Technical Note

Hydrodynamic modelling of the St. Lawrence River at Cornwall in support of Sediment Remediation Development by the MOE Eastern Region

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BACKGROUND

The MOE Eastern Region has hired a consultant, (Golder Associates Ltd.), to assess the long-term stability and fate of contaminated sediments within 3 sediment "zones" previously delineated through the ongoing Cornwall RAP process. In support of this initiative, the MOE-EMRB modelling section was asked by the Eastern Region to provide supporting information, if possible.

The MOE Environmental Monitoring & Reporting Branch acquired the "Surface Water Modelling System" ("SMS") in 2000. This modelling package incorporates various models which can be used to evaluate fully 2-dimensional, dynamic river hydrodynamics and contaminant dispersion. This modelling system is also capable of providing information important to the estimation of sediment transport. Of particular importance, is the capability to estimate detailed bed shear stress in the Cornwall near shore zones of the river, where much of the in-place historic mercury still resides.

The modelling system was previously applied to the St. Lawrence River at Cornwall, to examine potential plume impacts that might occur from a dredging failure associated with the removal of PCBs contaminated sediment from the near shore vicinity of the GM facility in Massena, New York. The modelling grids developed for this previous work were reviewed and utilized in providing the results presented in this assessment. The remainder of this note summarizes, very briefly, the modelling procedure and application results.

<u>Modelling procedure</u>

Dan Walker of Golder Associates Ltd., requested that information regarding the river current field be provided, for a range of possible river flow rate conditions. Of particular interest, are the 3 river flow regimes associated with: maximum, average, and minimum; daily river flow.

To provide information for this request, the following strategy was followed:

(a) The total river flow rate and water levels associated with these regimes were identified.

(b) The hydrodynamic model was then calibrated, (via a series of simulations), to match available measured data. This was carried-out separately for each of the flow regimes.

(c) Once calibrated, the model was run to provide results for the 3 sediment areas of interest. (Results are also provided for Zone # 4, at the North-East shore of Cornwall Island, with the Zone # 2 results). The results summarized include: depth-averaged water velocity and water depths. These parameters were also used in deriving estimates of the shear stress likely to act upon the river bed, for the 3 sediment areas.

<u>Model grid</u>

The grid selected for this assessment consists of a little over 9,000 triangular elements. These cover the entire water surface of about a 20 km segment of the river, from about 1 km east of the Moses Saunders Dam, downstream as far as Summerstown. The Western (upstream) half of the grid, which includes the area around Cornwall Island, is illustrated in Figure 1.

The "RMA2" model (from the "SMS" system) is used to simulate river hydrodynamics. This simulation involves namely the prediction of internal water levels and currents within a modelled section of the river. In order to apply the model, a "boundary condition" must be defined at the upstream / downstream boundaries. For typical river simulations, the upstream and downstream boundary condition are namely: a total river flow rate and surface water elevation, respectively.

The reasons for selecting these boundaries are as follows:

(i) the downstream boundary is located at a transect of the river where water elevation information is available. This is essential for model calibration,

(ii) the upstream boundary is located upstream of Cornwall Island, where the total river flow has not yet been divided (i.e. to the North and South of Cornwall Island). This upstream boundary location thus helps provide a "validation" test of the model, since it must simulate this important river split.

(iii) the boundaries are located well upstream / downstream of the potential areas of interest, for the Cornwall waterfront. This helps to avoid impact from any boundary "irregularities" upon the areas of interest.

River flow regimes

Based upon review of available river flow-rate and water level measurements, 3 periods of time were identified, which correspond to the "maximum", "minimum" and "average" river flow regimes, as identified by the RAP team. These are all from 1998, and are summarized in Table 1.

Table 1. Average measured conditions associated with the 3 St. Lawrence River flow regimes.

FLOW REGIME	MINIMUM	AVERAGE	MAXIMUM
Date of measurements (all in 1998)	April 2-3	October 17-22	March 25
Average River flow-rate (m^3/s) *(used as upstream boundary condition)*	4,700	7,470	10,240
Water Surface Elevations, (metres a.s.l. -1985 IGLD), at:			
"Cornwall"	*46.668*	*46.958*	*47.133*
"Summerstown" *(used as downstream boundary condition)*	*46.560*	*46.739*	*46.799*

Model calibration

The model was initially run, using hydrodynamic parameters (eddy viscosity and bed roughness coefficients) derived for previous modelling work. This work was carried-out for river flow-rates of approximately 7,000 cms. The predicted water level at the Cornwall gauging station, before any model calibration, was: 2.6 cm low, 1.4 cm low and 4.1 cm high; in comparison to that measured for the “minimum”, “average” and “maximum” flow regimes, respectively, as identified above.

While these differences are not likely that significant, (in terms of predicted water velocities), it was decided to calibrate the model (additionally for this assessment) for each of these flow regimes. This is reasonable, owing to the large variation in flow-rate under the 3 regimes. With no other available data within the model domain, at the time of these 3 flow regimes, it was decided to adjust the Manning’s roughness coefficient, (“n”), in a proportionate manner, in order to match the water levels at the Cornwall gauging station. From past external studies, it has been found that Manning’s “n” will vary to some degree, with water depth changes.

The final results of the calibrations, are provided in Table 2. Also shown is the percentage of total river flow-rate that the model estimated to pass North of Cornwall Island, (i.e. into the channel that contains the 3 sediment areas of interest).

Detailed results from the hydrodynamic model

A series of figures is provided for each of the three flow regimes. These include:

(i) depth-averaged velocities for the entire Cornwall channel vicinity,
(ii) water depths for each of the 3 sediment zones. (For the average flow regime only, with approximate depth differences for the other 2 flow regimes indicated on the figures.),
(iii) depth-averaged water velocities for each of the 3 sediment zones, and
(iv) estimated bed shear stress for each of the 3 sediment zones.

The bed shear stress (in Newtons / m^2) was estimated through the modelling package’s “data calculator”, by using the Manning bed shear stress equation, as follows:

$$\tau_{bed} = \rho_w \times \left\{ \frac{g \times (\bar{u} \times n)^2}{D^{1/3}} \right\} \quad .....(1)$$

where: g = gravitational acceleration, (m / sec^2),
$\bar{u}$ = depth-averaged water current velocity, (m/sec), *from RMA2*
n = Manning’s “roughness” coefficient, (sec/$m^{1/3}$), and
D = water flow depth, (m), *from RMA2.*

However, as discussed above, the depth-averaged velocity and water depth fields have also been provided, to permit the consultant to estimate bed shear stress via a different approach, if deemed necessary.

The series of figures are hopefully, self-explanatory. While a good reference base-map is not available, a 100-metre (dashed) grid has been artificially added, to help permit scaling of the results, as necessary, (a 500-metre grid is used for the 4 figures of the entire Cornwall Island area).

Table 2. Results from the hydrodynamic model calibration.

FLOW REGIME	MINIMUM	AVERAGE	MAXIMUM
Date of measurements (all in 1998)	April 2-3	October 17-22	March 25
Average River flow-rate (m^3/s) *(measured average & upstream boundary condition for model)*	4,700	7,470	10,240
Calibrated Manning's roughness coefficient "n", in:			
upper Cornwall channel (including Sediment Zone # 1)	0.0300	0.0273	0.0240
lower Cornwall channel (including Sediment Zones # 2 & 3)	0.0275	0.0250	0.0219
Water Surface Elevations, (metres a.s.l. -1985 IGLD), at:			
"Cornwall" *(model predicted)*	*46.667*	*46.956*	*47.131*
"Cornwall" *(measured average)*	*46.668*	*46.958*	*47.133*
"Summerstown" *(measured average & downstream boundary condition for model)*	*46.560*	*46.739*	*46.799*
Total River Flow % entering "Cornwall Channel" (model predicted)	*28.5*	*30.9*	*33.3*

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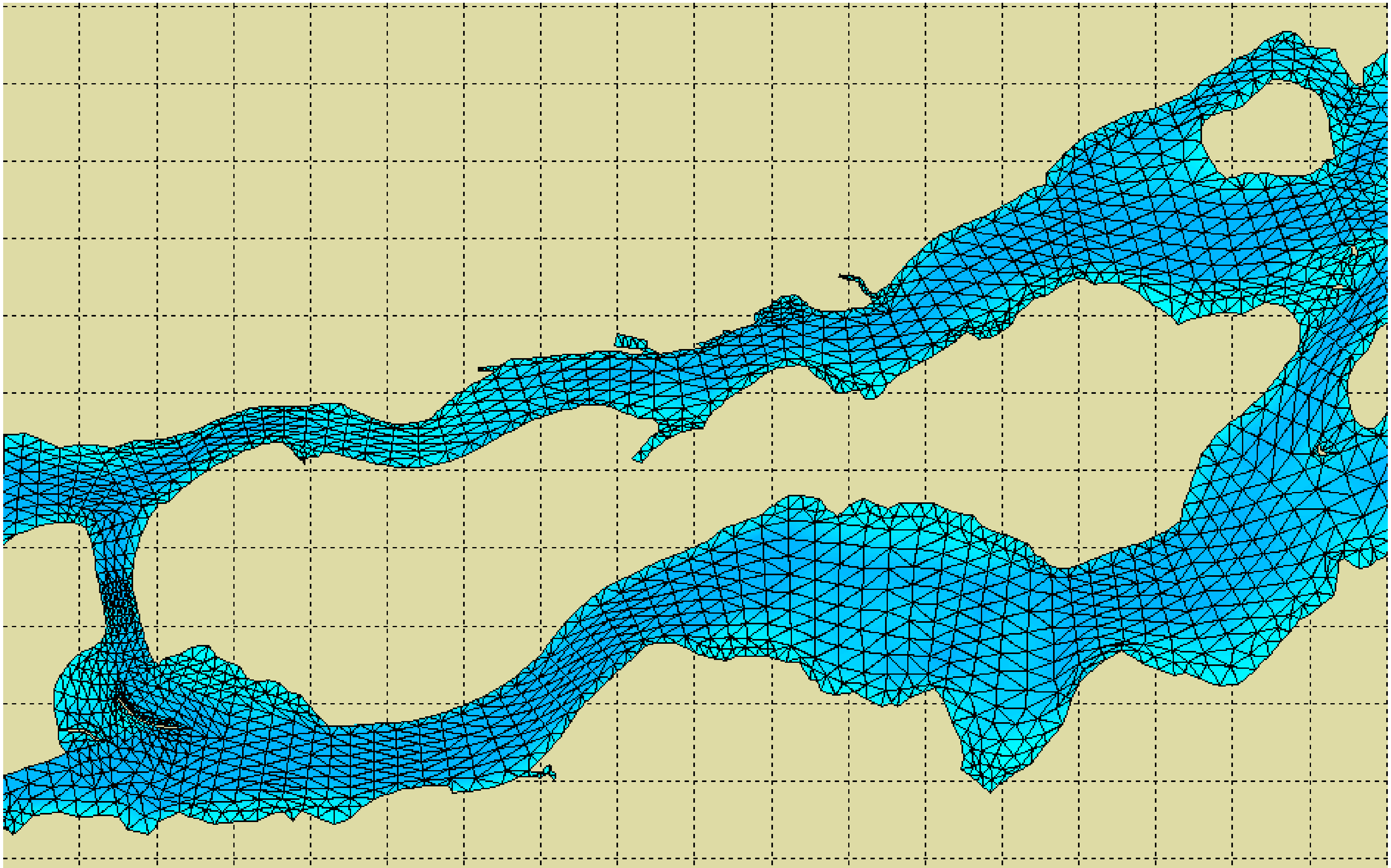

Figure 1. The model grid around Cornwall Island, (the Western-half of the total grid used).

