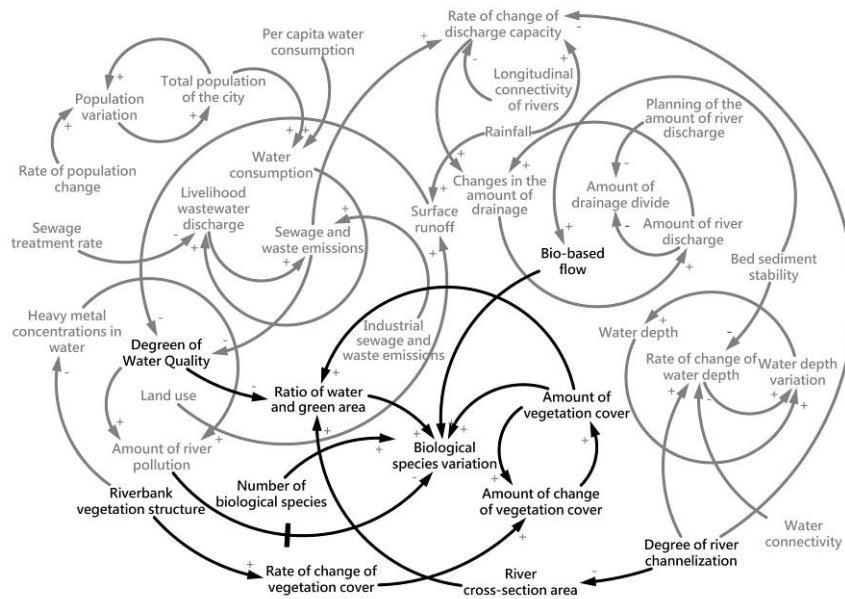

Fig. 5 The causal feedback diagram of the biosecurity sub-system

4-2 The systems dynamics flow diagram

The elaboration of the causation among the urban river ecology security system indicators provide an approach for exploring the relevance of the feedback system, which shall serve as the basis for the dynamic model construction. In this study, the statistical data of Taipei City's Tamsui River from 1998 to 2009 serves as the input source of the various exogenous variables. Based on the causal feedback loop from the above analysis and based on the historical evolution of Taipei City's Tamsui River's ecological security and calibration parameters, the model mathematical equations were screened and setup. Indicator changes and non-linearity have been processed using Vensim lookup, thus the establishment of the system dynamic flow diagram (Fig. 6).
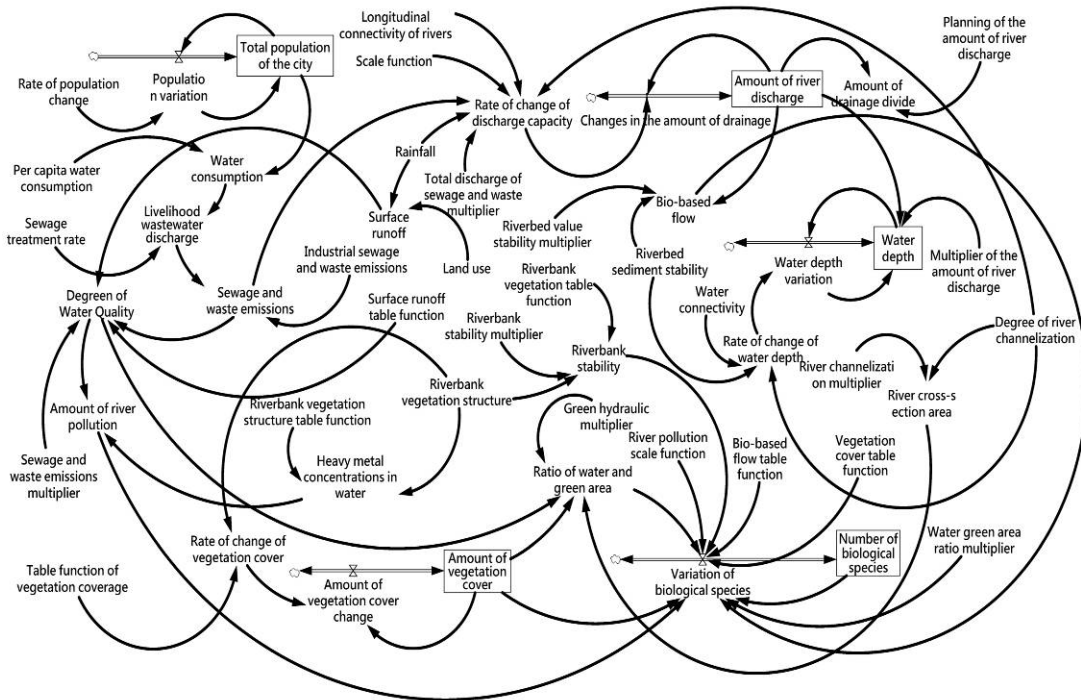
Fig. 6 The dynamic flow diagram of the urban river ecology security system

The urban river discharge security sub-system includes an level (River discharge), one rate (Variation of discharge), eight auxiliary variables (longitudinal connectivity of rivers, rainfall, variation of discharge capacity, the discharge difference, surface runoff, bio-based flow, riverbed sediment stability multiplier, total sewage and wastewater emission multiplier), and one constant (the river discharge planning). In the dynamic flow diagram of the discharge security sub-system (Fig. 5-8), the total of river discharge is one level, which is the accumulated change in the amount of drainage inflow. The product of river discharge and discharge rates of change are the change values of the annual river discharge, indicating the total of the annual river discharge. Through the longitudinal connectivity of rivers and the degree of river channelization, the variation of discharge was measured and calculated. Then, based no the variation of discharge, the Variation of discharge was calculated, and the river discharge security sub-system was calculated. The main dynamic equations are as shown in Table 2.

Table 2 The dynamic equation of the discharge security sub-system

Index type	Index name	Equation
Level	River discharge	INTEG Variation of discharge, 5.88813e+008)
Rate	Variation of discharge	River discharge*Variation of discharge capacity
Auxiliary variable	Longitudinal connectivity of rivers)	Exogenous variables, Source Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan)
Auxiliary variable	Rainfall	Exogenous variables, Taipei City Government, The Central Weather Bureau
Auxiliary variable	Variation of discharge capacity	Degree of river channelization*longitudinal connectivity*rainfall lookup (rainfall)* Sewage and wastewater emissions* Total sewage and wastewater

		emission multiplier
Auxiliary variable	Discharge difference	River discharge planning-River discharge
Auxiliary variable	Surface runoff	Land use* rainfall
Auxiliary variable	Bio-based flow	River discharge*riverbed sediment stability*riverbed sediment stability multiplier
Auxiliary variable	Riverbed sediment stability multiplier	Determined based on the non-linear relationship between the riverbed sediment stability and bio-based flow
Auxiliary variable	Total sewage and wastewater emission multiplier	Determined based on the non-linear relationship between the total wastewater discharge and variation of discharge
Constant	River discharge planning	Exogenous variables, 1.3608e+009

The purification security sub-system is constituted by six auxiliary variables (the amount of river pollution, Degree of Water Quality, heavy metal concentrations in water, embankment vegetation structure, land use, and sewage and wastewater emission multiplier. The amount of river pollution is the total of the Degree of Water Quality and heavy metal concentrations in water; the land use is the product of the different land use types and areas and permeability, resulting in disparities in the surface runoff and changes in the heavy metal concentrations in water; the heavy metal concentrations in water is the product of the embankment vegetation structure and embankment vegetation structure lookup; the Degree of Water Quality are subjects to the effects of surface runoff, ratio of water to green area, and sewage and wastewater emissions; if first-hand data of the embankment vegetation structure values cannot be acquired from the database, historical aerial photographs shall be used to depict the number of trees and shrubs and the areas they occupy. The total number of the trees and shrubs is the number of the vegetation structures. The main dynamic equation is as shown in Table 3.

