ISSN 2616-5872 Vol.7, Issue 2: 1-6, DOI: 10.25236/AJEE.2025.070201

Study on the impact of Fish habitat suitability based on Hydrodynamic model under Waterway remediation

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Abstract: *This paper examines the impact of waterway remediation on fish habitat suitability in the Xiaolaitan spawning ground of the Liujiang River using the hydrodynamic model. The study simulates changes in water depth and flow velocity before and after the remediation and assesses their effects on habitat suitability for the "Four Major Chinese Carps." The results show that the impact is flow-dependent. In low-flow conditions, the spawning area decreases, but habitat suitability improves due to stabilized water depth. When the upstream flow is between 383-1000 m³/s, the remediation enhances spawning ground suitability. However, at higher flows, natural hydrodynamic forces dominate, reducing the effect of the remediation. The findings highlight the importance of flow regulation in balancing waterway navigation and ecological protection. The study recommends flow management strategies and ecological compensation measures to sustain fish habitats, especially during low-flow periods, ensuring both ecological protection and shipping efficiency.*

Keywords: *Waterway remediation, Habitat suitability index, Hydrodynamic model*

1. Introduction

The formation and maintenance of fish spawning grounds depend on the synergistic effects of environmental factors such as water temperature, current, water quality, substrate, light and attachments. When these conditions are met in a particular section of the river during the breeding season, an ecological hotspot for spawning in clusters is formed. The high sensitivity of these environments makes it possible for any human disturbance to affect fish reproduction, highlighting the ecological value of spawning ground protection. At present, the extensive implementation of waterway remediation projects has improved the shipping capacity through dredging and reef blasting, which has significantly changed the local hydrological characteristics while stabilizing the waterway and widening the waterway. Variations in key hydrodynamic parameters (e.g., water depth, flow velocity) may disrupt the environmental compatibility of the original spawning grounds, which in turn affects the reproductive success of fish [1].

This paper, the spawning ground of Xiaolaitan in Liujiang River was taken as the research object, and the MIKE21 hydrodynamic model was used to predict the hydrological change characteristics of the waterway after the remediation. By simulating the spatiotemporal evolution of key indicators such as water depth and flow velocity before and after the implementation of the waterway remediation the influencing mechanism of engineering measures on the suitability of fish habitat was revealed, and finally the regulation strategy of the coordinated development of shipping optimization and ecological protection was proposed, which provided a scientific basis for the protection of water ecology in the basin [2].

2. Introduction and validation of predictive models

2.1. Hydrodynamic model

MIKE21 is a two-dimensional mathematical model developed by the Danish Institute of Hydraulics, which can be used for better numerical simulation of two-dimensional free surface flow in the plane. The

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MIKE21 hydrodynamic model is based on the two-dimensional non-compressible Reynolds average N-S equation based on Boussinesq and hydrostatic pressure assumptions. The turbulence was modeled using the Smagorinsky (1963) sublattice-scale model in the large eddy simulation method. In this model, a vortex viscosity value related to the eigenlength scale is used to describe the subgrid scale transport. [3]

2.2. Model verification

2.2.1. Selection of calculation parameters

The roughness coefficient used in the two-dimensional digital model calculation is actually a comprehensive coefficient, which can reflect many factors such as the change of river plane morphology, water flow resistance, and topographic generalization. Generally, the measured hydrological data such as water level and flow velocity are reversed, and the adjustment is carried out according to the topography. The roughness coefficient of the river is 0.03~0.05.

2.2.2. The model calculates the range of the river section and the grid setting

The calculation area of this study is 1.2 km to 17.5 km downstream of the Honghua hydroproject and the total length is about 16.3 km. The number of grids in the calculation range was 12439 and the number of nodes was 6778, of which 1514 were in the Xiaolaitan fish spawning ground. The calculation range and grid settings of the model are shown in Figure 1.

