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Using the Characteristics of River Confluence to Reduce the Negative Impact of Supersaturated Total Dissolved Gas (TDG)

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ABSTRACT

Total dissolved gas (TDG) can be easily induced in high dams spilling. It will create adverse effects for fishes. Generally, the hydropower stations built on the embranchment are smaller and the supersaturation of TDG is much lower than the main stream. According to this, a separated region at the confluence, which will become the refuge for fish to survive the supersaturated TDG, can be formed with lower TDG concentration under appropriate structural measures. In this study, a numerical simulation is established to the simulation region which is 5 km downstream the river from discharge structures. Under the condition of tunnel-spillway flood discharging in a hydropower station, the study especially focuses on the hydraulic characteristics and distribution of supersaturated TDG at the confluence. Coupled with the simulation on hydrodynamics, the distribution of TDG under different structural measure conditions are simulated, including setting up longitudinal embankments and water-blocking piles. At last, considering the feeding ground hydraulic requirements of the fish, which is paid significant attention, the study analyses the effectiveness of the refuge region created before. The result shows that the case with 2 water-blocking piles and longitudinal embankments of 200 m length can effectively increase the area of the refuge for fish to avoid the adverse effects of TDG supersaturation. Besides, the simulation of adopting sturctural measures can satisfy the hydraulic conditions of the concerned fish as well. This study provides new directions and references to construct shelter for fishes against the detrimental effects of supersaturated TDG.

INTRODUCTION

High dams discharging water easily cause the supersaturation of the total dissolved gas (TDG) which threatens the survival of fish (Weitkamp 2008). The researches about the influence of TDG supersaturation caused by high dam discharging water started in 1960s. The death of salmon in Columbia river caused by TDG supersaturation attracted much attention and researches (Dawley 1975). In China, there are also many incidents of fish death caused by supersaturation of TDG after high dams discharging water (Tan 2006). In recent years, based on the researches about the regulation of generation and release TDG supersaturation, researchers have achieved some results in relieving the adverse effects for fish. In the aspect of reducing TDG generation, United States Army Corps of Engineers (USACE) mounted deflectors to achieve the aim of reducing the generation of TDG in some spillway dams in Columbia River (Weitkamp 1980). With a two-phase flow model based on the Wells Dam of TDG dynamics, Politano (2010) proposed some feasible suggestions on spill operations for the purpose of optimizing the discharge dispatching. In light of China's actual situation of the hydroelectric engineering, the joint operations of the upstream and downstream power stations was needed to minimize the negative effect on the reservoir in Feng Jingjie's study (Feng 2014). As the research moved along, Ma (2016) developed a two-dimensional (2D) model of two-phase flow in high-dam plunge pool with established computational fluid dynamics (CFD) software to simulate the behaviour of dissolved gas. In respect of researches of the TDG release, the fluctuations due to wind on the surface of the water could enhance the release of TDG was found by Schneider & Barko (2006). Besides, based on experiments, (Yong 2012) proposed that flows around, backflow and some other hydraulic phenomena within complex waters were beneficial to the release of TDG. Shen (2014) experimentally investigated that the supersaturated TDG dissipation coefficient increases with the temperature and turbulence intensity. Lichtwardt (2001) found that aeration could be used to relieve TDG in water and that the mitigation effect was related to the dissolved oxygen content in water and the aeration rate. For a tentative sorting and discussion of large-scale prototype measurements, Qu (2011) suggested diluting the supersaturation TDG with the turbine discharge. Several experiments designed for Prenant's schizothoracin found that the fishes had a sense of the TDG gradient and thus had the ability to find regions with lower TDG concentrations (Zhou 2016).

