CONSIDERING CLIMATE CHANGE PROJECTIONS IN THE ASSESSMENT OF HYDRODYNAMIC LOADS AND SCOUR RISKS ON BRIDGE PIERS – A PILOT CASE AND RESULTS OF THE EU PROJECT RISKADAPT

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RISKADAPT Modeling of Risks and Adaptation

Introduction

Climate change driven by global warming is disrupting the runoff regime in river catchments by increasing temperatures and altering precipitation patterns. To assess these impacts, researchers use meteorological, hydrological, and hydraulic models to determine river discharges and associated risks. In this study, a hydrological model was used to convert precipitation scenarios with different return periods (for current and future climate change projections) into river discharges. The river discharges were then simulated using hydraulic modelling to estimate water flow velocity and water depth and to assess the risk of horseshoe scour formation at the bridge piers of the Polyfytos Bridge.

Methodology

The hydrological and hydraulic simulations were performed using the Hydrologic Engineering Centre River Analysis System (HEC-RAS) software, version 6.5, from the US Army Corps of Engineers.

Since the full-2D modelling approach in HEC-RAS allows the inclusion of direct precipitation (i.e., Rain-on-grid) data in the hydrodynamic surface flow simulations, it can also be used for hydrological modelling. Runoff in the Aliakmon River catchment, which feeds Polyfytos Lake, was estimated using a full 2D hydrological model based on extreme rainfall and catchment features (topography, land use, soil). Three return periods were analyzed—50, 100, and 1,000 years.