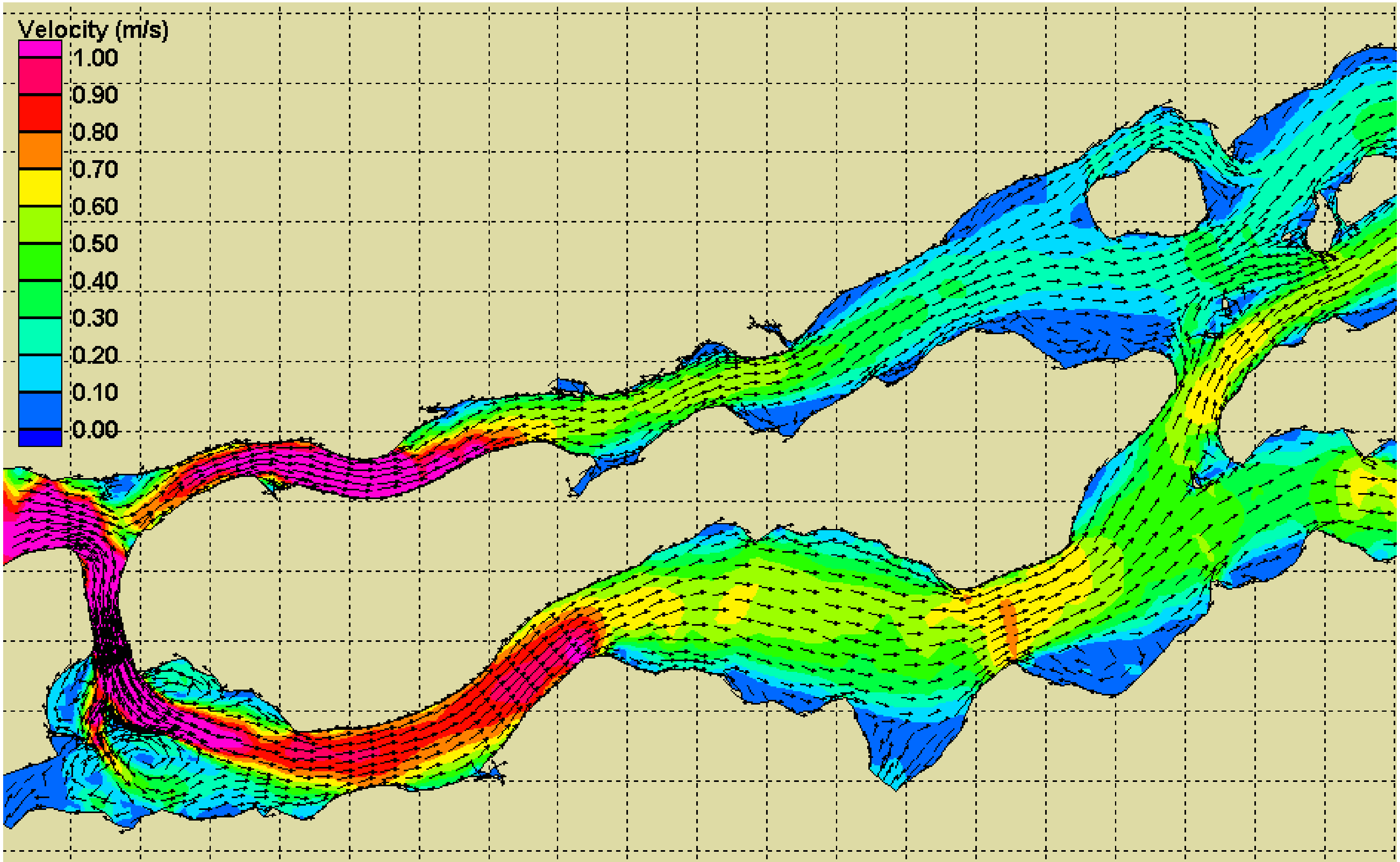

Figure 2(a). Depth-average velocities around Cornwall Island under the "minimum" river flow-rate regime.

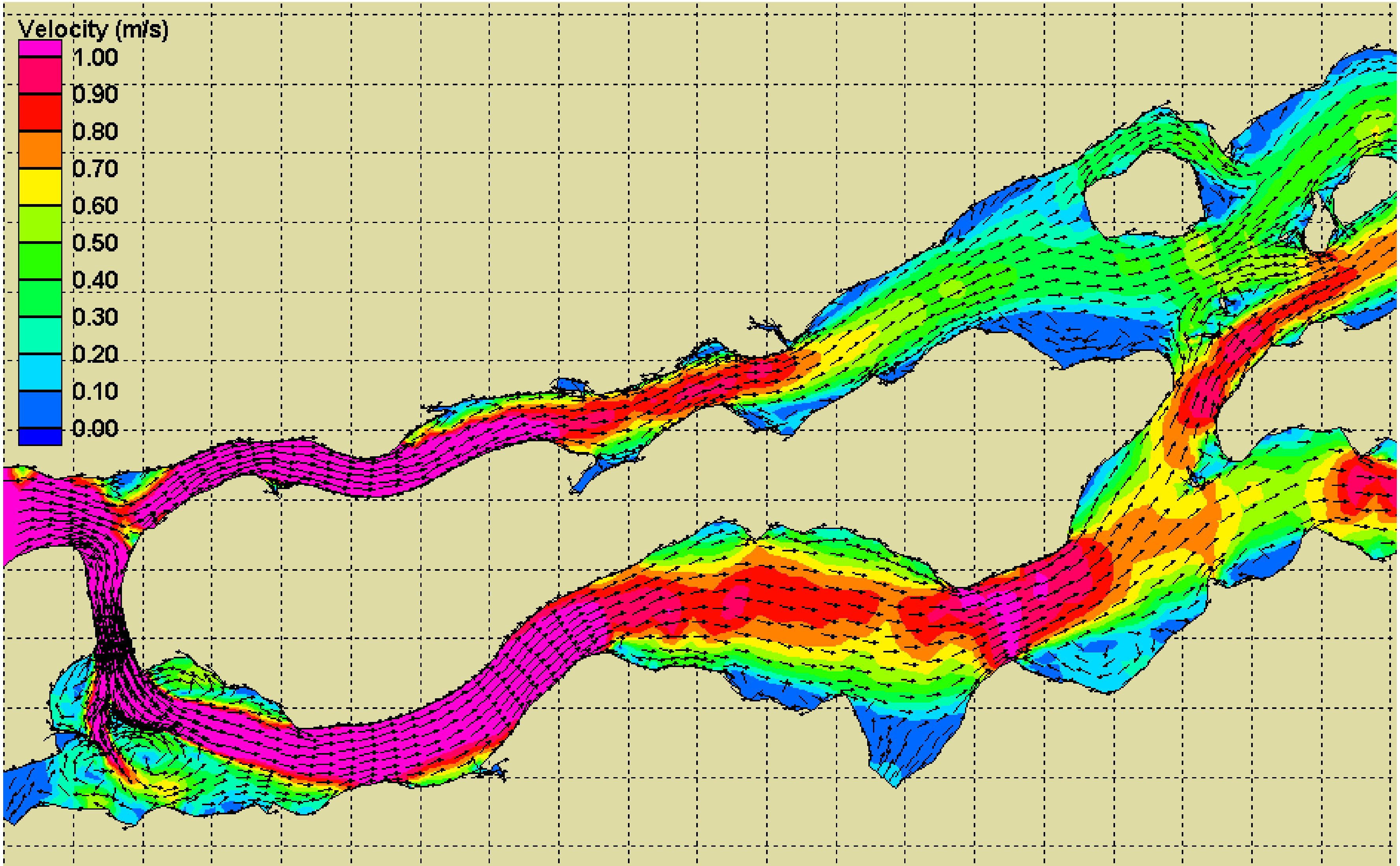

Figure 2(b). Depth-average velocities around Cornwall Island under the "average" river flow-rate regime.

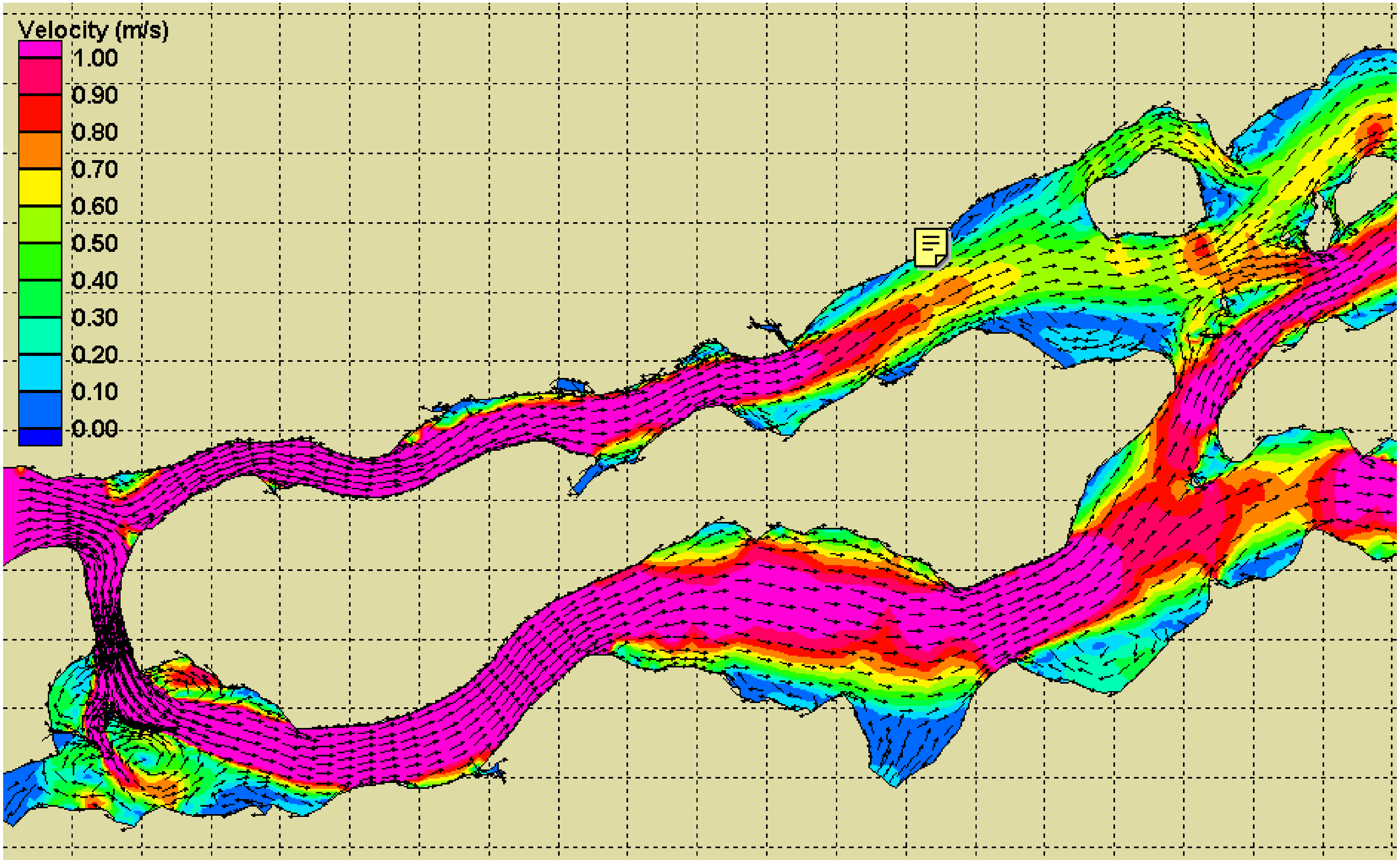

Figure 2(c). Depth-average velocities around Cornwall Island under the "<u>maximum</u>" river flow-rate regime.

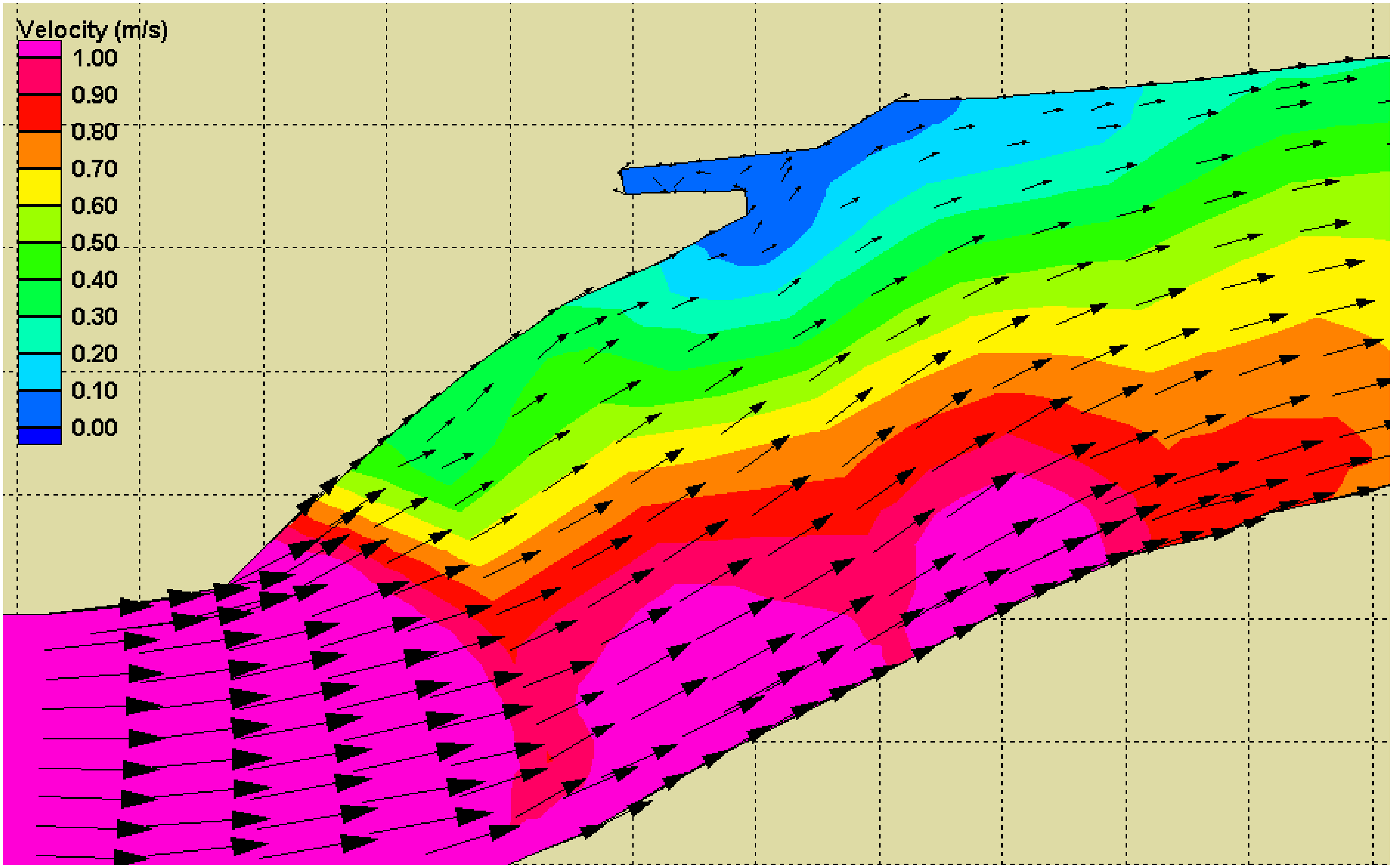

Figure 3(a). Depth-average velocity in the vicinity of " Zone 1", under the "minimum" river flow-rate regime.