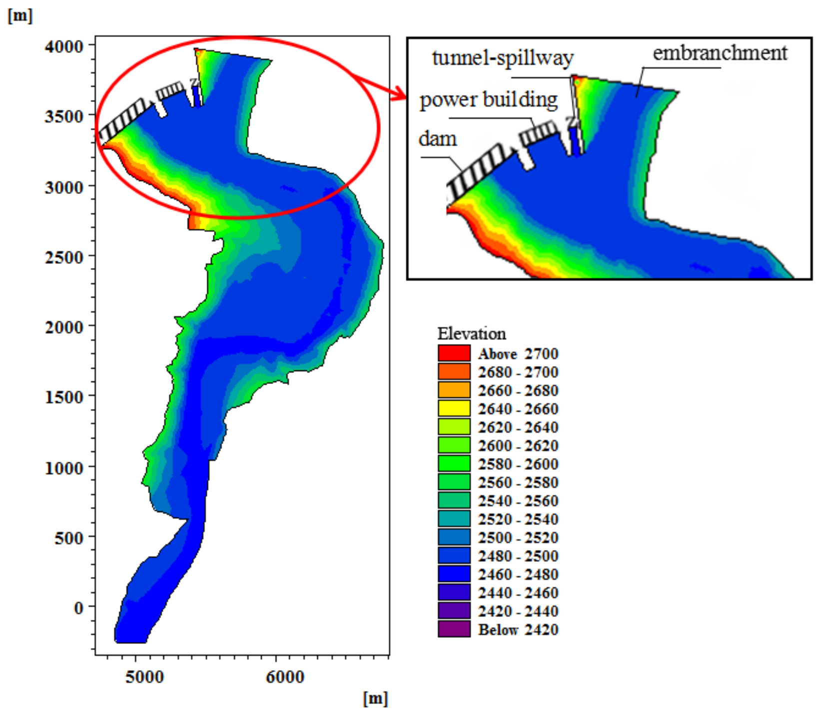

Fig. 1: The sketch map of simulation region.

Furthermore, a study by Wang (2015) stated that Prenant's schizothoracin exhibit varying degrees of horizontal escape from, and strong vertical avoidance, of TDG-supersaturated water .

The flow turbulence, sediment deposition and nutritive salt enrichment make confluences important places where fish can search for food and rest (Ginney 2001, Benda et al. 2004, Rice 2001). In addition, lower dam structures on the embranchments lead to lower TDG concentration flows. However, few studies have been done by using the dilution effect of the lower TDG water to improve the living space of the natural fish. Embranchment can not only dilute the TDG concentration in the main stream, but can also develop a separate region with a lower TDG concentration at the confluence. By adopting the appropriate structural measures to restructure the confluence, a lower TDG concentration region can be created for fish to avoid adverse conditions. This idea is of great significance for fish protection and constructing safe areas for fish population.

Considering the hydraulic characteristics of the confluence, one-dimensional hydrodynamic model cannot abundantly simulate the flow turbulence and the secondary flow in the confluence. In addition, three-dimensional hydrodynamic model has lesser application in such hydraulic calculations because of its difficulties in the implementation of algorithms and its long computation time. A depth-averaged, two-dimensional model is employed to simulate the TDG transportation and distribution at 5 km downstream of the discharging structures in addition to hydrodynamics. Structural measures, such as longitudinal embankments and water-blocking piles, are adopted to create a lower TDG concentration region at the confluence. Different conditions in the supersaturated TDG areas after adopting the structural measures described above are also illustrated. To explore the availability of regions for fish to survive TDG supersaturation, combining the optimum conditions with hydraulic conditions required by fish must be given significant attention.

MATHEMATICAL MODEL AND VALIDATION

According to the distribution characteristics of the hydraulic properties of supersaturated TDG in the confluence area, a depth-averaged two-dimensional turbulent mathematical model implemented in MIKE software is established in this study. The model equations apply a discretized finite volume method equation, which is solved by the chasing method. The discrete method is shown as follows:

Continuity equation:

$$\frac{\partial z}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0 \qquad ...(1)$$

Table 1: Simulated condition settings.

Case number	Stuctural Measures	Specifications (length×width)/m×m	The total length of structures/m
1	None	\	\
2	200 m longitudinal embankment+ 2 water-blocking piles	longitudinal embankment 200×20, each water-blocking pile 25×20	350
3	400 m longitudinal embankments+ 2 water-blocking piles	longitudinal embankment 400×20, each water-blocking pile 25×20	550
4	4 water-blocking piles	each water-blocking pile 25×20	250
5	8 water-blocking piles	each water-blocking pile 25×20	550

Table 2: Boundary conditions settings.

