Machine-learning based analysis and modelling of hourly potential thermal refuge area: case study of the Ste-Marguerite River

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In response to high summer river temperatures, much effort is being expended to improve environmental conditions for cold-water river dwellers such as salmonids. They retreat to discrete areas of cold-water known as thermal refuges to avoid heat stress. Unlike any other form of thermal refuges, tributary confluence plumes tend to be much more persistent/stable as sources of cold water over time. In the present paper, potential thermal refuge areas (PTRA) and their variability were investigated on an hourly time step over the summers of 2020 and 2021 at two tributary-river confluences in the Ste-Marguerite River (Canada). Different machine-learning models are proposed to predict hourly PTRA, which are first estimated from spatial interpolation of water temperatures performed using Inverse Weighted Distance (IWD). The proposed models were: (i) general additive model (GAM), (ii) multivariate adaptive splines regression (MARS), (iii) the support vector machine (SVM) regression, and (iv) the random forest (RF) regression. The models were developed using three to five hydro-meteorological variables as inputs. Several performance metrics were used to evaluate the results. SVM and RF regressions outperformed the benchmark models (GAM and MARS), which were previously employed for daily PTRA forecasting. The tree-based model RF indicated the best performance and worked best with high accuracy at both confluences (relative Root Mean Square Error $\leq$ 15% and Nash-Sutcliffe efficiency coefficient $\approx$ 93%). We also quantified PTRA's diel variability with an emphasis on an extreme low flow event. This was achieved by investigating the coefficient of variation across different periods of the day (Early, Mid & Late) and across the two warmest months (July, August). In this study, smoothing and tensor tools from GAM were used to model the diel cycle of the cold-water plume based on Julian day and hour components. The results showed the adverse effect of low water level conditions on PTRA. Specific time windows illustrate PTRA's extreme values during a period of low flow. Nonparametric models were found useful for describing hourly PTRA estimates. The ability to predict the size (area) of hourly thermal refuges and investigate its diel variability using non-deterministic approaches may be beneficial to improve management strategies that conserve these critical habitats.