

MODELING OF CONTAMINANT DISPERSION IN STREAMS – 1D VERSUS 2D MODEL USE COMPARISON: CASE STUDY ON THE ONDAVA RIVER

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Abstract

Article is focused on comparison of some aspects of 1D and 2D water quality model use for modeling of contaminant spreading in rivers. Properties of numerical models MODI and HEC-RAS were tested at 422 m long reach of the Ondava River. Results showed that HEC-RAS model can be used only for scenario or river reach along which the transverse pollution spreading can be complete. Better choice for this case study represents the model MODI that in 2D schematization shows detailed spatial structure of contaminant distribution in time as well as to specify the exact position of pollutant source outlet that effect the character of pollution cloud downstream transported. The results of simulations have proved that numerical models MODI as well as HEC-RAS model allow a reasonable support in decision making process connected to river water quality management.

Key words: water quality modeling, HEC-RAS, MODI model, 1D and 2D water quality models

INTRODUCTION

The present legislation evaluating the quality of water bodies in Slovakia is based on implementation of the Water Framework Directive (2000/60/ES) (Torma & Fazekašová, 2007). Climate and hydrological changes, modification of physical conditions in streams affect, inter alia, transport phenomena including pollution propagation in stream channel (Babošová et al. 2006; Boltížiar, et al. 2012; Horák & Šiška 2008; Supuka & Halada 2011). The water quality predictions affect uncertainty in inputs related to the analyzed transport process (Igaz et al. 2008; Igaz, et al. 2010; Macura et al. 2012) Solution of processes connected to transport and mixing of water with substances transported downstream by the flowing waters has wide practical application, especially in the studies of wastewater spreading and mixing of waters of different quality below the confluence. Knowledge of the dispersion processes in flowing waters maybe useful for river modification, outlet design or river confluence design to mitigate the potential negative impacts on instream biota. Numerical simulation is one of useful, helpful and advantageous tools in water management, especially for transport pollution problems in surface water. Solute transport models try to simulate the solute concentration changes in downstream transport with flowing waters. Use of numerical models provides possibility to simulate the effects of different scenarios of water quality problems, to optimize the design of water quality improvement measures or to assess the parameters value with limited information for the precise determination. When solving problems relating to water quality in streams its importance is even greater when considering the impact of adverse effects on the environment. Use of numerical models provides possibility to simulate the effects of different scenarios of water quality problems, to optimize the design of water quality improvement measures or to assess the parameters value with limited information for the precise determination.

MATERIAL AND METHODS

For analysis of pollution wave propagation from outfall in headwater reach of the Ondava River were used two-dimensional dispersion model MODI and one-dimensional model HEC-Ras. The MODI is a numerical model based on the advection-diffusion equation, which can simulate the spread of contamination in prismatic channel for steady-state flow conditions (Veliskova & Sokáč, 2012). MODI model was developed by researches of the Institute of Hydrology SAS Bratislava (Velísková & Kohutiar) in 1995. The model uses a concept of streamtubes. This concept is based on a coordinate system which divides the flow across the channel width in stream-tubes of unequal width, but with the same flow rate (Yotsukuru & Sayre, 1976).

The simulation of non-conservative transport in longer stream reaches may be carried out by taking into account the self-purification processes. The discharge of pollution source outlet may be given as a steady or unsteady

flow and can be located at any point along the river cross section. Input data of model MODI may be simple obtained for any stream. It is necessary to describe the cross sections and velocity distribution in the river cross-sections and the transverse dispersion coefficient values (and if it is necessary also reaction coefficient) (Table 1.). Hec-Ras model was developed by the United States Army Corps of Engineers (USACE 2006) and is designed to model complex phenomena and processes in the river systems. This software allows calculations of one-dimensional steady non-uniform and unsteady flows, solving of hydraulic engineering tasks, design of modifications stream channels, design of water works, pollution transport modelling, modelling of temperature of surface water, bed load transport, modelling of accumulation-erosion processes in stream channels, etc. This module applied the QUICKEST-ULTIMATE explicit numerical scheme to solve the one-dimensional ADE using a control volume approach.