In\out flow boundary	Power building	Tunnel spillway	Embranchment	Downstream 5km
Flow (m^3/s)	2016.8	1553.2	198	/
TDG concentration (%)	100	120	100	/
Surface elevation (m)	/	/	/	2482.7

Momentum equation:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial z}{\partial x}+g\frac{n^2u\sqrt{u^2+v^2}}{h^{4/3}}=v_t(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}) \quad ...(2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial z}{\partial y}+g\frac{n^2v\sqrt{u^2+v^2}}{h^{4/3}}=v_t\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \quad ...(3)$$

TDG transport and diffusion equation:

$$\frac{\partial G}{\partial t}+u\frac{\partial G}{\partial x}+v\frac{\partial G}{\partial y}=\frac{\partial}{\partial x}\left(v_t\frac{\partial G}{\partial x}\right)+\frac{\partial}{\partial y}\left(v_t\frac{\partial G}{\partial y}\right)+k_{\text{TDG}}S_G \quad ...(4)$$

In the equations, t(s) is time; x, y is on the right-hand side of the descartes two-dimensional coordinate system; h(m) is the water depth; z(m) is the water level; u(m/s) and v(m/s) are the vertical velocity in the x and y directions, respectively; n is the manning coefficient; (m^2/s) is the eddy-viscosity coefficient; G(%) is the TDG concentration; k_{TDG} (s^{-1}) is the release coefficient of TDG; and S_G is the source-sink term.

The simulation of hydrodynamics in the river confluence area and the validation of the pollutant transport model are used existing research outcomes. The depth-averaged two-dimensional hydrodynamic model is applied to verify the simulation calculation and compare the measurements of the water flow exchange process in return periods and with different durations for three typical floods in a typical wetland ecosystem in Hulun Buir Steppe. According to the outcomes of the model computation, the relationship between the reservoir discharge and changes in the downstream wetland waters is reflected (Wang 2014).

In the pollutant transport model, salt is treated as a trace material in the confluence between mainstreams and tributaries. The errors of simulation value compared to the observational measurements are 2.9% and 9.8%, which are both in the acceptable range (Shen 2016).

APPLICATION EXAMPLE

General Situation of the Construction

This study simulates downstream flow from the discharging structures of a hydropower station, including an inflowing confluence from the left bank at 0.7 km downstream from the main stream. A fish feeding ground stretches from the confluence to 1.5 km downstream. The pivot of the hydropower station consists of retaining structures, power buildings and flood-releasing energy dissipator structures. The tunnel spillway discharges flood waters, with energy dissipation occurring via bottom flow.

The computational domain is shown in Fig. 1. The region of simulation stretches from the power buildings section to 5 km downstream.

Simulated Condition

The study sets 5 simulated conditions. Condition 1 simulates the TDG distribution of tunnel spillway discharge under the natural conditions. Condition 2-5 simulate the TDG distribution with different structural measures adopting at the confluence. The specific information of the five sets is given in Table 1. Longitudinal embankments can properly prevent supersaturated TDG water mixing in order to increase the area of low TDG concentration. However, the engineering quantity can be cut down by the structural measures with water-blocking piles, comparing with the

