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Editorial

Fluvial Hydraulics Affected by River Ice and Hydraulic Structures

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1. Introduction

Water on earth moves from one place to another by way of hydrologic processes such as precipitation, runoff, infiltration, evapotranspiration, melting, and ground-water flow. When water generated from a watershed enters a river or stream, flow conditions in the channel depend on the features of the river such as the channel slope, the properties of the bed material, and obstructions or vegetation in the channel.

Fluvial hydraulics deals with the flow of water, motion of sediment, and erosion of channel beds in rivers. Fluvial hydraulics becomes more complex as the velocity, slope, depth, and channel roughness are all subject to changes resulting from erodible beds and sediment transport due to the presence of in-stream infrastructure, vegetation in channel beds/banks, and ice cover on the water surface.

(1) *In-stream infrastructure*. The presence of in-stream structures leads to changes in the flow condition, and thus local scour around the in-stream structures. Local scour is sediment movement caused by a drastic change in flow obstructed by in-stream structures. Local scour is one of the leading causes of in-stream structure damage, and researchers have extensively investigated this issue based on flume tests, on-site measured data analysis, and numerical simulations. According to Brandimarte et al. [1], bridge damage and failure due to local scour in the vicinity of bridge piers have huge negative social and economic impacts in terms of reconstruction, the maintenance of existing structures, disruptions to traffic flow, and cost in human lives. It has been estimated that 60% of bridge failure cases in the USA are due to scour, and approximately 50 to 60 bridges annually collapse in the USA [2].

(2) *River ice*. In winter, ice cover can last up to six months in some northern regions. River ice is an important factor affecting riverbed deformation in cold regions. Under ice-covered flow conditions, the location of the maximum flow velocity is closer to the riverbed than during open-flow conditions due to the extra boundary imposed by the ice cover, which results in increased flow turbulence and bed shear stress, which typically occurs around bridge piers and abutments [3,4]. Therefore, the riverbed scour depth under ice cover is greater than in the absence of ice [5]. Under ice-covered flow conditions, local scour processes around in-stream infrastructure such as bridge piers may lead to disasters, such as the collapse of a bridge over the White River in Vermont in 1990 due to the deterioration of the bridge foundation [6] or the collapse of the Highway 16 bridge across the Bulkley River at Smithers, British Columbia, in April 1966 due to ice-induced local scour around bridge piers. Most recently, in February 2018, a bridge collapsed in Port Bruce, Ontario. Although the deformation of a riverbed under ice cover has often been a grave concern for engineers, little appears to be known about this subject [7]. Clearly, there is a critical need to study fluvial hydraulics under ice-covered flow conditions.

(3) *Vegetated channels*. In wetland environments, streams are commonly filled with either partially or fully submerged diverse aquatic plants, such as grasses, shrubs, and bushes. Both vegetated and non-vegetated zones in streams have a major impact on the hydrodynamic characteristics of flow, including velocity distributions, turbulence

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intensity, and coherent structures, as well as mass and momentum exchanges. Additionally, vegetation creates ecological habitats and plays an active role in maintaining and protecting biological diversity by providing food and shelter for fish and other aquatic creatures. There is an interaction between vegetation and bed deformation. On the one hand, vegetation influences flow structure, sediment erosion, and deposition. As a result of sediment erosion and deposition, organic materials attached to sediment particles spread throughout riverbeds/banks and affect vegetation growth and spread.

The aim of this Special Issue is to bring together research that improves our knowledge of sediment transport, local scour around in-stream infrastructure, and fluvial processes in the presence of either vegetation in a channel bed or ice cover on the water surface. It aims to include the latest advancements not only in the mechanics of sediment transport and local scour around in-stream infrastructure but also the impacts of vegetation in a channel bed on bed deformation and flow structure. Research dealing with the interaction between river ice, riverbed deformation, and in-stream infrastructure is also included.

2. Overview of This Special Issue

Before the manuscript submission deadline for this Special Issue, we received many manuscripts on fluvial hydraulics in the presence of either ice cover or in-stream infrastructure. All manuscripts have been through the normal peer-review process according to the journal requirements. In this Special Issue, twelve original contributions have been selected for publication [8–19]. Among the topics of interest for this Special Issue are:

- Turbulent flow structure, Reynolds stress, and local scour around in-stream infrastructure under ice-covered flow conditions [8–11];
- Interactions between ice jam accumulation, channel bed deformation, and in-stream infrastructure [12–14];
- The flow structure, Reynolds shear stress, and turbulence intensity of flows in the presence of vegetation in the channel bed [15–17] or under shallow flow conditions [18];
- Numerical simulation of the interaction between flow and sediment [10,19].

To equip readers with more information about this Special Issue book, a variety of innovative results from these twelve articles are summarized below:

Valela et al. [8] conducted experiments in a laboratory flume to better understand the local scour process around bridge piers under both smooth and rough ice-covered flow conditions. They found that an increase in ice cover submergence results in a greater maximum velocity and an associated increase in the near-bed velocity gradient. Rougher ice cover causes the maximum velocity close to the bed, and thus the near-bed velocity gradient is even greater. Rough ice cover generates more scour than smooth ice cover.