Table 1. Input data for solution of transport model obtained on base of field measurements in experimental reach of the Ondava River

Discharge Q the Ondava River [$\text{m}^3 \cdot \text{s}^{-1}$]	1.28
Discharge Q the Lodomirka River [$\text{m}^3 \cdot \text{s}^{-1}$]	0.075
Bed slope S (the Ondava River) [‰]	3.3
Width B [m]	14.5 - 20.4
Hydraulic depth H [m]	0.16 - 0.17
Flow area A [m^2]	2.36 - 3.36
Roughness coefficient n [-]	0.030- 0.040
Lateral dispersion coefficient D_y [$\text{m}^2 \cdot \text{s}^{-1}$]	0.015
Longitudinal dispersion coefficient D_x [$\text{m}^2 \cdot \text{s}^{-1}$]	0.84- 1.36

By using of MODI and HEC-RAS models we can simulate different situation connected to location and parameters of pollution source. Our case study simulates and analyzes pollution spreading coming to the Ondava River from the Lodomirka River

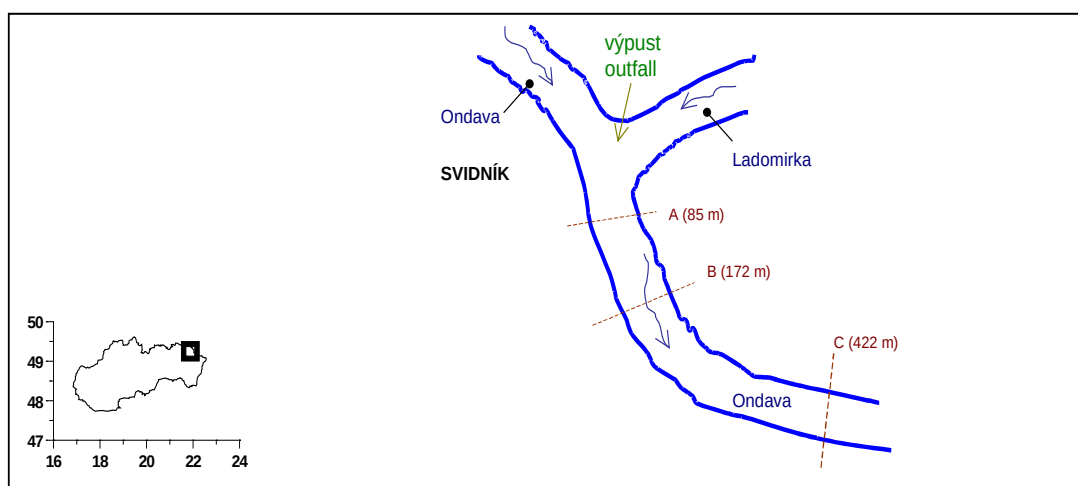


Figure 1. Schematic map of experiment site

RESULTS AND DISCUSSION

The results of numerical simulations of the scenario are graphically shown in Figures 2 (model MODI) and Figures 3-9 (model HEC-RAS). Simulation results of model MODI (Figure 3) show that the pollution from the Lodomirka River is transported downstream the Ondava River almost along whole simulated river reach close to

the left bank. It is probably caused by flow direction in this reach (see sketch in Figure 1) resulting velocity distribution in cross-section profiles and also by situation of the confluence. The simulated river reach is formed by left-hand side curvature (Figure 1) and therefore thalweg trajectory migrates from left convex bank to the right concave bank. Higher velocities near the right bank of the Ondava River push pollution wave coming from the left tributary to the left bank and pollution cannot be spread across the whole river width along the simulated reach. Besides that, it can be seen that pollution at the edges of concave bank (right side part of pollution wave) are accelerated by higher velocities and the transported substances close to left bank are decelerated due to lower velocities..

It resulted to gradual deformation of the pollution wave and distribution of pollution concentration in experimental reach. This pollution scenario was simulated in a relatively short reach of the Ondava River due to limitations of input data availability. However, the MODI model has potential to simulate river reaches with greater lengths. The results of pollution transport simulation with HEC-RAS model (Fig. 3-9) provide another view on process of pollution transport. Due to 1D spatial schematization, the mean concentrations of contaminant at the cross-section profiles in simulated river reach come up from 3 to 7-times smaller values than maximal concentration at identical time and distance from injection profile (Table 2.)

