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Modeling peak discharge on the Siret River (Romania)

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Abstract

The purpose of this study is to identify potentially flood-prone areas in the section between the Siret hydrometric station and the confluence of the Siret River with the Suceava River.
Data related to water flow and specific flow parameters were incorporated into a dedicated hydrodynamic modeling program, in accordance with its requirements (DHI). The construction of the model focused on reproducing the field's reality as faithfully as possible. Flow parameters were individually configured for each calculation section, taking into account their specific characteristics. Roughness values were determined non-uniformly based on the areas traversed by each cross-sectional profile.
Great emphasis was placed on model calibration, using monitored data from the Zvoriștea and Huțani hydrometric stations as reference points. A time series spanning 15 years, including two of the largest floods recorded in the sector, was used. Following the simulation of two scenarios, Q1% and Q0.1%, three types of files were generated, describing the flood boundary, water depth at each point on the boundary surface and water velocity at each point within the flood boundary. Localities and types of potentially flood-prone surfaces were identified on a map using GIS techniques. Furthermore, flood boundary limits from different scenarios were overlaid to quantify areas at risk of flooding. Although the scenarios were simulated on a previously calibrated model, the fact that the simulated flows exceeded the observed flows required several post-calibration steps. In the case of the first scenario, the simulation did not show significant errors, precisely because the Q1% flow is close in value to the maximum flows observed during the calibration period. In the case of the second scenario, the fact that the flow extended to non-specific areas even during historical maximum flows, resulted in stability errors or non-conforming results obtained by the program, inconsistent with research and studies in the field.
Keywords: *hydrodynamic modeling, 1% probability flow, 0.1% probability flow*

Introduction

The Siret River in the analyzed section between the Siret hydrometric station and its confluence with the Suceava River includes two reservoirs (Figure 1). These reservoirs do not have a direct role in flood wave attenuation, but through various operating regimes and exploitation rules, they can influence the discharge. Furthermore, the presence of a reservoir on a river course brings about changes in the flow regime by altering the slope, water velocities, flow patterns during low and moderate flows, sediment transport (Wu, 2004), and the morphology of the riverbed both upstream and downstream of the reservoir (Cojoc, 2016; Burdulea, 2007). The purpose of flow regulation is to meet the water requirements of various uses and prevent the destructive effects of floods. Meeting the water requirements of different uses can be achieved through reservoirs, diversions, channel regularization, and combinations.

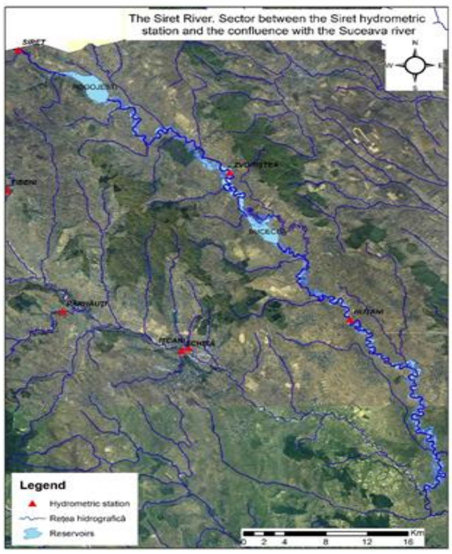

Figure 1: Study area

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The mathematical model to be used in hydraulic modeling has the capability to integrate anthropic elements that can influence discharge flow into the calculations (Burnash et al., 1973). Given that there are two reservoirs within the studied section, one of the objectives of this work is to highlight the impact of these two reservoirs on flow patterns during flood periods. It involves analyzing different scenarios that can influence the magnitude of the hazard and assessing the effects of these two reservoirs on the upper section of the Siret River (Adamo et al., 2020; Gâștescu et al., 2003).

Materials and methods

Building hydraulic model

The hydrodynamic modeling was carried out using the Mike Zero application. The choice of this program was based on several factors, both due to its capacity to incorporate and simulate a detailed set of elements and because of its ease of use and stability in constructing the model. Although the program has the capability to simultaneously simulate a rainfall-runoff model and a hydrodynamic model, the rainfall-runoff modeling (RR) was omitted for several reasons (Horrit and Bates, 2002). The drainage basin area of 1639 km² associated with the starting point of the modeling is entirely within the territory of Ukraine. To calibrate the flows recorded at the Siret hydrometric station, a series of data spanning at least 10 years is needed. These data include information on precipitation quantity, precipitation type, air temperatures, and evapotranspiration. Besides being difficult to obtain, these data are measured according to different standards than those used in Romania (measurement intervals, processing methods). Additionally, since the analysis of the sector from the Siret hydrometric station to the confluence with the Suceava River is conducted from a hazard perspective, the flows used in modeling have already been identified through previously developed statistical methods. The simulation involves describing unique events rather than a time-based analysis of the sector (Diaconu and Șerban, 1994; French, 2003). The module selected for simulating hydrological hazards is Mike HYDRO River. This module allows for detailed configuration of several parameters to calibrate and simulate flood wave propagation (Gogoașe-Nistoran, et al., 2016).The roughness coefficients that determine hydraulic resistance were established based on the local characteristics of both the minor and major riverbeds along the analyzed sector. The average values ranged from 0.030 to 0.055 for the minor riverbed and from 0.055 to 0.1 for the major riverbed.