Table 3 The dynamic equation of the purification security sub-system

Index type	Index name	Equation
Auxiliary variable	Amount of river pollution	Heavy metal concentrations in water
Auxiliary variable	Degree of Water Quality	Surface runoff lookup (surface runoff flow)*sewage and wastewater emissions*sewage and wastewater emissions multiplier
Auxiliary variable	Heavy metal concentrations in water	Embankment vegetation structure*embankment vegetation structure lookup (embankment vegetation structure)
Auxiliary variable	Embankment vegetation structure	Exogenous variables, determined based on historical aerial photographs.
Auxiliary variable	Land use	Exogenous variables, source: Taipei City Government
Auxiliary variable	Wastewater discharge multiplier	Determined based on the non-linear relationship between the sewage and wastewater emissions and Degree of Water Quality.

The water security dynamic model includes one level (the total population of the city), one rate (population variation), seven auxiliary variables (rate off population change, per capita water consumption, sewage and wastewater emissions, sewage treatment rate, water consumption, livelihood sewage and wastewater emissions, and

sewage and wastewater emissions). The sewage and wastewater emissions indicate the comprehensive performance of the urban water consumption and sewage treatment rate. At present, Taipei City's sewage treatment rate (sewage and wastewater pipes) has shown a yearly increase trend, and the rate reached 100% in 2010. Therefore, the sewage treatment rate after 2010 has been set as 100%. The main dynamic equation is as shown in Table 4.

Table 4 The dynamic equation of the water security sub-system

Indicator type	Indicator name	Equation
Level	Total population of the city	INTEG (Population variation, 2.63994e+006)
Rate	Population variation	Total population of the city*rate of population change/1000
Auxiliary variable	Rate of population change	Exogenous variables, source: Directorate-General of Budget, Accounting and Statistics, Executive Yuan, R.O.C. (Taiwan)
Auxiliary variable	Per capita water consumption	Exogenous variables, source: Water Resources Agency, Ministry of Economic Affairs
Auxiliary variable	Sewage and wastewater emissions	Exogenous variables, source: Water Resources Agency, Ministry of Economic Affairs
Auxiliary variable	Sewage treatment rate	Exogenous variables, source: Taipei City Government
Auxiliary variable	Water consumption	Total population of the city*per capita water consumption
Auxiliary variable	Livelihood sewage and wastewater emissions	Water consumption*0.8*100- Sewage treatment rate)/100
Auxiliary variable	Sewage and wastewater emissions	Industrial sewage and wastewater emissions + livelihood sewage and wastewater emissions

The habitat security sub-system includes one level (water depth), one rate (water depth variation), six auxiliary variables (Rate of water depth variation, riverbed sediment stability, the degree of river channelization, riverbank stability multiplier, and river discharge multiplier), and one constant (water connectivity). As the riverbed sediment stability is the product of the riverbank stability multiplier, embankment vegetation structure, and embankment vegetation lookup, the river channelization and water connectivity were to measure the rate of water depth variation. Based on the rate of water depth variation, the water depth values were determined. The river course cross-section area and river stability jointly affect the number of biological species, which are considered important indicators of the habitat security sub-system. The main dynamic equation is as shown in Table 5.

Table 5 The dynamic equation of the habitat security sub-system

Indicator type	Indicator name	Equation
Level	Water depth	INTEG (Water depth variation, 9.54474)
Rate	Water depth variation	Water depth* Rate of water depth variation
Auxiliary variable	Rate of water depth variation	Water connectivity*the degree of river channelization*riverbed sediment stability
Auxiliary variable	Riverbed sediment stability	Exogenous variables: source: Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan)

Auxiliary variable	Riverbank stability	Riverbank stability multiplier*embankment vegetation structure*embankment vegetation lookup(embankment vegetation structure)/1e+006
Auxiliary variable	Degree of river channelization	Exogenous variables; estimated and determined by the history aerial photographs
Auxiliary variable	Riverbank stability multiplier	Determined based on the non-linear relationship between the embankment vegetation structure and riverbank stability
Auxiliary variable	River discharge multiplier	Determined based on the non-linear relationship between River discharge and water depth
Constant	Water connectivity	Exogenous variables: estimated and determined based on historical aerial photographs

The biosecurity dynamic model contains two levels (number of biological species and the amount of vegetation cover), two rates (variation of biological species and the amount of change of vegetation cover), six auxiliary variable(River cross-section, ratio of water to green area, variation of vegetation cover, water green area ratio multiplier, river channelization multiplier, and green hydraulic multiplier). The amount of vegetation cover, riverbank stability, number of biological species, the amount of river pollution, bio-based flow, and ratio of water to green area affect the biological species' survival rates, which further affect the number of biological species; the river cross-section is the product of the degree of river channelization and ratio of water to green area; Degree of Water Quality that jointly affect changes in the number of biological species were used to calculate the amount of vegetation cover that is relative to the Degree of Water Quality. The product of the said values and the river cross-section was used to estimate the ratio of water to green area, and the action of the three was used to calculate the number of biological species, thus the constitution of the biosecurity sub-system core. Based on this correlation, the dynamic flow diagram of the biosecurity sub-system was constructed. The main dynamic equation is as shown in Table 6.

Table 6 The dynamic model of the biosecurity sub-system

Indicator type	Indicator name	Equation
Level	Number of biological species	INTEG (Variation of biological species, 21)
Level	Amount of vegetation cover	INTEG (The amount of change of vegetation cover, 145)
Rate	Variation of biological species	Riverbank stability* Number of biological species* The amount of vegetation cover* Vegetation cover lookup (amount of vegetation cover)* River pollution lookup (amount of river pollution)* Bio-based flow lookup (Bio-based flow)/100*(Ratio of water to green area*10000)* Water green area ratio multiplier
Rate	Amount of change of vegetation cover	Amount of vegetation cover*variation of vegetation cover
Auxiliary variable	River course cross-section area	Degree of river channelization* River channelization multiplier
Auxiliary variable	Ratio of water to green area	(Amount of vegetation cover/river course cross-section area)*Degree of Water Quality*green hydraulic multiplier
Auxiliary variable	Variation of vegetation	Embankment vegetation structure*vegetation coverage lookup(embankment vegetation structure)/10

	cover	
Auxiliary variable	Water green area ratio multiplier	Determination of the non-linear relationship based on the ratio of water to green area and variation of the number of biological species
Auxiliary variable	River channelization multiplier	Determination of the non-linear relationship between river channelization and river course cross-section area
Auxiliary variable	Green hydraulic multiplier	Determination of the non-liner relationship between the ratio of water to green area and Degree of Water Quality

Regarding the system dynamic model validation, Coyle, Exelby (2000) and Sterman (2002), etc. advocate that, the system dynamic model building and the dynamic simulation process need to inter-contrast compare repeatedly the model simulation results and the real system quantification information, in order to constantly test and adjust the model validity, to confirm all the behavioral characteristics of the model, and to demonstrate the behavioral characteristics of the real-world.

