TELEMAC hydrodynamic models over time: A case study with the Danube

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***Abstract* – The Danube River, an essential waterway in Europe, poses complex hydrodynamic challenges due to its varying flow conditions. In this study, we focus on the Bulgarian segment of the Danube River to compare the TELEMAC simulations with different mesh configurations and assess the differences when used with real and with forecasted water level and discharge data. We study the riverbed in two points in time – 2010 and 2017 to investigate the accuracy of the TELEMAC simulations. The study area encompasses one hydrodynamic environment along the Bulgarian stretch of the Danube River. To evaluate the performance of the TELEMAC simulations, we compare the model results from forecasts obtained from in-situ measurements, referred to as real data and from forecasts obtained from high-resolution earth observation data of meteorological features like precipitations, soil moisture, vegetation index, combined with in-situ measurements. The analysis focuses on key hydrodynamic variables, such as water velocities, free surface elevation and riverbed. In addition, we explore the discrepancies between real and forecasted data when incorporating GAIA sediment transport data into the TELEMAC simulations. We assess the impact of this data source on model performance, identify potential areas for improvement in sediment transport modelling and data assimilation techniques. This paper contributes to the advancement of river engineering practices and the development of more accurate and reliable hydrodynamic models for decision-making and flood risk management in the Danube River Basin and beyond.**

Keywords: TELEMAC, GAIA, Danube, River, Forecast, AI.

I. INTRODUCTION

The TELEMAC software is recognized for its ability to perform 2D and 3D modelling of various hydrodynamic phenomena, including the movement and behaviour of water bodies, sediment transport, and water quality assessments. TELEMAC employs the finite element method to the shallow water equations , allowing it to simulate and predict a wide range of scenarios [10].

The Danube River, with its diverse geographical and hydrological features, is a perfect example for this study. As one of Europe's longest and most important rivers, traversing multiple countries, it presents a myriad of hydrodynamic phenomena. The complexity and diversity of the Danube make it a suitable site for demonstrating the robustness and versatility of the TELEMAC system.

The TELEMAC system has been instrumental in predicting and understanding the hydrodynamic behaviour of the Danube [13,2]. Researchers have leveraged this tool to anticipate a range of scenarios, encompassing potential flood incidents, patterns of sediment transport, and water quality parameters [6].

This case study takes a closer look at a specific segment of the Danube River - the area around Svishtov in Bulgaria. Svishtov is located in the middle part of the Bulgarian segment of the Danube.

Our study examines how the hydrodynamic models outputs have evolved when used with data from two time periods with 10 years difference. This article provides a detailed exploration of comparing hydrodynamic models derived with real and with forecasted data using TELEMAC. It is important to note that this comparison involves two distinct meshes, and the resulting data is displayed through charts and tables for a more visual analysis. Two types of data for the hydrological features – discharge and water level were used for the experiment – real data gathered from in-situ measurements and forecasted data generated by a trained neural network. The comparison reveals a significant similarity between real and forecasted data due to the high accuracy of the forecasting model.

II. PREPARATION

Mesh comparisons provide insight into geographical changes, environmental dynamics, and various anthropogenic effects.

This examination is centred around comparing two distinct meshes, one from 2010 and the other from 2017, both depicting the Danube region around Svishtov, an area of significant economic and ecological importance. The differences and similarities between these meshes will help us understand the changes that occurred in the river morphology over these seven years.

Such analyses can lead to conservation strategies and environmental impact predictions for future development.

For the Bulgarian segment of the Danube River around Svishtov, two unique Selafin objects were developed using BlueKenue, each with a mesh resolution of 50 meters. The 2010 mesh represents a river segment of 45.5 km in length and width of 0,67 km at the west end edge and around 1,2 km at the east end edge.

The first Selafin object is based on bathymetric data, the riverbed, from 2010 (see Figure 1). This object was tailored to encapsulate the unique topographical and hydrological features of the critical area of Danube river around Svishtov.

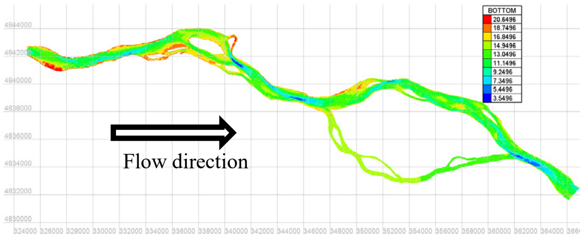

Figure 1. Mesh of the area around Svishtov with data from 2010

The second Selafin object with bathymetric data, the riverbed, was developed using data from 2017 (see Figure 2). This object was designed to model the critical area of the Danube River around Svishtov, focusing on a different set of hydraulic conditions and characteristics. It has a length of 57.2 km and features river width of around 0,7 km meters at the west end edge and 0,9 km meters at the east end edge of the mesh.