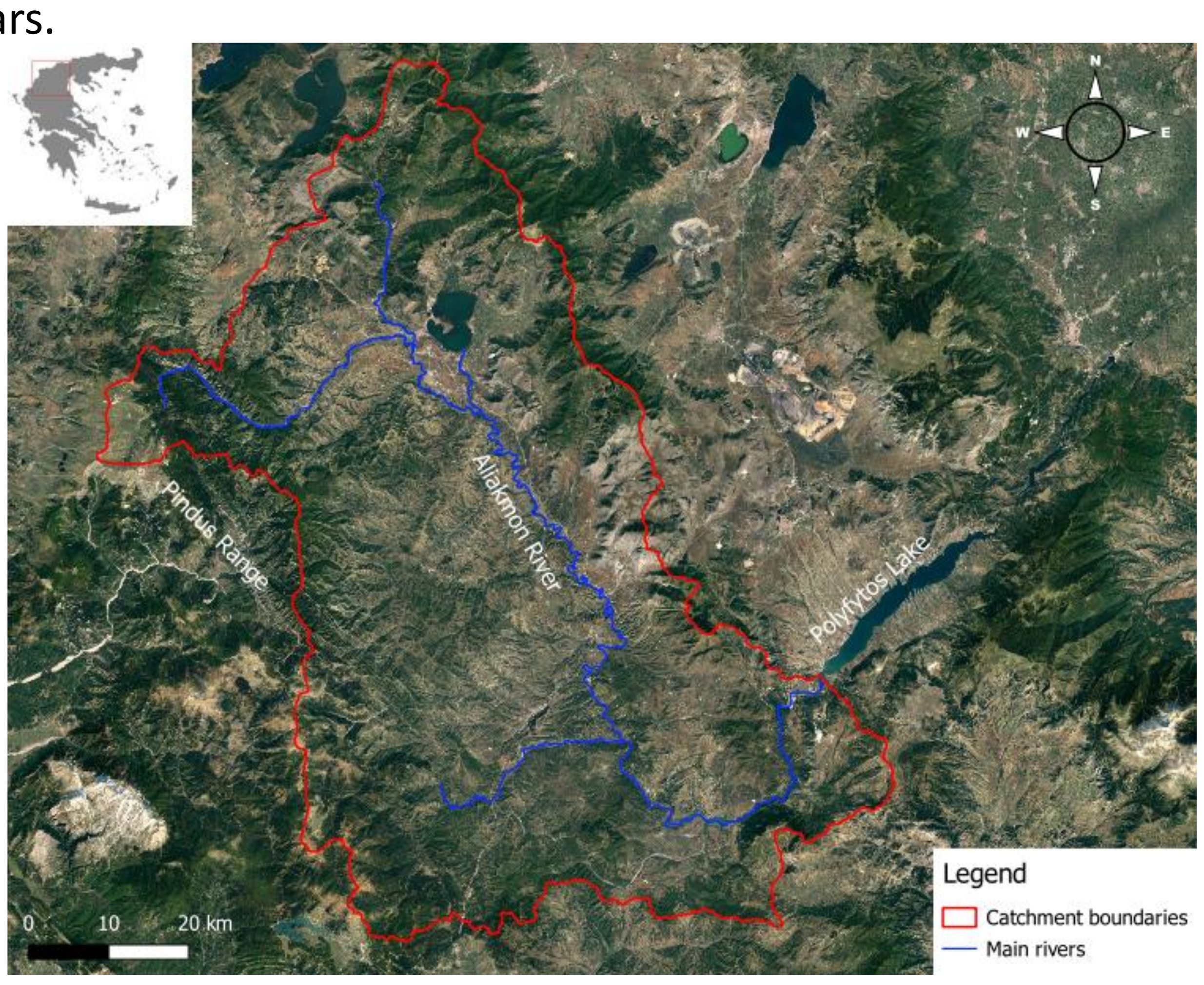

Figure 1: Aliakmon River catchment contributing to the Polyfytos Lake

The hydraulic model comprised a 12 km long reach along the Aliakmon River. It spanned 6.5 and 5.5 km upstream and downstream of the Polyfytos Bridge, respectively. The mesh of the full 2D model, initially set at 10 × 10 m for the entire domain, was refined around a 1 km bridge section. To improve accuracy near the piers, element sizes were gradually reduced to 6 × 6 m, 4 × 4 m, 2 × 2 m, and 1 × 1 m in a narrow belt around the bridge, extending both upstream and downstream.