Table 2. Comparison of contaminant concentration computed by models MODI and HEC-RAS

Concentration of contaminant	Time in seconds			
	120	420	720	960
$c_{\max}$ – MODI [g.m^{-3}]	1.8	2.3	1.2	0.8
c_{mean} – HEC-RAS [mg.l^{-1}]	0.24	0.31	0.28	0.25
Cross section distance from injection profile [m]	11	102	295	370

Results presented by figures and tables show limitations of HEC-RAS model in case of contaminant transport simulation in short reaches of streams. The high level of transport process schematization provides mean values of contaminant concentration; it is not possible to simulate pollution spreading in more details. For this reason, HEC-RAS model can be used only for scenario or river reach along which the transverse pollution spreading can be complete. Only after that moment The HEC-RAS model gives correct results. Better choice for this case study represents the model MODI that in 2D schematization shows detailed spatial structure of contaminant distribution in time as well as to specify the exact position of pollutant source outlet that effect the character of pollution cloud downstream transported.

CONCLUSIONS

In the paper are presented possibilities and advantages of numerical simulations to solve water management problems, especially problems linked with pollution spreading in rivers. Properties of numerical models MODI and HEC-RAS were tested at 422 m long reach of the Ondava River. There was simulated the situation when the contamination is coming from the Lodomirka River, the left tributary of the Ondava River, and it is transported downstream of the Ondava River. The results of numerical simulations are cited graphically in Fig. 3 – 9. These results provided information connected to pollution transformation in given level of schematization. From them comes out that the proper choice of a numerical model (1D versus 2D) depends on character and complexity of water management problems, spatial, temporal and accuracy requirement on results generated by a model.

