Research on the transport and dispersion of Asian carp eggs in the “man-made flood pulse” in the middle Yangtze River by Reynolds-averaged numerical simulation

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Abstract. Eggs and early larvae of fishes is important to the early life stages of fish, it is closely related to the fish hatching and resource supplementation, the fish egg movement is essential to studied for re-operation ecological-flow determination, re-operation effect evaluation and fish spawning ground repair. In this paper, fish eggs of Four major Chinese carps were used as the object of study, and the fish eggs were generalized to sediment-like particles. Assuming that their diameter was constant and other mechanical properties were given, the analytic solution considering the change of lateral velocity along the curve were proposed, and the improved three-dimensional hydrodynamic model was used to simulate the distribution characteristics of the fish eggs of the sediment-like particles in the curved channel. (1) cross-section: In straight river section, cross-section of eggs distribution is more uniform in vertical direction, the middle concentration is slightly larger than the two sides in horizontal direction; in the bent river, from the convex bank to the depression concentration gradually reduced. (2) Longitudinal section: the overall concentration of eggs showed a decreasing trend along the trend, the bank near the shore, the egg concentration is increase in a certain time and region, affected by the flow field conditions. The research results can provide the basis for the egg movement simulation by the sink channel and the law of its movement.

1. Introduction
Rivers have variety of topographical features and a rich variety of aquatic life. Yangtze river is the most important river in China, the fish resources of the Yangtze river system are particularly abundant, which is a treasure house of the cradle and fish genes of the freshwater fishery, and it is home to the famous rare and unique fishes of China. With the development of water conservancy and hydropower development, the construction of dams and cascade reservoirs has blocked the migration channels of fish vertically and changed the habitats of fish. In order to alleviate the ecological effect of major water conservancy and hydropower projects, the ecological system of damming river is improved and restored, and ecological restoration measures such as ecological scheduling and propagation streamflow are taken. But how to design, measure and evaluate these ecological protection measures and their improvement effects has always been the focus and difficulty in actual work. n different life cycle stages of the fish, the river water has different adaptation mechanism, fish eggs, and incubation period is eggs passive adaptation to water flow, water flow in the spawning and the limit on eggs survival plays an important role. Ecological operation meet the demand of fish eggs, hatching water flow scheduling is an important ecological restoration measures, therefore, through the drift movement
of the fish eggs and fish early resource estimation, can directly evaluate ecological operation results.

River morphological diversity is the core of ecosystem habitat and the basis of biodiversity. Natural river is winding, provides convenience for fish habitat and breeding places, the hydrodynamic characteristics of riverbed and fish habitat, has a strong correlation between complex terrain, river sand and rocks to form the complex flow state, offers all kinds of habitat for aquatic organisms, feeding, reproduction, and shelter. Black carp (Mylopharyngodon piceus), Grass carp (Ctenopharyngodon idellus), Silver carp (Hypophthalmichthys molitrix), Bighead carp (Aristichthys nobilis) called the "Asian carp ", is the main object of freshwater aquaculture and fishing in our country, belongs to the typical for floating eggs, fish, in the breeding season in August 5 - year, its only mature ovulation fertilization activities not only need appropriate hydrological conditions, also by water fluctuation, the stimulation of natural environment, such as flood process [1-3]. At present, the study on the influence of the spawning factors of Asian carps is limited to the analysis of the relationship between raising water level and the number of spawning, but the quantitative research on the distribution characteristics of fish eggs is seldom. The author adopts the means of numerical simulation to quantify the water processing, the detailed analysis from the Angle of hydraulic for fish spawning period, and typical curved reach eggs drift characteristics and flow characteristics, the ecological flow needed to provide theoretical support for Asian carp natural reproduction.

Eggs is biological particles, characteristics change over time (hatch), the eggs movement research mainly used the following three methods, in laboratory and abroad on the study of the motions of eggs, which is generally through the wild fish eggs investigation and markers discharge test manner [4-6]. The research results mainly focus on the distribution characteristics of roe, drift speed, drift and safe drifting distance. A few studies are based on the simulation of the mechanical behavior of fish eggs based on indoor flume test [7]. Mainly for the distribution of fish eggs section and the velocity range of safe drifting. In recent years, there have been sporadic studies on the three-dimensional hydrodynamic and Largrange method particle tracking of the fish egg movement [8,9]. Most of the research focuses on the longitudinal distribution of the path.