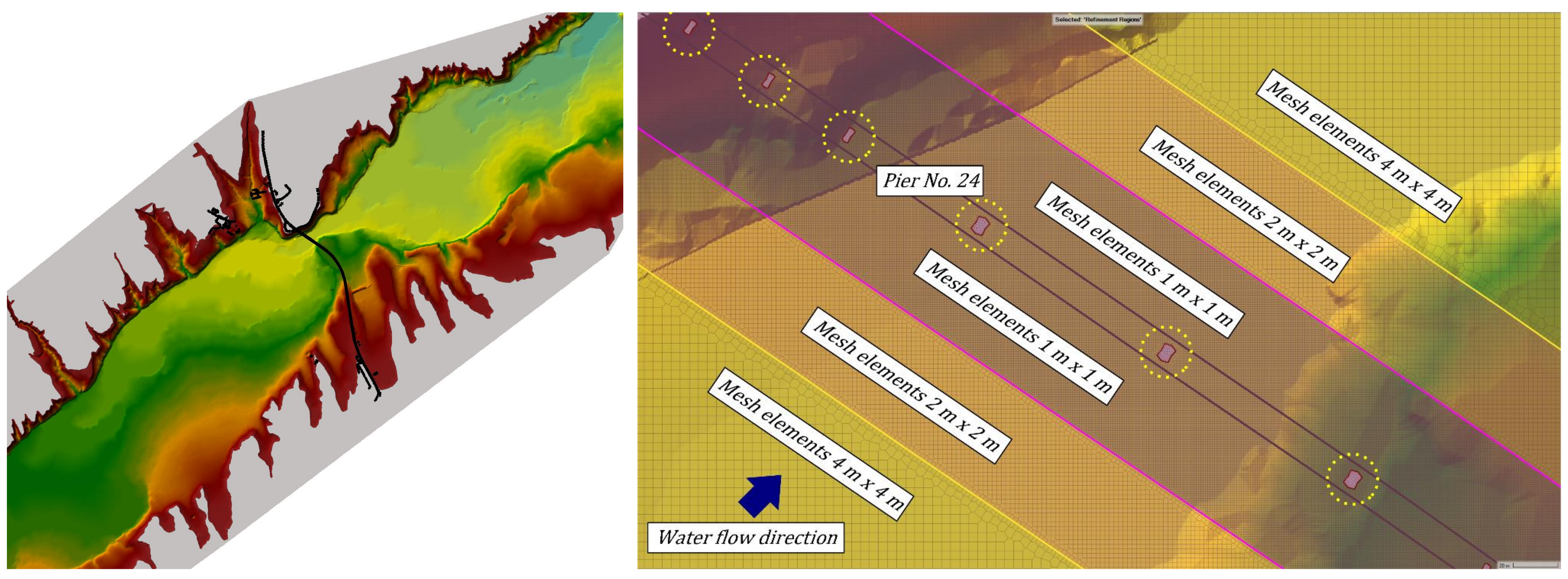

Figure 2: The underlying digital elevation model of the Polyfytos Lake and the gradual refinement of the computational mesh upstream and downstream of the bridge.

Results & Discussion

To identify the most critical rainfall duration, the Aliakmon River catchment model was run with varying precipitation inputs. Hydrographs at the lake inflow showed that a 72-hour rainfall produced the highest discharge peaks: 2,400, 3,100, and 6,350 m^3/s for 50-, 100-, and 1,000-year return periods, respectively. In addition to hydrographs, flood extent maps and depth and velocity data were also generated. Future climate scenarios were simulated using the same model as for the present climate, with only precipitation data adjusted for three GCM-RCM scenarios, focusing on 72-hour events producing the highest discharges.

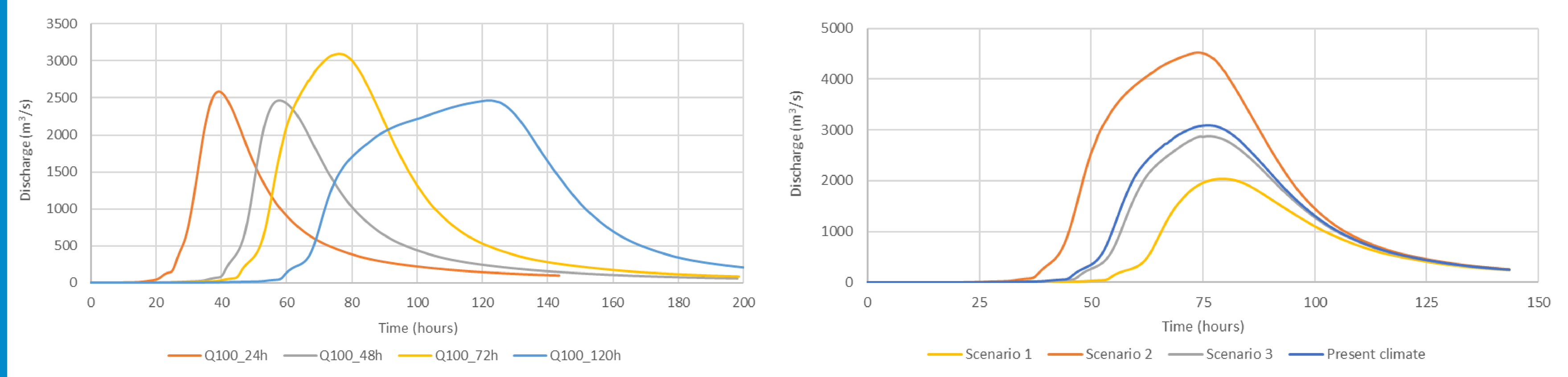

Figure 3: Hydrograms for present (left) and future climate scenarios (right), for the return period of 100 years.