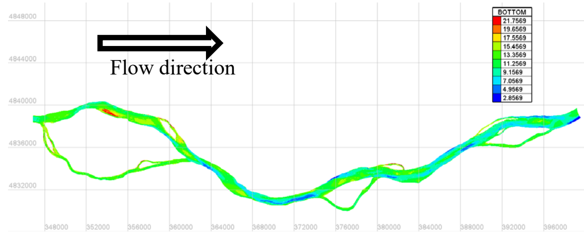

Figure 2. Mesh of the area around Svishtov with data from 2017

To provide fair comparison the common parts of the two meshes were extracted and studies. Figure 3 below shows the riverbed in years 2010 to the left and 2017 to the right in this common parts of the mesh of approx. 20 km river length with width of ~0,7 km in the west end edge and ~1,2 km at the east end edge. The differences in the riverbed in 2010 and 2017 can be clearly seen through the different colours of the two images.

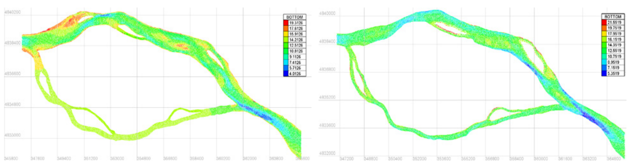

Figure 3. Common area between the meshes from year 2010 and 2017

It can be seen with bare eye that the colors of the two mesh images differ, indicating the difference in the riverbed in the two years 2010 and 2017 with deeper stretches in 2010 and shallower stretches in 2017.

Upon the generation of these meshes, boundary conditions were established. At the upstream boundary discharge is prescribed, whereas water level is used at the downstream boundary.

In conjunction with the creation of these Selafin objects, a comparative analysis was performed to highlight the differences between the two datasets using the common area and a thalweg. These differences are illustrated in Figure 4, which explicitly displays the changes in the bathymetry between 2010 and 2017, the curve in red for 2010 and the curve in green for 2017. The x axis shows the mesh stretch in consecutive points and the y axis shows the coresponding depth in meters. It shows similarities and discrepancies in the curves that correspond to the two images on Figure 3. Some of the discrepancies might be due to the seasonal effects of the different time of the year the two bathymetry measures have been performed, though.

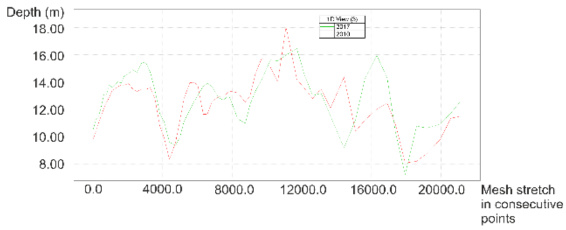

Figure 4. Difference in the Riverbed of the common area between the two bathymetries for years 2010 (red) and 2017 (green).

The development of two unique Selafin objects for the Bulgarian segment of the Danube River around Svishtov has provided important insight about the river's hydraulic and topographical changes over the years. Through the use of high-resolution meshes and the careful application of boundary conditions, it has been possible to accurately model the specific features and conditions of this segment of the river in 2010 and 2017. Not only does this provide a detailed snapshot of the past, but it also lays a robust foundation for predicting future conditions.

III. FORECASTING METHOD

Building on the constructed meshes, we insert timeseries of forecasted values for discharge and water levels in order to obtain TELEMAC simulations and output of forecasted values for a series of hydrodynamic features [7], supporting informed decision-making for the region's future.

For the forecasts of discharge and water level we adopt an EO4AI[1] method, where we use earth observation data describing meteorological features, such as precipitations, soil moisture, vegetation index, snow cover, solar irradiance, each offering a unique viewpoint on the environmental and hydrological conditions impacting the Danube River, mixed with timeseries with daily in-situ measurements for discharge and water level and apply them to a pipeline of neural network architectures using the TensorFlow framework [11]. These include Convolutional Neural Networks (CNNs), known for their pattern recognition prowess; Long Short-Term Memory networks (LSTMs), which effectively handle long-term dependencies in time series data; Recurrent Neural Networks (RNNs), ideal for short-term forecasting due to their proficiency in recognizing temporal patterns and Convolutional Long Short-Term Memory networks (ConvLSTMs), combining the spatial pattern recognition of CNNs with the temporal dependency capturing of LSTMs.