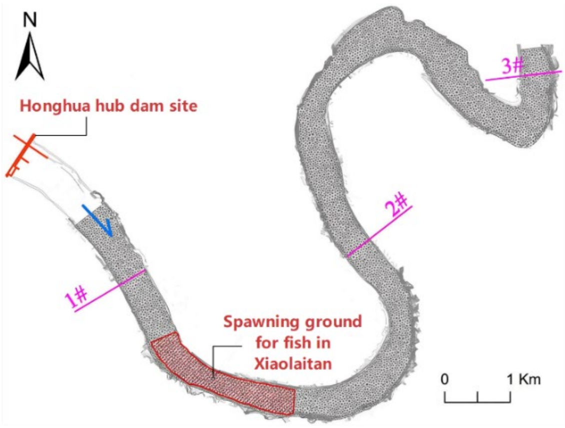

Figure 1: Calculate the river segment extent and grid settings.

2.2.3. Verification of water level and flow rate

Table 1. Comparison between calculated and measured values of verification section.

Verification sections	Measured water level	Calculate water level	Deviation
1#Left	60.22	60.18	-0.04m
1#Right	60.22	60.20	-0.02m
2#Left	59.32	59.35	+0.03m
2#Right	59.33	59.34	+0.01m
3#Left	59.00	59.03	+0.03m
3#Right	59.00	59.02	+0.02m

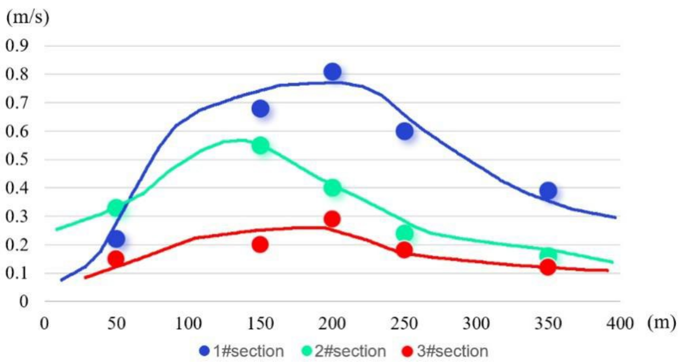

Figure 2: Comparison of flow velocity distribution in hydrological verification sections.

ISSN 2616-5872 Vol.7, Issue 2: 1-6, DOI: 10.25236/AJEE.2025.070201

Three hydrological verification sections were set up along the calculation section to observe the water level and flow velocity distribution of the left and right banks. The model verification was based on the comparison of the calculated water level and flow velocity on the left and right banks of the river section with the actual measured values when the flow rate was 500 m^3/s under the Honghua hydroproject on May 31, 2022. The comparison results of the calculated water level and the measured values of each hydrological verification section are shown in Table 1, and the comparison results of the calculated flow velocity of the sections are shown in Figure 2. The comparison results show that the deviation between the calculated value of water level and the measured value is less than 0.1m, and the flow velocity distribution of the calculated section is basically close to the distribution trend of the measured flow velocity, and the flow velocity error of most of the measured points is within 0.1m/s, and the maximum error is not more than 0.2m/s, indicating that the model can basically reflect the flow velocity of this river section. The results of the calibration verification of the water level and cross-section flow velocity distribution of the model show that the roughness coefficient selected this time can better reflect the comprehensive situation of the river section, and the calculated flow movement law of the river section simulated by the model is basically close to the actual situation, which can be used for the calculation and analysis of the hydrodynamic model.

2.3. Hydrohydraulic indexes and parameters of fish habitats

Habitat suitability index is a commonly used fish habitat evaluation method, which selects one or more variables from environmental factors and calculates the results according to a specific formula to quantitatively reflect the suitability of the region to the habitat of the species. The spawning habitat of "Four major Chinese carps" was greatly affected by two environmental factors, water depth and flow velocity, and the suitability curve of water depth and flow velocity of "Four major Chinese carps" is shown in Figure 3. [4]