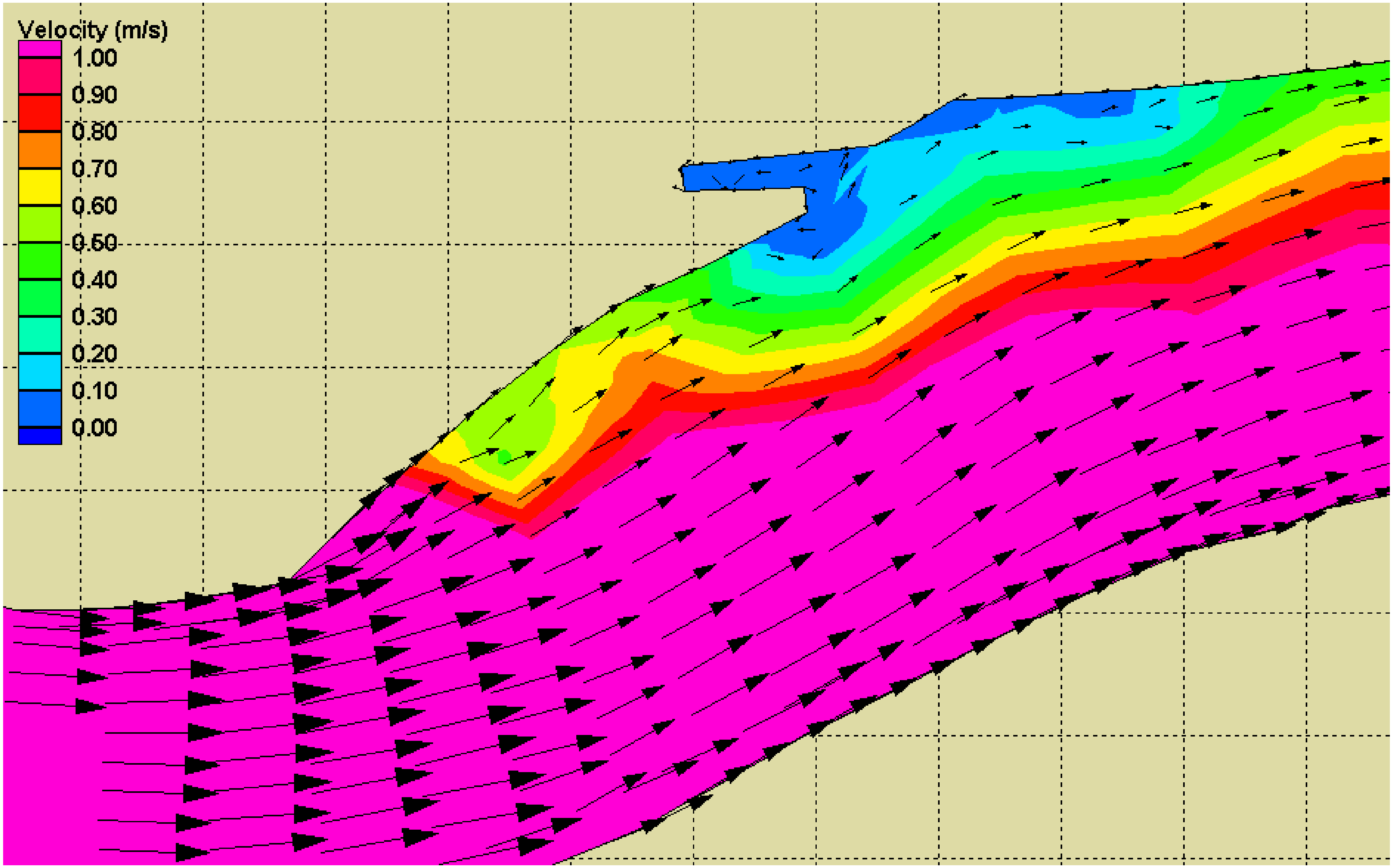

Figure 3(b). Depth-average velocity in the vicinity of “ Zone 1", under the “average” river flow-rate regime.

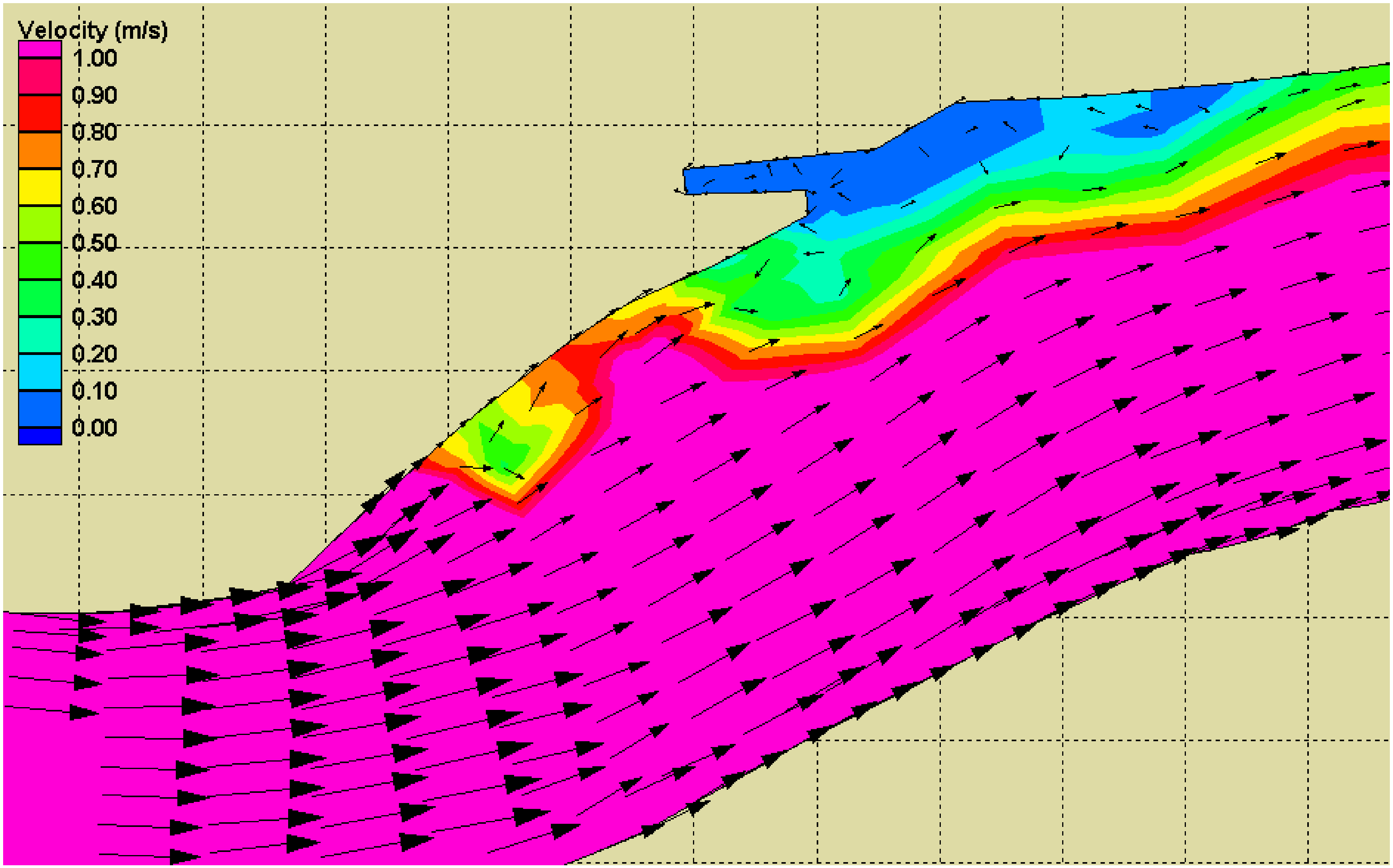

Figure 3(c). Depth-average velocity in the vicinity of “ Zone 1", under the “maximum” river flow-rate regime.

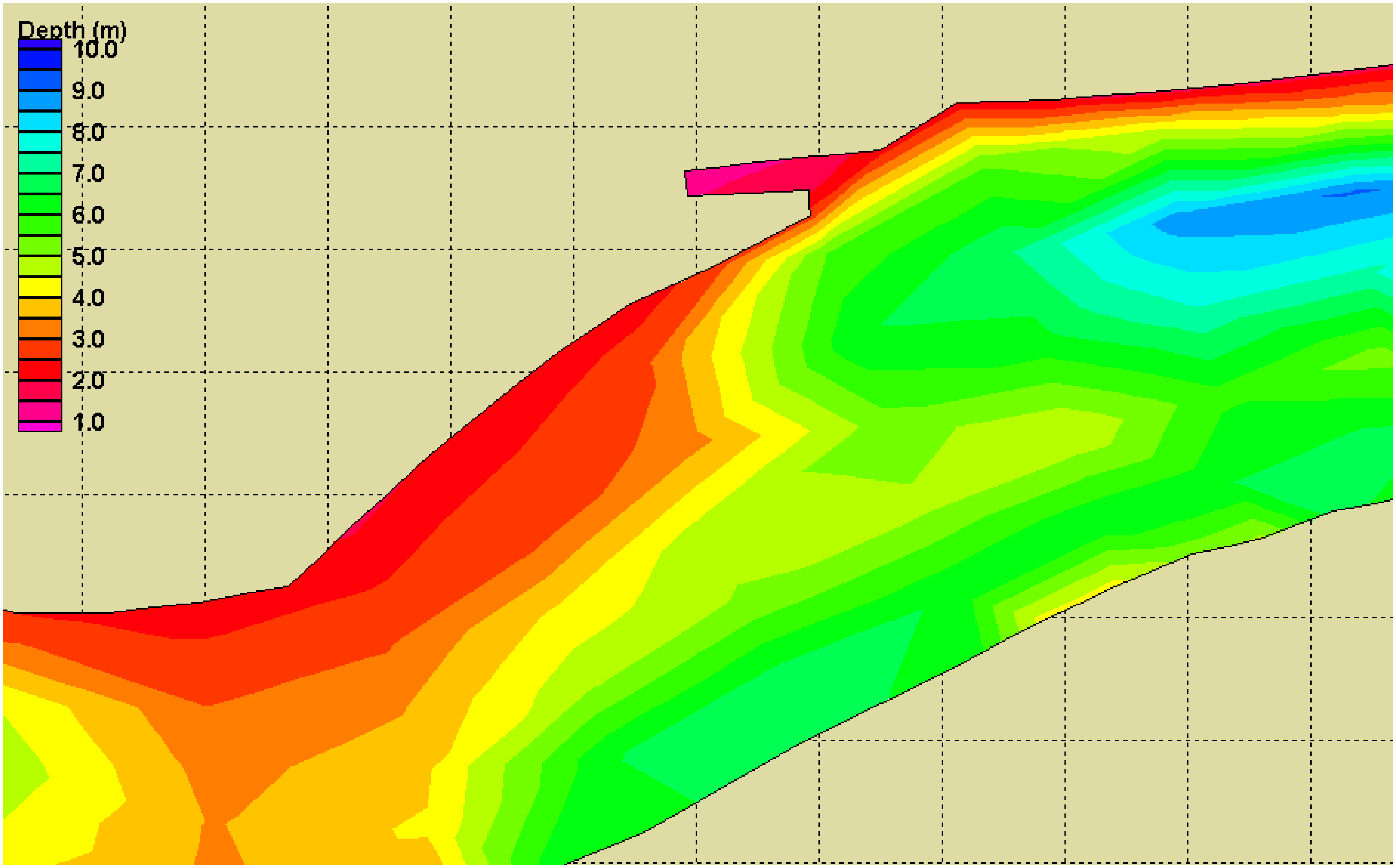

Figure 4. Water depths in the vicinity of "Zone 1", under the "<u>average</u>" river flow-rate regime. *{The water depths associated with the "<u>minimum</u>" and "<u>maximum</u>" river flow-rate regimes are about: 0.29 metres less than, and 0.14 metres greater than; respectively, the depths associated with the "<u>average</u>" flow-rate regime}.*

