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# Three-dimensional numerical modeling of water temperature distribution in the Rozgrund Reservoir, Slovakia

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The Rozgrund water reservoir is one of the oldest reservoirs of the water supply system in the vicinity of Banská Štiavnica. In the past, it was one of the important reservoirs supplying the population with drinking water. Knowing the spatial and temporal variations of water temperature in the reservoir is the primary step to investigate and model water quality. Therefore, the present study was planned to simulate water temperature distribution in the Rozgrund Reservoir by incorporating atmospheric and bathymetric conditions using MIKE 3 FM model and took a step forward to model extreme hydrological and meteorological events impacts. The simulations were performed for July 2022 and the model provided 3D visualization of water temperature variations and corresponding temporal differences during the entire simulated period. The results revealed that the Rozgrund Reservoir experienced temperature stratification (i.e. non-isothermal layers) in the period of simulation when the initial temperature was given to the model, while the constant initial temperature condition needs a long time to reproduce water temperature stratification. In addition, this study assessed the impacts of high inflows on patterns of current flows and water temperature throughout the Rozgrund Reservoir. The present work has implications for improving the understanding of changes in water temperature distribution in the Rozgrund Reservoir and similar reservoirs and supports further works, as well.

KEY WORDS: 3D hydrodynamic model, Rozgrund Reservoir, spatial and temporal variability, water temperature distribution and stratification

## Introduction

The reservoirs in Slovakia are part of a water impoundment system commonly used for domestic, drinking, irrigation and industrial purposes as well as for flood control (Negm and Zeleňáková, 2019). They have stored more than 1,890 M $m^3$ of water in Slovakia together with dams (GWP, 2011). Water temperature is a key variable in the hydrodynamic and water quality conditions of a reservoir. Additionally, water temperature plays an important role in the water flowing and mixing processes due to a developed cycle of temperature stratification, influencing the reservoir ecosystem functioning (Hlevca et al., 2015). The thermal structure of the reservoirs is relevant to internal influences such as lake morphometry (Han et al., 2000) and external influences such as wind forces, precipitation and heat exchange (Helfer et al., 2010).

There are a number of studies that have investigated reservoir water temperature distribution illustrating that all physical-chemical-biological processes are influencing temperature stratification and mixing processes (Lawson and Anderson, 2007; Kirillin and Shatwell, 2016; Zhang et al., 2020). The temperature stratification is subject to change by processes affecting heat transfer through the surface layer of a reservoir. These processes include heat exchange, heat flux caused by evaporation and precipitation and wave radiations from the sun, atmosphere and surface waters nearby (Boehrer and Schultze, 2008). The deep layers are less affected by mentioned processes and mainly influenced by turbulence, wind-induced currents and heat diffusion (Zhang et al., 2020). The temperature differences between the surface layer and deep layers result in water density stratification which introduces positive buoyancy gradients and directly affects reservoir hydrodynamic conditions (Kirillin, 2010).

Reservoirs consist of the main inflow with many tributaries and an outflow located near the dam wall such that three distinct zones in reservoirs are formed as riverine, transition and lacustrine. The longitudinal features in morphology, hydrodynamic and water quality properties are different in these three zones (Ji, 2017). The difference in water temperature between the inflow and reservoir water reverses the inflow current direction, known as thermocline erosion which significantly influences water temperature distribution over the transition and lacustrine zones (Zhang et al., 2020). Hence, three-dimensional (3D) numerical tools are useful to depict water temperature distribution in reservoirs and decipher the temperature stratification. The vertical variations of water temperature in reservoirs are commonly measured by high-frequency in situ sensors (Webb et al., 2008) and more recently by the use of remote sensing methods (Sima et al., 2013). Nevertheless, both methods reflected flaws in visualizing the horizontal plane and vertical distribution of the water temperature. Sensor device suffers from the horizontal measurement of water temperature, and the remote sensing method is just only applicable for short-time monitoring of water temperature variations due to the coarse temporal resolution. To better understand spatial and temporal variations in water temperature over entire reservoirs and employ frequent changes in the heat exchange and flow pattern as well as changes in the morphological features of the reservoirs, hydrodynamic models have become powerful tools for representing present or future conditions of reservoirs.

Numerical hydrodynamic modeling has been widely applied for simulating the water movements within reservoirs (Zhang and Chan, 2003; Chao et al., 2010; Torriano et al., 2012; Zhang et al., 2020). León et al. (2007) and Li et al. (2018) have simulated spatial and temporal variations of water temperature using hydrodynamic models. Other water temperature modeling studies e.g. Mahanty et al. (2016) found that spatial variations of water temperature have been greatly influenced by wind forces and meteorological conditions. The study of Li et al. (2017) has numerically evaluated the dominant factors influencing water temperature stratification of Poyang Lake, China through the 2D hydrodynamic model MIKE 21. Zhang et al. (2020) have also investigated the thermal structure of a drinking water reservoir in Tarago, Australia, and shown the impacts of rainfall and wind on water temperature stratification using a 3D version of MIKE. In a recent study, Dadashzadeh et al. (2021) simulated flow patterns and water temperature distribution over a very large lake in Iran (Urmia Lake) with MIKE 3 to investigate the effects of a causeway structure located in the middle of the lake. The above-mentioned research studies have shown the strong applicability of using 3D numerical models for the investigation of water temperature stratification in natural water bodies like reservoirs. To date, the literature on water temperature distribution is less consistent in reservoirs and further studies should address horizontal and vertical variations of water temperature over morphological changes, and extreme meteorological and hydrological conditions with special attention to water quality properties.

The main objective of this study is to investigate and simulate the water quality of the Rozgrund Reservoir in Slovakia, mainly an indicator of water temperature. Rozgrund Reservoir was critical for domestic use in the previous time when it served as a reservoir for drinking supply, nowadays is in standby mode. The water temperature variations act as a basic element of water quality control such that the investigation of the spatial and temporal water temperature distribution and water temperature stratification in the Rozgrund Reservoir is of paramount importance. Also, Rozgrund is an example of a reservoir subjected to significant changes in water quality due to the seasonally dynamic river-reservoir system, hydrological events, and the size, shape and morphological conditions. Therefore, the goal of this study was to simulate the horizontal and vertical variations of water temperature during the summer time, for example specifically for July 2022 in the Rozgrund Reservoir as the preliminary stage for a greater simulation of water quality for strategic reservoirs in Slovakia with the purpose of the water resources management in extreme events. Accordingly, the present study used and validated the MIKE 3 hydrodynamic model to follow these specific goals:

1) visualizing hydrodynamic data and flow behavior using field measurements,
2) investigating spatial and temporal water temperature distribution over the reservoir using the simulation results,
3) exploring the effects of extreme hydro-meteorological events on water temperature distribution and stratification in the reservoir.