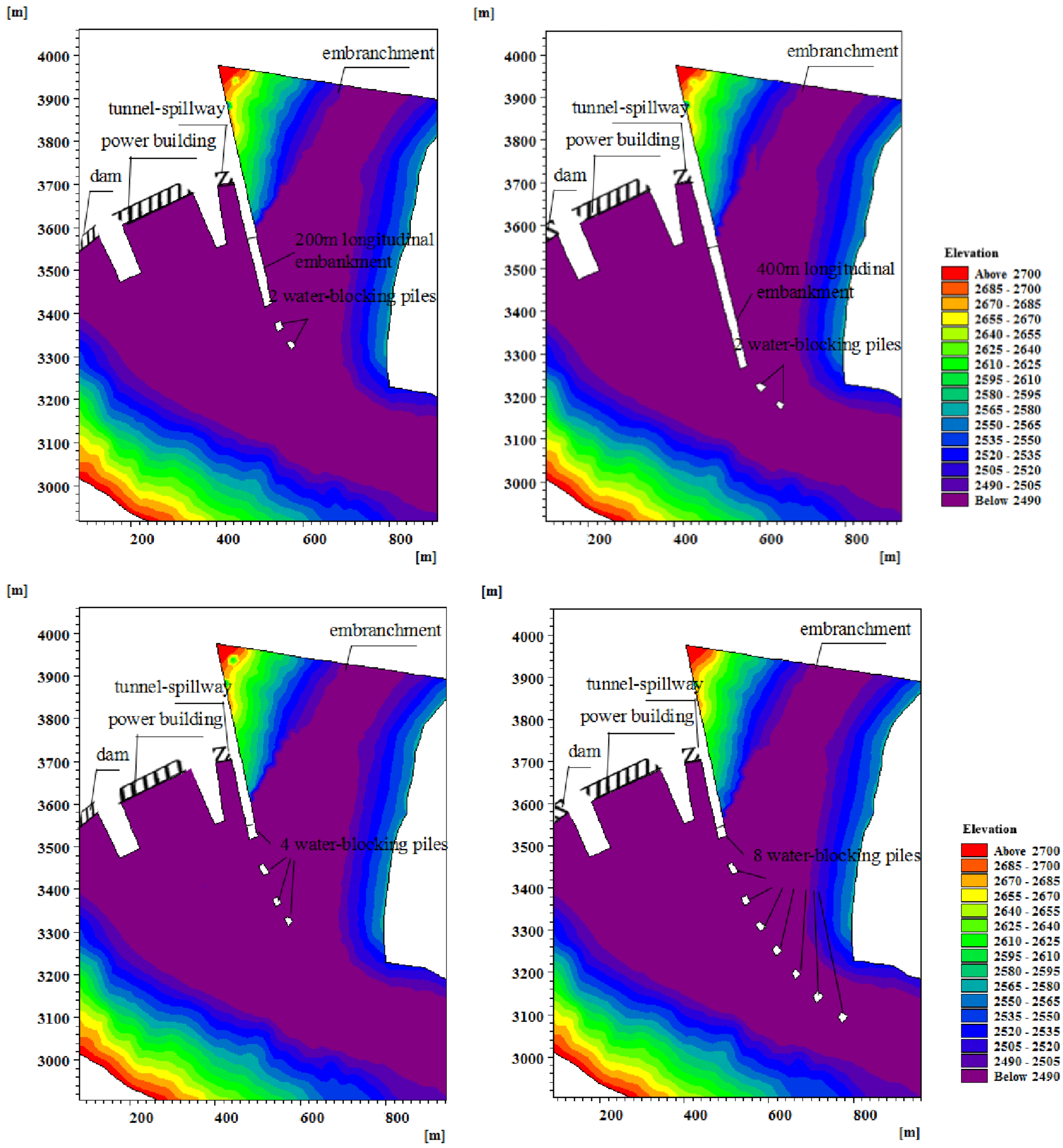

Fig. 2: The layout of longitudinal embankments and water-blocking piles.

longitudinal embankments. Note that longitudinal embankments and water-blocking piles are waterproof structures. The concrete layout of longitudinal embankments and water-blocking piles are shown in the Fig. 2.

Boundary Conditions and Parameter Determination

The boundary conditions of simulation are given in Table 2. In particular, the TDG concentration of the tunnel-spillway flood discharging was assumed to be 120%.

According to the characteristic of the water course, the manning coefficient is set equal to 0.032. Eddy viscosity is calculated from Smagorinsky equation which is equal to 0.28. The simulation of the release of supersaturated TDG is not taken into consideration.

PREDICTION RESULTS AND ANALYSIS

The Environmental Protection Agency (EPA) in the U.S. sets a TDG concentration of 110% as the maximum level of supersaturated TDG in natural streams, according to tolerance experiments conducted using salmon and trout (U.S. EPA 1986). An evaluation of the supersaturated TDG is shown below based on the threshold.

Fig. 3 shows the results of the TDG distribution. The result of natural conditions (Case 1) shows that the distribution extends into the embranchment. The distribution influences the confluence on the left bank. The area of TDG