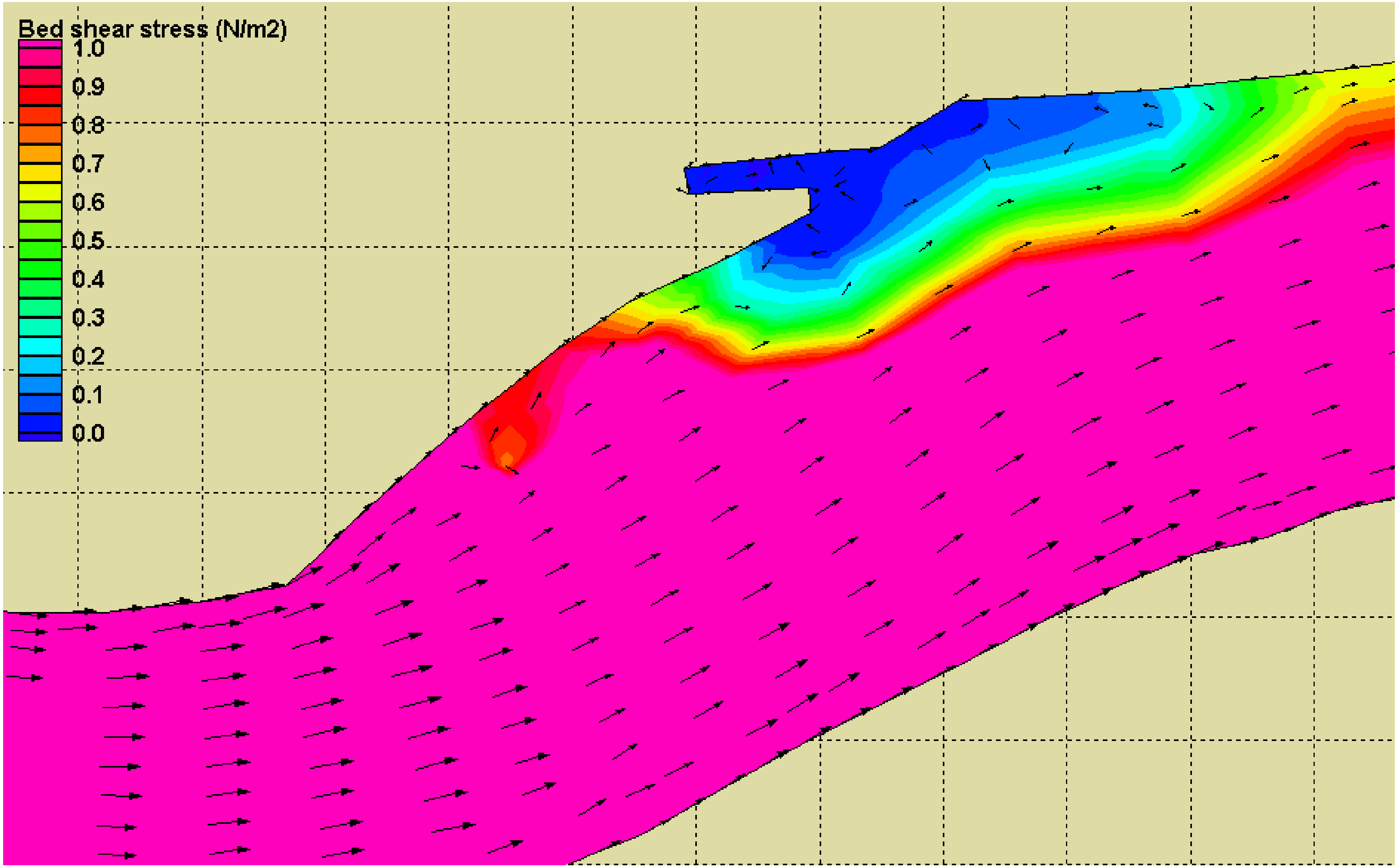

Figure 5(a). Bed shear stress in the vicinity of " Zone 1", associated with the "<u>minimum</u>" river flow-rate regime.

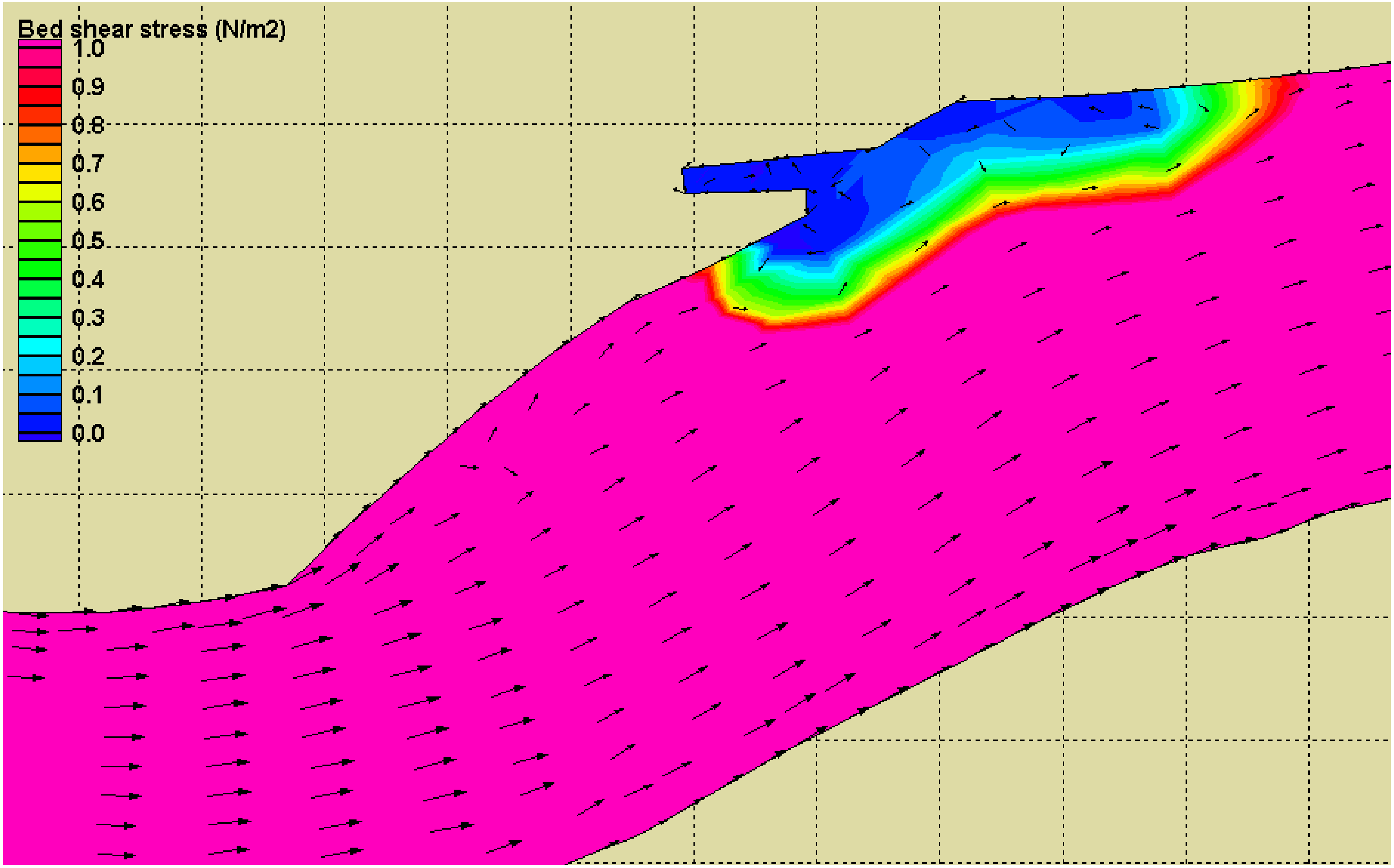

Figure 5(b). Bed shear stress in the vicinity of " Zone 1", associated with the "average" river flow-rate regime.

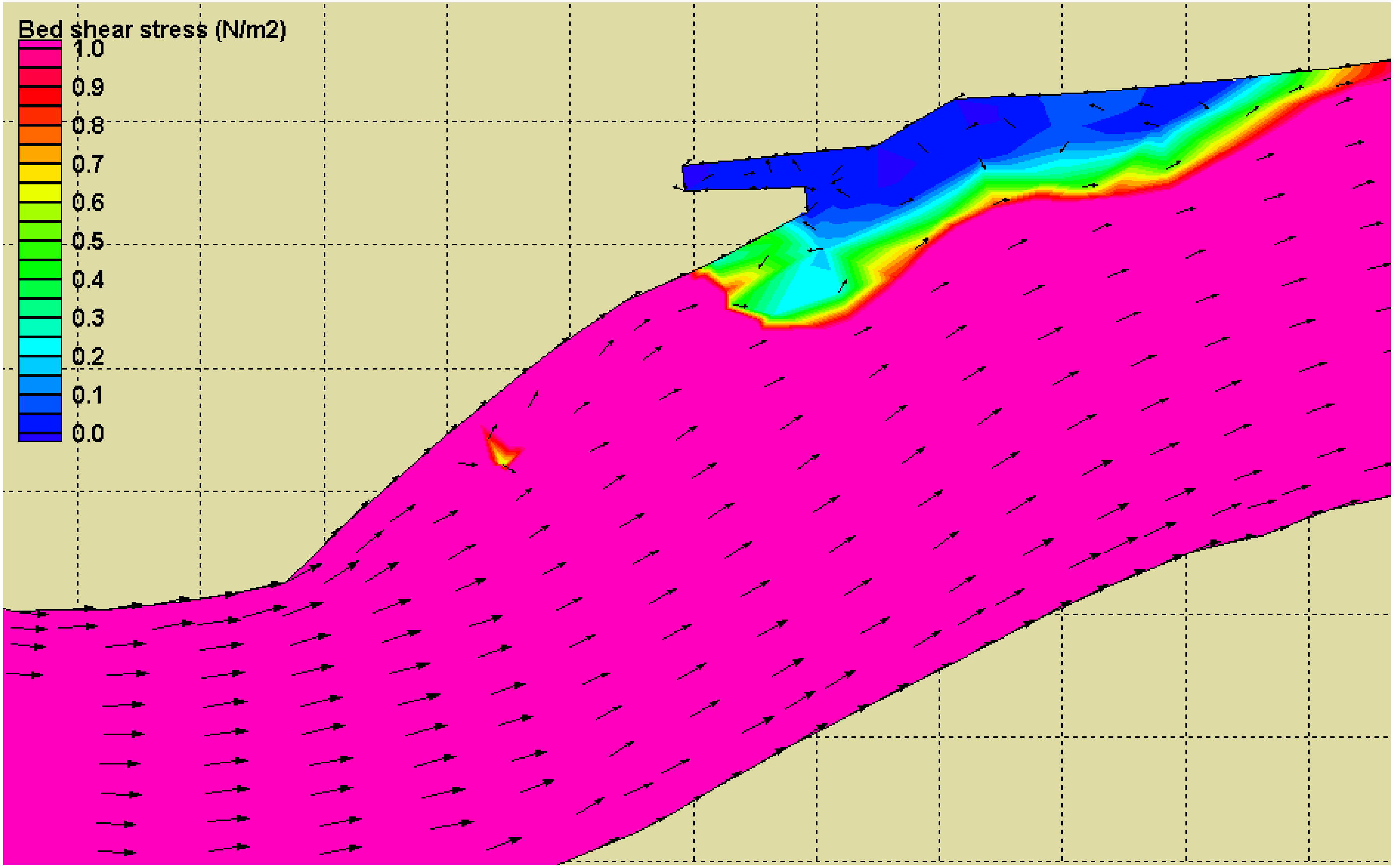

Figure 5(c). Bed shear stress in the vicinity of " Zone 1", associated with the "maximum" river flow-rate regime.

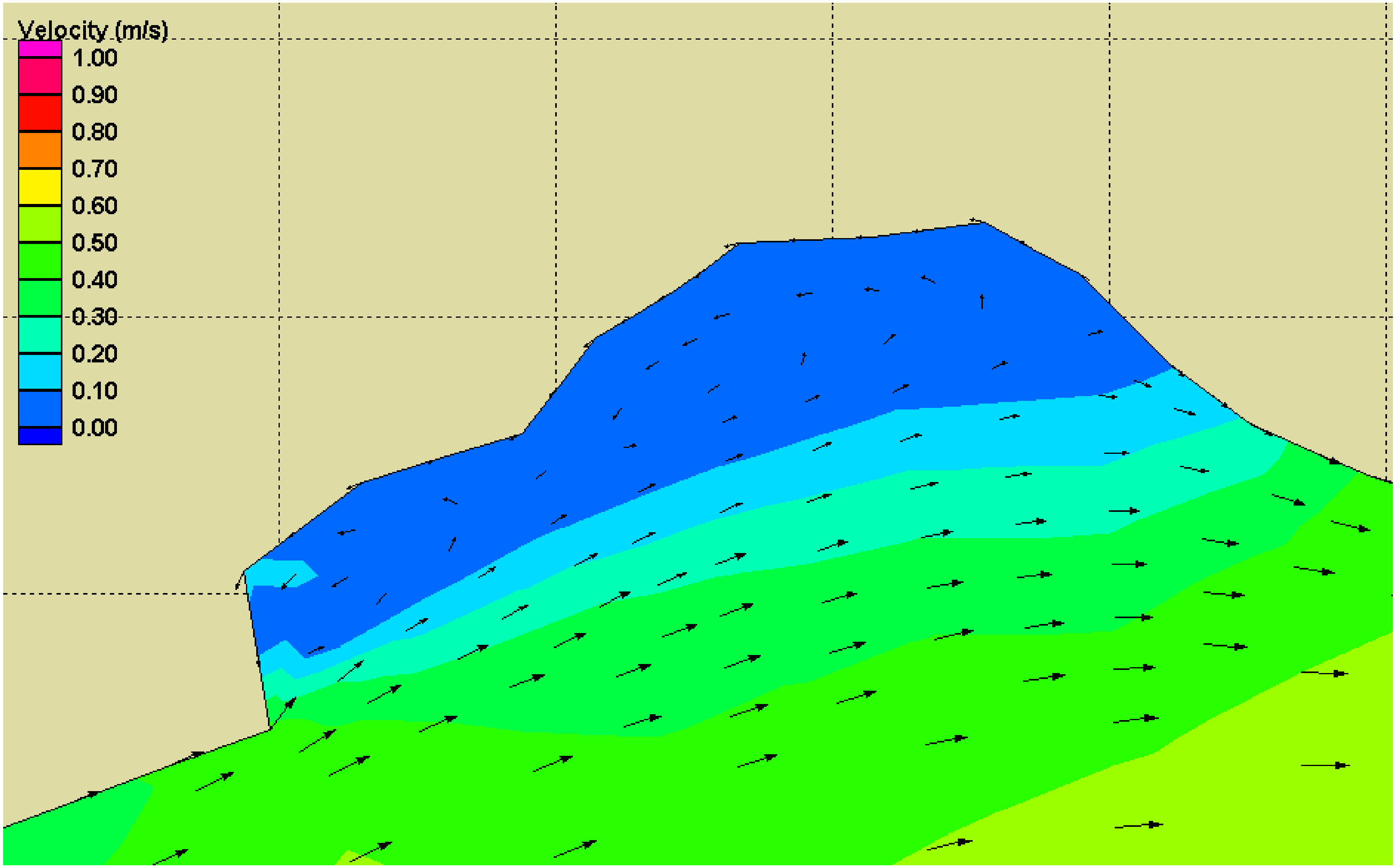

Figure 6(a). Depth-average velocity in the vicinity of “ Zone 3", under the “minimum” river flow-rate regime.