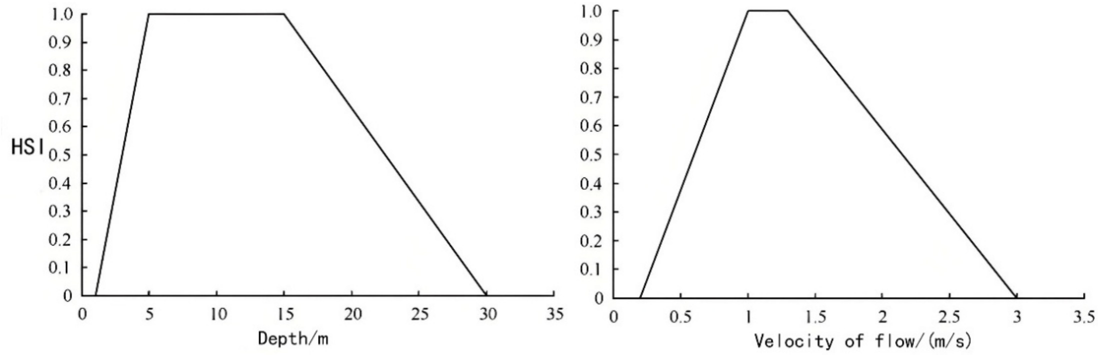

Figure 3: Spawning water depth and flow rate suitability curves.

The habitat suitability index (HSI) is calculated using the following equation:

$$HSI=(I_h \times I_v)^{1/2} \quad (1)$$

Where HSI is the habitat suitability index, and the suitability is bounded by 0,1, the higher the calculation result, the more suitable for fish spawning. I_h and I_V are the suitability of water depth and flow velocity, respectively, which are determined by the suitability curve. [5]

3. Predictive scenario

3.1. Upstream and downstream hydroproject

3.1.1. Upstream Water Conservancy Hub Dispatch and Operation

The dead water level of the Honghua Water Conservancy Hub is 77.13m, and the normal storage level is 77.63m. The hub is dispatched based on the upstream inflow in three flow ranges: when the upstream flow is less than 4800m^3/s, the normal storage level of 77.63m is maintained; when the flow is between 4800m^3/s and 9000m^3/s, to ensure that the water level at Liujiang Bridge does not exceed 78.63m and to facilitate reservoir recovery, discharge and storage are managed according to the water level in front of the dam, forecasted flow, and actual flow; when the flow exceeds 9000m^3/s, the reservoir discharges to 72.63m, and during larger floods, it will continue to discharge until the forecasted flow is less than 4800m^3/s and the actual flow is less than 8200m^3/s, at which point the reservoir will gradually recover to

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77.63m.

3.1.2. Downstream Water Conservancy Hub Dispatch and Operation

The downstream water conservancy hub maintains the reservoir water level at the flood limit level (power generation dead water level) of 47.73m during the flood season from June to August, and operates according to the maximum allowable power generation water level of 59.73m in April, May, and September. From October to March, the maximum allowable power generation water level is 61.13m, the normal storage level. When the flow during the flood season exceeds 20,000m³/s, the reservoir implements flood control measures, and the water level can be lowered to the minimum flood control level of 44.13m.

3.2. Contextual traffic

The spawning month of the " Four major Chinese carps " is mainly May ~ July every year, that is, the flood season of Liujiang, so the influence of the flood season is mainly considered. The fish spawning ground is located at the tail of the downstream hydropower hub, with a maximum water storage level of 61.13m, which can be connected with the water level of the Honghua Water Conservancy Dam, but under the flood water level during the flood season, the water level in front of the downstream hydropower hub dam is significantly reduced, and the long river section of about 66 km under the Honghua Water Conservancy Dam is restored to a natural waterway. In summary, it can be seen that during the flood control dispatch in June~August of the flood season, the downstream water conservancy hub maintains a low water level, and the river section of Xiaolaitan fish spawning ground is restored to a natural river waterway, and the hydrological situation of the river section is mainly affected by the upstream water at this time. Combined with the design documents of the Liujiang waterway remediation, the statistical data of Liuzhou Station, the nearest hydrological station in the upstream of the river section, and the dispatching and operation mode of the Honghua Water Conservancy Hub, the typical upstream water volume selected for the model calculation is determined, as shown in Table 2.

Table 2: Selection of Typical Inflow Volume.

flow rate(m^3/s)	383	700	1000	2500	4800	9000	14100	22500
remark	Navigable minimum flow	/	/	/	Dispatch eigenvalues	50% Flood	10% Flood	1% Flood

4. Prediction results and analysis

In this study, the changes of water depth and flow velocity in the river section of Xiaolaitan fish spawning grounds before and after the improvement of the waterway were compared and analyzed, and the suitability of the fish spawning grounds before and after the improvement of the fishcourse was used as the standard to quantitatively analyze the changes of the area and suitability of the fish spawning grounds before and after the improvement of the waterway, and the calculation results are detailed in Table 3 and Figure 4.