## Study domain and material

### *Study area*

The Rozgrund Reservoir is part of the Hron basin with a location of 6154800N and 2101200E (projection system: WGS84/World Mercator) and is approximately 6.5 km northwest of Banská Štiavnica in central Slovakia and has a maximum capacity of 960,000 $m^3$ of freshwater (Fig. 1), but current water storage is about 430,000–515,000 $m^3$. It was built in 1,744 to collect water for domestic people in the vicinity and the maximum depth of the reservoir is approximately 21 m near the earthen dam wall. The Rozgrund surface area in flooded conditions at the maximum allowed level is 53,820 $m^2$, almost 5.4 hectares (Fendek, 2019). The annual temperature range is -3 to 19°C and the average annual rainfall is about 950 mm. The reservoir is surrounded by mountains; the maximum water level in the reservoir is 705 m above mean sea level (amsl) and the elevation of the top of its dam is 706.20 m amsl. The Rozgrund Reservoir was the highest earthen dam in Europe until the second half of the 19th century and in former Czechoslovakia until the second half of the 20th century. The Rozgrund Reservoir used to provide a significant drinking water resource for the town of Banská Štiavnica since the beginning of the 20th century until the recent past. Currently, the Rozgrund Reservoir serves as a standby source of drinking water, for flood protection purposes and fish breeding with the aim of increasing the water quality in the reservoir through the biological system of the reservoir. The reservoir is characterized by lacustrine and riverine morphological processes that exhibit distinct seasonal variations (Chen et al., 2011). The reservoir receives inflow predominantly from two sources fed by creeks (small streams) (Fig. 1) as well as groundwater flow, rainfall, minor stream discharges and small ditches. The shape of the reservoir is narrow and long and its water depth gradually increases from the main inflow to outflow, reaching its maximum near the dam. Water surface elevation drop can be up to approximately a level of 693 m amsl in the dry period.

***Data availability***

The bathymetry measurements of the Rozgrund Reservoir were carried out using an AUV (autonomous underwater vehicle) of type EcoMapper (manufactured by YSI) (https://www.ysi.com/ecomapper). The meteorological conditions of the reservoir, such as air temperature and precipitation were provided from the gauging station directly at the Rozgrund Reservoir locality. Additionally, this station provided daily records of water temperature and in-and-out flow discharge of the Rozgrund Reservoir. Other meteorological terms such as relative humidity, clearness, wind speed, and wind direction are available from the meteorological stations at Banská Štiavnica and Vyhne. We also performed measurements of water temperature in several vertical profiles during the field measurements on July 28 this year. The multi-parameter water quality probe (YSI Professional) was installed on the boat and the water temperature below the surface was measured by this vertical profiling system (Fig. 2). Fig. 3 shows the measured vertical variations of water temperature for the date 28/07/2022. Because the Rozgrund Reservoir is relatively large (Li et al., 2017), it could be assumed that the reservoir does not experience large daily changes in water temperature.

**Methodology**

***3D hydrodynamic model description***

The present study adopted the three-dimensional simulation model of DHI company, MIKE 3D FM (flexible mesh), to simulate the spatial and temporal variations of water temperature in the Rozgrund Reservoir by solving differential equations describing flow dynamics (integration of momentum and continuity), advection and dispersion, heat exchange and other processes driven by physical and climate conditions of the modeled reservoir. The mathematical foundation of the governing equations is based on the hydrodynamic module for solving 3D incompressible Reynolds Averaged Navier-Stokes (RANS) equations with the assumption of hydrostatic pressure together with a turbulent closure scheme and variable density, and the conservations of mass, momentum, temperature and salinity (DHI, 2017). Thus, the dynamically-coupled transport equations for water levels, velocity and temperature under external forces such as river inflows will result in the simulation of flow and temperature distribution in a 3D waterbody.

The heat exchange in the model must be included to represent the interaction of heat in the water with the atmosphere. The heat exchange calculation is based on four processes: latent heat flux (evaporation), sensible heat (convection), short wave radiation and long wave radiation. The heat exchange has a significant effect on water temperature simulation. In this study, the default values of latent heat, sensible heat, short and long wave radiations were used, while the constant values for the atmospheric conditions including relative humidity and clearness coefficient were set up to 71% and 60.4% according to mean values driven from data between 1991–2021 by the meteorological stations at Banská Štiavnica and Vyhne. In addition, the air temperature was included in the atmospheric conditions according to the daily averaged data series (Fig. 4).

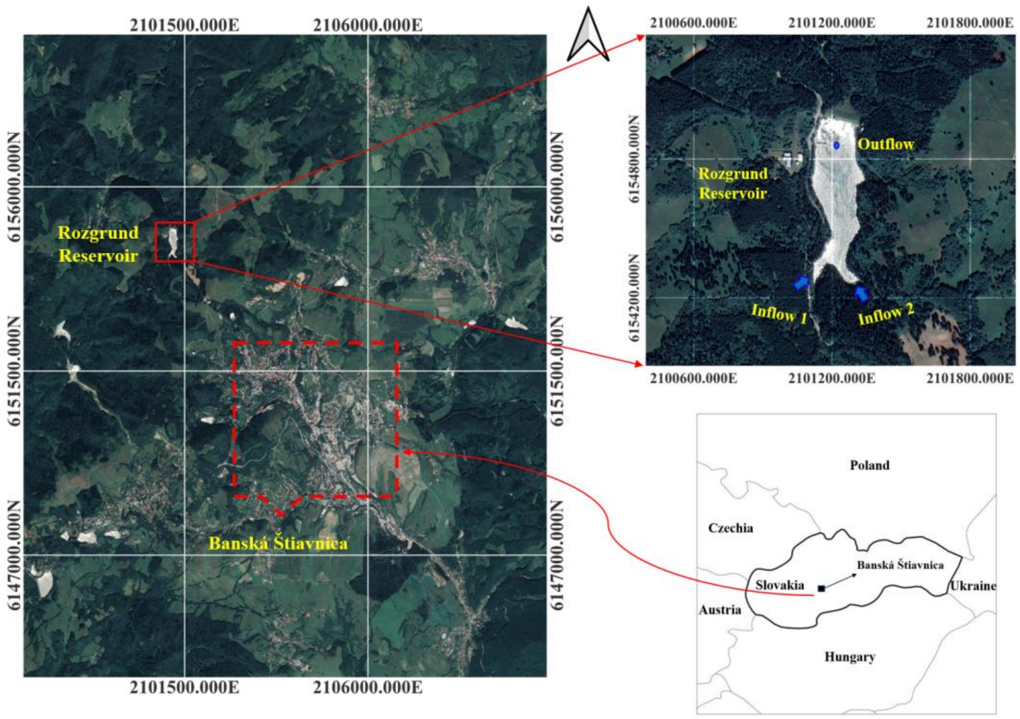


*Fig. 1. Geographical map showing the location and shape of the Rozgrund Reservoir (map data: Google).*