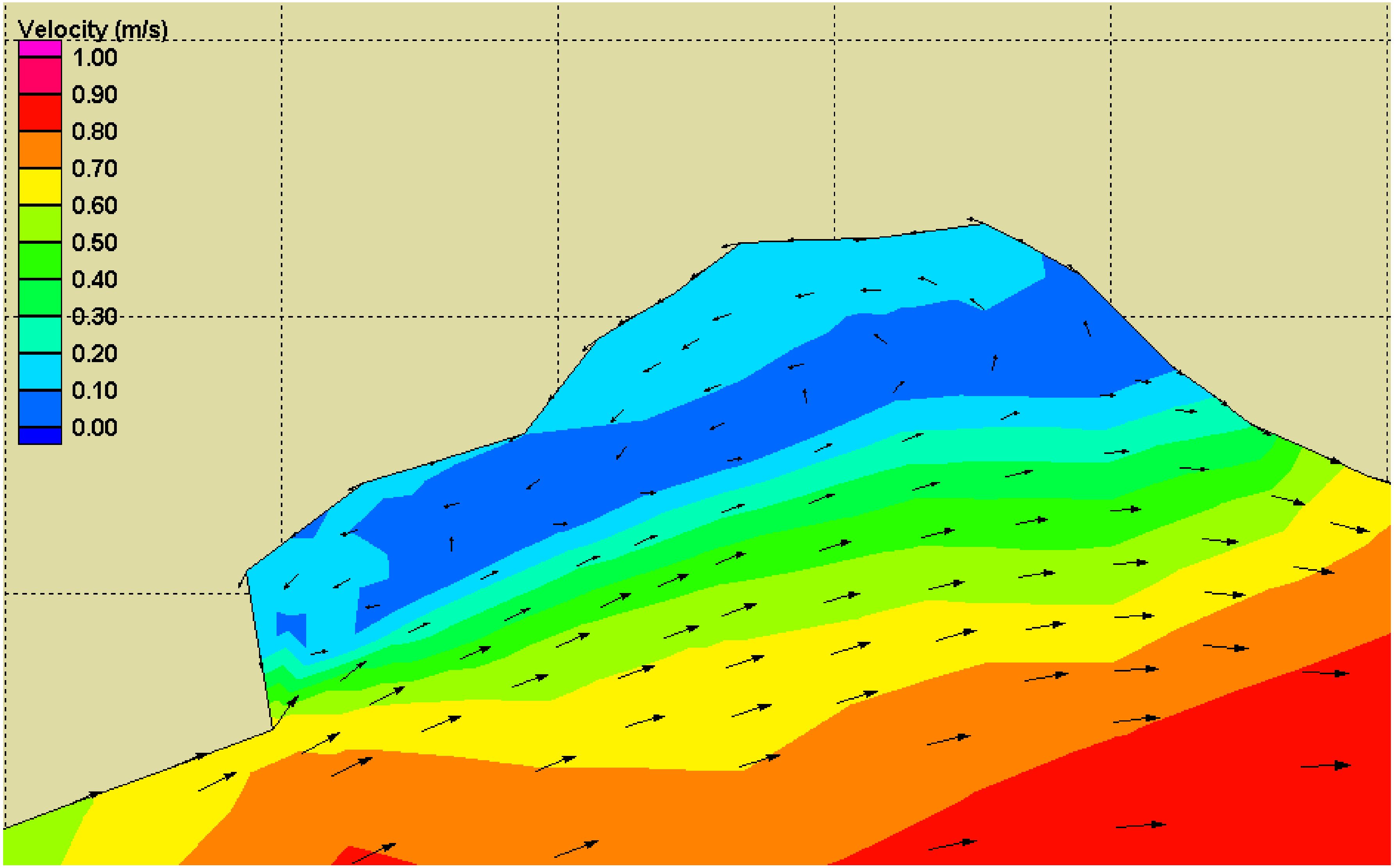

Figure 6(b). Depth-average velocity in the vicinity of " Zone 3", under the "average" river flow-rate regime.

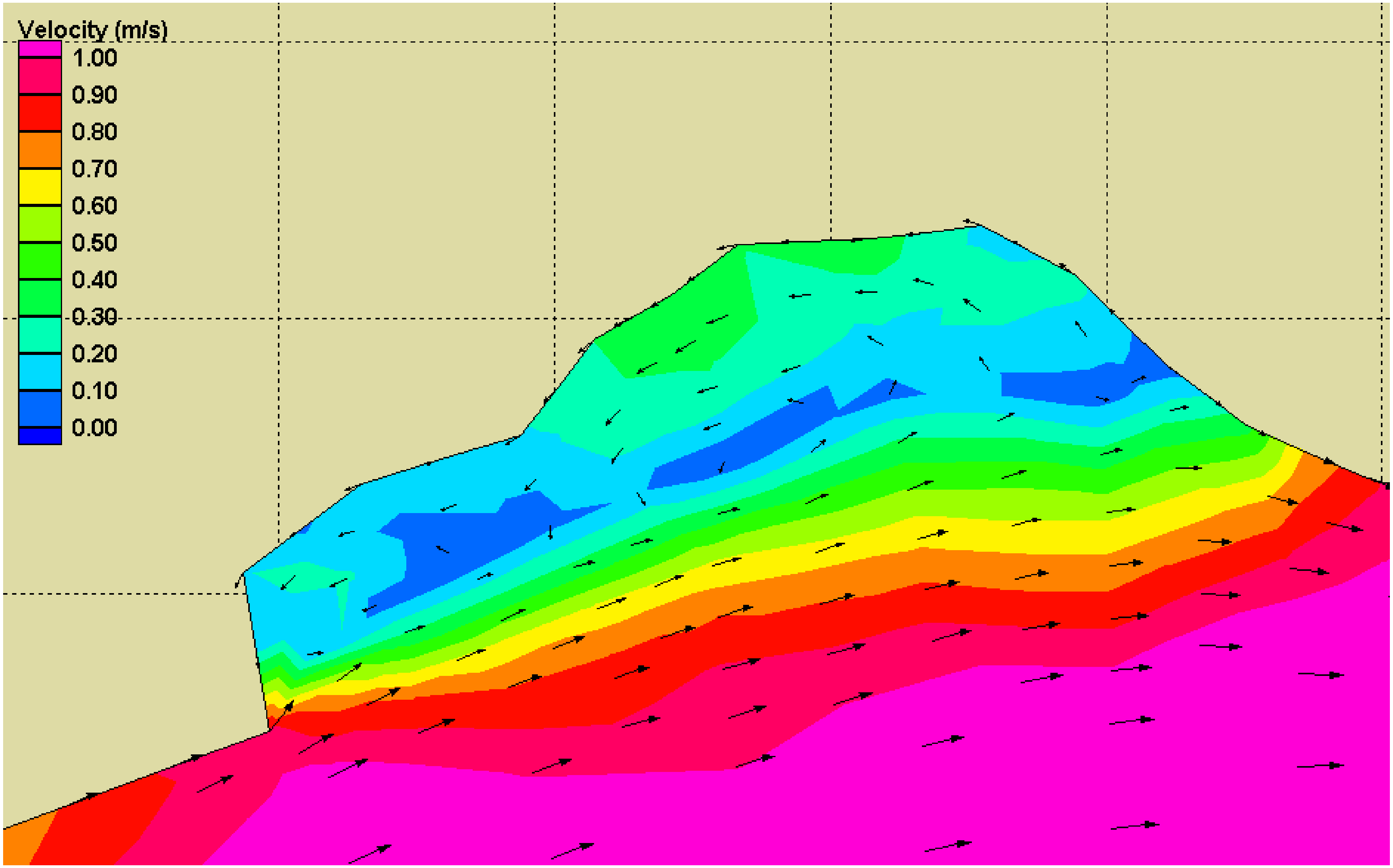

Figure 6(c). Depth-average velocity in the vicinity of " Zone 3", under the "maximum" river flow-rate regime.

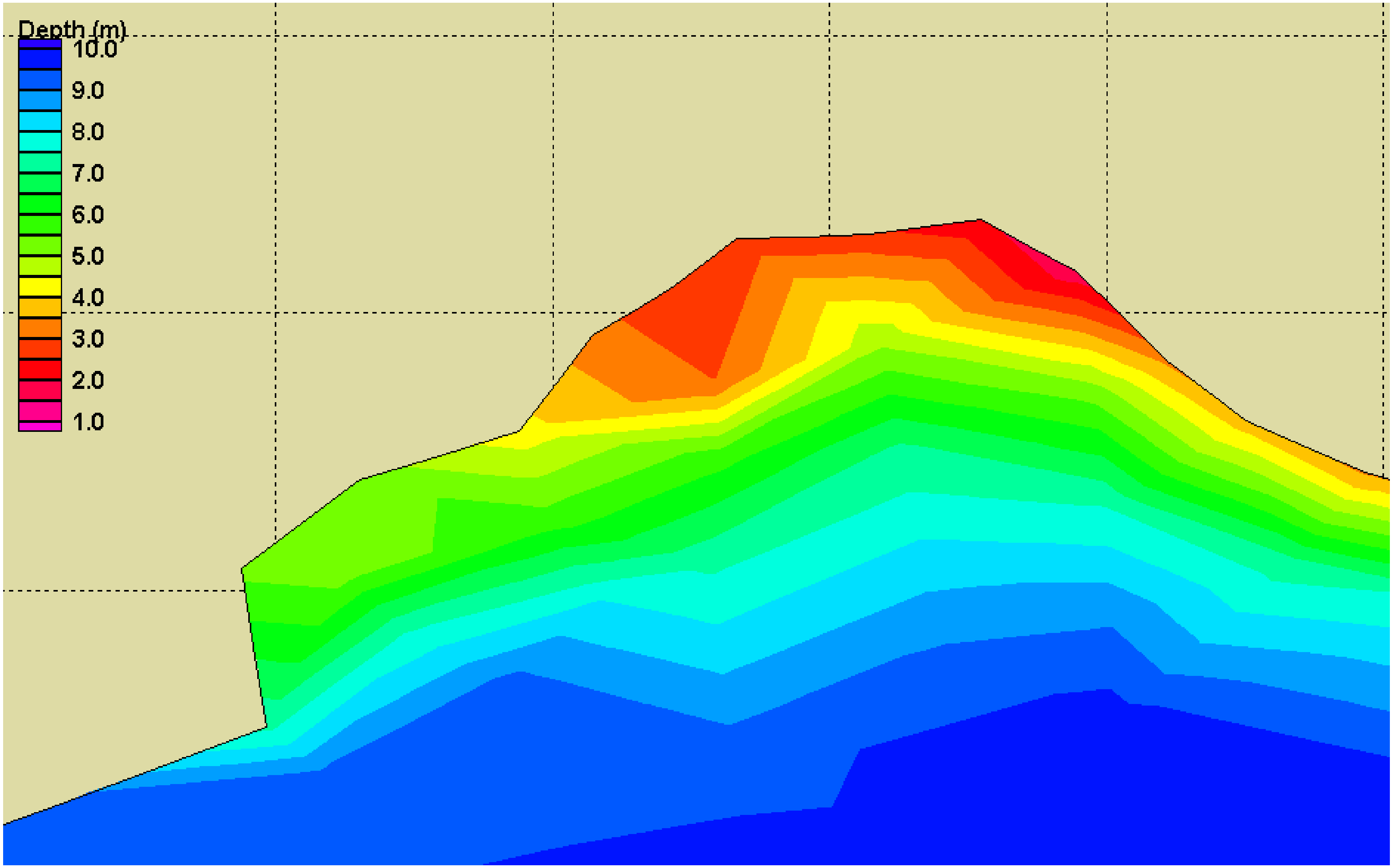

Figure 7. Water depths in the vicinity of “Zone 3", under the “average” river flow-rate regime. *{The water depths associated with the “minimum” and “maximum” river flow-rate regimes are about: 0.29 metres less than, and 0.16 metres greater than; respectively, the depths associated with the “average” flow-rate regime}.*