In conclusion, eggs movements and egg seedling distribution characteristics research adopts the method of field investigation, it can't explain the mechanism of the pressing machine, Indoor test is needed to reveal eggs movement rule and the influence mechanism. Future research can be from different types of fish eggs (floating eggs, sticky eggs), design different series of flume experiment, systematic study hydrodynamic characteristics of fish eggs and movement rules, such as viscosity attached eggs implantation rate, drifting eggs floating suspension rate, and safety distance to the flow conditions, terrain response relationship. Therefore, ecological properties of fish eggs reasonable generalized is important for studying the dispersion and transport of fish eggs and their impact mechanism.

In this study, the fish eggs are treated as sediment particles, and the other motion characteristics of fish eggs are given as a constant value, which can be simulated with the basic theory of sediment particles. In the form of river, most of the curved rivers are curved channels with transitional zones, and there are continuous curved channels, which are aimed at the motion characteristics of the sediment particles in curved channels. In this paper, a numerical model is used to solve the distribution of fish eggs in curved channels. It can provide a basis for the simulation and movement of the flume of fish eggs.

2. Materials and methods

2.1. Numerical model
The 3D model of the flow field of the curved channel determines the necessity of simulating the water sand movement using the 3D model. Reynolds-Averaged Numerical Simulation (RANS) is the most commonly used numerical model of flow and sediment. RANS solves Reynolds-Averaged Naviers-Stokes Equations as list below:

Continuity equation:
\[ \frac{\partial u_i}{\partial x_i} = 0 \]  

Momentum equation:

\[
\begin{align*}
\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}(u_i u_j) &= \frac{\partial}{\partial x_j}\left((v + v_i)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right) + \rho f_i - \frac{\partial p}{\partial x_i} \\
\end{align*}
\]

(2)

k-ε turbulence model is used to determine the eddy viscosity \( v_e \).

The suspended sediment transport equations is:

\[
\frac{\partial S}{\partial t} + \frac{\partial}{\partial x_j}(u_i S) = \frac{\partial}{\partial x_i}\left((v + v_i)\frac{\partial S}{\partial x_i}\right) + \frac{\partial}{\partial z}\left(\rho \omega_s S\right)
\]

(3)

The model adopts the finite volume method, the non-orthogonal curve with the same bit grid, the C type variable layout (the variables that are solved are distributed in the center of the cell). The interface interpolation adopts the mixed interpolation or QUICK format to solve the linear equations with the strong implicit scheme. The specific construction of the model is detailed in the bibliography [10].

2.2. Key parameter

Physical characteristics of Asian carp egg, diameter is around 4 ~ 5.5 mm, Relative density: 1.0014 ~ 1.003. Its shape approximates as a sphere, and its sink velocity can be solved by the formula of Wuhan water conservancy and hydropower institute (1962) formula [11],

\[ \omega = [\frac{(13.95 V)}{D}^2 + 1.09 \frac{\gamma_s - \gamma}{\gamma} gD]^{1/2} - 13.95 \frac{V}{D} \]

\[ \omega \] is the fish egg sinking speed, D is the fish egg diameter, the simulation calculation D = 4.5 mm; For the motion viscosity coefficient, because the water temperature of the fish is above 18 degrees, it will not spawn. Therefore, in the simulation calculation, it is equal to 10-6 m²/s, and the water temperature is 20 degrees Celsius. In order to simulate the weight of fish eggs, the simulation calculation, \( \gamma_s = 1.002 \text{ kg/m}^3 \); \( \gamma \) is the weight of the water.

2.3. Simulated condition

This study mainly focused on the section distribution of curved section (figure 1), as generalized model of the Zhi city in Yangtze river. By using the generalized curve mode, the bending radius of 4.5 m, 180° corner, width 1 m, 6 m long straight and inward and outward depth of 0.4 m, the average velocity of 0.5 m/s, bed surface grade 0.0005, flow rate of 0.2 m³/s, wall function of the coefficient of 0.35.

3. Results

3.1. Hydrodynamic characteristics

Hydrodynamic of the river segment is showed by figure 2, Section 1 is located in the entrance of the river bend, it has not yet formed a complete circulation structure in cross section, but the lateral velocity of points from the concave bank to the convex bank, this is because the mainstream from the middle to the convex bank. Section 2-4 is located in river bend curved roof area before and after, there are full circulation by visible figure structure, but the location of the maximum longitudinal velocity,
by section 2 to section 4, the maximum longitudinal velocity position from the surface of the convex bank to move to the concave bank near bottom section 5 of exports, which is located in river bend mainstream near the concave bank, circulation structure still exists. The section 6 is located in the model exit, which is adjusted by the line segment with the adjustment of the line segment. The flow intensity is greatly reduced.

**Figure 1.** The schematic diagram and the section distribution of the river.

Note: according to the characteristics of the curve, It is divided into I, II, III and IV.