Regarding the structural characteristics of the reservoirs (bottom releases, spillways, crest levels, etc.), these were configured based on the information present in the Operating Regulations (Figure 3). For each element or characteristic, a time series file was created and assigned in accordance with the model's requirements.

Since none of the reservoirs in the modeling have the real capacity to attenuate flood waves, they were configured to operate at maximum transit capacity.

Although the Operating Regulations of the Rogojești Reservoir provide for an attenuation volume of 10.87 million m³, in the modeled scenarios, Q1% - 1336 m³/s and Q0.1% - 1984 m³/s, the value of this volume in relation to the total volume of the flood wave is insignificant.

In the case of the Rogojești Reservoir section, the total average duration of a flood is 95 hours. For a shape coefficient γ = 0.3, in the case of the 1% probability flow, a total flood volume (Wt) of 137 million m³ can be estimated. In the case of the rupture scenario, which assumes a 0.1% probability flow, the total flood volume increases to 203.5 million m³.

The next step in building the hydrodynamic model was the creation of cross-sectional profiles (Figure 2), where the program would simulate water flow.

The selection of these sections considered both the morphology of the riverbed and the presence of inhabited areas.

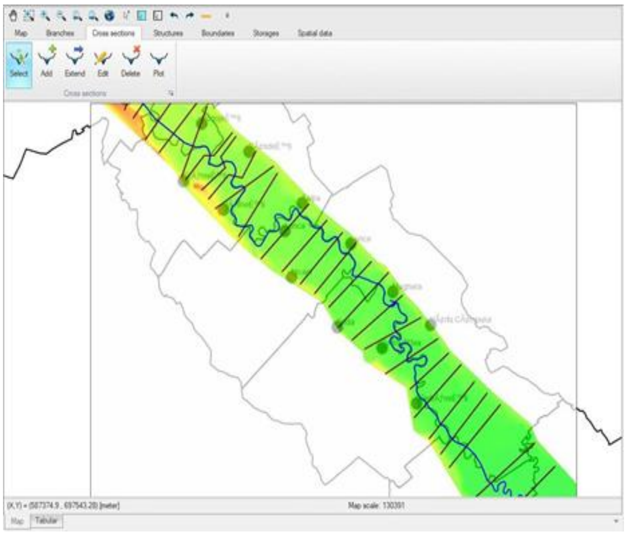

Figure 2: Definition of Calculation Sections

The program has the capability to interpolate elevations directly from the Digital Elevation Model (DEM) and assign them along the alignment, thereby generating cross-sectional profiles.

The values of the roughness coefficients for the minor riverbed were determined based on the grain size analyses conducted at the three hydrometric stations in the sector, while those for the major riverbed were determined based on the applicable instructions applied in river hydrometric studies (Ramesh et al., 2000). Their application along the sector in the major riverbed area was done by assigning coefficients based on land use type. This allowed for the determination of different roughness coefficients along a cross-sectional profile, where necessary, depending on the nature of the terrain (Figure 3).

Calibration of the hydraulic model

The selected simulation period was 15 years, spanning from 2008 to 2022. The reason for choosing this period is due to the significant floods that occurred in the early years, particularly in 2008 and 2010, which were the largest recorded in recent history. Additionally, during this period, there were no major morphological changes in the riverbed, including up to the present time. This fact ensures that the results of simulating the 1% and 0.1% probability flows are as representative as possible for the current situation of the analyzed sector.

Subsequently, calibrating the simulated results is closely related to the correct definition of calculation parameters. The program has the capability, starting from the configuration phase of flow parameters, to calculate in real-time, based on the configured parameters, the characteristics of the cross-sectional profile. These characteristics are represented through graphs of the "discharge value versus elevation" type and are calculated for the entire capacity of the cross-sectional profile. The model calibration was based on the observed flows at the Zvoriștea and Huțani hydrometric stations on the Siret River, which, due to their location, are the most representative for the area. The flows were simulated as a boundary condition upstream from the Rogojești Reservoir and verified at the hydrometric stations downstream. The time series was created based on daily average flows over a period of 15 years with a time step of one day (Haktanir and Ozmen, 1997).

The purpose of the calibration phase was primarily to correctly identify the flow parameters and to configure the hydraulic stability of the model. The ultimate goal was to simulate the levels recorded at the Zvoriștea and Huțani hydrometric stations as closely as possible.