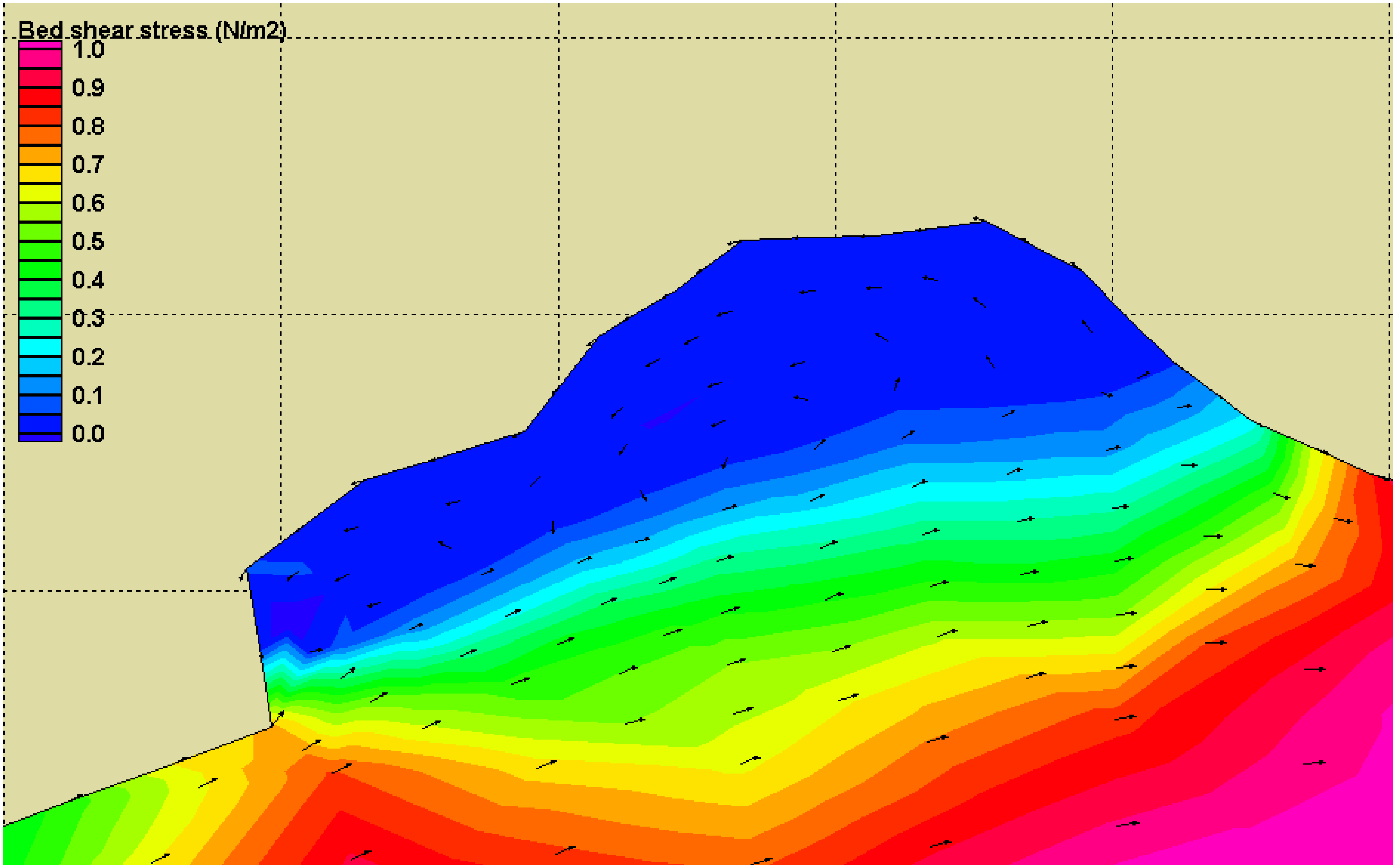

Figure 8(a). Bed shear stress in the vicinity of " Zone 3", associated with the "minimum" river flow-rate regime.

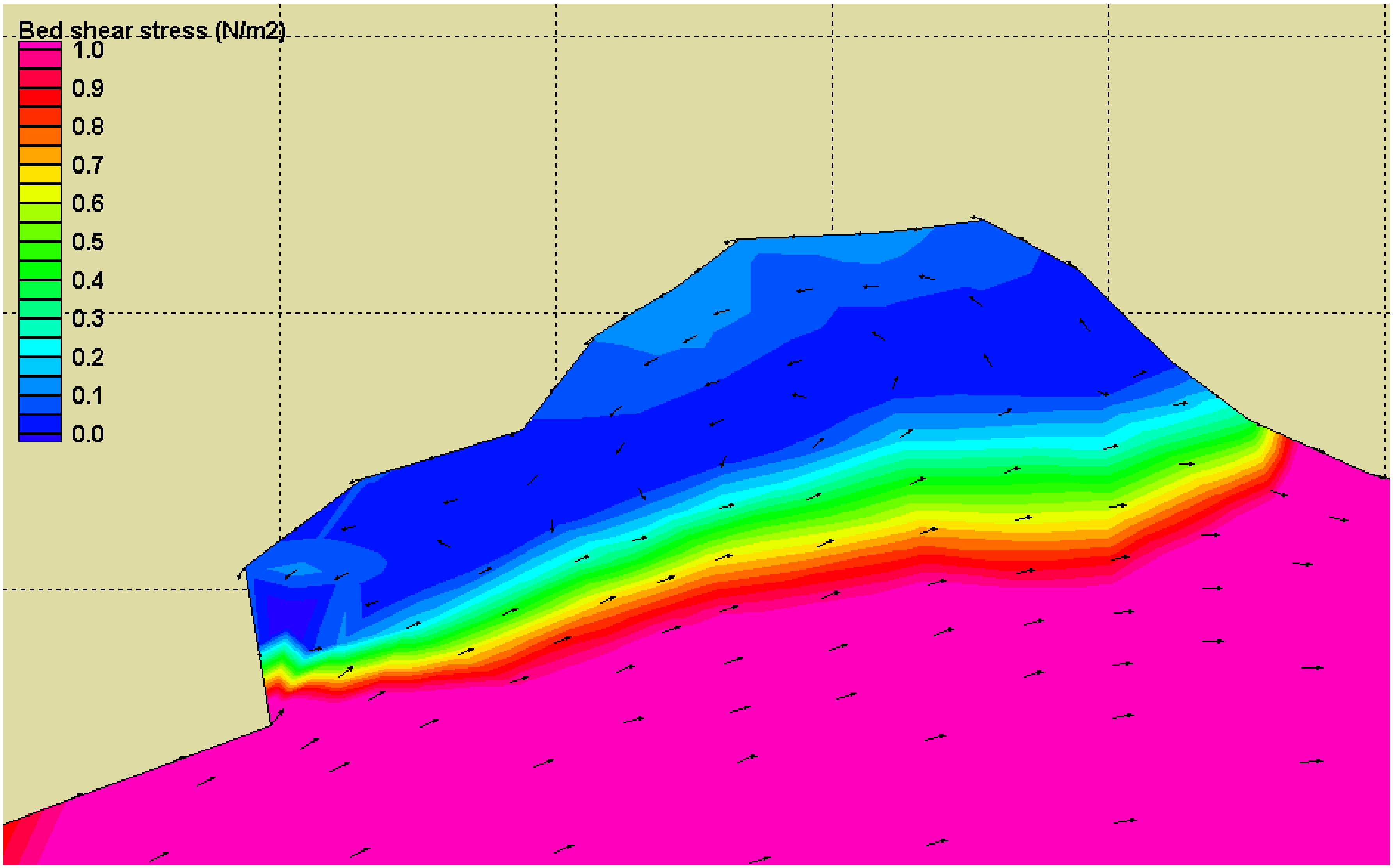

Figure 8(b). Bed shear stress in the vicinity of " Zone 3", associated with the "average" river flow-rate regime.

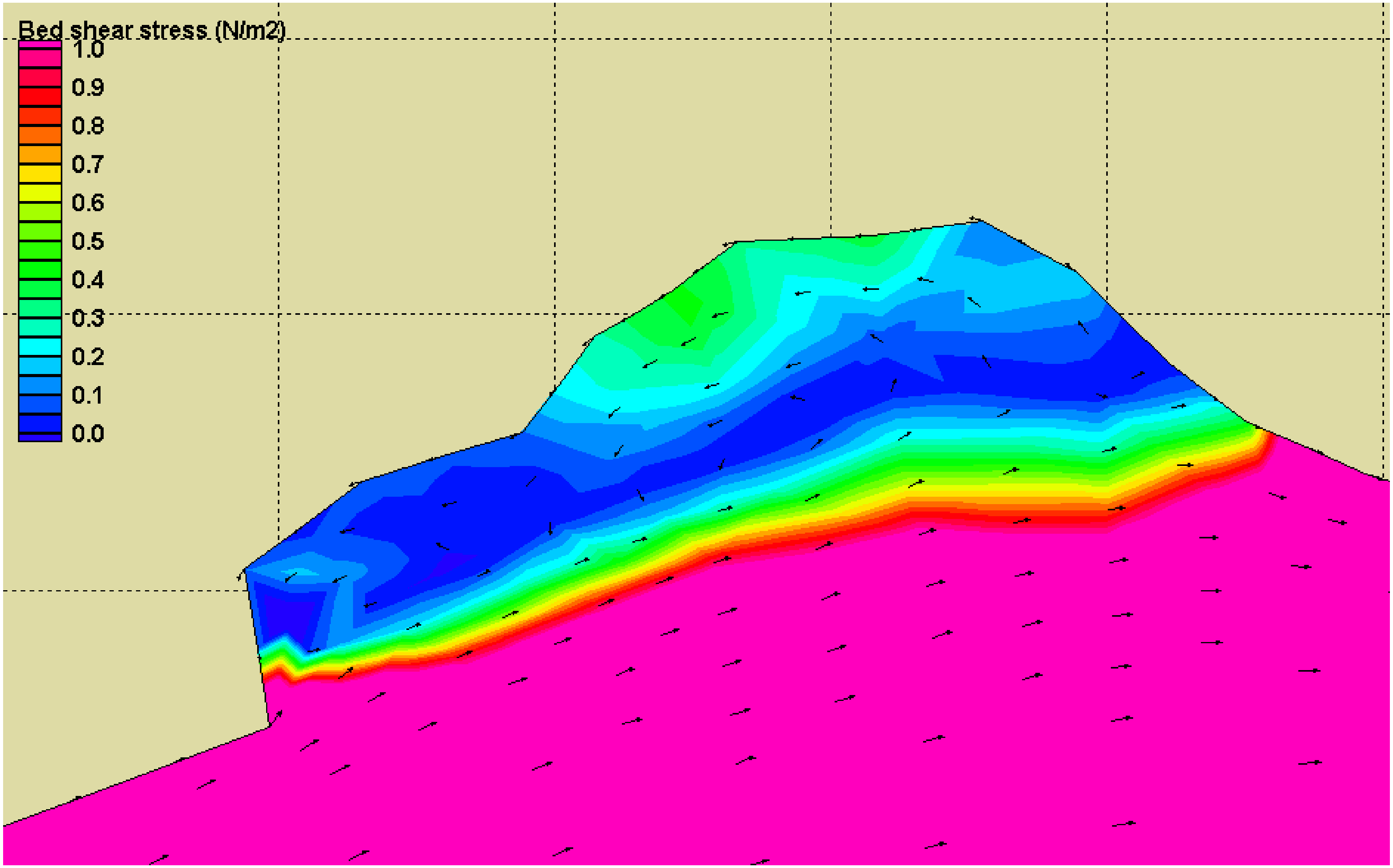

Figure 8(c). Bed shear stress in the vicinity of " Zone 3", associated with the "<u>maximum</u>" river flow-rate regime.