The indicator parameter confirmation is to compare the simulated parameter values with the real system values in order to make the simulated behavior of the model reasonable and consistent with the behavioral characteristics of the real system. By examining the data of 12 years from 1998 to 2009, this study analyzed the mean deviation between historical values and the simulated values to confirm the validity of the model. This urban river ecology security dynamic simulation system with the level as the object, through the parameter test (Table 7), all mean deviations were below 4.54%, and the mean deviation of all observed indicators were only 1.69%. These results satisfy the threshold requirement of "the number of indicators with deviation <5% accounted for 70%, and the deviation of a single indicator is not larger than 10%", fit quite accurately the real situation of the Tamsui Rive ecology security in Taipei City. The forecast capability for the real historical trend is fairly accurate.

4.3 Variables Sensitivity Analysis

Through the variables sensitivity calculation and analysis, this study sorted out the variables that had larger impact on the system to understand the main reasons for the system status changes, divided the variables into the active set and the passive set, and observed through the "Impact - Response Matrix" (Kano Noriaki 1999) the direct impact of strategy changes on the observed indicators. The active set variables contains all the exogenous variables in the system, accounting for a total of 12 indicators. The passive set variables are of five levels plus bio-based flow, the amount of water pollution, Degree of Water Quality, and the ratio of water to green area, accounting for a total of 9 indicators. The active set variables crossed the passive set indicators, generating 1188 data and accounting for a total of 108 kinds of changing relationships. This study conducted tests on 20% of the variation for each variable in the active set to observe the change extent of the passive set variables. As the value of the change extent may show positive impact of positive value or negative impact of the negative value, so after the change of the exogenous variables, the active set

Table 7 Comparison table of the historical value and simulated value of the Tamsui River ecological security in Taipei City

Item	Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Mean Deviation	χ2
River discharge (M³)	Historical value	588813408	289080576	444951360	317196864	99498240	139848768	324298080	412177248	375193728	444737952	287871840	226458720	0.00%	0.0000
	Simulated value	588812992	289080352	444950976	317196608	99498176	139848672	324297856	412176960	375193472	444737664	287871648	226458560		
	Deviation	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		
The total population of the city(persons)	Historical value	2639939	2641322	2646474	2633802	2641856	2627138	2622472	2616375	2632242	2629269	2622923	2607428	0.00%	0.0000
	Simulated value	2639940	2641323	2646475	2633803	2641857	2627139	2622473	2616376	2632243	2629270	2622924	2607429		
	Deviation	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		
Water depth (m)	Historical value	9.54	9.34	9.53	9.30	9.01	9.08	9.17	9.14	8.82	8.50	7.69	7.48	3.09%	0.0169
	Simulated value	9.54	9.42	9.48	9.37	9.28	9.29	9.30	9.29	9.16	9.05	8.21	8.34		
	Deviation	0.00%	0.92%	0.54%	0.82%	3.07%	2.31%	1.43%	1.67%	3.89%	6.44%	6.76%	9.24%		
Number of biological species(species)	Historical value	21.0	34.0	14.0	24.0	45.0	36.0	19.0	59.0	48.0	35.0	21.0	43.0	0.83%	0.0013
	Simulated value	21.0	34.0	13.8	23.7	44.8	35.9	19.2	59.8	48.5	35.2	20.6	42.9		
	Deviation	0.00%	0.00%	1.62%	1.26%	0.52%	0.18%	1.09%	1.39%	1.06%	0.54%	1.92%	0.33%		
The amount of vegetation cover(m²)	Historical value	145.00	161.00	150.00	152.00	149.05	161.05	183.00	177.00	172.00	188.00	196.00	202.00	4.54%	0.0330
	Simulated value	145.00	149.33	154.53	159.08	163.79	168.68	175.94	181.13	186.45	194.49	202.88	208.86		
	Deviation	0.00%	7.25%	3.02%	4.66%	9.89%	4.74%	3.86%	2.33%	8.40%	3.45%	3.51%	3.40%		

Note: The simulation value of this model is by chi-square test to judge its degree of similarity with the historical value, a significant level is 0.05. If $\chi^2 \leqq \chi^2_{0.05}$ (n -1=11)= 19.675, it will be considered that the historical value of the variable is consistent with simulation value. $\chi^2 =$ $\sum_{n=1}^{18}\left(\frac{\beta-\alpha}{\beta}\right)^2$, where, α is the simulation value of system dynamics model; β is the historical value; n is the number of tests.

variables were taken to contrast with the original simulation data, to obtain the arithmetic mean of the absolute value of the gap in 12 years and then conduct the contrast with the mean difference of the original simulation data in 12 years. The evaluation method is to give 0 points to the ones that completely have no change; 1 point to the ones with mean difference less than 1/8; 2 points for between 1/8 and 1/4 ; and 3 points for larger than 1/4.

The results show (Table 8) that the variables in the active set that has the largest impact on the overall system in sequence are per capita water consumption, sewage treatment rate, rainfall, the degree of river channelization, longitudinal connectivity of rivers, and the embankment vegetation structure; in the passive set, the ones that are most affected by this active set are in sequence ratio of water to green area, bio-based flow, the amount of river pollution, Degree of Water Quality, and the number of biological species. In this analysis, those variables with high PS values as highly sensitive indicators of the table the same way the system can be inferred the impact of higher In this analysis, those variables with high PS values as highly sensitive indicators, likewise the indicators impact highly on trend of system change. Overall, water security-oriented strategy implementation has the highest correlation with the development of urban river ecology security, followed by habitat security, and the discharge security. This study uses the sensitive indicators of embankment vegetation structure, the degree of river channelization, longitudinal connectivity of rivers, etc. as the bases for scenario simulation to understand the extent of the impact of the active set variables after the implementation of strategy, and by changes of the indicators of the number of biological species, the amount of river pollution, the amount of river discharge, etc., to conduct evaluation of the relevant strategy (Table 8).

Table 8 The sensitivity analysis (variables - response matrix) of urban river ecology security system

Variable name	Longitudinal connectivity of rivers)(*)	Rainfall(*)	The river discharge planning	Embankment vegetation structure)(*)	Land use	Rate of population change	Per capita water consumption(*)	Industrial sewage and wastewater emissions	Sewage treatment rate(*)	Riverbed sediment stability	Water connectivity	The degree of river channelization(*)	PS
River discharge	3	3	0	0	0	1	3	1	3	0	0	3	17
Total population of the city	0	0	0	0	0	2	0	0	0	0	0	0	2
Water depth	2	3	0	0	0	1	3	1	1	2	2	2	17
Number of biological species	1	1	1	3	1	1	3	1	3	1	1	2	19
Amount of vegetation cover	0	0	0	2	0	0	0	0	0	0	0	0	2
Bio-based flow	3	3	0	0	0	1	3	1	3	3	0	3	20
Amount of river pollution	1	2	1	3	2	1	3	1	3	1	1	1	20
Degree of Water Quality	1	3	1	1	3	1	3	1	3	1	1	1	20
Ratio of water to green area	1	3	1	2	3	1	3	2	3	1	1	3	24
AS	12	18	4	11	9	9	21	8	19	9	6	15	

Note: 1. AS: impact value, AS = Σ-line value, indicating the summation of the active impact value of the variables.