Given its proficiency with sequential data, the ConvLSTM is a fitting choice for the task of generating forecasts. It processes timeseries data, learns from historical patterns, and forecasts future water levels and discharge rates.

The method generates forecasts for 30 days into the future, a critical aspect of this study. It enables us to project the potential changes in the Danube River's conditions over a month, providing useful insights that could inform river management decision-making and planning processes.

The satellite data come from ADAM (adamplatform.eu), through ESA NoR service. They provide the data from different satellites depending on the meteorological feature required, including for example SMOS, MODIS, SENTINEL, IMERG. This allows us to provide with a unique set of data allowing for a comprehensive environmental and hydrological assessment of the Danube River region. The combination of these satellite data ensures a multifaceted understanding of the environmental and hydrological conditions impacting the Danube River region. They not only help in understanding the current conditions but also aid in making accurate forecasts for future developments.

IV. Experiments with Telemac Simulations

Experiments with TELEMAC simulations were made using two different meshes from the years 2010 and 2017. Each of these meshes were paired with measured Liquid Boundary File (LBF) containing real data and forecasted data. For the simulation we have adopted the following hydrological features: VELOCITY U, VELOCITY V, FREE SURFACE, BOTTOM and FRICTION.

A visual representation of one of these variables – velocity U, faciliating a comprehensive spatial understanding is shown (see Figure 5).

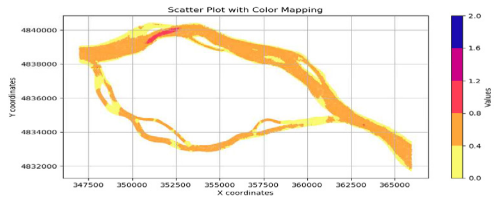

Figure 5. Velocity U output from Telemac on a maps plot

The use of two meshes in the experiment allows to explore and analyse the outputs of the simulations with data of two different time periods.

We used timeseries of daily data for discharge and water level from year 2015 to year 2019 to generate simulations with the two meshes, the 2010 and the 2017 one, their resolution being of 50 meters.

The visual representations, such as the one shown on Figure 5, of the experiment output facilitate a clear comparison between real and forecasted data. The differences between the results of the TELEMAC simulation are detailed in the comparison section, underscoring its reliability in forecasting future hydrodynamic conditions.

V. Comparison Process

The comparison process involves extracting data from the four Selafin objects generated from both real and forecasted data simulations for the 2010 and 2017 meshes. This data is then cross-examined, and provide insight into the performance and reliability of the forecasting model used.

In studying river dynamics, it is crucial to focus on the most informative features. In this context, the 'FREE SURFACE' and 'VELOCITY MAGNITUDE' were selected. The 'FREE SURFACE' offers crucial information about the elevation of the water level, which is essential in predicting flood events and understanding water flow patterns. On the other hand the 'VELOCITY MAGNITUDE' delivers a comprehensive perspective on both the speed and direction of water flow in the river. This is a key aspect for interpreting erosion rates, sediment transport, and overall river hydrodynamics. Importantly by having a clear understanding of the velocity components (along the X and Y axis), we can calculate the 'VELOCITY MAGNITUDE', which provides a more complete picture of the river flow dynamics and speed. Examining these variables at the upstream, middle stream and downstream points of the river provides a more holistic understanding of the behaviour of the Danube River.

We examined thoroughly how the river's state varied over time by analysing it for the two time periods covered. Thus, we have been able to observe the intricate transformation patterns of the river. This has enabled us to highlight the various states the river can transition through and to predict future scenarios based on our observations.

The extraction of these parameters was performed on all four Selafin objects. Once extracted the values of the processed features can be visualized and studied using various toolsets. For visualization of the 'FREE SURFACE' variable in the upstream

[1] EO4AI – Earth observation for AI

see Figure 6, where the date is on the x axis and the depth is on y axis in measurement unit of meters (M). It shows a comparison between the 'FREE SURFACE' feature and the calculated magnitude from the hydrodynamic model, built with the 2010 data for the mesh and that of hydrodynamic model, built with data 2017 data for the mesh, utilizing both real and predicted values. Figures 6 – 8 below show these comparisons for three points - upstream, middle stream and downstream one.