The work of Sang et al. [9] is about the local scour around tandem double piers under ice-covered flow conditions. They found that as the pier spacing ratio of tandem double piers increases, the scour depth around the front pier gradually decreases. When the pier spacing ratio is 5, sediment scoured around the front pier begins to deposit between the two piers. The existence of the rear pier leads to an increase in the length of the scour hole but a decrease in the depth of the scour hole around the front pier. When the pier spacing ratio is 9, the scour depth around the rear pier is the lowest. When the pier spacing ratio is more than 17, the scour around the front pier has hardly any influence on that around the rear pier.

Jafari and Sui [10] studied velocity fields and turbulence structures around spur dikes with different alignment angles under ice-covered flow conditions. They found that an increase in the upstream dike angle leads to a larger scour hole. Both the cover roughness coefficient and blockage ratio of a spur dike leads to a further increase in the turbulence kinetic energy and 3D velocity component values. The streamwise velocity contributes much to the turbulence intensity and Reynolds shear stress, leading to the development of scour holes. The lateral velocity component has the highest level of irregularities inside and outside scour holes. The Reynolds shear stress is negative inside scour holes and becomes positive toward the flow surface. It reaches its maximum slightly above scour holes. The negative values of the Reynolds stress are caused by the upward vertical momentum transport generated by a negative velocity gradient.

Zhang et al. [11] developed a theoretical model to describe the vertical distribution of longitudinal velocity, shear stress, and turbulence intensity. A two-power-law function was adopted to predict the vertical profile of velocity. It was found that the location of zero shear stress is not the same as that of the maximum velocity and is closer to the smooth boundary.

The work of Chen et al. [12] is about the waved-shape accumulation of ice jams based on fixed-bed experiments in a laboratory flume. A characteristic curve was developed to assess whether waved-shape ice accumulation occurs. An equation for calculating the ice wavelength was derived using the results of laboratory experiments. The relationship between the migration speed of ice waves and the ratio of ice discharge to the water flow rate were also studied. Furthermore, case studies were conducted with respect to ice accumulation in the St. Lawrence River, the Beauharnois Canal, and the La Grande River. The results of the case studies on ice accumulation in natural rivers also show that the relative thickness of an ice jam of 0.4 is the criterion for assessing whether an ice jam in a river should be considered an ice dam.

In the study of Hou et al. [13], it was found that the migration of ice waves affects pier scour. The interaction between ice accumulation and local scour around a pier is a very complicated process since not only does the channel bed deform, but the development of an ice jam occurs simultaneously. By conducting a series of flume experiments and by applying both continuity and momentum equations, an equation is been derived for predicting the thickness of ice waves around a pier. The thickness of the wave crest and the migration speed of the ice waves were investigated. Similar to a scour hole in a sand bed, an "ice scour hole" appeared at the bottom of the ice jam around the pier. The existence of an "ice scour hole" affects the development of ice waves.

In the study by Hu et al. [14], laboratory flume experiments were implemented to better understand the interactions between bed deformation and ice jam evolution around bridge piers. Their results show that in the presence of a local scour at bridge piers, both the ice jam thickness and water depth for flow are larger after an ice jam reaches its equilibrium state when compared with in the absence of a local scour at the pier. An equation was developed to determine the scour depth around a pier under ice-jammed flow conditions that considered related factors such as the flow Froude number, ice jam thickness, ice discharge rate, etc.

The aim of the study by Kazem et al. [15] was to experimentally investigate the characteristics of turbulence in the downstream region of a vegetation patch. The changes in turbulent structure were tracked in sequential patterns by reducing the patch size. The velocity profile, TKE, turbulent power spectra, and quadrant analysis were used to study the behavior and intensity of the turbulent structures. The results indicate that there are three different flow layers in the region downstream of the vegetation patch, including the wake layer, mixing layer, and shear layer. Flow structures, Reynolds shear stresses, TKE, and intermittent turbulent kinetic energy were investigated. As the size of the vegetation patch decreases, von Karman vortexes appear in the wake layer and form the dominant flow structures in the downstream region of a vegetation patch.

Kazem et al. [16] investigate the formation of coherent flow structures beyond vegetation patches. For a channel with a small patch, both the flow passing through the patch and the side flow around the patch have a considerable effect on the formation of flow structures beyond the patch. The von Karman vortex street splits into two parts beyond the vegetation patch: the strong part near the surface and the weak part near the bed. The middle part of the flow is completely occupied by the vertical vortex, but the horizontal vortexes cannot be detected in this region.

Nabaei et al. [17] investigated the effect of vegetation on flow structures and turbulence anisotropy around semi-elliptical abutments. When compared to channel beds without the presence of vegetation, channel beds with vegetation have a dramatically reduced primary vortex, but there is little difference in terms of the wake vortex. This causes a noticeable decrease in the Reynolds shear stress. An analysis of the Reynolds stress anisotropy indicates that the flow has a tendency to be isotropic in vegetated beds. The anisotropy profile changes from a pancake shape to a cigar shape in unvegetated channels.