2. PS: response value, PS = Σ column values, indicating the summation of the passive impact value of variables.

4-4 Analysis of Strategy Scenario Simulation

This study, by goal-orientation, set up clear strategy objectives and implemented the strategy step by step (Legasto & Maciariello, 1980). With the increase of the number of biological species as the check basis, the improvement of river ecological conservation function, reduction of river pollution index, the enhancement of flood dredging capacity of the river as strategic objectives, this study observed the trends of behavioral change after the implementation of a single and complex strategies of the system model on embankment vegetation structure, the degree of river channelization, longitudinal connectivity of rivers, and the trends of the changes of 9-sensitive endogenous variable indicators. This test method can be used to observe the behavior characteristics performed by sensitive endogenous variables under the stimulation of the input variables in the absence of other noise interference to assist decision makers to find the leverage points of effective strategies.

1. Single Scenario Simulation Analysis

(1) Strategy 1 - Environmental purification strategy – implementation of multi-layer planting of embankment vegetation, to create a hydrophilic green riverbank

Taipei City proposed the "Clean, Green, Hydrophilic Taipei City" concept as the environmental and ecological development vision in 2020. Plans have been made to build or rebuild many riverside parks to actively promote the development and construction of park greens. In 2009, the Tamsui River reduced to moderate pollution (PRI value is 4.18), but was limited by river management regulations. As trees cannot be planted within 20 meters of the surface of the water, the enhancement of plant diversity and amount of green is limited. This study targets to increase the numerical value of the embankment vegetation structure by 2 times in 2020, and conducted different approaches to enhance the vegetation structure during 2011-2020 by simulation approaches that the Strategy 1-1 to increase by 7% slowly each year, Strategy 1-2 to increase by 70% in the initial stage, while Strategy 1-3 to increase in small scale in the initial stage and to increase in high-intensity in medium stage.

Strategy 1-1: after the interference of raise by 7.0% embankment vegetation structure, the amount of vegetation cover continued to increase slightly, causing the situation of a slight rise continuously in the number of biological species, ratio of water to green area, while the heavy metal concentrations rapidly decline in short-term, but showing increase in medium-term and long-term; the situation that the amount of river pollution continues to increase slightly after initial dropping explains that the major role of the interference rise of embankment vegetation structure was to increase the amount of woods, shrubs, although there is long-term influence on the growth of biological species for the river, it is the short term benefits in reducing the amount of river pollution, but for long-term and medium-term administrative implementation to curb the pollution is disadvantageous.

Strategy 1-2: to implement reinforced planting of multi-layer plants for the strategy of green embankment. This case simulated river green renovation program to increase amount of vegetation by 70% in the initial stage, and then with the increasing rate of 3.5% per year starting from 2016 to raise the amount of river bank vegetation. In this case, the number of biological species shows decline in short-term (2010-2012), increased year by year in long and medium-term, the numb of biological species in 2020 compared to Strategy 1-1 were increased by 10%, the amount of river pollution compared to Strategy 1-1 were increased only by 2%. In the short term reinforced green strategy, the amount of river pollution rises only in the initial stage, but in long- and medium-term showed fluctuations in a steady state, Therefore it is not conducive to the purification security in the initial stage, but the long and medium-term trends of steady state can help control of the implementation of changes in river pollution, Reinforced green strategies should take into account of the status of both biosecurity and purification security, in implementation must propose the immediately effective measures to respond for river pollution prevention and control, by two-pronged approaches of the increase of planting of multi-layer plants and reduction of the amount of pollution to ensure the effective maintenance of the river ecological security.

Strategy 1-3: continues to carry out 3.5% of embankment vegetation structure raise till 2015 and then implement reinforced 70% increase of embankment vegetation structure, observed the data performance, its mutation rate is similar to Strategy 1 -1, the number of biological species only slightly increased by 2013, a substantial increase after 2015. It shows Strategy 1-3 with slow-progress way to increase multi-layers of embankment vegetation structure can stimulate the gradual increase in the number of biological species; though the amount of river pollution is not obvious in an initial stage, but sustains a steady state in the final stage and will not increase any more but show a downward trend.

Strategy 1-1, the implementation of strategy of green embankment vegetation structure by slow-progress in 7% showed a slight increasing trend in the biological species and ratio of water to green area in the annual period of medium term, and showed the status of an unstable increase in the amount of river pollution, and is not conducive to long-term operation of river pollution control. Strategy 1-2 for the control of the amount of river pollution shows rising slowly, the relative number of the biological species shows decreasing trend initially and then increased year by year, the number of species in 2020 has the highest value among the three simulation strategies; the amount of river pollution shows increase in the initial stage then getting steady at later stage. The observation of the medium and long-term process shows that Strategy 1-2 has a positive efficacy in increasing river ecology security. Strategy 1-3 is a slow-progress way to increase the amount of embankment vegetation structure year by year, increase the number of biological species, so mitigation of the amount of river pollution is conducive to the control the amount of river pollution.
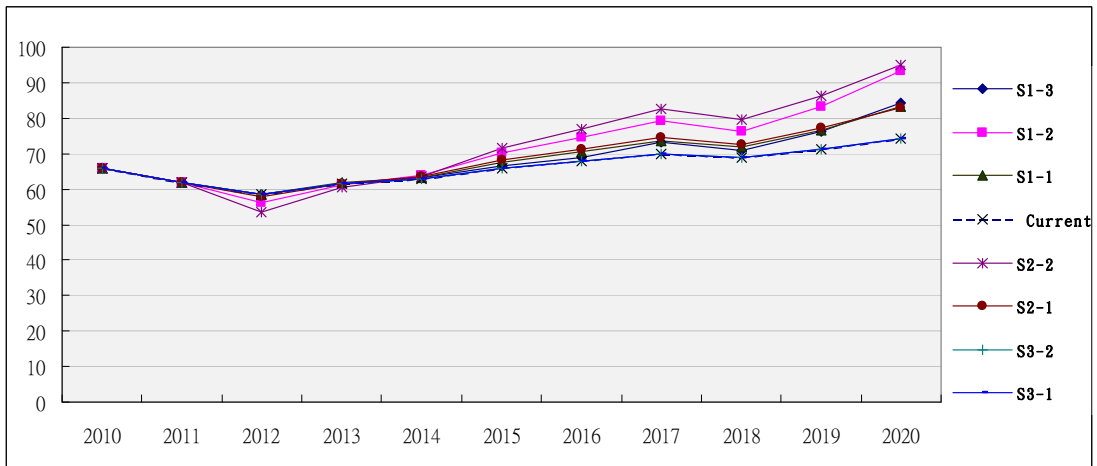
Figure 7 Diagram of the changing trend of the number of biological species under a single strategy
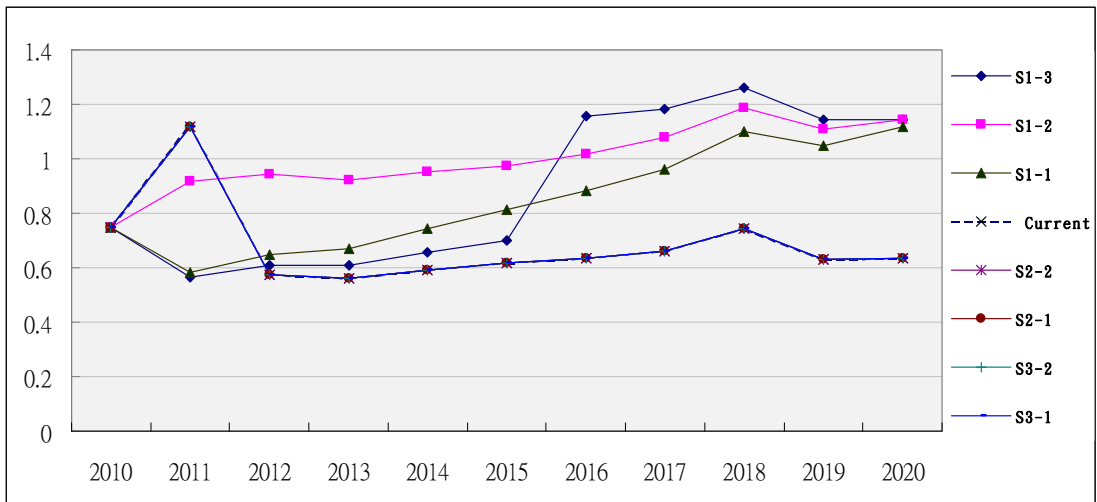