Table 3: Prediction of spawning area and suitability of fish in Xiaolaitan.

flow rate (m^3/s)	index		Spawning ground area and suitable area					
			0.0~0.2	0.2~0.4	0.4~0.6	0.6~0.8	0.8~1.0	total
383	before	area /hm^2	49.8	16.8	9.7	1.0	0	77.3
		proportion /%	64.5	21.8	12.5	1.2	0	100
	after	area /hm^2	30.7	20.6	8.7	4.1	2.4	66.5
		proportion /%	46.1	30.9	13.2	6.2	3.6	100
700	before	area /hm^2	23.3	16.5	27.1	11.6	0.6	79.1
		proportion /%	29.4	20.9	34.2	14.6	0.8	100
	after	area /hm^2	23.8	12.4	21.1	11.3	7.2	75.8
		proportion /%	31.4	16.4	27.9	14.9	9.5	100
1000	before	area /hm^2	16.2	13.6	26.7	20.7	4.7	81.9
		proportion /%	19.7	16.6	32.6	25.3	5.8	100
	after	area /hm^2	16.3	14.2	28.0	21.6	1.6	81.6
		proportion /%	19.9	17.4	34.3	26.5	1.9	100
2500	before	area /hm^2	5.9	4.1	7.2	17.3	49.0	83.6
		proportion /%	7.1	5.0	8.7	20.7	58.7	100
	after	area /hm^2	5.5	4.7	7.5	17.3	48.6	83.5
		proportion /%	6.6	5.6	9.0	20.7	58.1	100

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flow rate (m^3/s)	index		Spawning ground area and suitable area					
			0.0~0.2	0.2~0.4	0.4~0.6	0.6~0.8	0.8~1.0	total
4800	before	area /hm^2	2.0	1.2	3.0	7.5	70.9	84.6
		proportion /%	2.4	1.4	3.6	8.9	83.8	100
	after	area /hm^2	2.1	1.1	3.4	7.8	70.2	84.6
		proportion /%	2.5	1.3	4.0	9.2	83.0	100
9000	before	area /hm^2	0.4	0.2	1.0	25.1	58.0	84.8
		proportion /%	0.2	0.2	1.2	29.6	68.5	100
	after	area /hm^2	0.4	0.2	1.1	20.7	62.4	84.8
		proportion /%	0.4	0.2	1.3	24.4	73.6	100
14100	before	area /hm^2	0.2	3.5	25.2	40.6	15.3	84.8
		proportion /%	0.3	4.1	29.7	47.9	18.1	100
	after	area /hm^2	0.1	1.9	27.6	40.5	14.7	84.8
		proportion /%	0.1	2.2	32.5	47.8	17.3	100
22500	before	area /hm^2	21.1	36.4	16.1	7.7	3.5	84.8
		proportion /%	24.9	42.9	19.0	9.0	4.2	100
	after	area /hm^2	20.3	36.7	15.6	8.4	3.8	84.8
		proportion /%	23.9	43.3	18.4	9.9	4.5	100