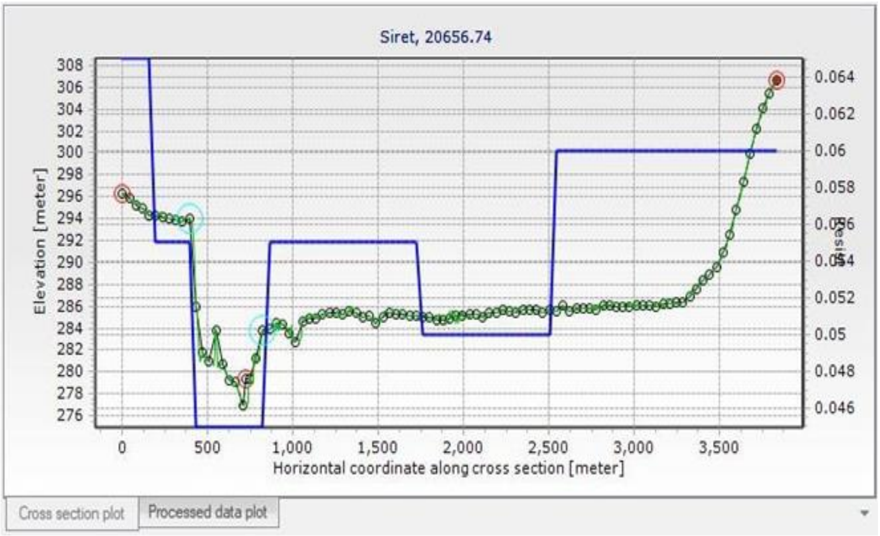

Figure 3: Configuring the Roughness Coefficients

Results and discussion

Since the Rogojești and Bucecea Reservoirs do not have a significant capacity to attenuate flood waves, in both scenarios, it was considered that they only pass through the maximum flows, so as not to influence the most unfavorable impact on the analyzed sector (Ichim and Rădoane, 1986; Jacobson and Galat, 2006).

Scenario 1 - Q1% Flow

The simulation was of the unsteady flow type, based on flow hydrographs rather than continuous flow. The reservoirs were configured at their maximum discharge capacity. The modeling results were exported to shape and raster files for a comprehensive visualization of the impact of this scenario (Chow et al., 2013). As can be seen from the images above (Figure 4), the 1% probability flow exceeds the capacity of the minor riverbed for most of the sector, resulting in flooding over a total area of approximately 4,000 hectares. The width of the flooded areas varies from 98 meters to 2,596 meters and affects all the municipalities along the Siret River.

Regarding water depths in the flooded areas (Figure 5), the height of the water column ranges from a shallow flow with only a few centimeters in the major riverbed to a maximum depthof 11.28 meters in the Rogojești Lake section and 6-8 meters in the minor riverbed sections. In terms of depth, the global average, this was calculated to be 1.98 meters. It can be observed that the greatest depths are found in sections with reduced overflow, especially downstream of the Bucecea Reservoir, where the high banks of the Siret River allow for much better flow of the 1% probability flow.

It can also be observed that the river Siret's abandoned channels and meanders are reactivated, indicating the actual extent of its riverbed. An interesting aspect is seen at the Vârfu Câmpului Reservoir, an unfinished construction, where on the right bank, the upstream part of the reservoir lacks the capacity to

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convey the 1% flow, with a portion of the flow bypassing the embankment through the backside. This justifies the efforts made so far to widen that section near the Zamostea Forest. The simulated velocities for the 1% probability flow, occurring once every 100 years, range from 0 to 3.2 m/s, with the highest velocities occurring in the Rogojești Reservoir and the minor riverbed, and the lowest velocities in the floodplain areas and abandoned meanders.