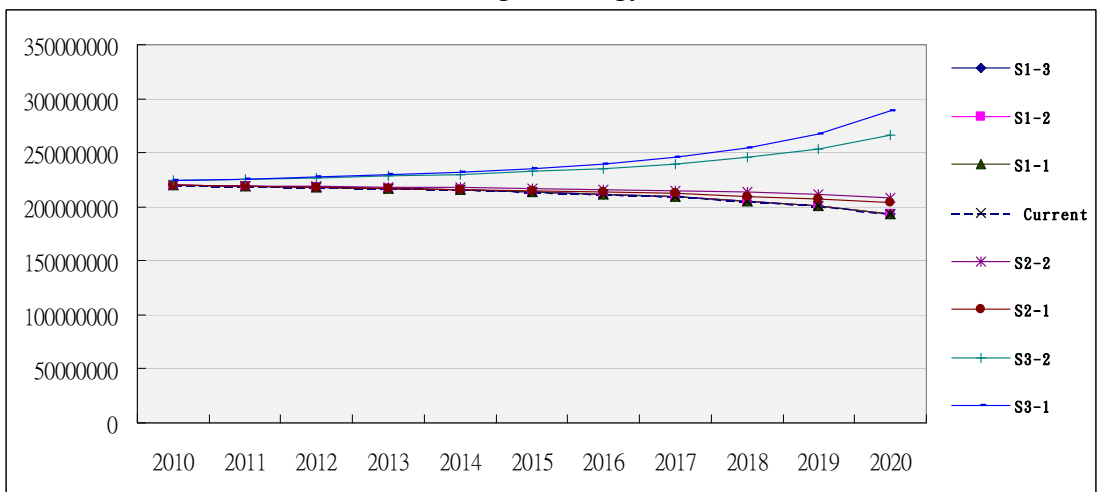Figure 8 Diagram of the changing trend of the amount of river pollution under a single strategy

Figure 9 Diagram of the changing trend of the amount of river discharge under a single strategy

(2). Strategy 2 - reduce the degree of river channelization, to improve breeding habitat opportunities

The cement layer at the bottom of the river is removed to enhance vegetation, and the cement slope is replaced by a masonry slope to revive the river's ecosystem. All concrete ditch rivers have the possibility of ecological restoration. However, whether or not the effectiveness of its implementation will conflict with flood control and discharge function is to be determined. In this study, by the simulated Strategy 2-1 reinforced de-channelization strategy in short-term, Strategy 2-2 low intensity de-channelization strategy in long-term, contrast the trend of change in indicator value to observe the Tamsui River ecology security changes in Taipei City.

Strategy 2-1 implementation in the short-term (2011) is to remove the concrete structure of the river bed and river banks in low intensity, then change the river course structure in the way of slow-progress (-5.0%) year by year, initially producing no stimulation change in the number of species, increasing at a medium stage year by year, the number of species in 2020 will be higher than the simulated values by 10%, indicating that the implementation of river de-channelization engineering methods to improve the river ecology can relatively improve the ratio of water to green area, and has a positive efficacy for the number of biological species. The amount of river pollution did not generate a significant interference, indicating that the change of channelization is not a beneficial practice for the control of the amount of river pollution. The implementation of slow-progress of de-channelization caused a slight increase of the amount of river discharge, but the effect is not significant, only after medium and long periods were large differences in the amount of discharge observed.

Strategy 2-2 implementation strategies remove the concrete structure in riverbeds and riverbanks with high intensity in a short period (2011) as and Strategy 2-1 ,then keep the river course structure in the same statue (leave 2), have it change to the ecological engineering construction of river banks, and generated significant changes to the number of biological species; although the number of biological species decline in the short term, it showed the trend of continuous increase in medium and long-term, in the final simulation value the number of biological species is much higher than the simulation value. The ratio of water to green area increased substantially, the amount of river discharge is also relatively increased, although in the long-term it showed a downward trend, but its discharge value is still higher than the original simulation value. The results show that de-channelization strategy can provide more habitats for aquatic plants and animals; reduce the degree of channelization of riverbanks has a positive effect on bio-security and habitat security.

(3) Strategy 3 - Strengthen the Longitudinal Connectivity of Rivers to Reduce Flood Risk

Longitudinal connectivity of rivers characterized the change of budget of works departments for the river dredging. Remove mud base of the river bottom and the elimination of garbage and obstacles on river surface can increase the flow rate of river discharge and enhance discharge capacity. River dredging for 1998-2009 changed in the amount of investment by the annual rate of change in a great scale from -12% to 65%, and maintained an upward trend in the past two years. By 2011, apart from maintaining a fixed amount for the original model, it is proposed to invest 1 – 0.5 times of budget through longitudinal connectivity of rivers at the initial stage, by way of growth rate of 5% to observe urban river ecology security changes.

Strategy 3-1 After the implementation of longitudinal connectivity of rivers input with 1 time dredging rate on annual growth rate of 2011, compared with the original model, the amount of river discharge increased; the amount of river discharge was stable in the initial stage, the rate of change increased gradually in the medium stage; The rate of change reached up to 7.9% in 2020. The discharge value increased exponentially, indicating that the change in the amount of river discharge was positive subject to longitudinal connectivity of rivers. Bio-based flow showing an increasing trend is a positive benefit for biological and habitat security. Analysis by the amount of change shows no significant impact for the number of biological species and the amount of river pollution. Strategy 3-2 after the implementation of longitudinal connectivity of rivers with input of dredging rate 0.5 times of annual growth rate of 2011, compared with the original model, the amount of river discharge increased; the bio-based flow and the amount of river discharge was stable in the initial stage, rate of change increased gradually in the medium stage. The rate of change reached high up to 5.1% in 2020; discharge amount increased with the improvement of the longitudinal connectivity of rivers and bio-based flow showed an increasing trend, but with a lower rate of increase than the value of simulation 7.7% as in Strategy 3-1. Slightly declining in water depth, the simulation value of water depth is higher than that of Strategy 3-1, but the difference is not significant, the adjustment of longitudinal connectivity of rivers relatively reduced the height of the river water depth.