This Special Issue includes interesting research about the incipient motion of bed material under hydraulically transitional flow conditions [18]. The results show that the critical Shields parameter is located under the Shields curve, showing no sediment motion. This indicates that the incipient motion of sediment particles occurs with smaller bed shear stress in a region of hydraulic transitional flow than that estimated using the Shields diagram.

The article of Ni et al. [19] deals with changes in flow and sediment in the Huai River in China. Along a river reach of this river, the incoming sediment rate from upstream of the Huai River continuously decreases. Therefore, the characteristics of channel bed deformation are affected. To investigate the interaction between flow and sediment, a one-dimensional hydrodynamic model was developed, validated using field data, and applied. It was found that the study river reach has frontal erosion and backward deposition, although the variation rate is relatively slow.

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References

1. Brandimarte, L.; Paron, P.; Di Baldassarre, G. Bridge pier scour: A review of processes, measurements and estimates. *Environ. Eng. Manag. J.* **2012**, *11*, 975–990. [CrossRef]
2. Federal Highway Administration (FHWA). *Evaluating Scour at Bridges, NH1-01-001*; FHWA: Washington, DC, USA, 1998.
3. Beltaos, S.; Miller, L.; Burrell, B.C.; Sullivan, D. Hydraulic effects of ice breakup on bridges. *Can. J. Civ. Eng.* **2007**, *34*, 539–548. [CrossRef]
4. Sui, J.; Wang, J.; He, Y.; Krol, F. Velocity profiles and incipient motion of frazil particles under ice cover. *Int. J. Sediment Res.* **2010**, *25*, 39–51. [CrossRef]
5. Sui, J.; Faruque, M.A.; Balachandar, R. Local scour caused by submerged square jets under model ice cover. *J. Hydraul. Eng.* **2009**, *135*, 316–319. [CrossRef]
6. Zabilansky, L.J. *Ice Force and Scour Instrumentation for the White River, Vermont. CRREL-SR-96-6*; Cold Regions Research & Engineering Lab: Hanover, NH, USA, 1996.
7. Sui, J.; Wang, D.; Karney, B.W. Suspended sediment concentration and deformation of riverbed in a frazil jammed reach. *Can. J. Civ. Eng.* **2000**, *27*, 1120–1129. [CrossRef]
8. Valela, C.; Sirianni, D.A.B.; Nistor, I.; Rennie, C.D.; Almansour, H. Bridge Pier Scour under Ice Cover. *Water* **2021**, *13*, 536. [CrossRef]
9. Sang, L.; Wang, J.; Cheng, T.; Hou, Z.; Sui, J. Local Scour around Tandem Double Piers under an Ice Cover. *Water* **2022**, *14*, 1168. [CrossRef]
10. Jafari, R.; Sui, J. Velocity Field and Turbulence Structure around Spur Dikes with Different Angles of Orientation under Ice Covered Flow Conditions. *Water* **2021**, *13*, 1844. [CrossRef]
11. Zhang, J.; Wang, W.; Li, Z.; Li, Q.; Zhong, Y.; Xia, Z.; Qiu, H. Analytical Models of Velocity, Reynolds Stress and Turbulence Intensity in Ice-Covered Channels. *Water* **2021**, *13*, 1107. [CrossRef]
12. Chen, P.; Sui, J.; Cao, G.; Cheng, T. Waved-Shape Accumulation of Ice Jam—Analysis and Experimental Study. *Water* **2022**, *14*, 3945. [CrossRef]
13. Hou, Z.; Wang, J.; Sui, J.; Song, F.; Li, Z. Impact of Local Scour around a Bridge Pier on Migration of Waved-Shape Accumulation of Ice Particles under an Ice Cover. *Water* **2022**, *14*, 2193. [CrossRef]
14. Hu, H.; Wang, J.; Cheng, T.; Hou, Z.; Sui, J. Channel Bed Deformation and Ice Jam Evolution around Bridge Piers. *Water* **2022**, *14*, 1766. [CrossRef]
15. Kazem, M.; Afzalimehr, H.; Sui, J. Characteristics of Turbulence in the Downstream Region of a Vegetation Patch. *Water* **2021**, *13*, 3468. [CrossRef]
16. Kazem, M.; Afzalimehr, H.; Sui, J. Formation of Coherent Flow Structures beyond Vegetation Patches in Channel. *Water* **2021**, *13*, 2812. [CrossRef]
17. Nabaei, S.F.; Afzalimehr, H.; Sui, J.; Kumar, B.; Nabaei, S.M. Investigation of the Effect of Vegetation on Flow Structures and Turbulence Anisotropy around Semi-Elliptical Abutment. *Water* **2021**, *13*, 3108. [CrossRef]

18. Shahmohammadi, R.; Afzalimehr, H.; Sui, J. Assessment of Critical Shear Stress and Threshold Velocity in Shallow Flow with Sand Particles. *Water* **2021**, *13*, 994. [CrossRef]
19. Ni, J.; Yu, B.; Wu, P. A Numerical Study of the Flow and Sediment Interaction in the Middle Reach of the Huai River. *Water* **2021**, *13*, 2041. [CrossRef]