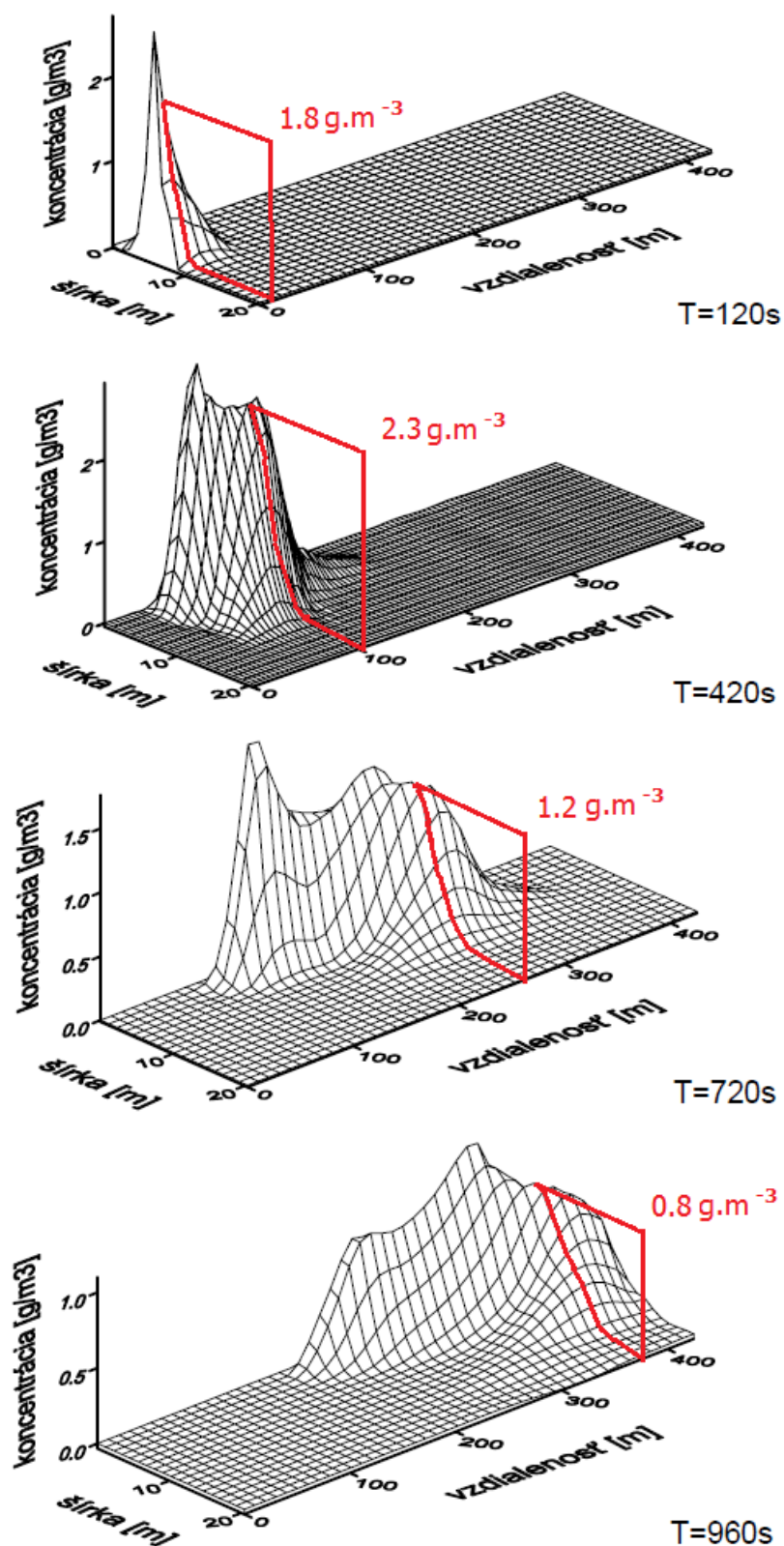


Figure 3. Results of pollution transport simulation with MODI model (T = time after starting of tracer injection, X axis – distance from injection profile in m, Y axis – channel width B in m, Z axis – concentration of contaminant in m.s^{-2})

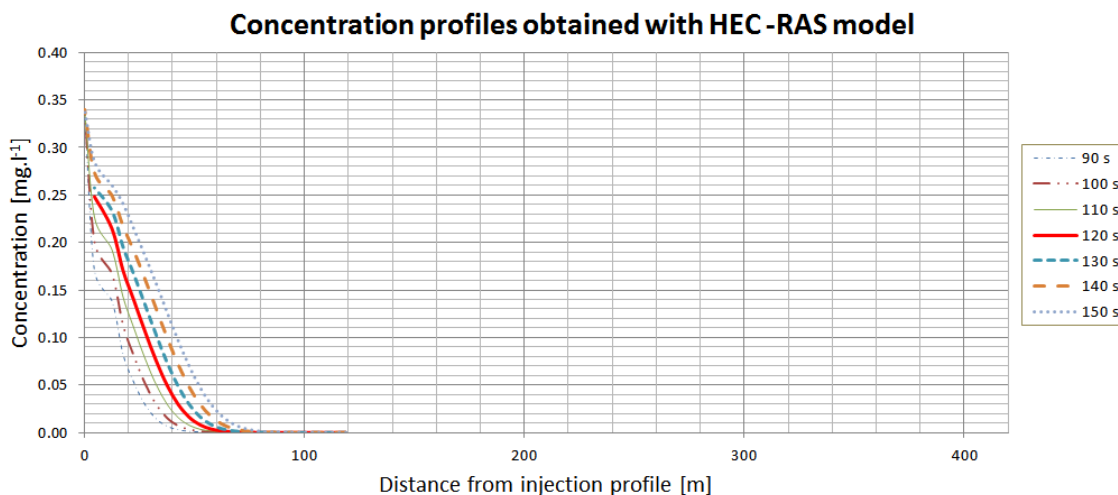


Figure 4. Concentration profiles obtained with HEC -RAS model in time = 120 s $\pm$ 10s, 20 and 30 s