Overall, to conduct control of longitudinal connectivity of rivers through the river dredging rate of control, both Strategies 3-1 and 3-2 will result in a decline of water depth indicators of the river generating a relatively upward affect to the amount of river discharge and the amount of bio-based flow; but does not affect the indicators of the number of biological species, the amount of river pollution, and ratio of water to green area, etc. Compared to the river dredging rate of high-intensity, discharge capacity of river dredging rate of low-intensity is lower, but in overall the input of slightly and continuously increasing dredging rate has a significant effect for the discharge security.

Found in a single scenario simulation was that to apply different strategic measures to mobilize embankment vegetation structure, the degree of river channelization, longitudinal connectivity of rivers will produce a number of biological species, partly different from that the strategy expected. The strategic purpose of the amount of water pollution, ratio of water to green area and the amount of river discharge to a limit achieved the strategy objectives to enhance the number of biological species, improve the environment purification, and reduce flood risk; if the comprehensive strategy objectives is expected, a variety of strategy scenarios is required to be provided simultaneously before multiple objectives can be achieved at the same time.

2. Comprehensive Scenario Analysis

"Urban river ecology security" refers to the result of interaction of the eco-system with the external interference of the environment, and more need for the use of integrated multi-strategy mechanism to regulate state-level of the urban river ecology security: As a single strategy input test cannot improve a variety of system behavior simultaneously, therefore, it needs to explore the effectiveness of the combination of a multifaceted strategy input to improve the system. In this study,

taking 2011 as the base period, compose the aforementioned strategies into two, to conduct the complex strategy simulation and strategy evaluation.

(1). Complex strategy 1 (cs1) - increase the number of biological species, improve the environment purification, and reduce flood risk

Complex strategy 1: Use this strategy to implement 7.0% slow-progress promotion on the embankment vegetation structure, remove the degree of channelization in low-intensity, raise longitudinal connectivity of rivers in high intensity, resulting in the presentation of continuously and slightly increasing status on the number of biological species, ratio of water to green area. The situation that the amount of vegetation cover continued to slightly rise, the amount of river pollution each year ramps-up shows the implementation of complex strategies 1 can improve relatively ratio of water to green area, the number of biological species, but also affect the changes in the amount of river pollution, resulting in the pressure on the control of the river pollution at later stage. The amount of river discharge was slightly increased, short and medium-term effects were not significant, but the long-term performance showed a large difference in the amount of discharge.

(2) Complex strategy 2 (cs2): increase the number of biological species to improve the environment purification, and reduce flood risk.

Complex strategy 2: Use this strategy for the green embankment to implement planting of multi-layer plant species in high-intensity (70%), remove the concrete structure of the riverbed and the riverbanks with high-intensity within the short term, raise longitudinal connectivity of rivers with high-intensity. In this reinforced scenario, the number of biological species showing status of short-term decline, medium and long-term rise, the number of biological species in 2020 is more than that of the Complex strategy 1 by 55%, the number of biological species in 2020 is 2.1 times of the original simulation value (74 species increased to 155 species) showed that the Complex strategy 2 for the number of biological species to enhance has a positive effect, more able to increase the ratio of water to green area, is conducive to the implementation of river conservation strategy. The amount of river pollution is more than that of the Complex strategy 1 by only 2.7%, compared of the two the implementation of Complex strategy 2 has a more positive effect on the indicators of the number of biological species; the implementation of Complex strategy 2 can improve the indicators values of the amount of river discharge, its discharge value is lower than that of Complex strategy 1 by only about 5%, has a positive effect.

Overall, in comparison of simulation difference between Complex strategy 2 with powerful means and Complex strategy 1 by means of slow-progress, Complex strategy 2 can provide the results of river management high number of biological species, and high amount of discharge; for the amount of river pollution it shows improvement in the initial stage and turned to be stable in the medium and long-term. It shows the greening strategy that has been promoted for several years with the way of slow-progress, in terms of greening construction for the river, space planning and construction of the initial stage, controlling the planting in the performance of ecological capacity in medium and long-term schedule, is a long-term effective strategy. If planting seedlings set to 3-5 years as the waiting period for the root growth of vegetation, to give the time for planting cluster to get matured, significant efficacy

can be seen, for construction costs and control of the ecological footprint is a better choice. However, both Complex strategy 1 or Complex strategy 2 will cause the rise of the amount of river pollution, Complex strategy 1 performed a rising trend year by year, Complex strategy 2 after the rise in the initial stage the changes got smaller in extent, the amount of pollution was greatly affected by land-use and foreign sewage and waste discharge, it is proposed the implementation of these strategies should be coped with the supportive measures for controlling the reduction of pollution sources; the implementation of complex strategy 2 for the initial control of reduction of pollution volume makes future control rectification of changes in smaller amplitude, is more effective for the implementation of the strategy.
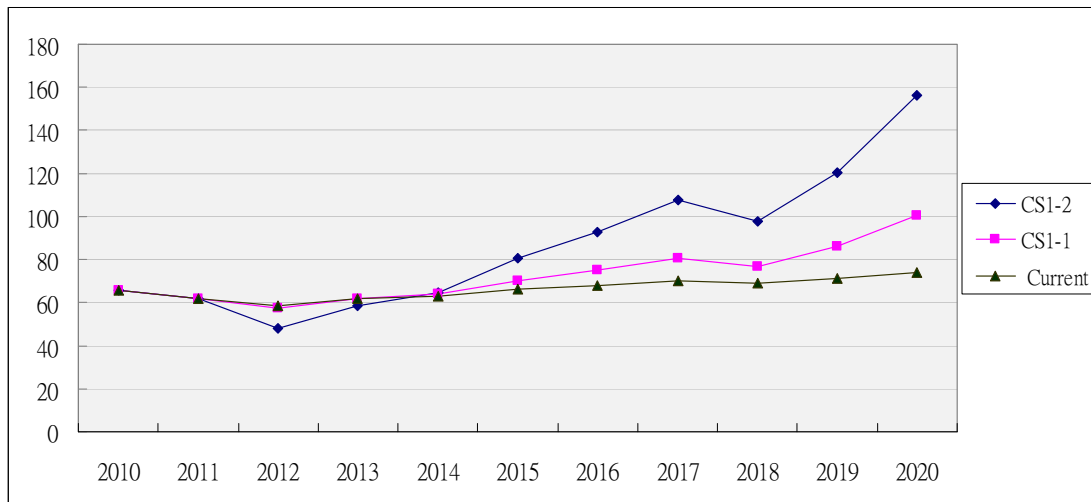