The hydraulic modelling produced time series data for key parameters needed for further assessment of hydrodynamic loads and scour risks on the piers of the Polyfytos road bridge—water depth, surface elevation, flow velocity, and discharge. Due to the 112 m high Polyfytos Dam, water depths in the reservoir can reach nearly 50 m. Therefore, water flow velocities at the Polyfytos Bridge piers remain low even during high-water events. Considering the relationship between flow velocities and the associated shear stresses and drag forces on the riverbed, it can be concluded that the bridge is not significantly prone to scour formation. In highly erodible soils, erodibility begins at velocities of around 0.3 m/s. In comparison, the movement of fine sands and alluvial silts is triggered at water flow velocities of over 0.5 m/s and 0.6 m/s, respectively. At the bridge, Q_{100} flow velocities stay below 0.5 m/s.

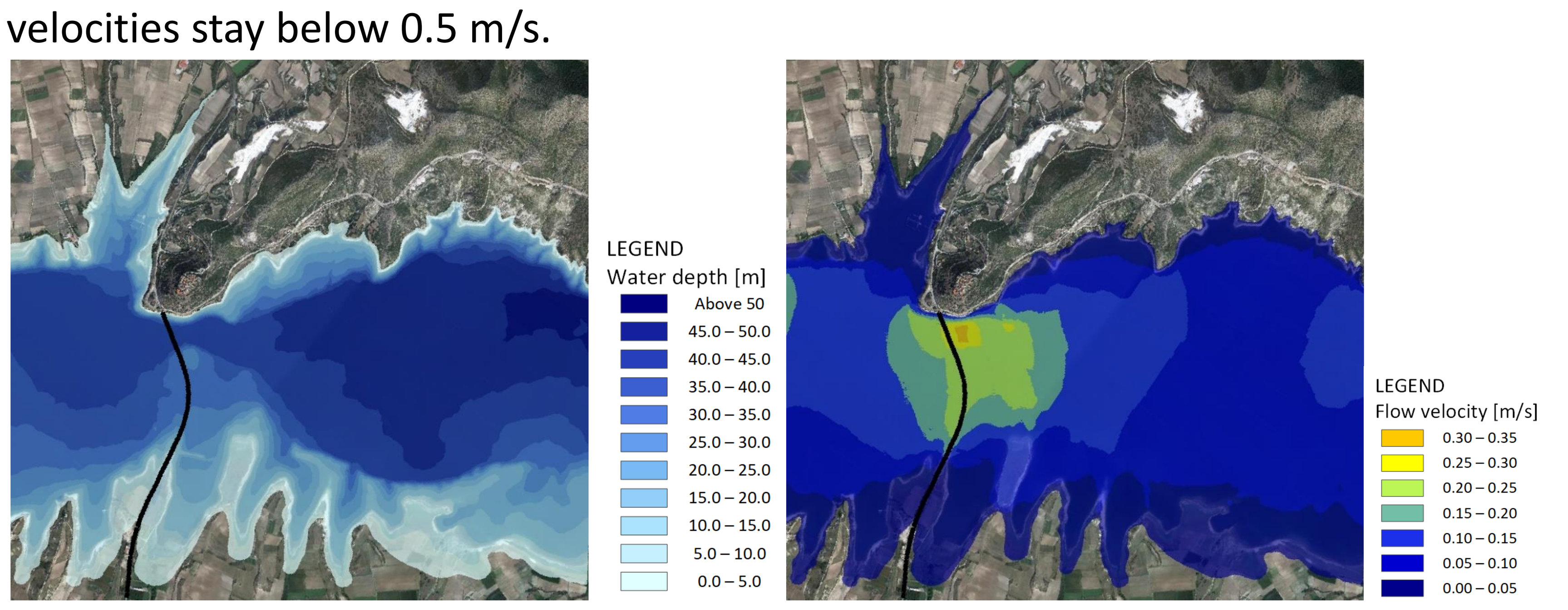

Figure 4: Maximum water depths (left) and depth-averaged water flow velocity for the flood wave $Q_{1,000}$ with the peak discharge of 8,250 m^3/s.