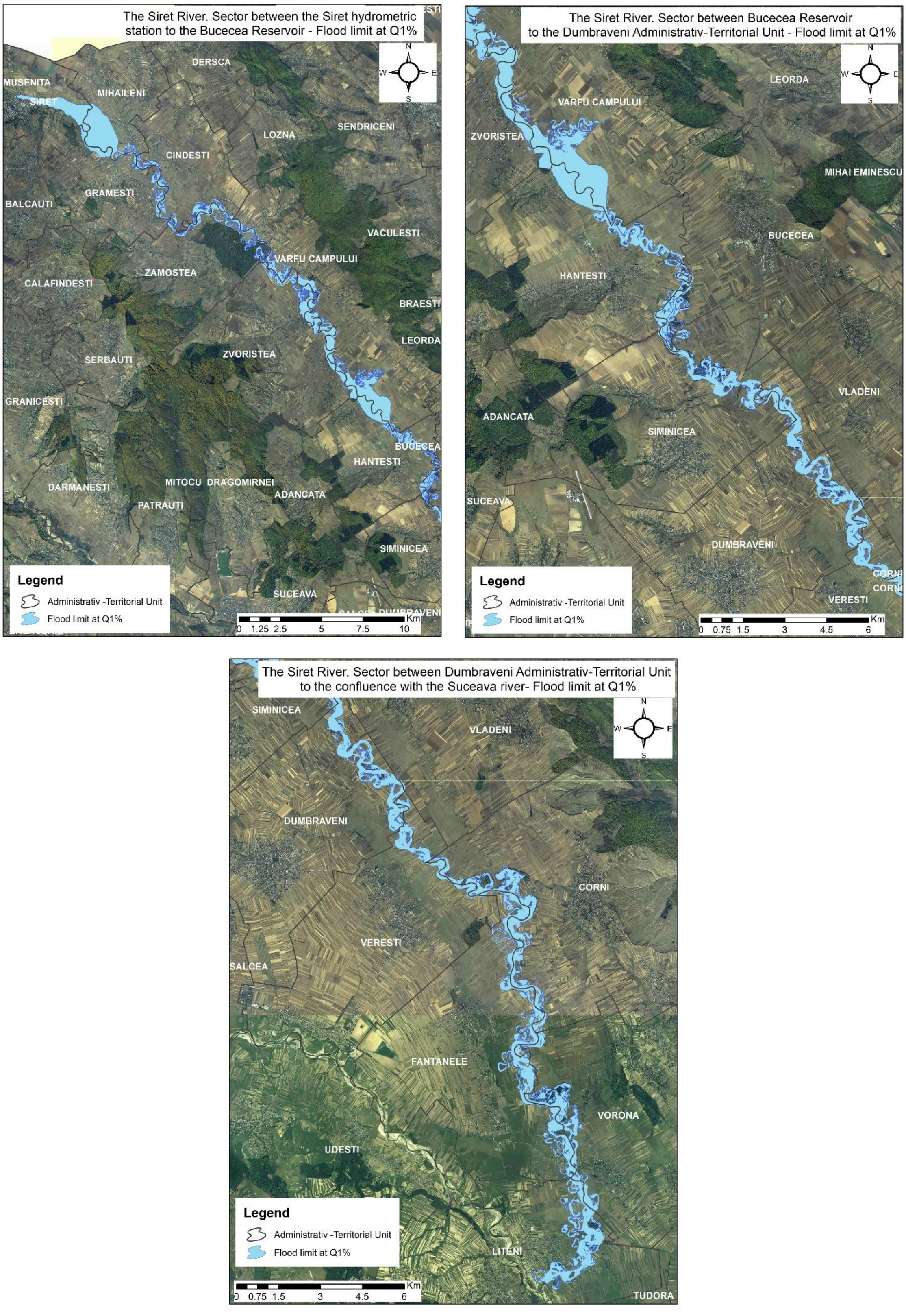

Figure 4: Flood boundary for the $Q_{1\%}$ flow

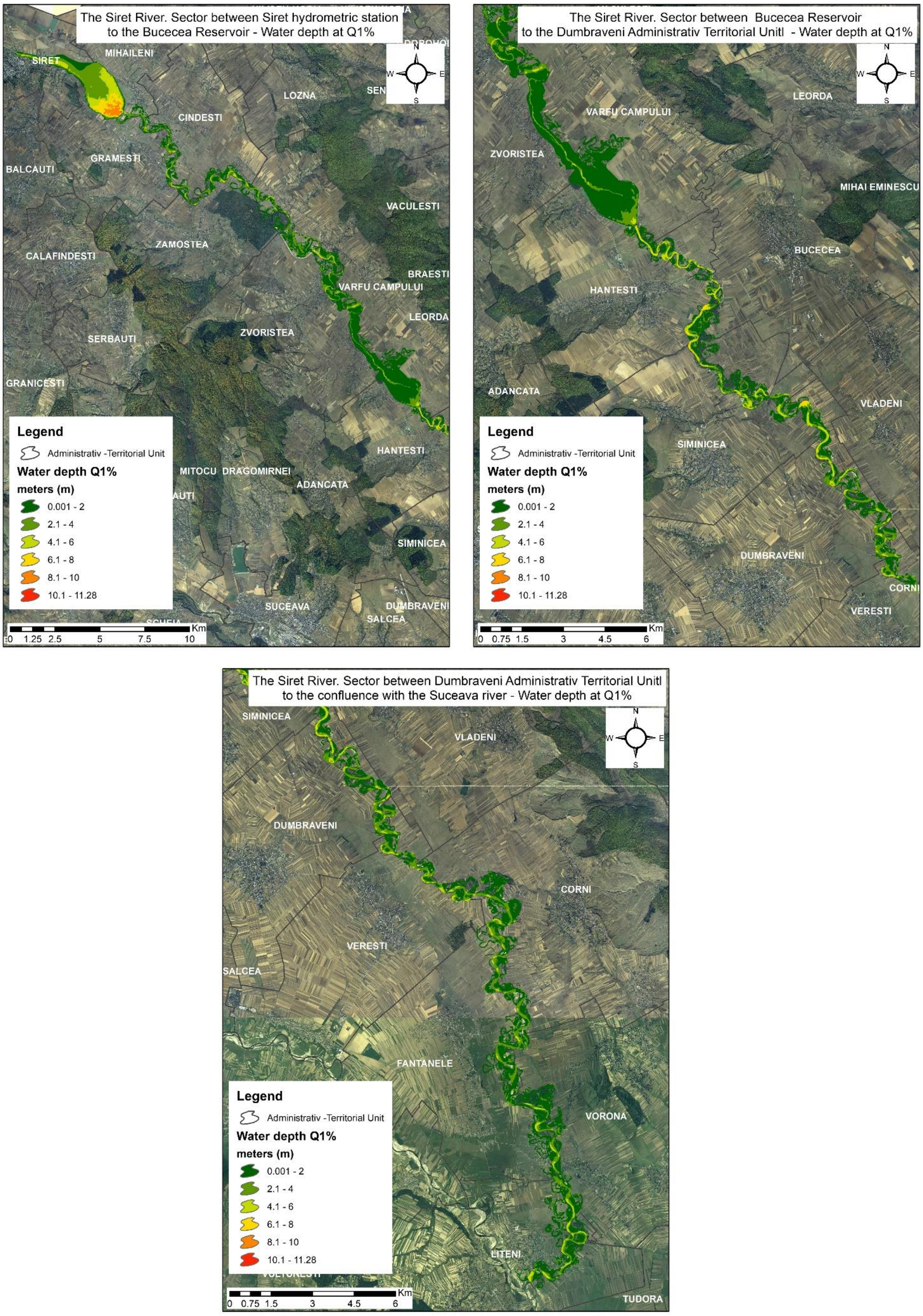

Figure 5: The spatial representation of water depth for the $Q_{1\%}$ scenario

As with water depths, the highest velocities are found in sectors where the capacity of the minor riverbed is significant (Figure 6). Minimum velocities are observed mainly at the edges of the flooded area, where more filling than drainage occurs, and in abandoned meanders, where, naturally, from a hydrodynamic perspective, the river presents much greater resistance to flow (Goodell and Walhin, 2009). These areas are often rich in vegetation and highly silted. The average flow velocity was calculated to be 1.3 m/s, indicating a propagation time of approximately 24 hours from the Rogojești Reservoir to the confluence with the Suceava River.