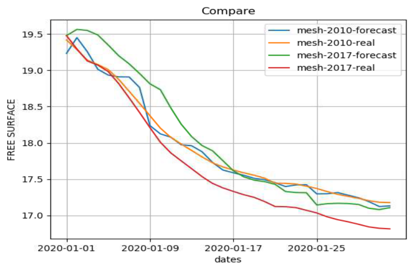

Figure 6. Free surface comparison for upstream

A comparison for the middle stream has been made for the free surface variable (see Figure 7).

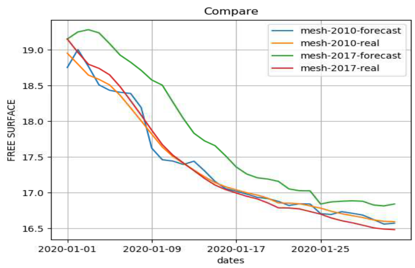

Figure 7. Free surface comparison for middle stream

A comparison for the downstream has been made for the free surface variable (see Figure 8).

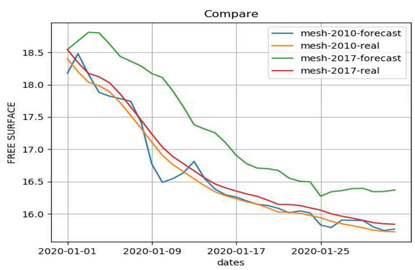

Figure 8. Free surface comparison for downstream

Same comparison has been made for the VELOCITY MAGNITUDE. The result for a upstream point is shown below (see Figure 9).

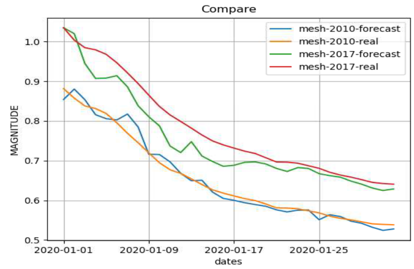

Figure 9. Magnitude comparison for upstream

A comparison for the middle stream has been made for the velocity magnitude (see Figure 10).

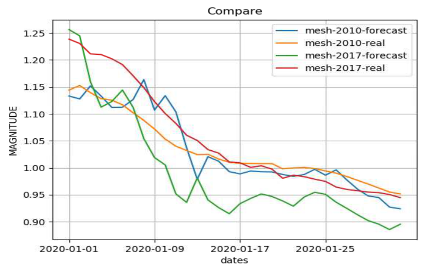

Figure 10. Magnitude showing middle stream

A comparison for the downstream has been made for the velocity magnitude (see Figure 11).

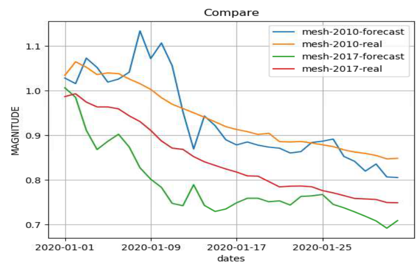

Figure 11. Magnitude showing a downstream

For further clarity, the comparison of the FREE SURFACE is shown in numerical values measured in meters (M) (see Table 1).

Table I Free surface bathymetries 2010 / 2017 with Real (R) and Forecasted (F) upstream / middle stream and downstream

Up stream / Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	19.48	19.48	19.23	19.42
1/2/2020	19.56	19.29	19.45	19.28
1/3/2020	19.55	19.13	19.25	19.14
1/4/2020	19.49	19.07	19.01	19.08
Middle stream / Date	**2010 bathymetry F (M)**	**2010 bathymetry R (M)**	**2017 bathymetry F (M)**	**2017 bathymetry R (M)**
1/1/2020	19.15	19.15	18.75	18.95

1/2/2020	19.25	18.96	19	18.8
1/3/2020	19.28	18.8	18.77	18.65
1/4/2020	19.24	18.74	18.51	18.59
Down stream / Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	18.54	18.54	18.18	18.4
1/2/2020	18.68	18.34	18.48	18.2
1/3/2020	18.81	18.17	18.16	18.04
1/4/2020	18.8	18.12	17.88	17.98

In Table II, we present the calculated VELOCITY MAGNITUDE in meters per second (M/S) values derived from Figures 9,10 and 11.