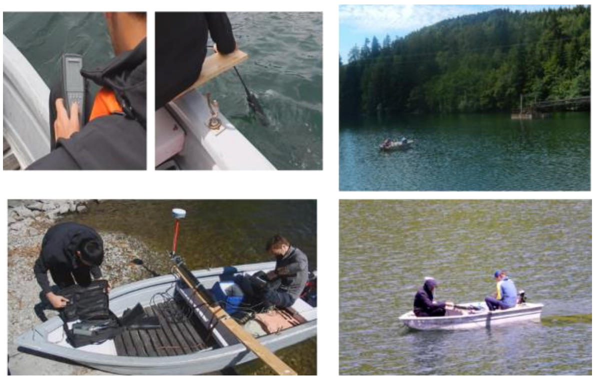

*Fig. 2. Field boat measurements of vertical water temperature profiles in the Rozgrund Reservoir.*

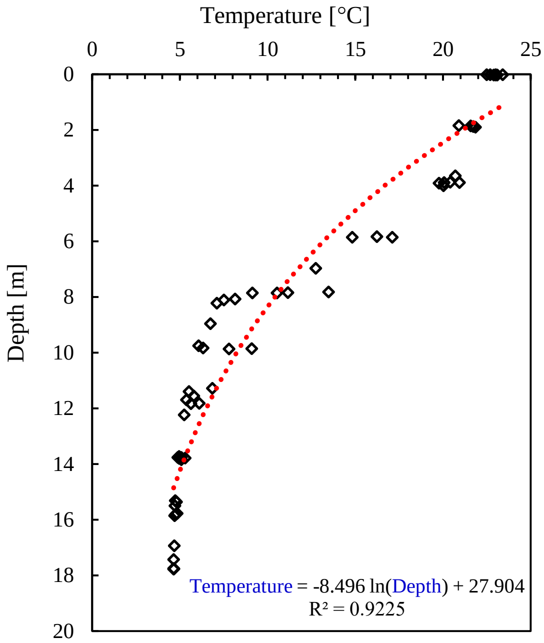


*Fig. 3. Vertical changes in water temperature in July 2022 at the Rozgrund Reservoir.*

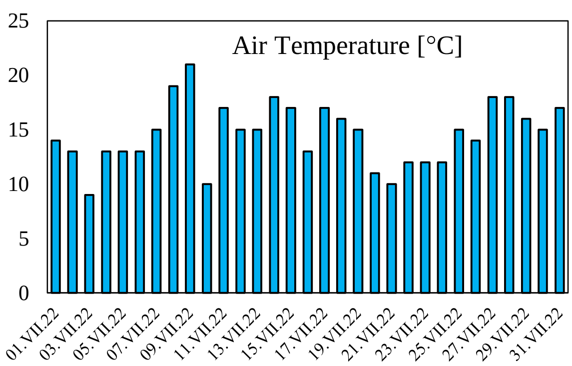


*Fig. 4. Air temperature variations in July 2022.*

***Reservoir bathymetry and grid quality***

The measured bathymetry (Fig. 5) data was used to make a flexible unstructured mesh of variable cell sizes. The grid map includes element sizes that vary between 5–15 m, resulting in a total number of 1159 nodes and 2057 triangular elements. The vertical distance was discretized uniformly with 1 m by a combined sigma and z-level method in which the sloping boundaries of the bathymetry are well-introduced. In detail, the vertical mesh was discretized into 19 layers with an equal distance of 1 m. In this hybrid *z*-sigma grid, 1 sigma layer for one meter below the water surface and 18 *z*-layers at the bottom of the sigma domain were defined. The cell sizes around the inflow and outflow boundaries are much denser due to the increased number of border points on the reservoir perimeter.

***Boundary and initial conditions***

The boundary conditions included the water discharge, water temperature and turbulence model characteristics at two inflows at the Rozgrund Reservoir. The bank of

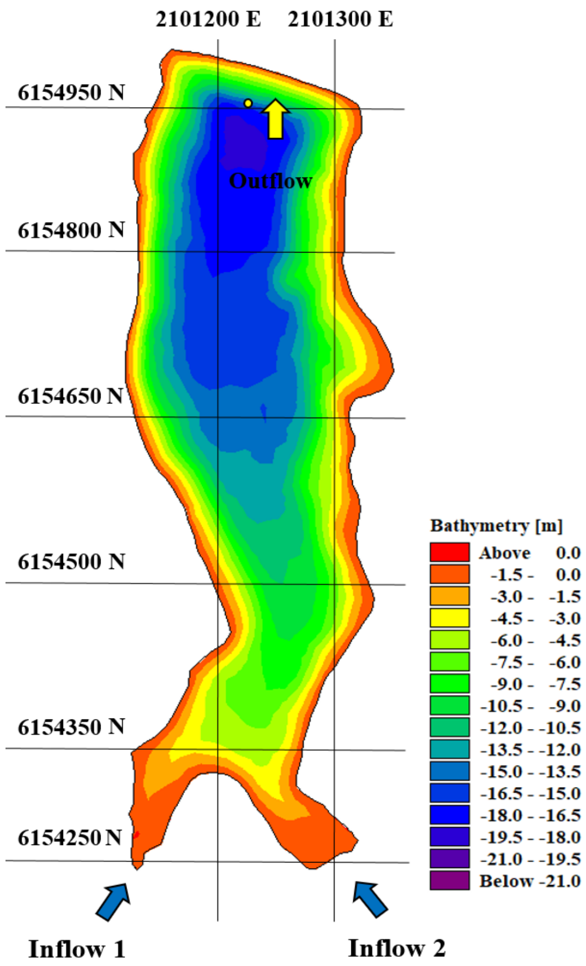


*Fig. 5. Bathymetry of the Rozgrund Reservoir.*

the Rozgrund Reservoir was defined as a zero normal velocity boundary. Furthermore, the water temperature at both inflows was 10°C and was assumed to be constant in the vertical direction. The water discharge and water temperature also have to be set to a point source outflow (Fig. 5). The initial conditions for the hydrodynamic module including surface elevation [m] and velocity in *x* and *y*-direction [m $s^{-1}$], temperature module including the vertical profile of water temperature (Fig. 3) and turbulence module including turbulent kinetic energy and its dissipation are also set for the start of simulations in the model setup.