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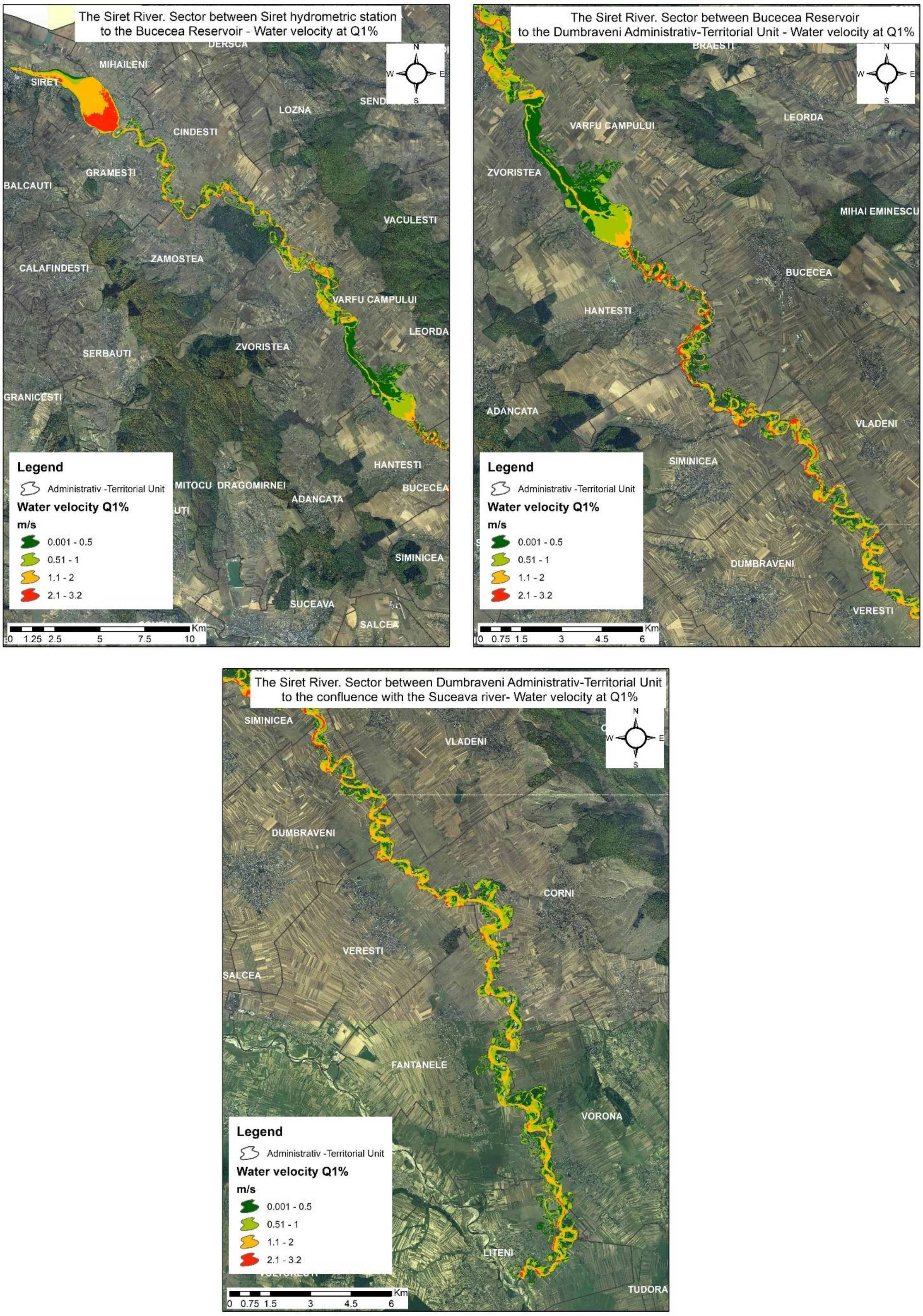

Figure 6: The spatial representation of water velocity for the $Q_{1\%}$ scenario

Scenario 2 - $Q_{0.1\%}$ Flow

For this scenario, the probability of the Rogojești Reservoir's verification flow was considered, based on its importance class. Similar to the first scenario, the simulation was of the unsteady flow type, based on flow hydrographs, with the starting point being the frontal dam of the Rogojești Reservoir. Since the maximum outflow of the Rogojești Reservoir is 2398 m³/s, it was considered that the 0.1% probability flow of 1984 m³/s can be passed by the reservoir. The simulation results were exported graphically in the form of shapefiles (flood boundary) and raster images (depths, velocities).