Scour at bridge piers and abutments can cause disruptions, structural failure, and even collapse, leading to significant economic losses and risk to life. Research has explored the hydraulic, geotechnical, and structural aspects of scour, which is influenced by factors such as pier geometry, flow depth and velocity, flow angle, and channel design. Key flow patterns driving scour are downward flow at the pier front, horseshoe vortices at the base, and wake eddies downstream.

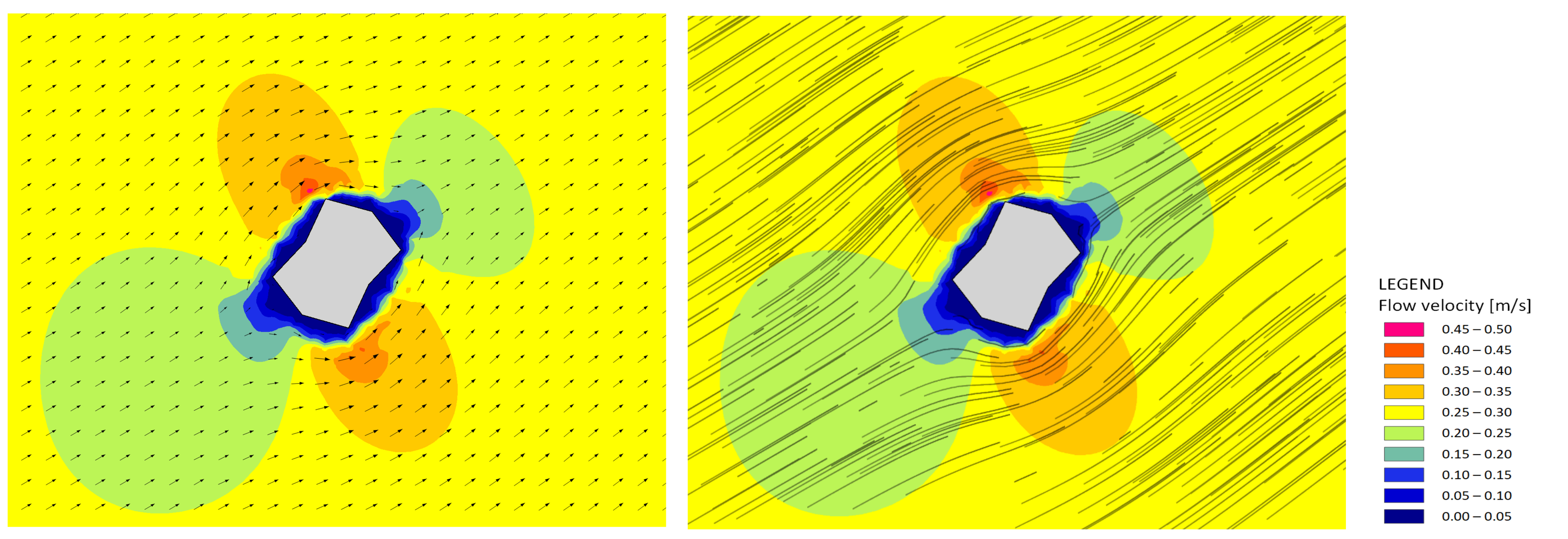

Figure 5: Maximum water flow velocity around a pier for the flood wave $Q_{1,000}$ for the most unfavourable scenario (velocity vectors - left) and (water flow streamlines - right).

Conclusions

This contribution presents the results of the hydrological and hydraulic modelling of the Aliakmon River catchment and the Polyfytos Lake. Various projections of possible future climate changes are considered, focusing on extreme flood events with return periods of 50, 100, and 1,000 years. The hydraulic modelling provided crucial insights into the critical input data, allowing an assessment of the hydrodynamic loads acting on the piers and embankments of the Polyfytos Bridge during these extreme events. The analysis shows that the bridge piers are not significantly susceptible to scour, even during flood events. This conclusion is based on the observation that the water flow velocities around the piers are relatively low, which limits the potential for scour formation.

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