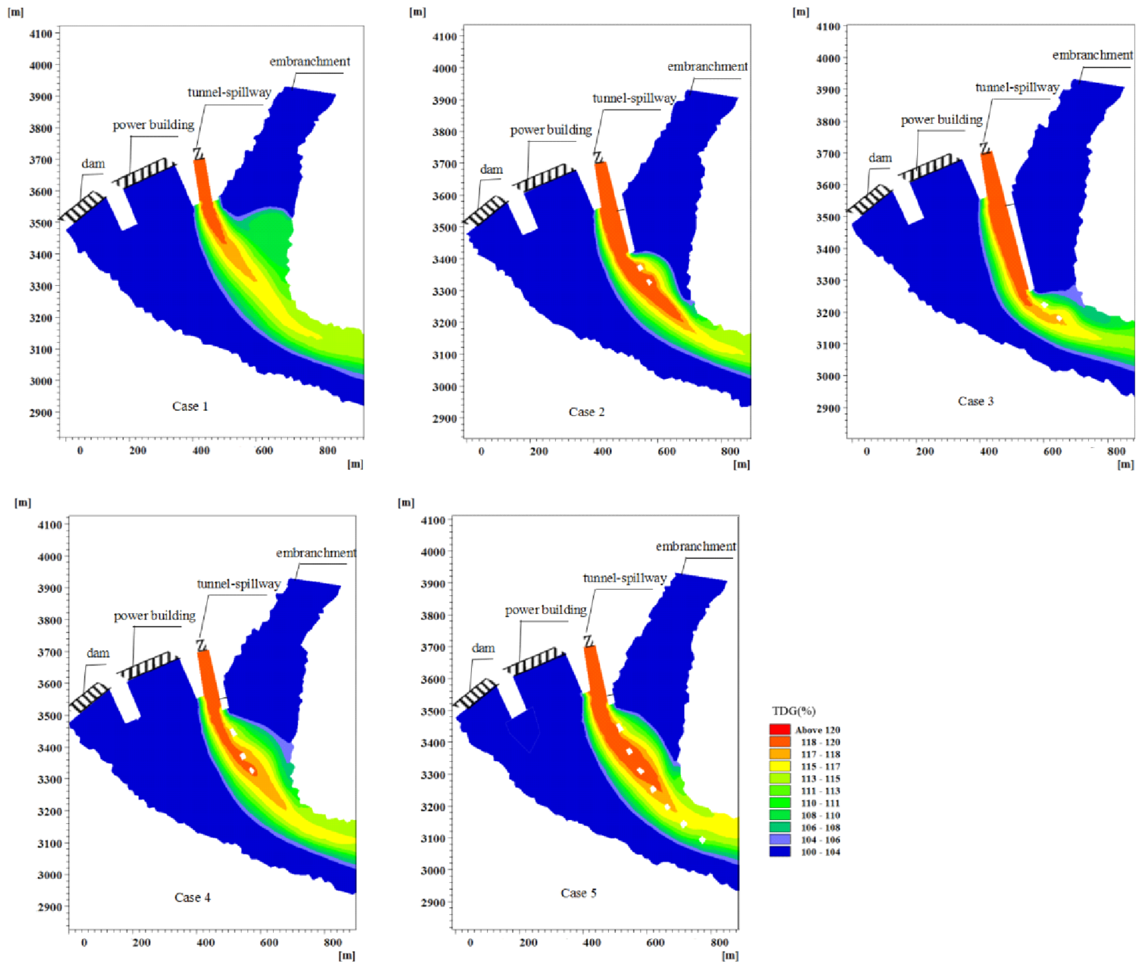

Fig. 3: TDG distribution at the confluence.

concentration above 110% is also mainly on the left bank of the river. The area in which the TDG concentration is over 110% is much larger.

The simulation of conditions that use the 200 m longitudinal embankment and 2 water-blocking piles (Case 2) shows that the distribution of a TDG concentration over 110% stretches along the longitudinal embankment and extends into the embranchment from the two water-blocking piles.

The case with a 400 m longitudinal embankment and 2 water-blocking piles (Case 3) shows that the distribution of a TDG concentration over 110% also progressed along the longitudinal embankment, mainly in the middle of the river. In comparison, the area of a TDG distribution over 110% on the left bank is lower than that in Case 2.

The simulation of 4 water-blocking piles (Case 4) shows that the area with a TDG concentration over 110% is distributed along the middle and the left bank at the confluence and stretches to the embranchment.

The simulation of 8 water-blocking piles (Case 5) shows that the area of TDG concentration above 110% increases compared with Case 4 and stretches further into the embranchment than does condition 4.