Figure 10 Diagram for the changing trend of Number of biological species in complex strategy simulation
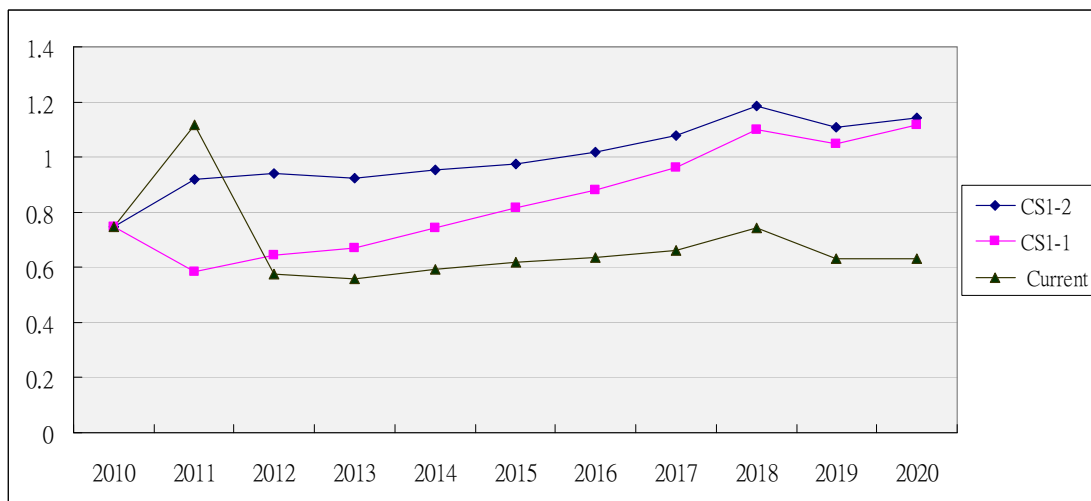

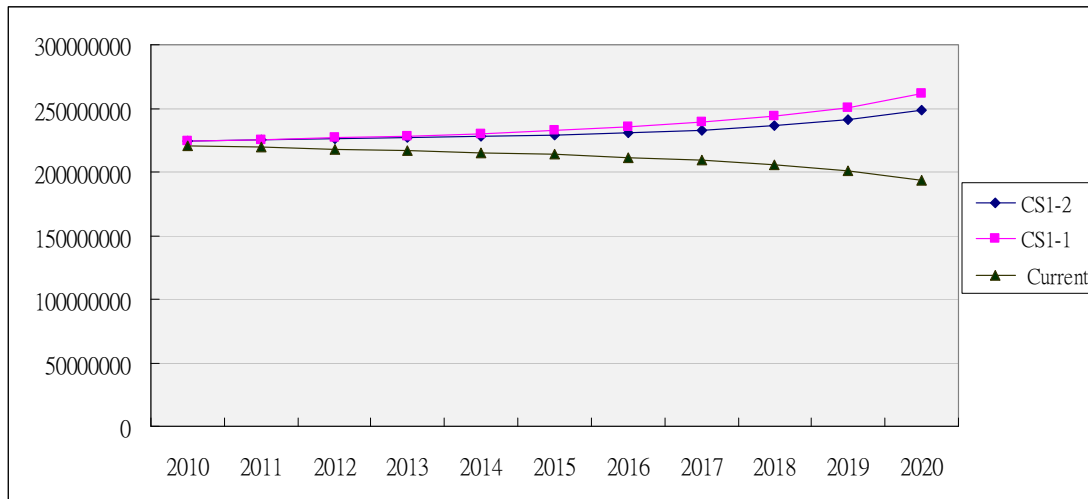Figure 11 Diagram for the changing trend of volume of river pollution in complex strategy simulation

Figure 12 Diagram for the changing trend of the amount of river discharge in complex strategy simulation
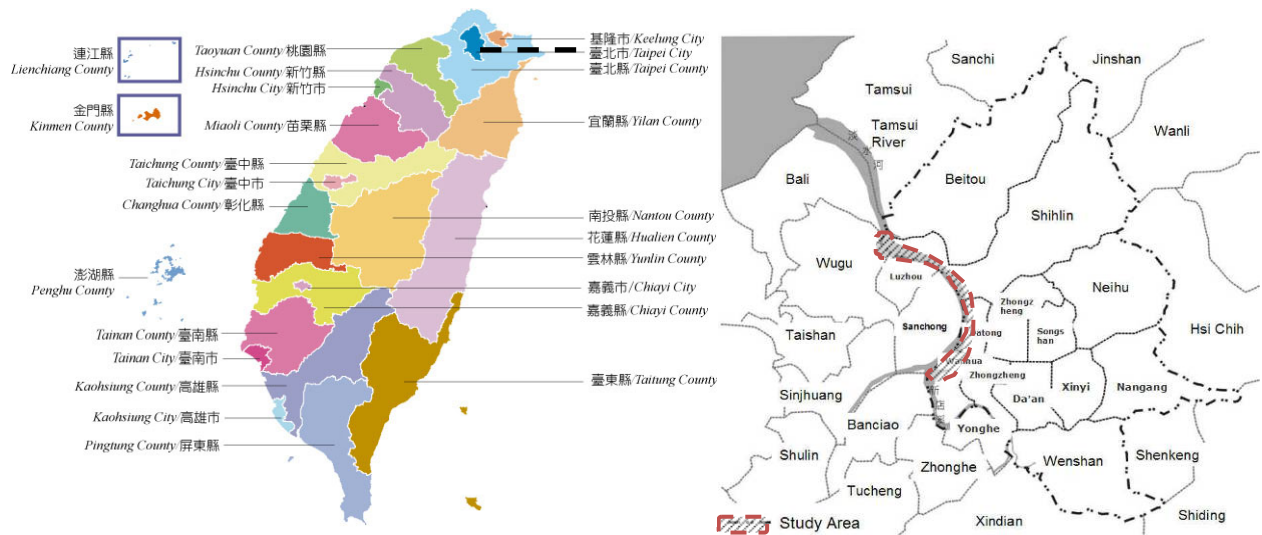

Fig13 The study areas boundary

5. CONCLUSIONS

In this study, we use literature reviews, Fuzzy Delphi expert opinion survey, to compile the indicator system for urban river ecology security by System Dynamics to survey the causation of the Tamsui River ecology security system in Taipei City and set up dynamic simulation model; through sensitivity analysis to grasp the key factors of the river ecological security. After the implementation of repeated testing, rectify the mode by means of constant testing of mode validity, to confirm all the behavioral characteristics of the mode, to make it able to demonstrate real-world behavior, and its validity tests including model purpose, structural behavior, confirmation of parameters and other processes, use of simulation results to improve the effectiveness of implementation of strategies, to achieve quality urban living environment.

This study made the strategic goal of securing efficient use of the ecological resources of urban rivers, creating a hydrophilic green river banks, improving breeding habitat opportunities for all organisms and reducing flood risk, the strategy

with changing trends of 9 sensitive endogenous variables to observe system mode in environmental purification - Conservation strategy to implement of planting multi-layer vegetation at embankment, - Discharge strategy to reduce the degree of river channelization, - The study of a single strategy of strengthening the longitudinal connectivity rivers and of the trend of the behavioral changes after the implementation of complex strategy shows that strategy simulation is viable, scientific, and flexible. Some conclusions of this study are the following:

1. Multi-approach association can be systemized and applied to the study of urban river ecology dynamics

Urban river ecology security is a high-order, nonlinear and time relay complex social - economic - natural systems, with systems engineering as the framework, through the systems engineering technology and science to construct the overall system and sub-system; through the Fuzzy Delphi method, questionnaires and consultation by experts effectively establish the objective, professional indicator system. By the System Dynamics Mold method, the complex can be simplified, clarify the causal and feedback relationship of each index variables in the system and the impact size of variation, and be able to implement strategy evaluation as a preventive measure, early warning facilities to become a feasible structure for the study of the urban river ecology security monitoring system.