In the case of the breach scenario, the Siret River causes flooding over an area of 4,859 hectares. The minimum width of the flooded area is 476 meters, and the maximum width is 3,240 meters (Figure 7). One of the reasons for such an extensive inundation is the morphology of the major riverbed of the Siret River, with extensive and very flat floodplains, in contrast to the minor riverbed, which is well-defined with average bank heights of 4.5 meters. Once the capacity of the minor riverbed is exceeded, the water spreads over very extensive areas. This is one of the reasons why floods on the Siret River behave differently from those of its tributaries with similar drainage areas. These are floods with high flows but very long total durations.

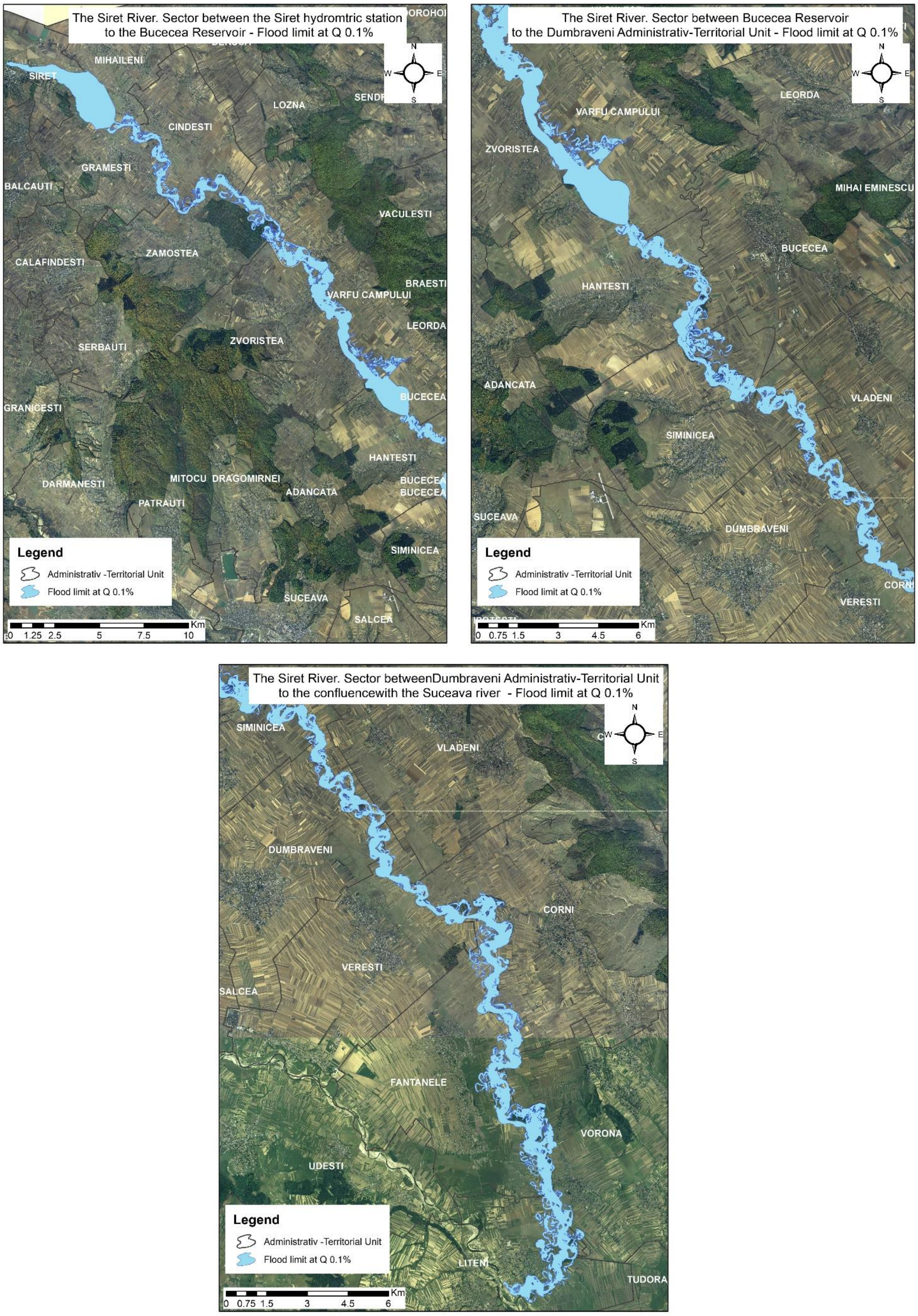

Figure 7: Flood boundary for the $Q_{0.1\%}$ flow

As in the case of Scenario 1, it can be observed that the modeled flows bypass the Vârfu Câmpului Reservoir on the right, inundating the Zamostea Forest. It is evident how the river follows its former riverbeds, not necessarily from a distant era, but relatively recent ones, a fact confirmed by the existence of roads in some sectors that closely follow the flood boundary. In the case of Scenario 2, water depths vary from shallow flow to a maximum of 11.58 meters in the Rogojești Reservoir and 8-10 meters on the Siret River. The average water depth across the entire