***Model setup***

MIKE 3 FM model serves the hydrodynamic module as the basis to reproduce the water flow pattern and dynamics of water surface elevations in the reservoir. The shallow water equations were adopted for the solution technique to better reflect water temperature stratification with fewer errors from the steep slopes and wall boundaries. The time step is restricted to 300 *s* to keep the critical Courant–Friedrich–Lewy (CFL) number at 0.8 considering the numerical stability of the model. The water depth near the two inflow boundaries is very low, thus the wetting and drying in the hydrodynamic model were adopted with the rule following drying depth (0.001 m) < wetting depth (0.1 m) in the DHI MIKE flow manual to keep the inflows active in the model. The water temperature simulation package was activated in the model with the definition of density variations as a function of water temperature. To simulate and map the water temperature distribution in the *x*-*y* plane and a vertical direction, the meteorological conditions need to be adopted by heat exchange (refer to section 3.1). The simulation period of this study was for 1–31 July 2022 to ensure that the simulation could experience the mixing processes. In July 2022, the mean water flow was almost zero from inflow 1 and the reported mean water discharge in inflow 2 was 0.3 l $s^{-1}$, while the outflow discharge was reported as 5 l $s^{-1}$. This study adopted 'cold start' initial hydrodynamic condition in which the velocity values in the *x* and *y* directions were set to zero at the beginning of the simulated period (the simulation for warming up the model is not considered). The turbulence model is a mixed Smagorinsky / *k*-*ε* model for which the horizontal and vertical eddy viscosity are calculated by Smagorinsky and standard *k*-*ε* formulation respectively. These formulations contain several empirical constant and diffusion parameters interpreting dispersion throughout the reservoir, which were determined by the previous reports and literature description (DHI, 2017; Zamani and Koch, 2020). Notably, wind forcing is not included in the present numerical modeling. A brief description of the model setup of the Rozgrund Reservoir is incorporated in Table 1. The performance of the model is appraised by absolute mean error (*AME*) and the root-mean-square error (*RMSE*). Also, the index of agreement (*Ia*) is a good index to evaluate the similarity between observed and simulated data since of presenting proper weight to the errors and differences (Eslamian et al., 2019). It should be mentioned that the *AME* and *RMSE* values close to zero and *Ia* close to 1 specify the optimal

**Table 1. Parameters used in the MIKE 3 FM simulations**

| Model component | Parameter description | Value and unit [] – note |
|---|---|---|
| Bed resistance | Bed roughness height | 0.1 [m] – calibrated |
| Turbulence module coefficient | Horizontal eddy viscosity in Smagorinsky formulation | 0.1 – default |
| | Vertical eddy viscosity in *k*-*ε* formulation | Minimum eddy viscosity: 1.8e-06 [$m^2$ $s^{-1}$] – default<br>Maximum eddy viscosity: 180 [$m^2$ $s^{-1}$] – default |
| Dispersion coefficients | Horizontal and vertical dispersion in scaled eddy viscosity formulation | 1 – default and 0.1 – default |
| Coriolis forcing | Coriolis type | Varying in domain |
| Heat exchange coefficients | Constant in Dalton's law | 0.5 – default |
| | Wind coefficient in Dalton's law | 0.9 – default |
| | Critical wind speed | 2 [m $s^{-1}$] – default |
| | Transfer coefficient for heating and cooling | 0.0011 – default |
| | Light extinction coefficient | 1 [$m^{-1}$] – default |
| | Sun constant, *a* in Ångstrøm's law | 0.295 – default |
| | Sun constant, *b* in Ångstrøm's law | 0.371 – default |
| | Beta in Beer's law | 0.3 – default |
| | Standard meridian for time zone | 0 – default |

values, thus indicating the best fit between the observed and simulated data (Okhravi et al., 2022).

$$\text{AME} = \frac{1}{N}\left(\sum_{i=1}^{N}|O_i - S_i|\right) \qquad (1)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \qquad (2)$$

$$\text{Ia} = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(|O_i - \bar{O}| + |S_i - \bar{O}|)^2} \qquad (3)$$

where

$\bar{O}$ – is the mean value of observed data;

$O_i$ and $S_i$ – are the observed and simulated values, respectively;

$N$ – is the number of data values.

## Results and discussion

Previous studies have shown that the application of 3D hydrodynamic models is validated with the generally accepted or standard coefficients in the literature without the need for calibration (Chung et al., 2009; Zamani et al., 2018). The calibration is usually associated with 2D hydrodynamic models (e.g. MIKE 21) where the flow characteristics along the cross-section have been averaged. 2D models suffer from difficulties in the establishment of a reliable relationship between water surface elevation and volume since each mesh cell represents a different cross-sectional area (Zamani and Koch, 2020). In addition, a 3D water body such reservoir cannot be fully calibrated directly by the use of in-situ sample data since they have been not yet fully available for calibration in general. Therefore, the present study made an effort to illuminate the 3D flow behavior and water temperature distribution in space and time dimensions in the Rozgrund Reservoir and provide a preliminary understanding of 3D reservoir hydrodynamic modeling for further planned studies in water quality modeling in reservoirs for extreme events. Hence, three scenarios are devised to simulate water temperature variations in horizontal and vertical directions according to the above-mentioned descriptions. The MIKE 3 simulations are as follows:

1) Reservoir modeling based on July 2022 implementation using water temperature profile (Fig. 3) as the initial condition for temperature module (reference case).
2) The reference case simulation with the constant initial conditions for the temperature module.
3) The reference case simulation including high inflows.

### *Spatial and temporal variations of water temperature*

The MIKE 3 model was run on a desktop PC with an AMD Ryzen 7 3700X 8-core processor (16 threads) and a Windows 10 operating system to simulate the one-month water temperature of the Rozgrund Reservoir (July 2022). The MPI (message passing interface) distributed memory approach allowed parallel computing within a multi-core processor. This approach assigns memory for several sub-domains saved in separate files, then they will be merged at the end of the simulation into the specified files. The one-month simulation with the grid mentioned before took 5 hours (CPU time).