Table II Magnitude between bathimetries 2010 / 2017 with real and forecasted data for up stream middle stream and down stream

Up stream / Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	19.48	19.48	19.23	19.42
1/2/2020	19.56	19.29	19.45	19.28
1/3/2020	19.55	19.13	19.25	19.14
1/4/2020	19.49	19.07	19.01	19.08
Middle stream / Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	19.15	19.15	18.75	18.95
1/2/2020	19.25	18.96	19	18.8
1/3/2020	19.28	18.8	18.77	18.65
1/4/2020	19.24	18.74	18.51	18.59
Down stream / Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	18.54	18.54	18.18	18.4
1/2/2020	18.68	18.34	18.48	18.2
1/3/2020	18.81	18.17	18.16	18.04
1/4/2020	18.8	18.12	17.88	17.98

The detailed comparison of the 'FREE SURFACE' and the 'VELOCITY MAGNITUDE' yielded significant insights into the performance of the two models. As evidenced by the tables and charts, the forecasted data from both models aligns closely with the real-world observations. Whether considering FREE SURFACE levels or VELOCITY measurements, the predicted values exhibit a strong similarity to the actual ones, which speaks volumes about the models' accuracy and reliability.

Tables I and II clearly demonstrate the close alignment of forecasted and real-world observations for both 'FREE SURFACE' and the 'VELOCITY MAGNITUDE'. This similarity underscores the effectiveness of our forecasting models, bolstering our assurance in their ability to predict the hydrodynamic behaviour of the Danube River with considerable accuracy.

VI. GAIA COMPONENT

To further expand our analysis on the Danube area around Svishtov, we turned to GAIA - another powerful modelling tool designed for the study and prediction of sediment transport phenomena. GAIA is specifically known for its ability to model sedimentary processes and their interaction with hydrodynamics [4]. In the GAIA configuration we have selected type of sediment to be NCO and we have set CLASSES SEDIMENT DIAMETERS with the value of 323D-6.

For the sediment transport equation we have used Engelund-Hansen sediment transport equation. It is an explicit function of stream power (V2τ3/2) and the d50 of the material [3]. It is not an "excess" stream power equation, so it does not control for competence and often can, therefore, compute low transports for large grain classes. Engelund-Hansen should usually be restricted to sand systems.

Within the context of this study, we utilized GAIA to extract two important hydrodynamic variable: the 'BED SHEAR STRESS' and 'CUMUL BED EVOL'. Measured in Newtons per square meter (N/m^2), this variable quantifies the force exerted by flowing water on the river bed. It provides crucial insights into sediment transport and erosion patterns, which are integral to understanding and forecasting the overall behaviour and evolution of the Danube River. Using the same approach as with the variables free surface and magnitude we have plotted the BED SHEAR STRESS (see Figures 12,13 and 14) showing on the x axis the dates and on y the calculated value.

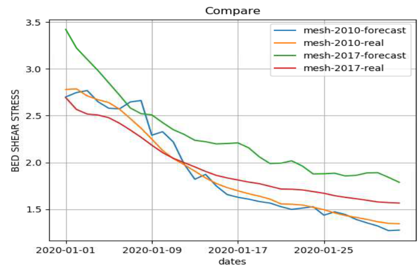

Figure 12. Bed shear stress showing a upstream

A comparison for the middle stream has been made for the bed shear stress (see Figure 13).

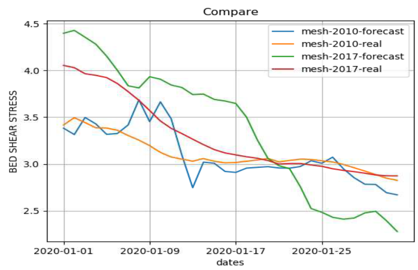

Figure 13. Bed shear stress showing a middle stream

A comparison for the downstream has been made for the BED SHEAR STRESS (see Figure 14).

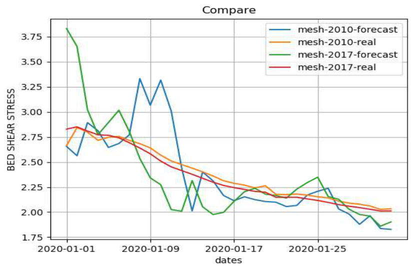

Figure 14. Bed shear stress showing a downstream

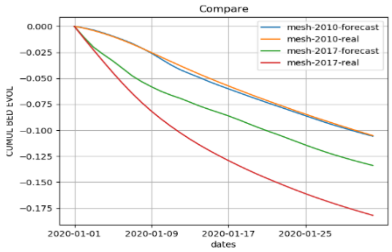

Figure 15. Cumul bed evol showing a upstream

For a table view of the BED SHEER STRESS see table III.