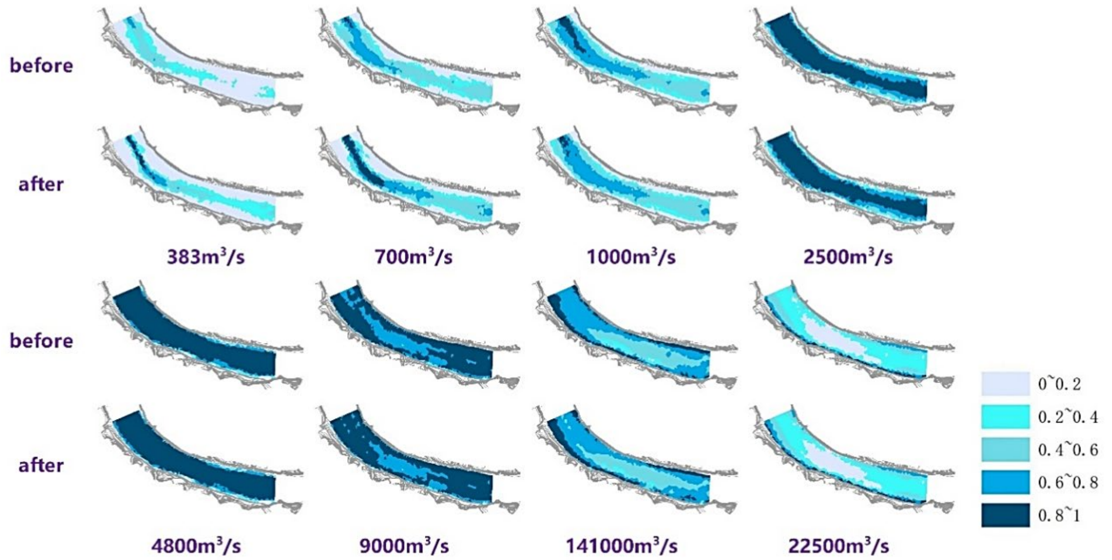

Figure 4: The area and suitability distribution of fish spawning grounds before and after waterway remediation.

4.1. Changes in spawning ground area

When the upstream water volume is less than 1000m^3/s, the spawning ground area after the waterway remediation is smaller than before the remediation, mainly because the elevation of some areas of the river bottom is reduced due to the waterway remediation, and the upstream water is preferentially collected in the waterway and surrounding areas under the action of gravity, which leads to the reduction of the fish spawning ground area when the upstream water is small. The smaller the amount of water coming from the upstream, the greater the difference between the spawning ground area before and after the waterway remediation, and the maximum spawning area after the waterway remediation was reduced by 10.8 hectares when the minimum flow was 383 m^3/s. When the upstream water volume is greater than 1000m3/s, the area of fish spawning grounds in Xiaolaitan before and after the waterway remediation is basically the same, and the impact of the waterway remediation on the area of the spawning grounds basically disappears.

4.2. Changes in spawning ground suitability.

Although the area of fish spawning grounds will be reduced due to the small amount of water coming from the upstream waterway, the area of the spawning ground suitability greater than 0.6 has increased significantly compared with that before the waterway remediation, indicating that the waterway remediation has created more habitat space suitable for fish production. When the upstream water flow is between 383~1000m^3/s, the waterway remediation has a great impact on the suitability of the spawning ground of Xiaolaitan fish, and when the flow is 700m^3/s, the waterway remediation has the greatest

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impact on the suitability of the spawning ground. When the upstream water volume is greater than 1000 m^3/s, there is no big difference in the suitability of fish spawning grounds before and after waterway remediation.

5. Conclusions

In this study, the MIKE21 hydrodynamic model simulation showed that the impact of Liujiang waterway remediation on the spawning grounds of Xiaolaitan fish showed a significant flow dependence. Under the condition of low flow, the water flow is concentrated in the waterway area due to the decrease of the elevation of the river bottom, and the area of spawning grounds is reduced compared with that before the remediation, but due to the formation of stable water depth in the waterway and the improvement of local habitat conditions, the suitability of the spawning grounds is improved. When the upstream water volume increased to 383–1000 m^3/s, the remediation project created a broader suitable spawning space by adjusting the water flow structure, the effect of spawning area reduction was weakened, and the role of habitat optimization was highlighted. However, with the further increase of flow, natural hydrodynamic forces gradually dominated the habitat conditions, and the effects of waterway remediation on the area and suitability of spawning grounds tended to weaken.

This conclusion provides a scientific basis for the coordination of inland waterway navigation and ecological protection. This study revealed the central role of flow regulation in balancing the function of waterways and fish habitat needs, suggesting that the priority of ensuring medium and high flow during the fish breeding period can take into account the shipping efficiency and ecological benefits. At the same time, ecological compensation measures (such as artificial fish nests) are required to alleviate the area loss in the low-flow phase, while the habitat can be actively improved through engineering optimization in the medium-flow period. This study also verifies the application value of hydrodynamic model in ecological impact prediction, and provides a methodological framework of "differentiated flow response management" for similar projects, so as to promote the transformation of hydraulic engineering from a single goal to ecological adaptive design, and promote the sustainable development of river basins.

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