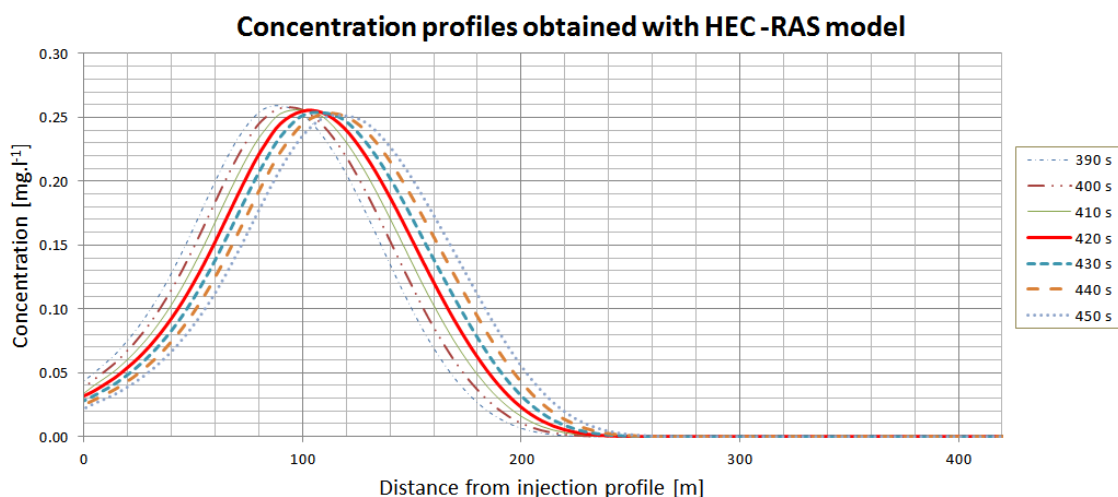


Figure 5. Concentration profiles obtained with HEC -RAS model in time = 420 s $\pm$ 10 s, 20 s and 30 s

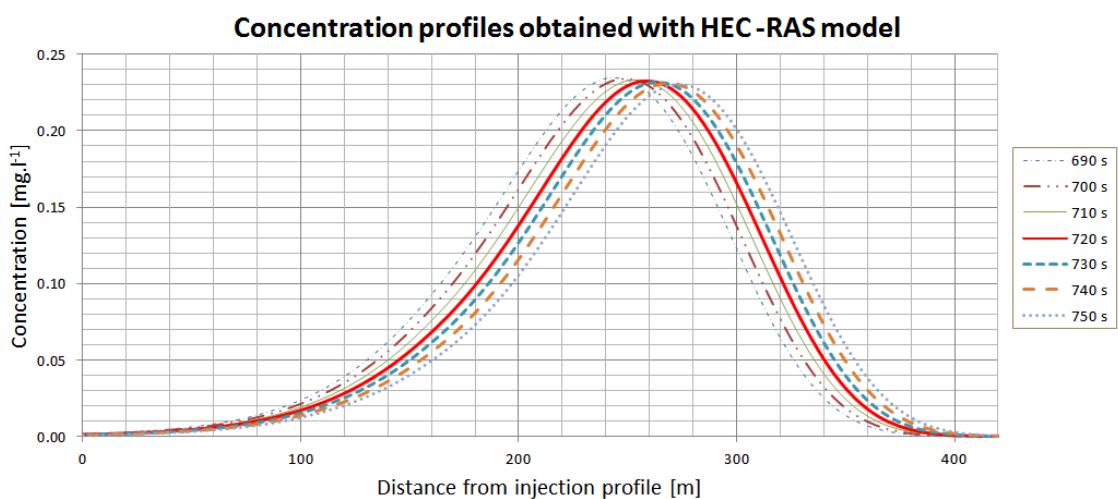


Figure 6. Concentration profiles obtained with HEC -RAS model in time = 720 s $\pm$ 10 s, 20 s and 30 s