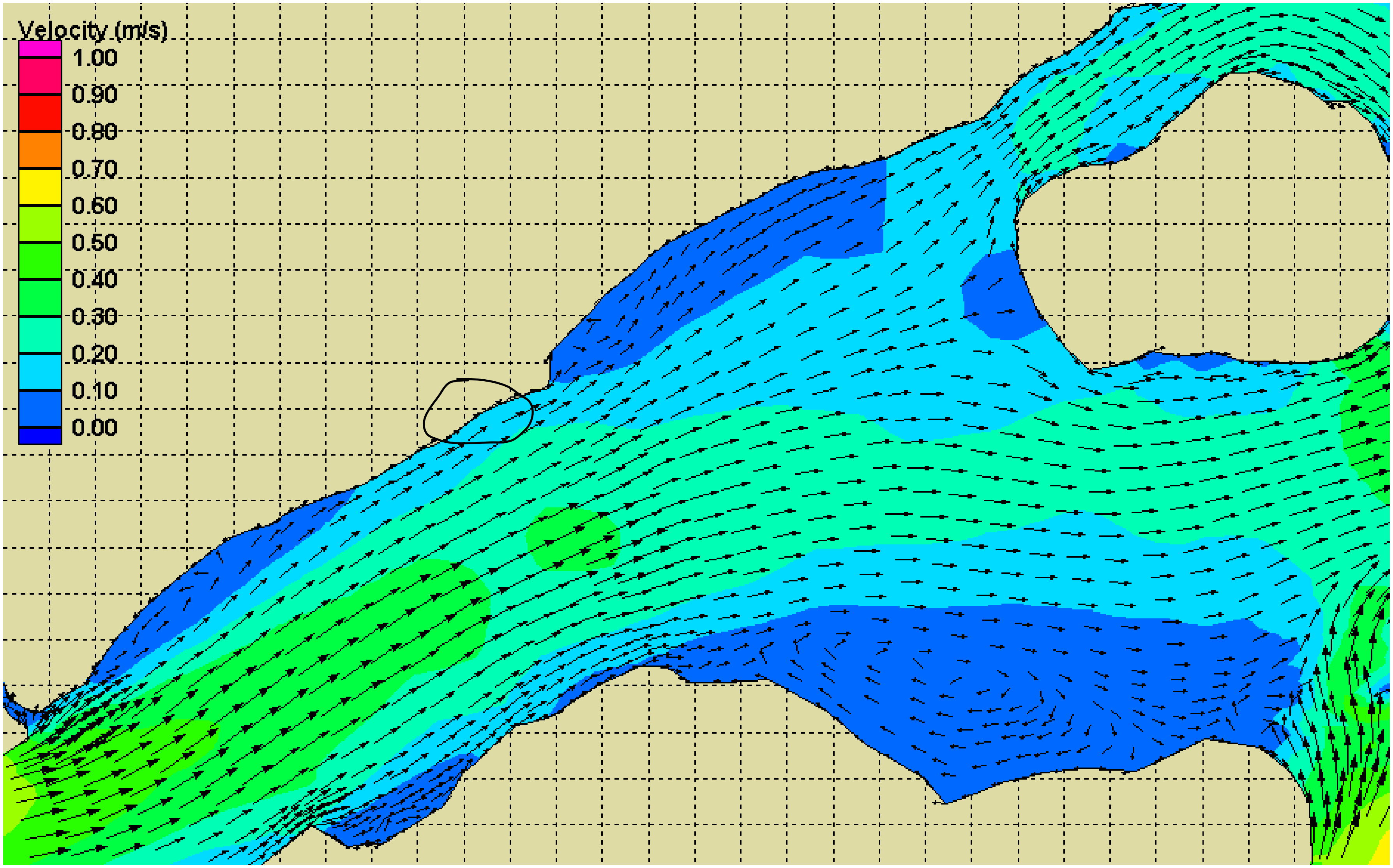

Figure 9(a). Depth-average velocity in the vicinity of " Zones 2 and 4", under the "minimum" river flow-rate regime.

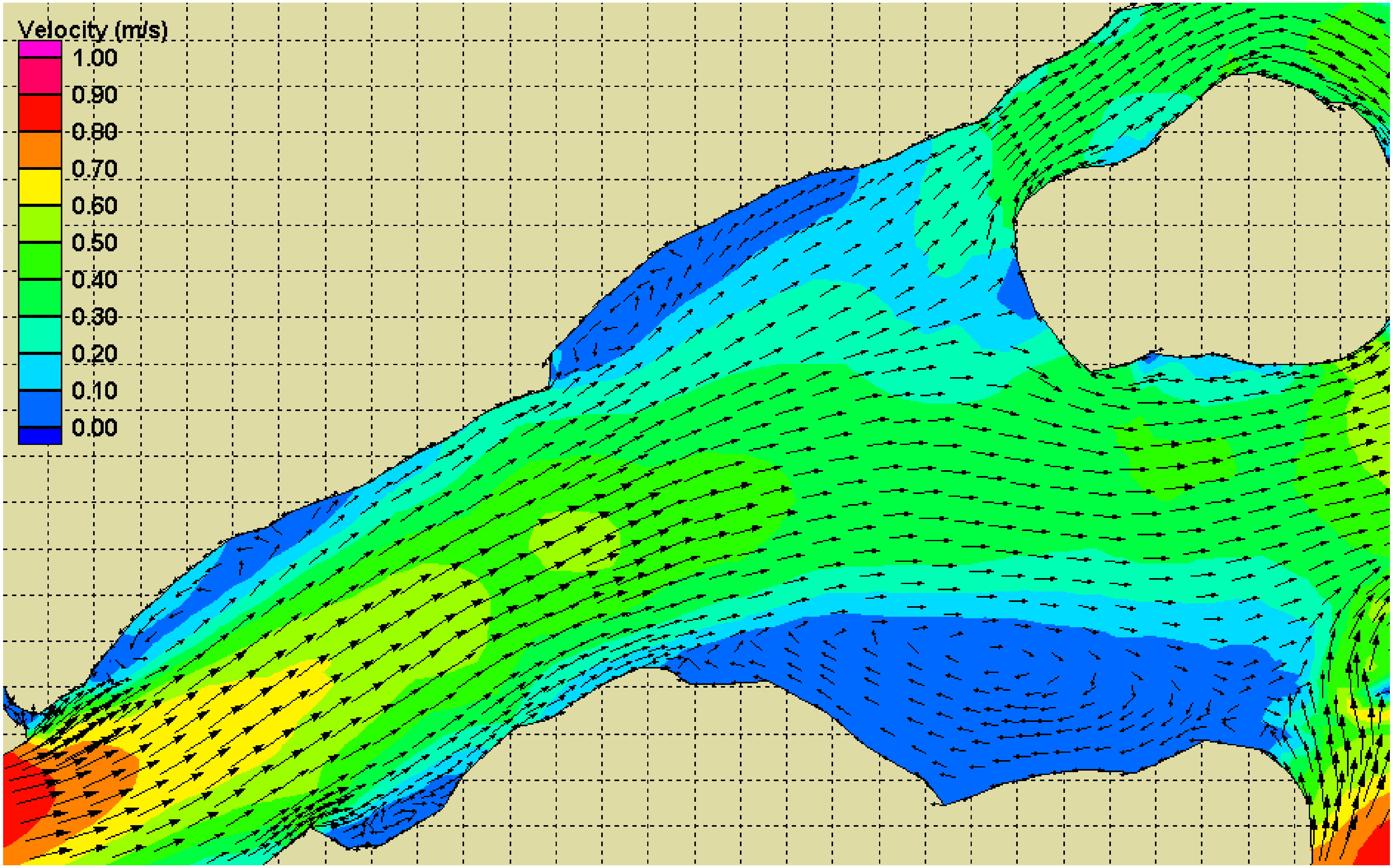

Figure 9(b). Depth-average velocity in the vicinity of " Zones 2 and 4", under the "average" river flow-rate regime.

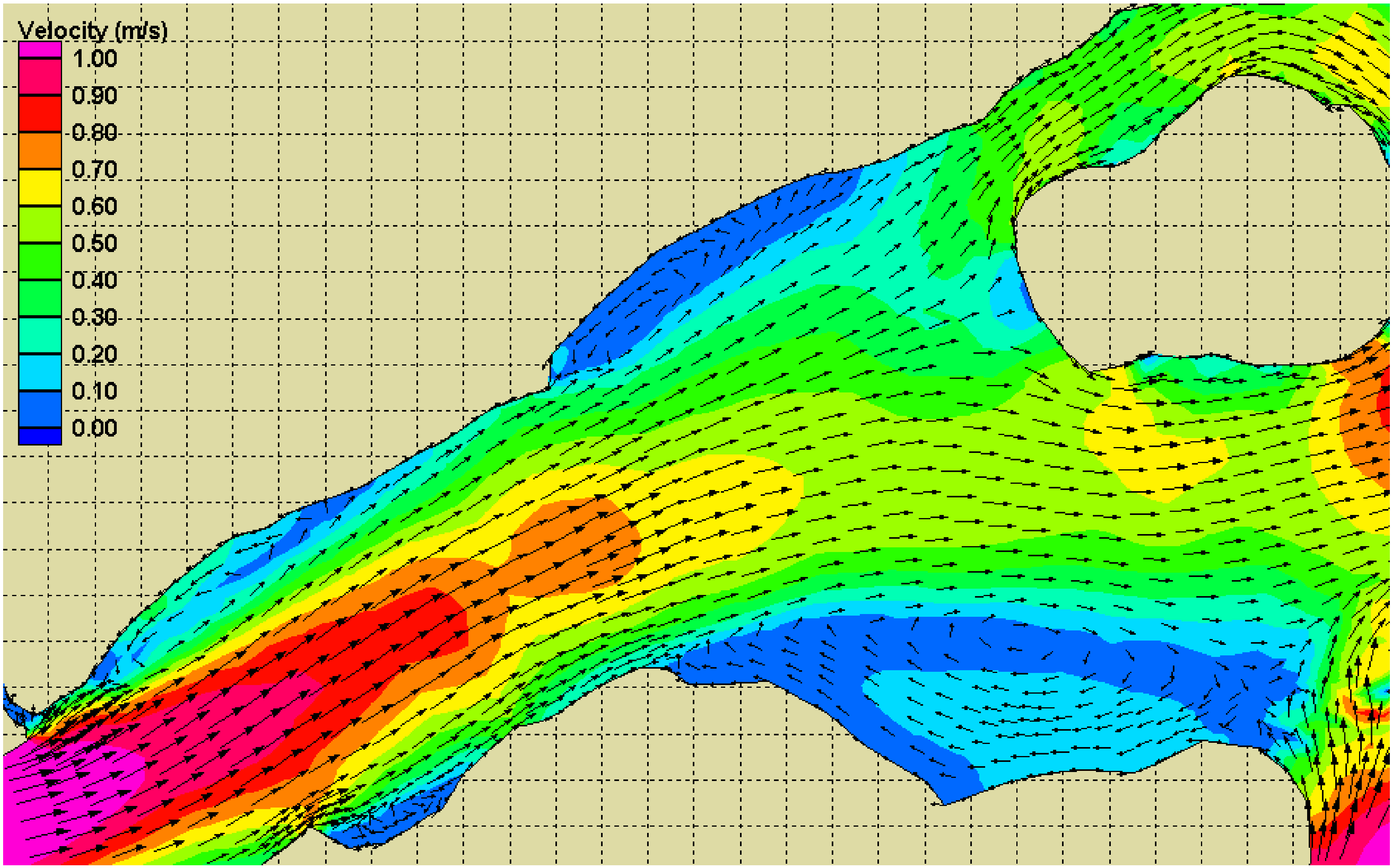

Figure 9(c). Depth-average velocity in the vicinity of " Zones 2 and 4", under the "<u>maximum</u>" river flow-rate regime.

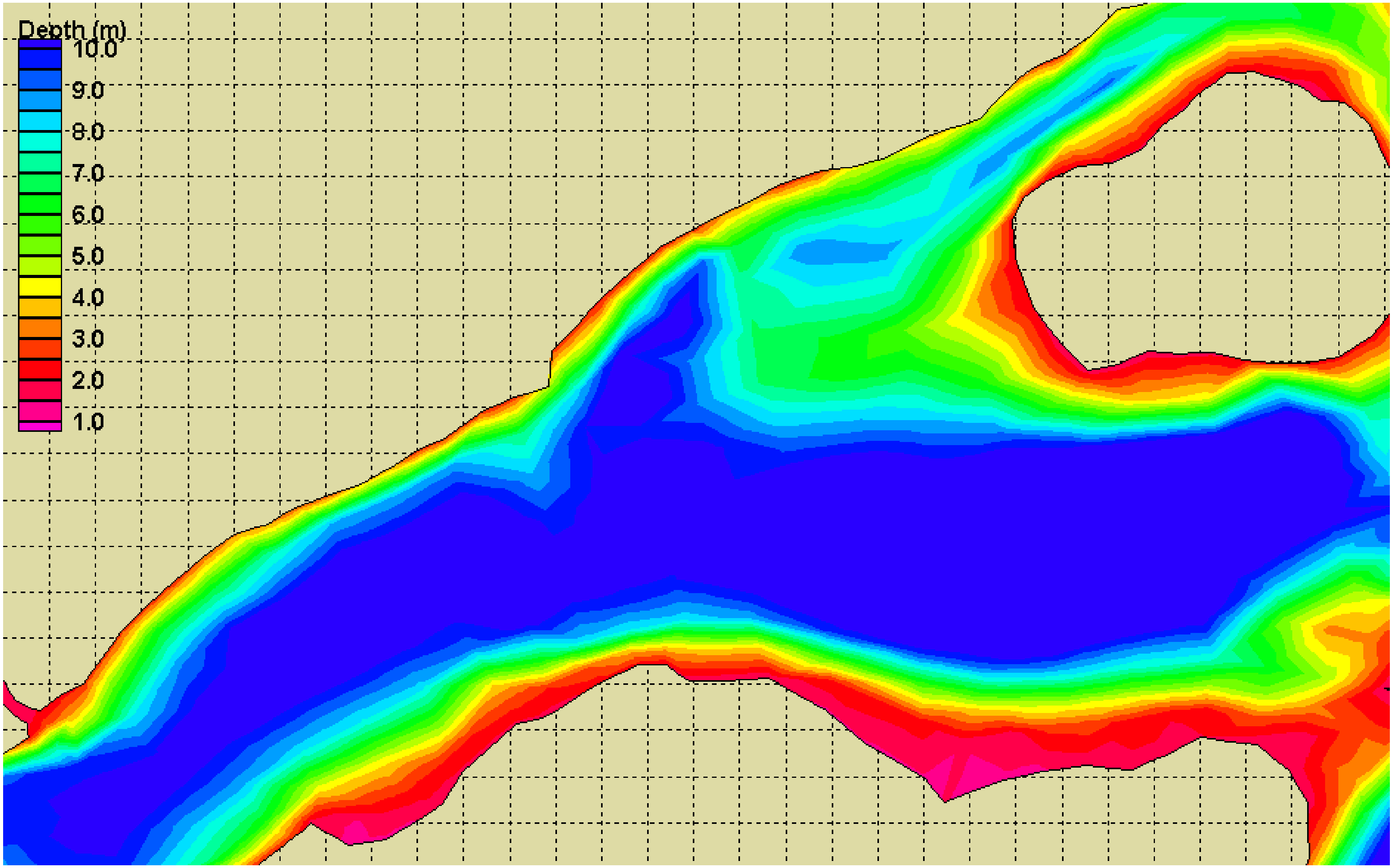

Figure 10. Water depths in the vicinity of "Zones 2 and 4", under the "<u>average</u>" river flow-rate regime. *{The water depths associated with the "<u>minimum</u>" and "<u>maximum</u>" river flow-rate regimes are about: 0.27 metres less than, and 0.16 metres greater than; respectively, the depths associated with the "<u>average</u>" flow-rate regime}.*