According to the model setup, the simulation was initiated by the imported vertical variations of water temperature as was presented in Fig. 3. 2D map of water temperature distribution at surface in the horizontal plane

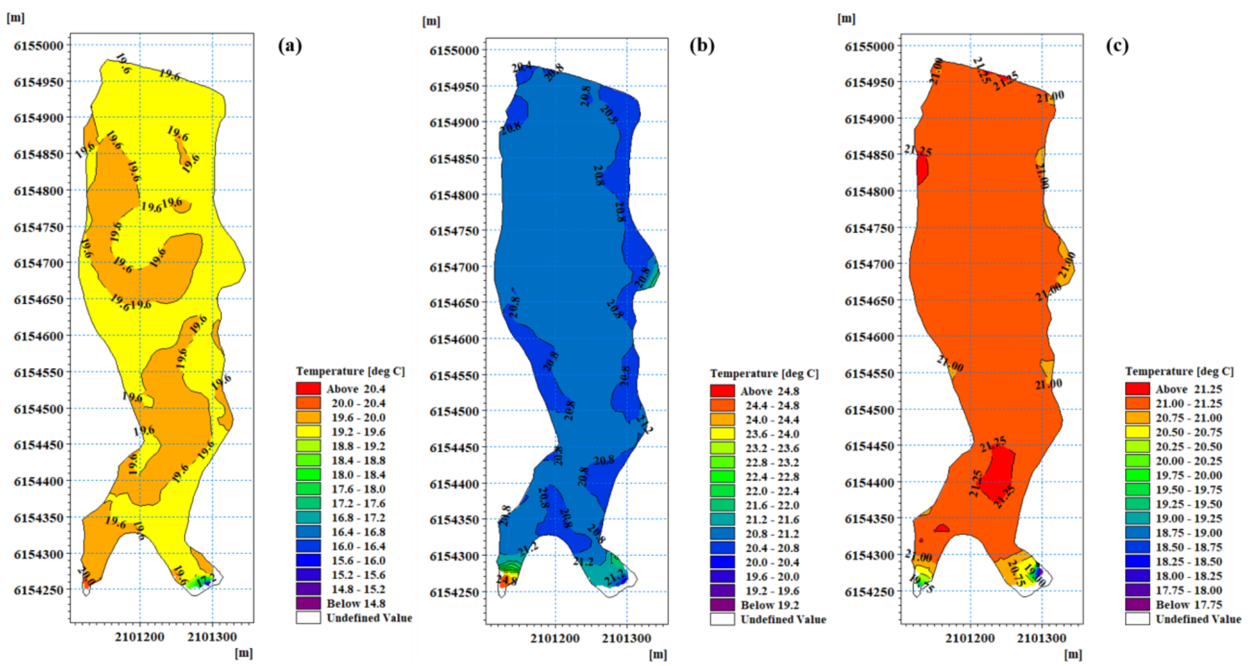


*Fig. 6. Simulated water temperature distribution in July for Rozgrund Reservoir: a) 6 days, b) 15, c) 31 days.*

for three moments is presented in Fig. 6. The minimum water temperature in July was recorded at 4.89°C in the deepest layer of the reservoir for a second time step in the simulation, while the initial water temperature in this location was 4.8°C. This interprets that the simulation follows the temperature stratification imported as an initial condition of the temperature module – the temperature difference is less than 1°C. The maximum value of water temperature was 22.33°C which is in the range of 10°C (inflow water temperature) <22.33°C<23.4°C (measured water temperature at surface, Fig. 3). The reservoir-averaged value of water temperature was 15.5°C.

A 2D display of current speed with current isolines at the surface of the reservoir (Fig. 7) in July showed very low velocities either in inflow 2 or near steep boundary slopes. It is worth noting that the current speed differences range from 0.001 to 0.05 m s$^{-1}$ and are all less than 0.2 m s$^{-1}$, indicating that temperature stratification cannot be affected by inflows in the Rozgrund Reservoir (Li et al., 2016). Indeed, the very low inflows are not expected to significantly impact the initial temperature field within one month of simulation time.

The vertical cross-section plane of water temperature from inflow 2 (the only inflow current in July) toward the outlet shows water temperature changes (Fig. 8) from the beginning of the simulation till the end of the simulated period. The results show the water temperature at the surface layers was predicted accurately in accordance with the initial measured water temperature. However, the water temperature at the deep layers experienced heating, and the water temperature rose to 16°C. The reasons for warming up deep layers could be attributed to a very small inflow and relatively large internal heat exchange in the reservoir when water mixing has not occurred. Notably, over a period of 1 month, the inflows will most likely not reach the sink at the north of the reservoir where the outflow is located (Fig. 5) and the water level was dropped to about 10 cm due to a significant unbalance of inflows and the outflow. Nevertheless, the results confirm that the model does retain water temperature stratification in the reservoir – the imported stratified water temperature for initial conditions has lasted up to the further time steps. The reservoir reveals non-isothermal and non-mixed layers for the entire waterbody since approximately all vertical temperature profiles show water temperature differences of more than 5°C (Fig. 8). According to Woolway et al. (2014), the reservoir is isothermal if the water temperature differences between the surface and deep layers decrease less than one unit (<1°C), which means that water temperature stratification can be neglected.