analyzed sector was 2.2 meters. Although the difference compared to the first scenario is not significant, this is due to the nature of the major riverbed of the Siret River. From the images above, we can see that nearly three-quarters of the flooded area has depths of up to 2 meters. As in the previous scenario, the deepest depths are found in the minor riverbed, where the capacity for flow is the highest (Figure 8).

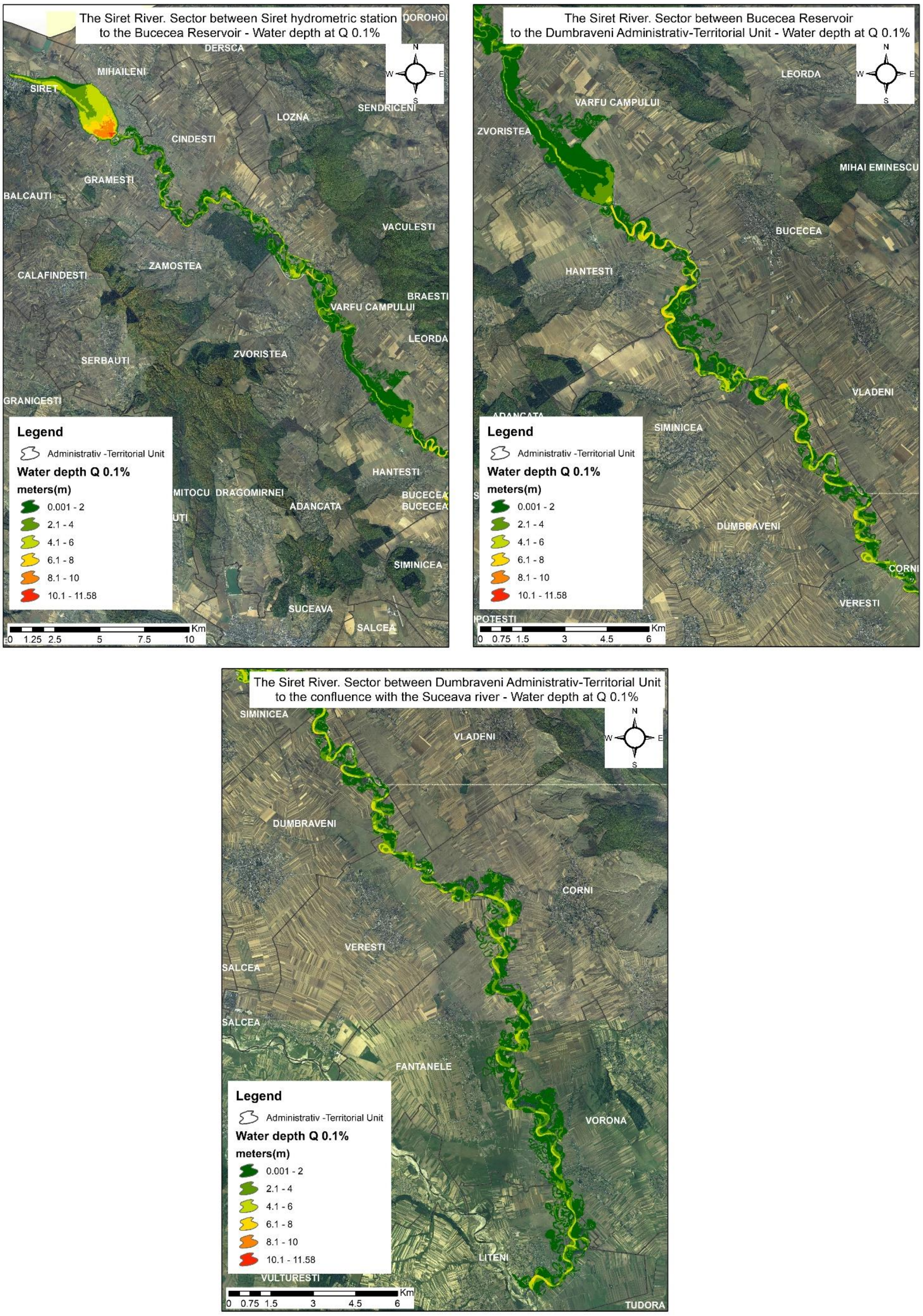

Figure 8: Spatial representation of water depth for the $Q_{0.1\%}$ scenario

Although the simulated maximum velocities reach up to 3.6 m/s in the minor riverbed section and in the Rogojești Reservoir, in nearly half of the flooded area, the water has velocities of up to 0.5 m/s, and about one-third the program simulates velocities ranging from 0.5 to 1 m/s (Figure 9). Furthermore, the global average velocity is 1.1 m/s, which is almost similar to the first scenario. This is due to the specific nature of average velocity profiles in rivers, which tend to flatten and sometimes even shift to the left, precisely because of the natural configuration of the entire riverbed, which determines a finite flow velocity, a maximum that water cannot exceed under natural flow conditions (Stematiu and Ionescu, 1999). The simulated velocities in this scenario also fall within the specific range of velocities measured at the hydrometric stations in the sector.