Table III Bed shear stress bathimetries 2010 / 2017 with real and forecasted data for up stream, middle stream and down stream

Up stream Date	2010 bathymetry F (N/m2)	2010 bathymetry R (N/m2)	2017 bathymetry F (N/m2)	2017 bathymetry R (N/m2)
1/1/2020	3.42	2.69	2.7	2.78
1/2/2020	3.22	2.57	2.75	2.79
1/3/2020	3.1	2.52	2.77	2.71
1/4/2020	2.98	2.51	2.65	2.67
Middle stream Date	**2010 bathymetry F (N/m2)**	**2010 bathymetry R (N/m2)**	**2017 bathymetry F (N/m2)**	**2017 bathymetry R (N/m2)**
1/1/2020	4.4	4.05	3.38	3.42
1/2/2020	4.43	4.03	3.31	3.5
1/3/2020	4.35	3.96	3.5	3.44
1/4/2020	4.28	3.95	3.43	3.39
Down stream Date	**2010 bathymetry F (N/m2)**	**2010 bathymetry R (N/m2)**	**2017 bathymetry F (N/m2)**	**2017 bathymetry R (N/m2)**
1/1/2020	3.83	2.83	2.65	2.66
1/2/2020	3.65	2.85	2.56	2.84
1/3/2020	3.02	2.81	2.89	2.8
1/4/2020	2.77	2.77	2.81	2.72

From Figures 12, 13, 14 and Table III, we can see that the predicted 'BED SHEAR STRESS' values from the two models align differently at various points with the observed data due to Danube River's hydrodynamic conditions. This shows the effect of the application of the different data about the river's flow for the two models, that lead to different predictions of the BED SHEAR STRESS.

CUMULATIVE BED EVOLUTION (CUMUL BED EVOL) is the other parameter through which we measured the difference in the simulations with data from the two time periods 2010 and 2017. It is a process by which the bed of a river or stream changes over time due to the deposition and erosion of sediment. This process is driven by a number of factors, including the flow of water, the composition of the sediment, and the slope of the riverbed.

On Figure 15 is shown the chart of CUMUL BED EVOL upstream displaying the date on the x axis and the corresponding value on y in meters.

A comparison for the middle stream has been made for the CUMUL BED EVOL (see Figure 16).

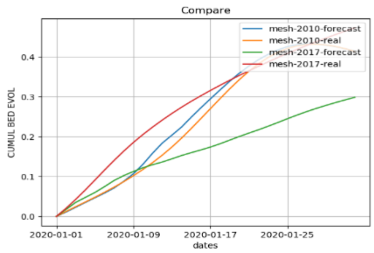

Figure 16. Cumul bed evol showing a middle stream

Same comparison has been made with a point on the downstream (see Figure 17).

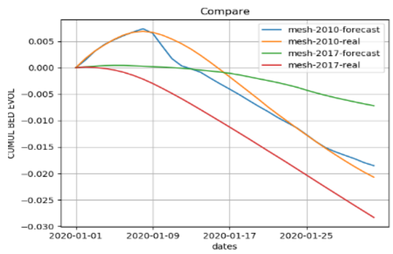

Figure 17. Cumul bed evol showing a downstream

In Table IV, we present the cumulative bed elevation from figures 15,16 and 17.

Table IV Cumul bed evol bathimetries 2010 / 2017 with real and forecasted data for upstream, middle stream and downstream

Up stream Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	0	0	0	0
1/2/2020	-0.01	-0.01	0	0
1/3/2020	-0.02	-0.02	0	0
1/4/2020	-0.03	-0.03	-0.01	-0.01
Middle stream Date	**2010 bathymetry F (M)**	**2010 bathymetry R (M)**	**2017 bathymetry F (M)**	**2017 bathymetry R (M)**
1/1/2020	0	0	0	0
1/2/2020	0.02	0.02	0.01	0.01
1/3/2020	0.04	0.04	0.02	0.02

1/4/2020	0.05	0.07	0.03	0.04

Down stream Date	2010 bathymetry F (M)	2010 bathymetry R (M)	2017 bathymetry F (M)	2017 bathymetry R (M)
1/1/2020	0	0	0	0
1/2/2020	0	0	0	0
1/3/2020	0	0	0	0
1/4/2020	0	0	0	0

Figures 18, 19 show the difference between the 'CUMULATIVE BED EVOLUTION' in the two meshes on the 18th day and their calculated difference on Figure 20.