**Figure 2.** The flow field diagram of the river segment (the contour line in the graph is the contour of the longitudinal velocity of the section, the vector is the secondary flow, and the numerical value is the cross-sectional label).

### 3.2. The spatial and temporal distribution of fish eggs

#### 3.2.1. The cross-sectional distribution of fish eggs.

As the density of fish eggs is larger than water, the vertical formation of large distribution characteristics, such as cross section 1. Influenced by the morphology of the river, the concentration of fish eggs is large and the distribution characteristics of the low bank concentration are small, such as the section 4-5. The main reason is that the water flows into the curve and forms a spiral structure. The concave water flows from the water to the bottom, while the convex bank is opposite, and the water flows from the bottom to the surface. The resulting concentration of small surface flow accumulates on the concave bank, and the higher concentration of the lower layer is collected on the convex bank.

The distribution features of each section are as follows (figure 3): Section 1 is in the straight section, the horizontal distribution of the fish eggs in the section is relatively uniform, and the intermediate concentration is slightly larger than the two sides. The concentration of fish eggs in the section is vertical distribution, and the distribution characteristics of large size are formed. Section 2 is in the first half of the curve, and the concentration of fish eggs in the section is significantly greater than that of the concave bank; The concentration of fish eggs in the section is vertical distribution, and the distribution characteristics of large size are formed. The section 3-5 is in the curve section, which is affected by the circumfluence of the curve. The horizontal distribution of the fish eggs is gradually reduced from the convex bank to the concave bank. The concentration of the middle layer of the fish egg concentration is large and the bottom concentration is small. The section 6 is in the simulated river section, and the residual curve circulation affects the horizontal distribution of fish eggs from the convex bank to the concave bank. The large distribution characteristics of vertical fish egg concentration.
3.2.2. The longitudinal section distribution of egg. Due to large eggs density than water, natural cases will occur along the subsidence, lead to concentration along the roe is reduced, but due to the formation of the spiral flow structure in bend, bend the concentration of the concave bank will decrease relatively (as shown in figure 4 - concave bank), the relative increase of bend convex bank concentration (as shown in figure 4 - convex bank).

Before the corner entrance (I), the concentration of fish eggs is basically the same in three longitudinal sections. In the curve, the concave bank of the concave bank is rapidly decreasing, the elevation of the convex bank is increased, and the concentration of the middle section decreases. In the second half of the curve (III), the dip of the concave bank continues to decrease, and the concentration of the middle section varies little along the path, and the elevation of the convexity decreases gradually. After the curve (IV), the concentration of the concave bank and the middle section continues to decrease, while the convex bank concentration increases.

4. Discussion

4.1. The cross-sectional distribution of fish eggs
Field experiment monitoring results show that some point density of floating objects drifting through the downstream is discontinuous change, the same time interval markers rafting density and the floating time presents the wave changes [6], which is based on a series of peak and low peak exists in the form of interaction, and the peak value with the increase of the number of decline in pairs drift time. The results of this study show that, in the coastal zone, the concentration of fish eggs will be affected by river morphology, and the concentration of fish eggs will continue to decrease in the near shore of the concave area. In the coastal area, the concentration of fish eggs in a certain time and region may be affected by the flow field condition, which is consistent with the results of Jiang wei [6]. In the middle longitudinal section of the simulated channel, the overall range of fish egg concentration decreases, and the concentration of fish eggs is small in the upper and lower strata after the bending top, and the distribution characteristics of the middle size are large.

4.2. The longitudinal section distribution of egg
There are some studies on the distribution of the horizontal distribution of fish eggs with passive drift [12-14]. There are two main kinds of research results, one is that the floating density of the shore is higher than that of the river [13,15], a kind of thought that the drift density in the middle of the river is higher than the coast [16,17]. The results of this study show that the horizontal distribution of the fish eggs in the cross-section is relatively uniform and the intermediate concentration is slightly larger than the two sides. In the curved section, the convexity to the concave bank decreases gradually. The main causes of this phenomenon mainly include several factors: (1) channel morphology and velocity distribution; (2) there is a great relationship between the development period of the objects being collected [13,16,18].

In this study, we did not consider eggs diameter changing with the time development, in this paper is the corresponding parameter D, as well as the related coefficient of viscosity change, fish eggs took the average diameter change, at the same time in the study did not consider seedling period near the condition of basic than young fish, water flow capacity limit. Therefore, the main mechanical properties of fish eggs have been basically reflected. In the future simulation study, it is necessary to study the changes of fish eggs over time and more accurately simulate the distribution characteristics of fish eggs, and clarify their movement patterns.

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