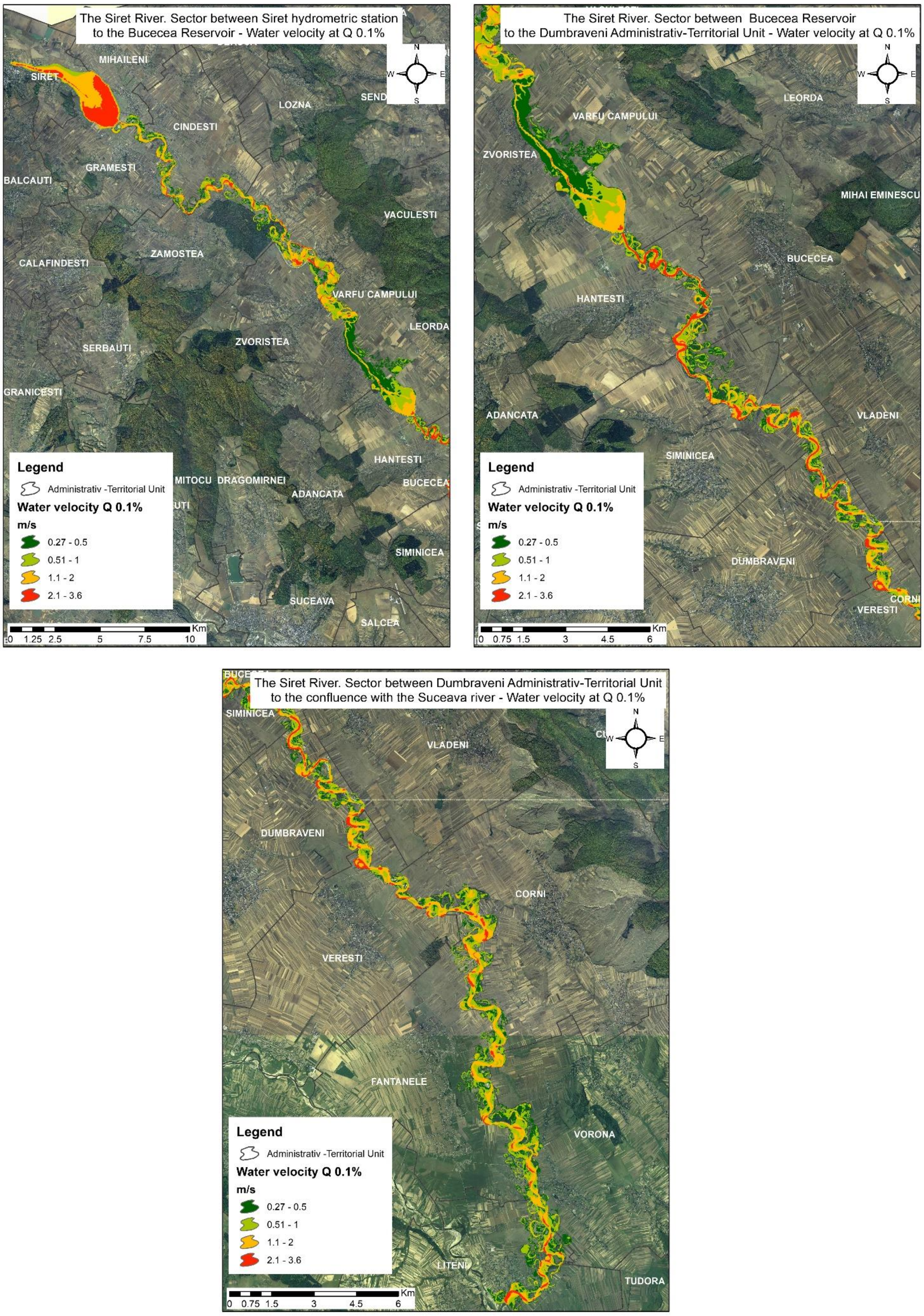

Figure 9: Spatial representation of water velocity for the $Q_{0.1\%}$ scenario

Conclusions

Although the simulated scenarios were run on a calibrated model, the fact that the simulated flows exceeded the observed flows required several post-calibration steps. In the case of the first scenario, the simulation did not present significant errors precisely because the $Q_{1\%}$ flow is close in value to the maximum flows observed during the calibration period.

In the case of the second scenario, where the flow extended to non-specific areas even for historical maximum flows, the program exhibited stability errors or results that were inconsistent with research and studies in the field. Multiple interventions were necessary, especially regarding the roughness coefficients in the ends of the major riverbed, to achieve a hydraulically stable model and obtain relevant results, particularly concerning the calculated velocities.

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Author contribution

All authors have an equal contribution in achieving the present paper.

Conflicts of interest

The authors state that they have no conflict of interests.

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