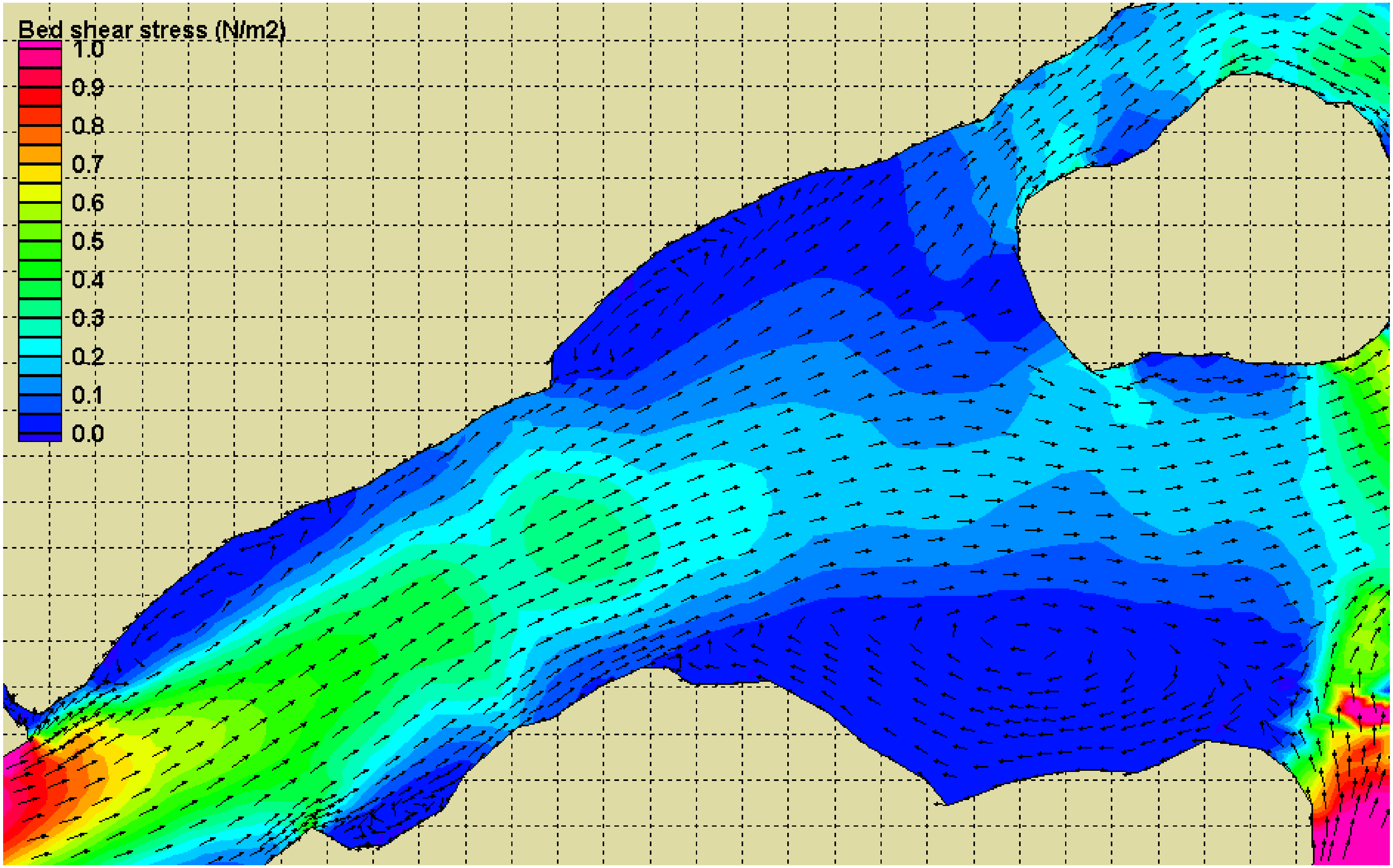

Figure 11(a). Bed shear stress in the vicinity of " Zones 2 and 4", associated with the "minimum" river flow-rate regime.

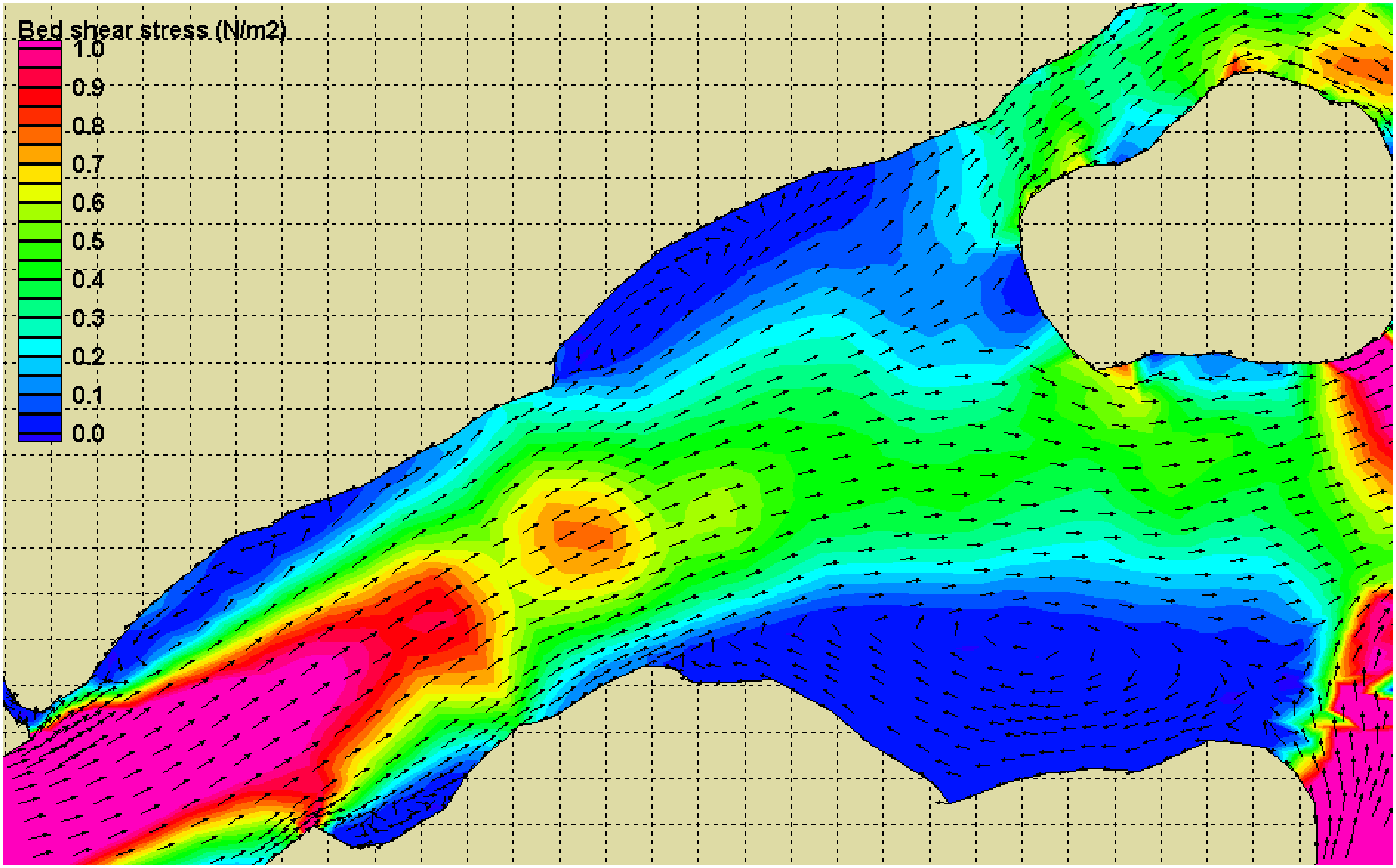

Figure 11(b). Bed shear stress in the vicinity of " Zones 2 and 4", associated with the "<u>average</u>" river flow-rate regime.

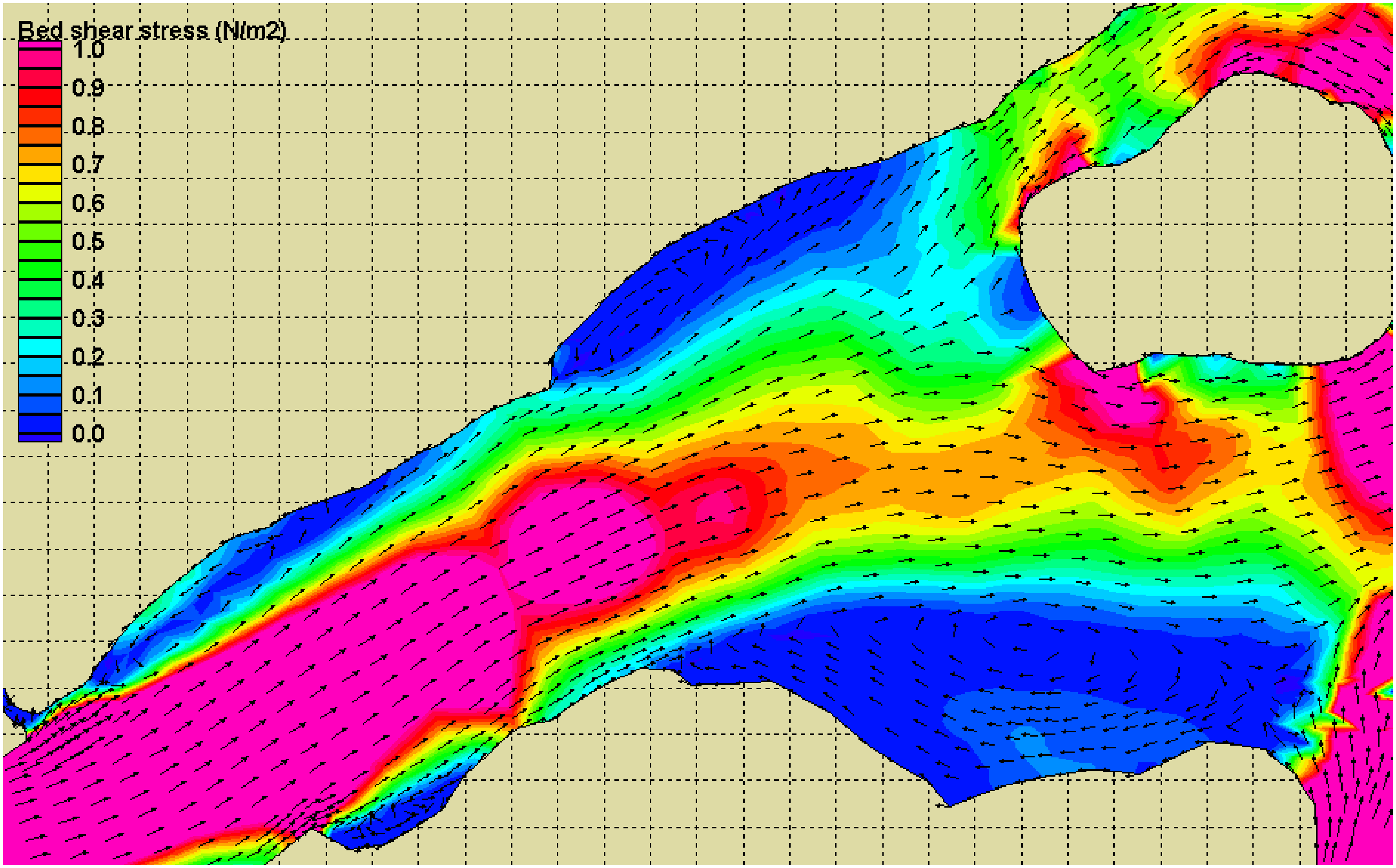

Figure 11(c). Bed shear stress in the vicinity of " Zones 2 and 4", associated with the "<u>maximum</u>" river flow-rate regime.