The areas with TDG concentrations below and above 110% are shown in Fig. 4. Statistics suggest that adopting a 200 m longitudinal embankment and 2 water-blocking piles (Case 2) maximizes the area of which the TDG concentration is below 110%, reaching 28.53×10^4 m^2. Compared with natural conditions (Case 1), the area in which the TDG concentration is below 110% in Case 2 increases by 11.8%. Further, the area with a TDG concentration over 110% is the smallest among the five simulated conditions. This result shows that adopting the 200 m longitudinal embankment and 2 water-blocking piles (Case 2) can effectively shelter the fish.

ANALYSIS OF FISH'S HYDRAULIC DEMANDS

The simulation results show that after adopting the 200 m

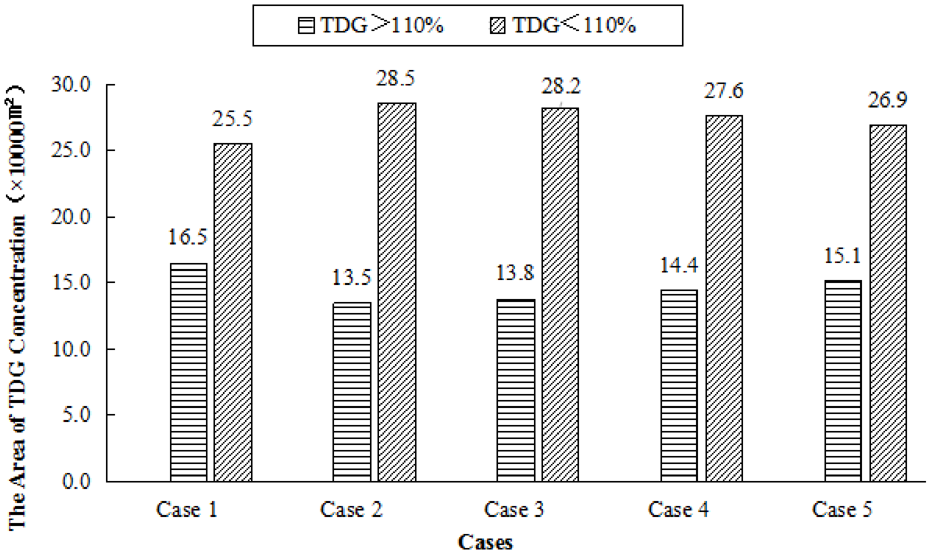

Fig. 4: TDG concentration distribution.

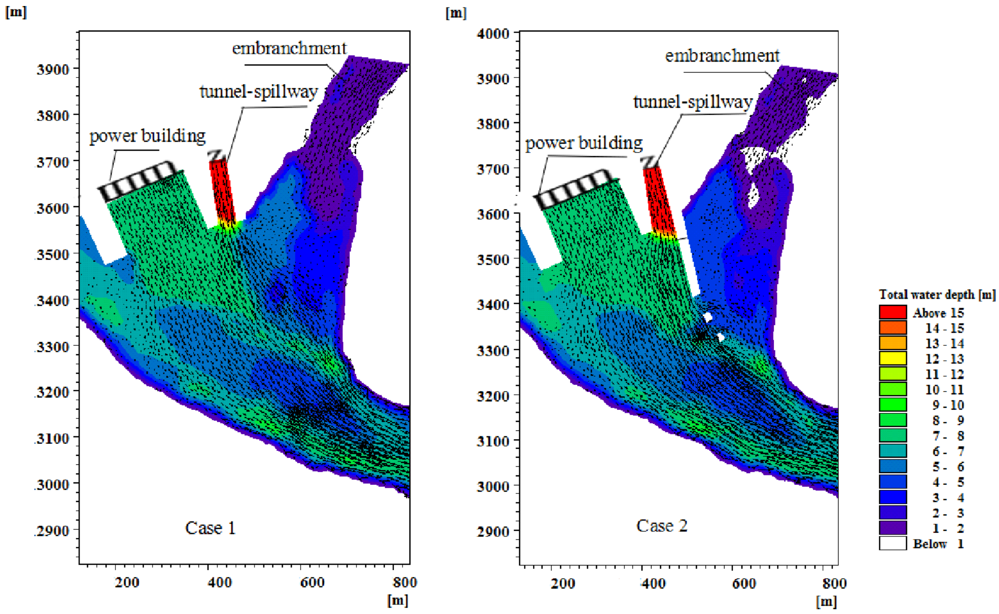

Fig. 5: Water depth and flow field at the confluence under different conditions.

longitudinal embankment and 2 water-blocking piles (Case 2), there is a significant increase in the area in which the TDG concentration is below 110%. However, employing the structural measures to upgrade the hydraulic conditions for the local fish's feeding ground still needs further discussion. This study addresses the feeding ground hydraulic demands of the Prenant's schizothoracin. The feeding ground of Prenant's schizothoracin is usually distributed along the shallows and rapids. The juvenile Prenant's schizothoracin prefers the shallows with slow flow. When water is abundant during the month of July, the average flow velocity of the Prenant's schizothoracin ranges from 1.5-3.5 m/s (Ginney 2001).