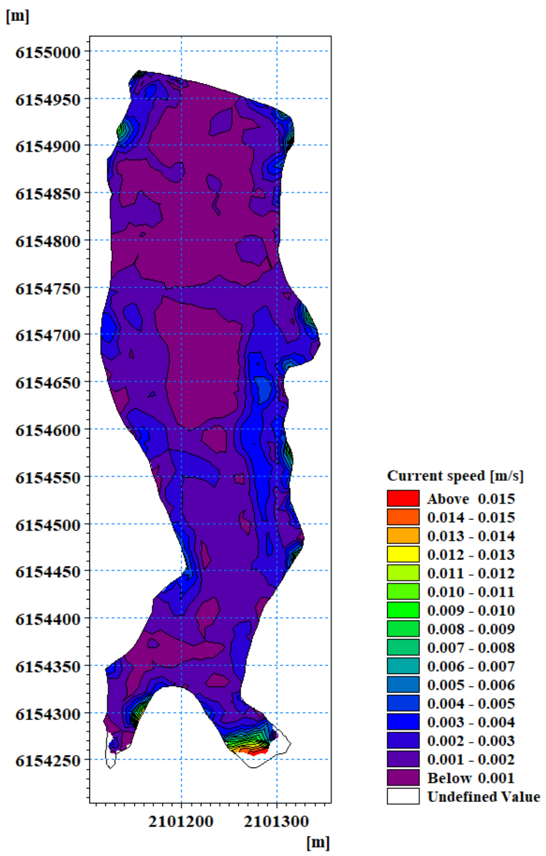


*Fig. 7. Simulated current speed in July (reference case).*

Temporal variations of water temperature (2 m below the water surface) are drawn in Fig. 9 for three different locations in riverine, transition and lacustrine zones. The value of the mean water temperature for each location was incorporated in Fig. 9. The temporal pattern of water temperature in the lacustrine and transition zones of the Rozgrund Reservoir is almost the same, while the temporal oscillations of water temperature in the riverine zone can be seen due to the influence of nearby inflow. As mentioned before, the water inside the reservoir cannot be mixed adequately over one month of simulation time such the water temperature at 2 m below the surface shows no distinct temporal changes in three zones. Additionally, the mean water temperature values between these zones are close and support the above-mentioned statements.

The next simulation was initiated with the constant water temperature as it was considered the same as the air temperature, 19.1°C (mean air temperature in July 2022 at the meteorological station in Banská Štiavnica). The water temperature distribution and current speed in the horizontal plane had similar patterns to the reference simulation while having different values. The results of this simulation also show that the Rozgrund Reservoir does not experience water temperature stratification during just a one-month simulation period when the initial water temperature was constant. Therefore, the vertically measured water temperature in July (Fig. 3) cannot be compared with simulation results and the model has to be extended for at least one year for the investigation of water temperature stratification in this reservoir (Li et al., 2017).

To assess the differences between results from these two simulations, the temporal changes in water temperature at a point location in the lacustrine zone at 2 m below the water surface were extracted and drawn in Fig. 10. The statistical analysis shows low values of *RMSE*

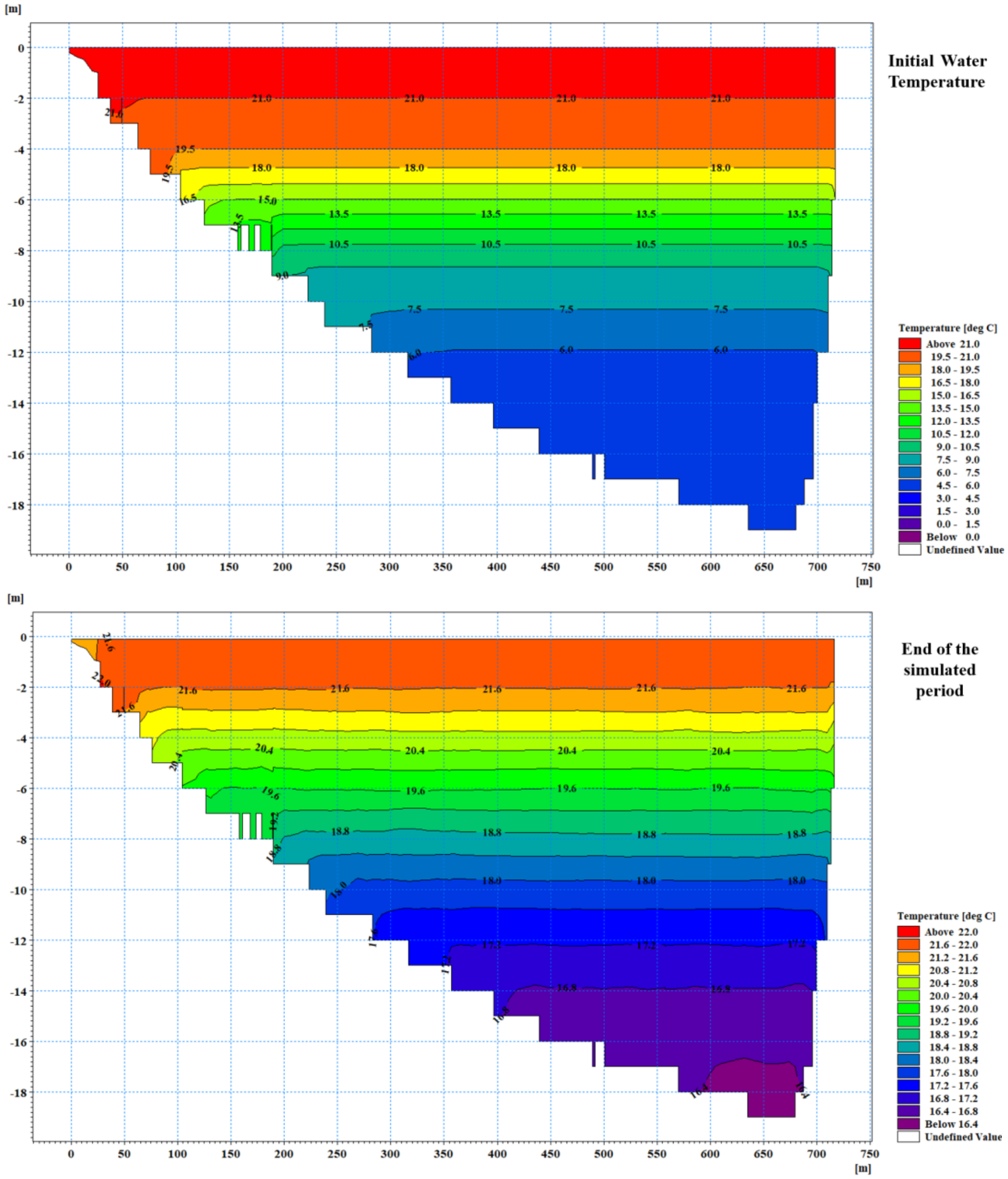


*Fig. 8. Simulated vertical temperature distributions from the inflow 2 to the outflow.*