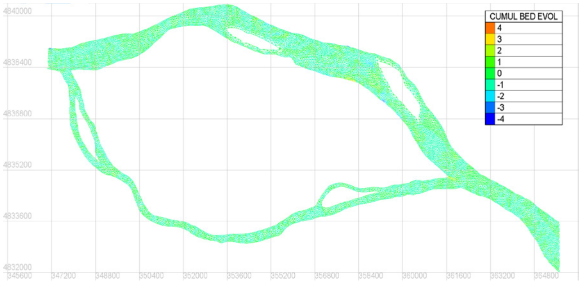

Figure 18. CUMUL BED EVOL variable using the 2017 mesh with real values on the 18th day

Figure 19 shows the GAIA result for the 18 day with the forecasted values.

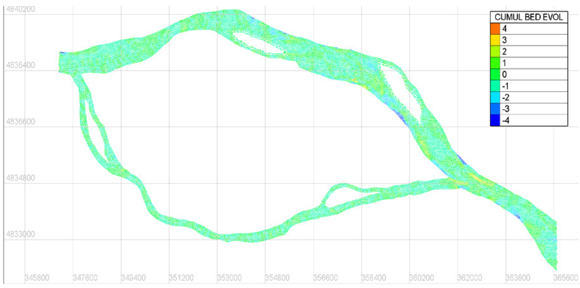

Figure 19. CUMUL BED EVOL variable using the 2017 mesh with forecasted values

Knowing the real and the forecasted values we were able to calculate the difference between them and the result is shown below. The calculated mesh is showing the absolute difference of each point between the cumulative bed evolution variable for the year of 2017 (see Figure 20).

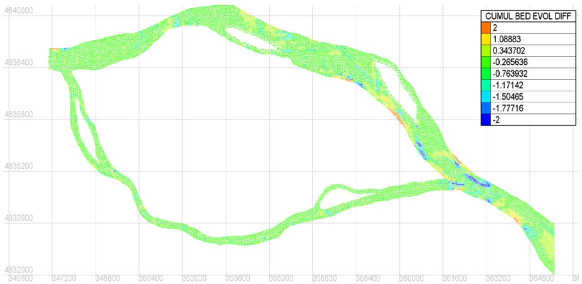

Figure 20. Calculated difference for CUMUL BED EVOL between real and forecasted values

The cumulative bed elevation with forecasted data for year 2020 is shown on Figure 21.

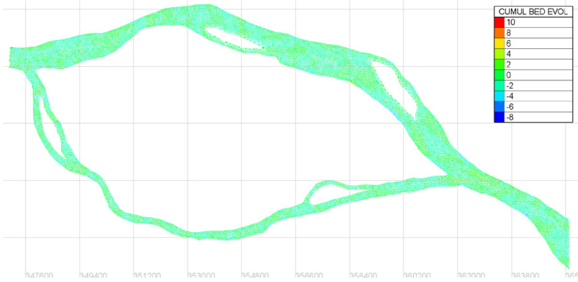

Figure 21. CUMUL BED EVOL values using forecasted data for year 2020

Lastly we have calculated the difference between the forecasted data for different years. For the calculation we have used the TELEMAC output for the cumulative bed evolution for year 2017 and year 2020 and plotted the absolute difference (see Figure 22).

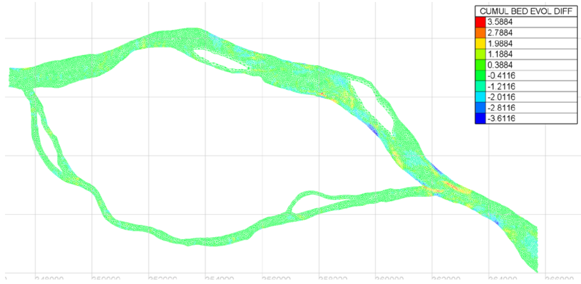

Figure 22. Calculated difference for CUMUL BED EVOL between forecasted data for year 2017 and 2020

Figure 22 shows that the maximum difference is 2.57 M which indicates that in certain areas the simulated 'CUMULATIVE BED EVOLUTION' was slightly higher than the forecasted values. These differences, while important to note, are relatively small, suggesting that our simulation is capturing the key dynamics of the terrain evolution quite well.