Fig. 5 shows the water depth and flow field at the confluence under different conditions and that the water depth changes are not significant.

Fig. 6 shows the flow velocity at the confluence under different conditions. The figure illustrates that setting the 200 m longitudinal embankment with 2 water-blocking

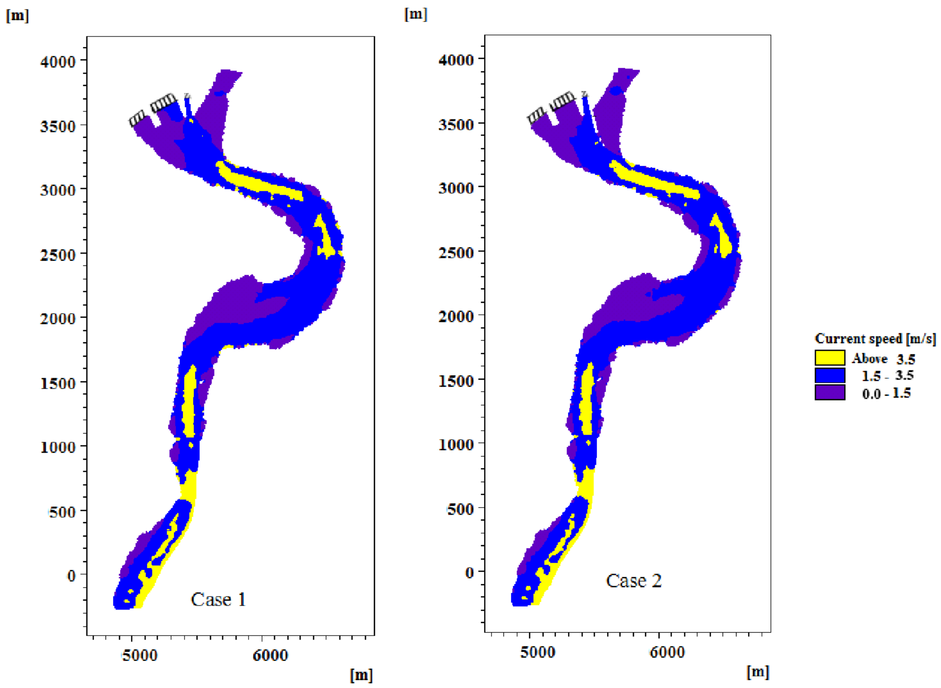

Fig. 6: Fow velocity at the confluence under different conditions.

piles (Case 2) has no significant influence on the flow velocity. Thus, the flow velocity at the confluence meets the feeding ground requirements.

CONCLUSION AND OUTLOOK

The study simulates the natural conditions and other conditions with different structural measures, based on an averaged-depth two-dimensional turbulent numerical simulation. The result indicates that setting a 200 m longitudinal embankment and 2 water-blocking piles (Case2) maximizes the area of TDG concentration below 110%. The area increases by 11.8% compared with the natural condition. The area of the TDG concentration above 110% on the condition with 200 m longitudinal embankment and 2 water-blocking piles (Case2) is the minimum among the five conditions. Meanwhile, the hydraulic conditions of the 1.5 km stretches from the confluence, meet the demands of the feeding ground of Prenant's schizothoracin. Therefore, setting 200 m longitudinal embankment and 2 water-blocking piles (Case 2) provides an effective shelter for Prenant's schizothoracin to abide the high supersaturated TDG.

This study explores the TDG distributions by discussing different sturctural measures set at the confluence, providing new directions and accordance to construct shelter for fish against the detrimental effects of supersaturated TDG.

