IAHR Young Professionals Network
Hosted by Spain Water and IWHR, China

Proceedings of the
**5th IAHR Young Professionals Congress**
Online. 27-29 November 2024
#iahrYPcongress

# Assessment of DFSEM for providing turbulent inflow boundary conditions to the Large Eddy Simulation of a T-shaped open-channel confluence

Alemu Tezera Dessie[1], Saeed Hashemikia[2] and Tom De Mulder[3]
[1] Dep. of Civil Engineering, Ghent University, Ghent, Belgium, AlemuTezera.Dessie@UGent.be
[2] Dep. of Civil Engineering, Ghent University, Ghent, Belgium, Saeed.Hashemikia@UGent.be
[3] Dep. of Civil Engineering, Ghent University, Ghent, Belgium, TomFO.DeMulder@UGent.be

**ABSTRACT**

The Divergence Free Synthetic Eddy Method (DFSEM) is explored for providing turbulent inflow boundary conditions to a Large Eddy Simulation (LES) of a T-shaped confluence of open-channels. The influence of the Reynolds stress values imposed at the domain inlets onto the quality of the predicted flow is assessed. Though the impact is significant upstream of the junction, it is small downstream, where the flow characteristics are dominated by the shear layers originating from the sharp junction edges.

**Keywords:** open-channel confluence; Large Eddy Simulation; DFSEM.

## 1 INTRODUCTION

Confluences of open-channel flows are ubiquitous in fluvial networks, as well as in networks of artificial channels. The confluence hydrodynamics is complex and is often studied in a schematized geometry, consisting of, e.g., a straight tributary channel merging with a straight main channel (Figure 1).

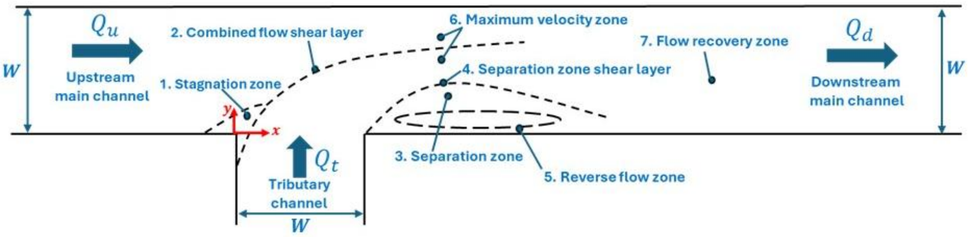



*Figure 1. Main flow features in open-channel confluence (after Best, 1987) and coordinate system*

Besides the common RANS-based numerical models, also Large Eddy Simulations (LES) are used nowadays for studying the details of such turbulent flows. Several ways have been exploited to limit the high computational cost of such an eddy-resolving model (see e.g. Ramos et al., 2019). Instead of resolving the wall boundary layers, wall functions can be adopted. To treat the free-surface, a (frictionless and impervious) rigid-lid can be used instead of an interface capturing method as the Volume of Fluid method. Furthermore, one can limit the extent of the computational domain upstream of the junction. It remains important, however, that the simulated flow in the zones of interest exhibits realistic turbulent characteristics, which may depend on the realism of the turbulent inflow conditions at the inlets of the upstream branches. Ramos et al. (2019) integrated short channels with periodic boundary conditions near the upstream ends of the upstream branches. Here, an alternative method is explored: the Divergence Free Synthetic Eddy Method introduced by Poletto et al. (2013). The DFSEM generates synthetic turbulence by advecting a number of eddies with a specific shape function and random intensities through the inflow boundaries. Application of the DFSEM requires the specification of a number of parameters in the inlets. The objective of the present contribution is to verify to which extent the values of the Reynolds stresses imposed at the inlets influence the quality of the flow in the upstream and downstream branches.

## 2 NUMERICAL SIMULATIONS

Use is made of a model developed in the OpenFOAM toolbox and having nearly the same characteristics as the one described in Ramos et al. (2019), except the change to DFSEM. A (different) case from the experimental dataset of Weber et al. (2001), acquired in a T-shaped confluence (with channel widths $W$ = 0.914 m), was simulated on a similar domain and fine mesh ($\sim 10.2$ M cells, after sensitivity analysis) as in Ramos et al. (2019). The case is characterized by a discharge ratio $Q_u/Q_d$ = 0.58, upstream bulk velocities $U_u$ = 0.330 m/s and $U_t$ = 0.237 m/s, downstream bulk velocity $U_d$ = 0.604 m/s and water depth (at $x/W$ = 8) $h_d$ = 0.308 m.