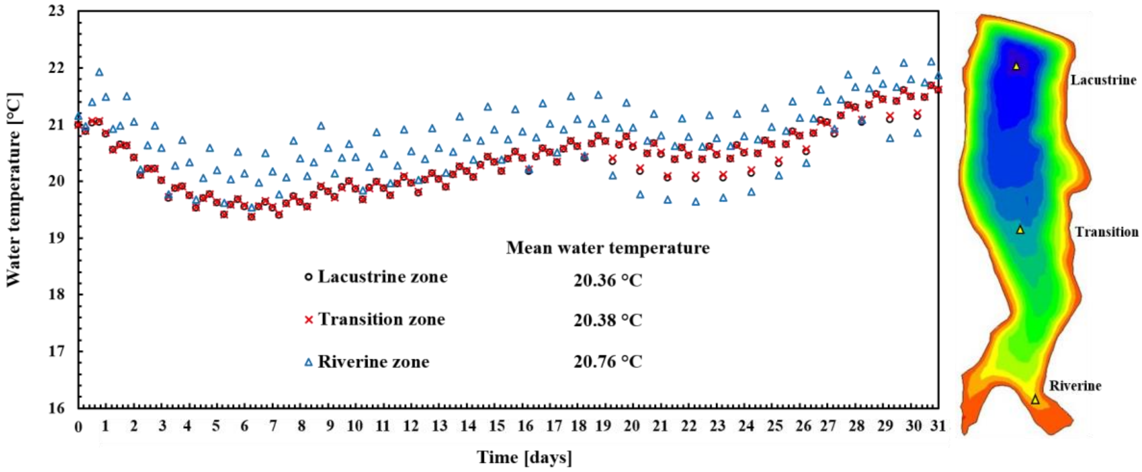


*Fig. 9. Temporal variations of water temperature at 2 m below the surface in different parts of the reservoir.*

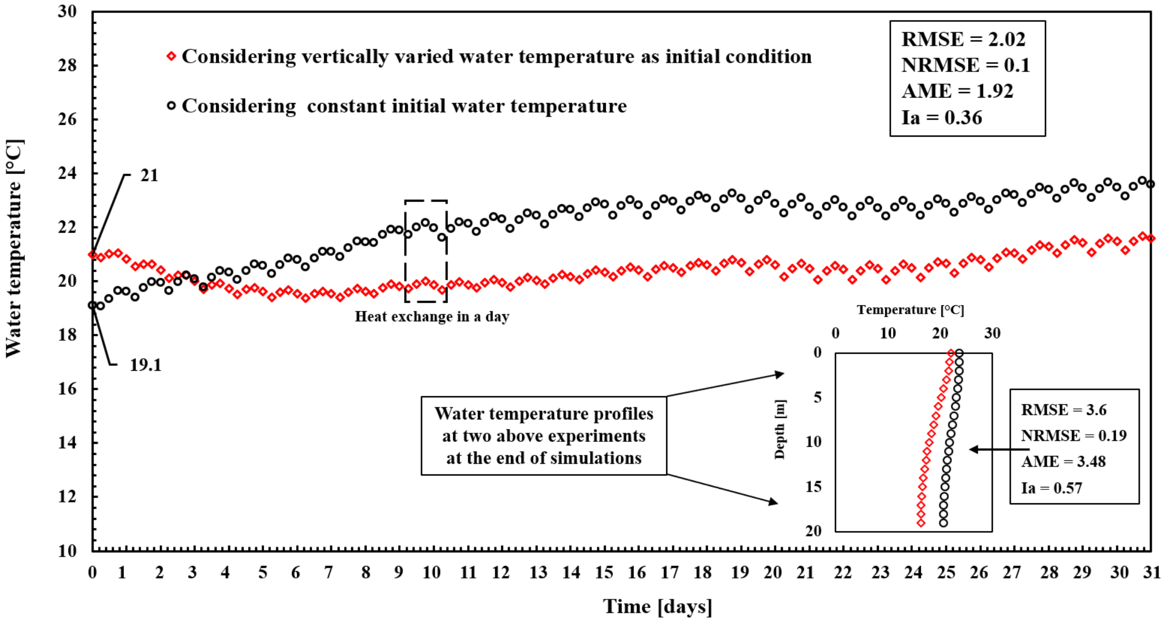


*Fig. 10. Temporal variations of water temperatures at the point 2 m below the surface in different initial conditions together with the vertical variations of water temperature at the end of the two mentioned simulations.*

(or $NRMES = RMSE/\overline{O}$) and $AME$, reflecting the good agreement between simulated water temperature in the case of the constant initial value for water temperature with vertically varied water temperature as an initial condition. Both the *AME* and *RMSE* are about 2°C, given that the range of numerical variations of water temperature was 19–24°C in July. Fig. 10 shows the significant effects of initial water temperature impact on temporal temperature variations such that the constant water temperature set for initial conditions always increase the water temperature during the simulation time unless the simulation continues for a long period. This fact could be confirmed with the vertical water temperature profile (Fig. 10), indicating the acceptable agreements ($Ia$ = 0.57) in simulated water temperature in depth for the two mentioned initial conditions. The low *NRMSE* (= 0.1) reflects the potential fit that would have been achieved by further modifications of the simulations.

### *Effects of high inflows*

In a reference simulation, the inflow to the computational model was only set to inflow 2 with 0.0003 $m^3 s^{-1}$ and an outflow discharge of 0.005 $m^3 s^{-1}$ (refer to model setup section). The planned third simulation was to investigate the effects of high flow on current speed and water temperature stratification of the reservoir. Thus, inflow 1 and inflow 2 were set with 0.003 and 0.007 $m^3 s^{-1}$, and the outflow was fixed with the previous value of 0.005 $m^3 s^{-1}$, which means that the inflow discharge was double of outflow discharge. The map of the current speed is shown in Fig. 11. Through comparing simulated results to the results from the reference simulation