The sturctural measures set in the simulations, contents the feasibility to reduce the adverse effects of supersaturated TDG. However, its engineering feasibility needs continued further professional analysis and demonstrations.

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REFERENCES

Benda, L.E.E., Poff, N.L., Miller, D., Dunne, T., Reeves, G., Pess, G. and Pollock, M. 2004. The network dynamics hypothesis: how channel networks structure riverine habitats. AIBS Bulletin, 54(5), pp.413-427.

Dawley, E.M. and Ebel, W.J. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steel head trout. Fishery Bulletin, 73: 787-796.

Feng, J.J., Li, R., Liang, R.F. and Shen, X. 2014. Eco-environmentally friendly operational regulation for supersaturated TDG. Hydrol. Earth Syst. Sci., 18: 1213-1223.

Ginney, E.M. 2001. Restoration opportunities at tributary confluences: critical habitat assessment of the Big Chico Creek/Mud Creek/Sacramento River confluence area. Chico, Bidwell Environmental Institute, California State University, 37.

Lichtwardt, M.A. 2001. Microbubble treatment of gas supersaturated water. U.S. Department of the Interior, Bureau of Reclamation.

Ma, Q., Li, R., Zhang, Qin, Hodges, B.R., Feng, J.J. and Yang, H.X. 2016. Two-phase flow simulation of supersaturated total dissolved gas in the plunge pool of a high dam. Environmental Progress & Sustainable Energy, 35(4): 1139-1148.

Politano, M., Arenas, A.A., Bickford, S. and Hay, D. 2010. Investigation into the total dissolved gas dynamics of Wells Dam using a two-phase flow model. Journal of Hydraulic Engineering, 137(10): 1257-1268.

Qu, L., Li, R., Li, J., Li, K.F. and Deng, Y. 2011. Field observation of total dissolved gas supersaturation of high-dams. Sci. China Tech. Sci., 54(1): 156-162.

Rice, S.P., Greenwood, M.T. and Joyce, C.B. 2001. Tributaries, sediment sources, and the longitudinal organisation of macro invertebrate fauna along river systems. Canadian Journal of Fisheries and Aquatic Sciences, 58(4): 824-840.

Schneider, M.L. and Barko, K. 2006. Total dissolved gas characterization of the Lower Columbia river below Bonneville dam. Unpublished report to US Army Engineer District, Portland, Oregon, pp. 104.

Shen, X., Li, R., Huang, J.P., Feng, J.J., Hodges, B.R., Li, K.F. and Xu, W.L. 2016. Shelter construction for fish at the confluence of a river to avoid the effects of total dissolved gas supersaturation. Ecological Engineering, 97: 642-648.

Shen, X., Liu, S.Y., Li, R. and Ou, Y.M. 2014. Experimental study on the impact of temperature on the dissipation process of supersaturated total dissolved gas. Journal of Environmental Sciences, 26(9): 1874-1878.

Tan, D.C. 2006. Research on the lethal effect of the dissolved gas supper-saturation resulted from three Gorges project to fish. Master Thesis, Southwest University, Chongqing. (In Chinese).

U.S. EPA 1986. Quality Criteria for Water. EPA Rep. 440/5-86-001, EPA, Washington, D.C.

Wang, R., Li, R., Li, J. and Hu, C. 2014. A hydraulics-based analytical method for artificial water replenishment in wetlands by reservoir operation. Ecological Engineering, 62(1): 71-76.

Wang, Y.M., Li, K.F., Li, J., Li, R. and Deng, Y. 2015. Tolerance and avoidance characteristics of Prenant's Schizothoracin Schizothorax prenanti to total dissolved gas supersaturated water. North American Journal of Fisheries Management, 35(4): 827-834.

Weitkamp, D.E. and Katz, M. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society, 109(6): 659-702.

Weitkamp, D.E. 2008. Total dissolved gas supersaturation biological effects, review of literature 1980-2007. Parametrix, Bellevue, Washington.

Yong, X.D., Yi, W.M., Li, R., Tang, C.Y. and Feng, J.J. 2012. The adoption of TDG release coefficients under the complex flow conditions. Advances in Science and Technology of Water Resources, 32(1): 62-66.

Zhou, C.Y. 2016. Effects of TDG supersaturated water with water temperature on survival in Schizothorax prenanti and its shelter construction. Sichuan Chengdu, Sichuan University.