2. Complex Scenarios Often Have a Better Strategy Evaluation than a Single Scenario

In a single scenario simulation, by applying different strategic measures to mobilize embankment vegetation structure, the degree of river channelization, longitudinal connectivity of rivers will produce number of biological species, the amount of water pollution, ratio of water to green area and the amount of river discharge partly differed from that expected by the strategy objectives. It is more likely to be unable to achieve the comprehensive objectives of the strategy. Complex scenario simulation is under the implementation of a multi-strategy, each still holds its own influence and can play a clustering effect, under the effects of conduction and synergistic, more able to comprehensively ensure the increase of the number of biological species, improve the environment purification and reduce the flood risk for the achievement of strategic objectives.

3. Optimization strategy must take into account the strategic objectives and the feasibility of limited resources

The optimization process of urban river ecology security strategy should first establish clear objectives, through the establishment and operation of system dynamics model, and run by the cause effect and logic of model, to identify strategy leverage point to improve the behavior of the system. Through strategy simulation to choose the preference to implement, in the general case, the program coordinated facilities worth more than the implementation of better performance, but natural resources are limited, should first look at the limitations of resources and the degree of difficulty in implementation; and to implement accordingly will have the optimum strategy evaluation, to achieve strategy objectives successfully.

REFERENCES

An, K.-G., Park, S. S., & Shin, J.-Y. ,2002, 《An evaluation of a river health using the index of biological integrity along with relations to chemical and habitat conditions", 《Environment International》, Vol. 28, No. 5, pp 411-420.

Barlas, Y. & Carpenter, S. , 1990,"Philosophical Root of Model Validation: Two Paradigm", 《System Dynamics Review》,Vol. 6 , pp 148-166.

Cheng, C.-B. ,2005,"Fuzzy process control: construction of control charts with fuzzy numbers ", 《Fuzzy Sets and Systems》, No. 154 , pp 287-303.

Ching-Ming ,Wang. ,1992, 《Rivers conservation》, pp.189 , National Museum of Natural Science, Taipei,

Chiung-Ying,Kuo., Yu-Ren,Guo.,Da-Yuan,Lin.,1995, 《The Guidelines of River Field Ecological Design》,Environmental Protection Administration Executive Yuan, ROC. (Taiwan), Taipei.

Chiung-Ying,Kuo.,2001, 《 Ecological considerations of River Design》, from http://www.tbroc.gov.tw/tbroc99 _3w/EcoEM/(at：11.March.2009)

Collins, K., Blackmore, C., Morris, D., and Watson, D. ,2007, "A systemic approach to managing multiple perspectives and stakeholding in water catchments: some findings from three UK case studies ", 《Environmental Science & Policy》, Vol. 10, No. 6 , pp 564-574.

Coyle, R.G. , 1996,《System Dynamics Modeling: A Practical Approach》, Chapman & Hall, New York.

Ho, Y. F., & Wang, H. L. ,2008, "Applying Fuzzy Delphi Method to Select the Variables of a Sustainable Urban System Dynamics Model ", Paper presented at the Proceeding of 《 the 26th International Conference of the System Dynamics Society》, Athens, PATRAS University ,Greece.

Ho, Y.F., Wang, H.L., Wang, H.C. & Liu, C.C. , 2009, "A System Dynamics Model for The Sustainable Management of Theme Park", 《Proceeding of the 27th International Conference of the System Dynamics Society》, Albuquerque, New Mexico, USA.

Ishikawa, A., Amagasa T.S., Tomizawa G., Tatsuta R. and Mieno H. , 1993, "The Max-Min Delphi method and fuzzy Deliph method viafuzzy in tegration ", 《Fuzzy Sets and System》" , No. 55 , pp 241-253.

Ladson, A. R., White, L. J., Doolan, J. A., Finlayson, B. L., Hart, B. T., Lake, P. S., et al. , 1999, Development and testing of an Index of Stream Condition for waterway management in Australia, 《Freshwater Biology》, Vol. 41, No 2 ,pp 453-468.

Legasto, A.A. & Maciariello, J. , 1980, "System Dynamics: A Critical Review", 《Studies in the Management Science》, Vol. 14 , pp 23-43.

Tong ,Qing-Bin, Wu, Ming-Jin, Li,Ming-Xu, Hung, Nian-Min, 《Establishment of Indicators and Framework of an Early Warning System for the Climate Change Impacts on Sustainability of River Assimilative Capacity》,Research Project report on the outcome,National Science Council Executive Yuan, ROC. (Taiwan), Taipei.

Sterman, J.D. , 2000, 《Business Dynamics: Systems Thinking and Modeling for a Complex World》, Irwin McGraw-Hill.

Wang, Y.-K., Stevenson, R. J. ,2002, "An ecological assessment framework for watershed management ", 《Journal of the Chinese Institute of Environmental Engineering》, No.12, pp 209-215.

Wang, H., Ho, Y., Wu, C. and Chen, K. ,2007, "Fuzzy evaluation method of virtual

reality for urban landscape design ", Paper presented at the《the International association of societies of design research》,Hongkong.

Wang, Lin,Gong Zhao-guo, Zhang Jiong, Li Yong-chang,2007,"Comprehensive Index System for Evaluation of Urban River Ecosystem Health", 《China Water & Wastewater》,Vol.23,No10,PP.97-100.

Wang, H.-L., and Wu, Y.-Y. ,2006, "The Construction of Urban Ecotourism Indicators-Application of Fuzzy Process Control ",《The 9th World Leisure Congress》.

Wu,E-nuo, Che,Yue, Yang Kai,2008, "Conceptualization and Characterization of River Health from a Distinct Criteria Approach by Using Content Analysis", Resources and Environment in the Yangtze Basin,Vol.17,No.6, pp.932-938.

Wu, Ching-I, 2011,《The Early Warning System Dynamics Simulation Model of Urban River Eco-Security》,Thesis of Phd.,Graduate institute of Architecture and Urban Design Chaoyang University of Technology.

Wu, Yi-Yen and Wang,Hsiao-Lin, ,2007,"Urban Ecotourism,a contradiction? ", 《International Ecotourism Monthly》, No. 90, pp 8-9.

Wu,Yi-Yen,2008, 《The Study of Urban Ecotourism System》,Thesis of Phd.,Graduate institute of Architecture and Urban Design Chaoyang University of Technology.

Xie,F. Zhang,G.,Zhou, Q., 2007, "The Influence of Ecological Security on City Ecosystem Service Value" ,J. Ecological Economy ,No.5S (2007),PP.362-364.

Yong-sheng Gao, Hao Wang,Fang Wang,2007, "Construction of Evaluation Index System for River's Healthy Life", Advances in Water Science, Vol.18 ,No.2, pp.252-257.

Zhao, R. and R.Govind. ,1991 , "Algebraic Characteristics of Extended Fuzzy Number ",《Information Sciences》, No. 54, pp 103-130.