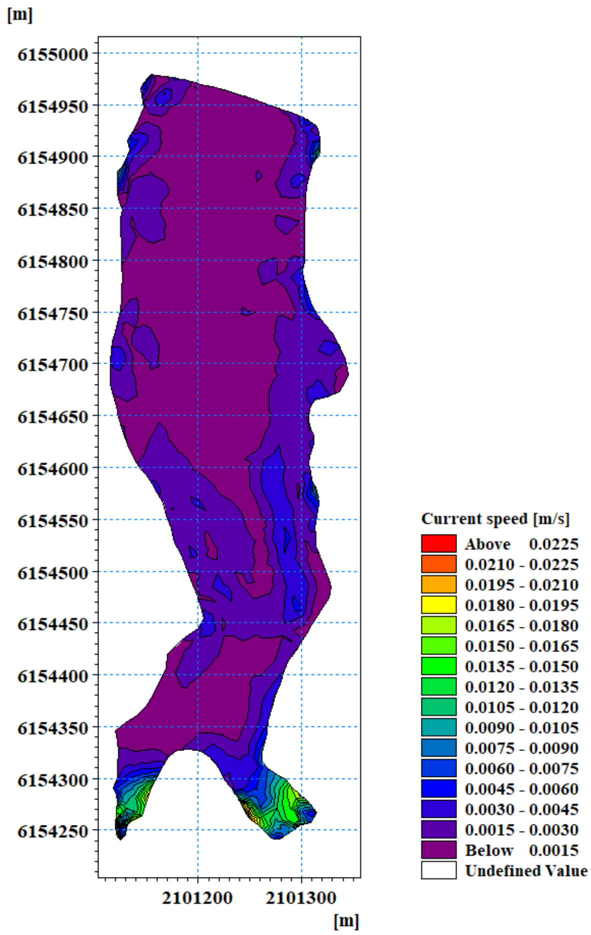


*Fig. 11. Simulated current speed in July (high inflows scenario).*

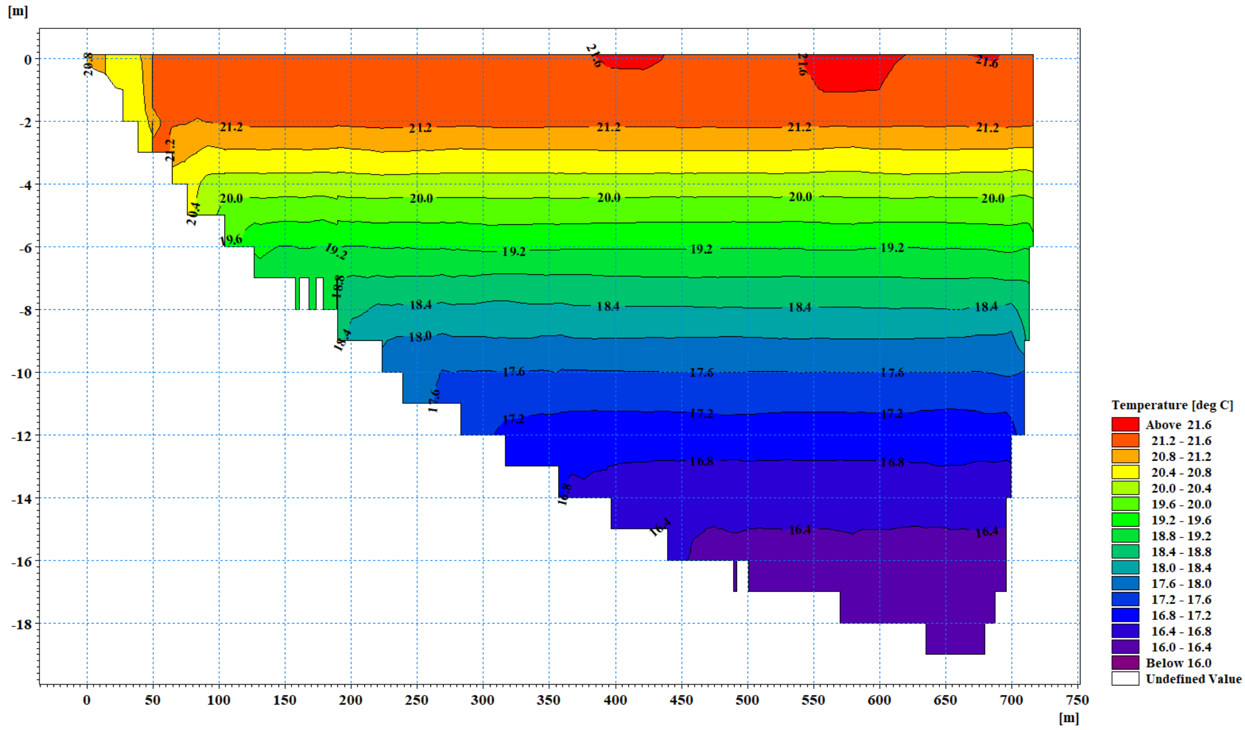


*Fig. 12. Vertical varied water temperature from the inflow 2 to the outflow during a high inflows scenario.*

(Fig. 7), the role of high inflows on the increase of current speed and probable mixing could be illuminated. The current speed was increased by more than 30% and the higher isolines appeared around two inflows.
The effects of high flow on water temperature stratification was also shown in Fig. 12. The water temperature profile did not reflect many changes compared to what was reported in the reference case in Fig. 8. The non-isothermal layers and temperature stratification were almost the same, but a 12 cm water level rise was predicted at the end of simulation time which is marked in Fig. 12.

## Conclusion

The 3D hydrodynamic model of the Rozgrund Reservoir (located in Slovakia) was established using MIKE 3 FM model to elucidate spatial and temporal variations of water temperature in this reservoir for the simulated period (July 2022). The influence of high inflows (e.g. extreme hydrological conditions) on the current speed and water temperature was investigated using hydrodynamic modeling. The simulation results showed an acceptable performance in reproducing the water temperature and water level variations within the Rozgrund Reservoir.
The simulation results showed that the Rozgrund Reservoir experienced water temperature stratification in July and the very low inflows did not have effects on the thermal structure of the reservoir since the mixing did not occur over one month of simulation time. Additionally, velocity differences way less than 0.2 m $s^{-1}$ confirmed non-mixed layers. Therefore, the spatial distribution of water temperature in three zones of the reservoir including riverine, transition and lacustrine was almost similar.
The water temperature results of two simulations with different initial conditions (vertically varied or constant initial water temperature) in the temperature module over one month, July, indicated the potential effects of constant initial water temperature to reproduce temperature stratification in the Rozgrund reservoir if long simulation time is grounded and further modifications on input files (e.g. heat exchange) are provided (the statistical analysis reported for Fig. 10).
The effects of high inflows on current speed showed rising water levels. Vertical stratification has not changed in the high inflows scenario over a one-month simulation. This research manifests time effects on the spatial and temporal variability of water temperature within the Rozgrund Reservoir, expressing that one month is a short time to simulate water temperature stratification changes. Thus, future research works would investigate long duration simulation e.g. one year of water temperature stratification changes. The focus of future research could be more on the degree and duration of water temperature stratification influenced by the intensity of external forces such as inflow, wind, precipitation and heat exchange conditions.
This present work aimed to depict water temperature distribution in scales of time and space in the Rozgrund Reservoir. The preliminary knowledge gained in this

research work will form the basis to study water temperature distribution and stratification in different reservoirs and finally benefit the investigation of water quality in a reservoir for better environmental management.


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