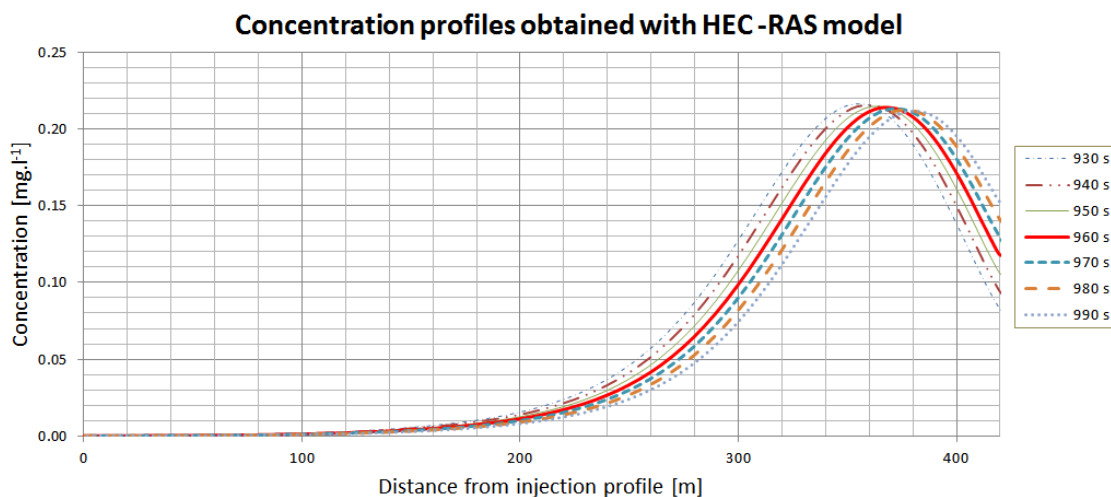


Figure 7. Concentration profiles obtained with HEC -RAS model in time = 960 s $\pm$ 10 s, 20 s and 30 s

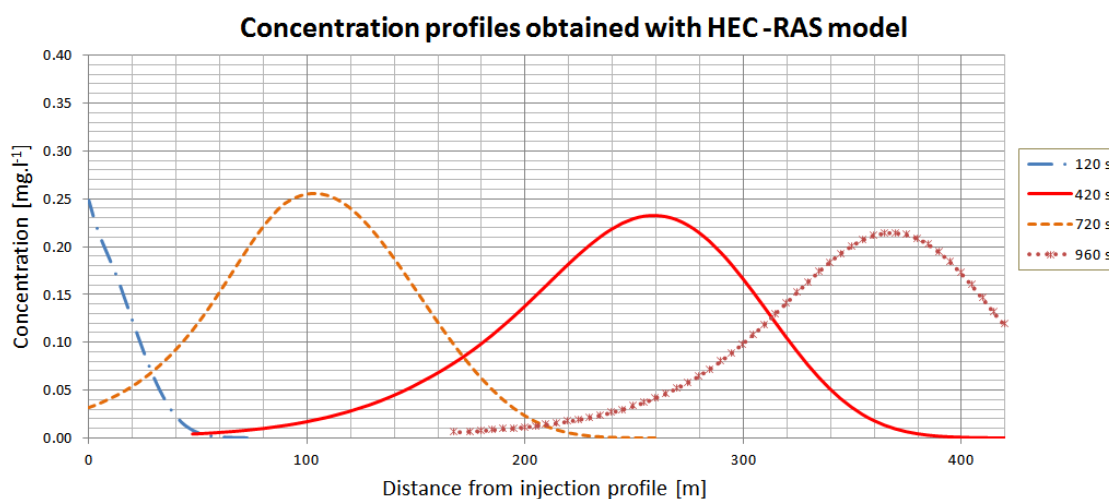


Figure 8. Concentration profiles obtained with HEC -RAS model in time = 120 s, 420 s, 720 s and 960 s.

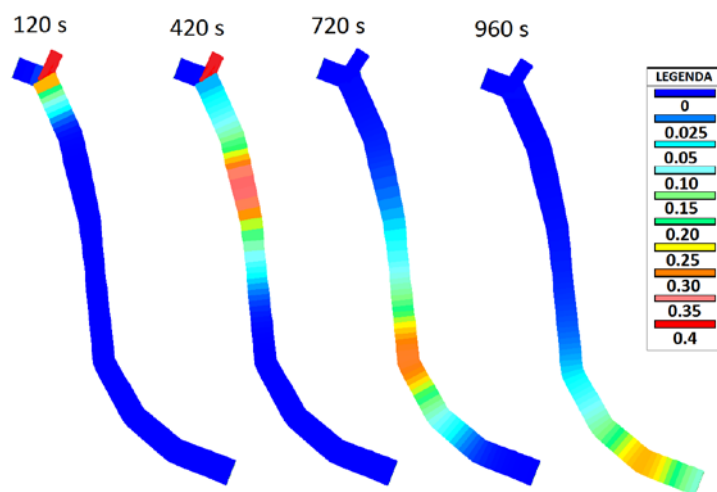


Figure 9. Schematic plot of time and spatial spreading of concentration in experimental reach (HEC-RAS model output modified by authors)

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