Despite using the same resolution for generating the Selafin objects, a slight distinction was noted between the meshes based on their geographical location. The difference is not in the level of detail or granularity provided by the meshes but rather the specific areas of the Danube River they represent. These variations led to subtly different calculated values for the featured variables free surface, velocity magnitude, 'BED SHEAR STRESS' using the LBF file for the year 2020 and the 'CUMULATIVE BED EVOLUTION' with Liquid Boundary File (LBF) for years 2017 and 2020. However, despite these minor differences, the overall trends and patterns remain consistent across both models, underlining their effectiveness and reliability in forecasting the river's hydrodynamic behaviour.

VII. Related Work

Hydrodynamic modelling [8] serves as the basis for numerous studies, prominently in domains like sediment transport and water quality. This type of modelling aids in understanding riverine phenomena, with a specific focus on currents. The development of diverse river models underscores the maturity of these modelling methods [1].

River dynamics have been monitored and predicted using a variety of mathematical models [12,14] which are gaining popularity in solving a range of natural fluid mechanical problems. Tools commonly employed for studying free-flow currents and sediment transport processes in open channels are one-dimensional (1D) and two-dimensional (2D) digital models. A recently developed approach combines hydraulic input forecasts, derived from historical satellite meteorological data and in-situ measurements from designated hydrometric stations, with the TELEMAC system, representing a novel advancement in the field of hydrodynamic modelling [7].

Several studies have delved into various aspects of river behaviour, analysing features such as daily flow, responses to extreme weather conditions, and the speed of water movement under different circumstances [9]. Data required for these detailed studies were compiled from multiple databases, including those providing daily river flow information, precipitation radar data, and specific flow data.

It is important to highlight that there are multiple neural network architectures capable of working with river dynamics.

One approach involves the use Deep Neural Networks (DNN). These neural networks, fundamental in their architecture, connect each neuron in one layer to all neurons in the subsequent layer. This extensive interconnectivity equips the network to uncover complex patterns and relationships inherent in hydrodynamic data. Although DNNs may not be specialized for dealing with temporal or spatial data, with appropriate data preprocessing and correct network tuning, they can effectively be used to predict river dynamics [16].

An alternate approach utilizes the Gated Recurrent Unit (GRU) networks. GRU networks are a type of Recurrent Neural Network (RNN) with an architecture that's simpler yet parallel in functionality to LSTM. Specifically designed to remember past information, GRUs are particularly adept at handling time-series data, such as river dynamics. Similar to LSTMs, GRUs can learn to recognize patterns over time, but with the advantage of being computationally more efficient. This efficiency can be beneficial in applications where computational resources or processing time are limiting factors [15].

For our specific study we have chosen to adopt ConvLSTM networks to forecast hydrological features for their ability to process spatial data from satellite imagery alongside their proficiency in handling temporal sequences from in situ measurements making them an exceptionally suitable tool for our hydrodynamic forecasting tasks. The results we obtained confirm the effectiveness of our chosen approach and the potential of ConvLSTM networks in the realm of hydrodynamic modelling.

VIII. CONCLUSION AND FUTURE WORK

Comparison of the simulations reveals a high degree of similarity between the real and forecasted data, indicating the forecasting model's high accuracy. The data points from the forecasted simulation align closely with those from the real-world observations, suggesting that the model has been successful in predicting fluid behaviour in this scenario. These findings highlight that our approach not only captures the current state of the river effectively but is also robust in its ability to anticipate future conditions.

Through our research, we focused on comprehending the river's different states using key hydrodynamic parameters: 'FREE SURFACE', MAGNITUDE, 'BED SHEAR STRESS' and ‘CUMUL BED EVOL’. Even when considering minor geographical variances, the models consistently portrayed the river's dynamic transformations. This reveals a solid potential for understanding and predicting the evolving hydrodynamic behaviour of rivers in future investigations.

We aim to extend our efforts to further areas, exploring different segments of the Danube River and other river basins. The high degree of alignment between our forecasted and actual observations provides a solid foundation for future research, underscoring the potential of these approaches to drive better river management and conservation strategies.

The proposed method and its outcomes has been integrated into ISME-HYDRO the integrated e-Infrastructure for water resources management of Mozaika [5].

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