In the domain inlets, the boundary layer length scale and the typical eddy size are kept constant, i.e. equal to $\delta \approx h_d/2$ and $L \approx \delta$ (which is inside the range of $(0.02-2)\delta$ explored by Wang et al., 2022), respectively. The 6

Reynolds stresses (in m²/s²) will be varied. Following McGrattan et al. (2014), a turbulence intensity $I$ is specified and isotropic turbulence is assumed in the inlets, yielding $R_{xx} = R_{yy} = R_{zz} = (IU)^2$, where $U$ (in m/s) is either $U_u$ or $U_t$, while $R_{xy} = R_{xz} = R_{yz} = 0$. Adopting 4 different values for $I$ (i.e. 0, 5, 10 and 30%) at the inlets, yields a cross-sectionally averaged streamwise turbulence intensity (Figure 2) which differs significantly upstream of the junction (at $x/W = -2$ and $y/W = -2$), while the influence in the downstream channel (i.e. $x/W > 0$) is small. It is found (not shown) that the secondary flow velocities and the turbulent kinetic energy at $x/W = -2$ grow with $I$. Downstream of the junction, at $x/W = 2$, the influence of $I$ upon the flow features is small (Figure 3 (a) to (c)). This is not surprising, since the flow features here are mainly governed by the shear layers originating from the sharp junction edges. The metrics for the entire main channel (Figure 3 (d)) show a good agreement between simulations and experimental data, irrespective of the chosen $I$ value.

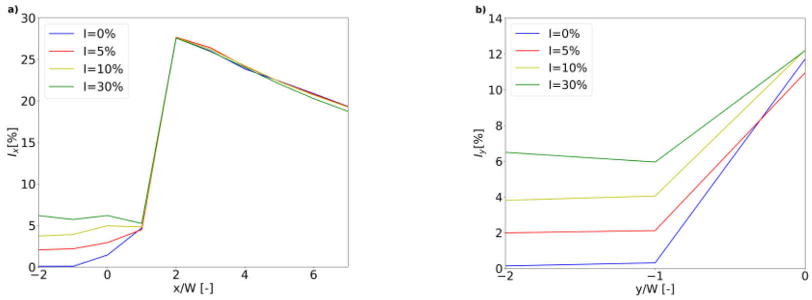
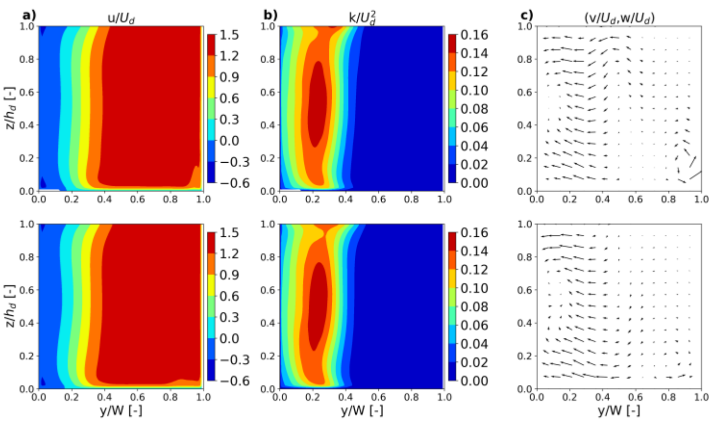



*Figure 2. Cross-sectional averages of (a) $I_x (= \sqrt{R_{xx}}/U_u)$ along main channel and (b) $I_y (= \sqrt{R_{yy}}/U_t$ )along tributary.*




d)

| | | u[m/s] | v[m/s] | k[m²/s²] |
|---|---|---|---|---|
| I=0% | Bias | -0.0228 | 0.0033 | 0.0006 |
| | RMSE | 0.0849 | 0.0355 | 0.0038 |
| I=30% | Bias | -0.0234 | 0.0016 | 0.0007 |
| | RMSE | 0.0806 | 0.0330 | 0.0036 |

*Figure 3. Simulation results downstream of junction at x/W=2 with $I$ = 0 % (top panels) and $I$ = 30 % (bottom panels) of (a) mean streamwise velocity, (b) turbulent kinetic energy, (c) secondary flow, (d) Metrics for simulation results with $I$ = 0 % and $I$ = 30 % in comparison to all experimental data available throughout main channel.*

## 3 CONCLUSIONS

The selected turbulence intensity when specifying the normal Reynolds stress values at the inlets for the DFSEM, has a significant impact on the flow upstream of the junction, but its impact on the flow features downstream is small, as they are dominated by the shear layers originating from the sharp edges.

## REFERENCES

Best, J.L. (1985). *Flow dynamics and sediment transport at river channel confluences*, Ph.D. thesis, Univ. London.

McGrattan, K. et al. (2014*). Fire Dynamics Simulator User's Guide*. NIST Special Publication 1019, 6th edition.

Poletto, R., Craft, T., & Revell, A. (2013). A new divergence free synthetic eddy method for the reproduction of inlet flow conditions for LES. *Flow, Turb. Comb.*, 91, 519-539.

Ramos, P. X., Schindfessel, L., Pêgo, J. P., & De Mulder, T. (2019). Flat vs. curved rigid-lid LES computations of an open-channel confluence. *J. Hydroinformatics*, 21(2), 318-334.

Wang, Y., Vita, G., Fraga, B., Lyu, C., Wang, J., & Hemida, H. (2022). Influence of turbulent inlet boundary condition on large eddy simulation over a flat plate boundary layer. *Int. J. Comp. Fluid Dyn.*, *36*(3), 232-259.

Weber, L.J., Schumate, E.D., & Mawer, N. (2001). Experiments on flow at a 90° open-channel junction. *J. Hydr. Eng.,* 127(5), 340-350.

ISBN: 978-90-834302-5-6