Assessing the utility of modeling tools to simulate watershed processes and their impact on the water quality reservoir in post-fire conditions

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Abstract

In recent decades fires have taken on a new form, becoming increasingly destructive. The latest catastrophic fires on Portuguese territory have forced the concerned entities to take hasty decisions. The use of models to support those decisions is a solution to hasten the application of remedies and to reduce the damage caused by fires. This master thesis focuses on the effects of the wildfires, occurred in the 2017 season, on the water quality of Castelo de Bode reservoir. During 2017, the basin under study has seen more than one hundred thousand hectares of land burn, making it one of the most affected areas in the country. Two models were created to achieve the goal of the study. The first one, through the modeling of a river basin, provided the necessary data for the implementation of the second model, capable of simulating the movements of the components within a large water body. It was important to correctly implement the burned areas, diversifying them according to the severity of the fires. In addition to the study on the effects on the water quality in the reservoir, the effects at the sub-basin and watercourse level were also examined. It is important to understand how changes caused by fires are transformed within the basin. The models implemented have proven to be able to simulate the effects of fires, showing a significant increase in nutrient concentrations and suspended sediments at the basin level and a reduced increase in concentrations in the reservoir.

Keywords: Wildfires, Water quality, ArcSWAT, CE-QUAL-W2

1. Introduction

Wildfires have always been an environmental concern around the world, in particular in the Mediterranean areas [27] [22] affecting the location and the growth of the first settlements. Fires have been used in the past as a tool for agriculture and livestock breeding. In the last century, a different trend from the global situation was observed in the Mediterranean. With the advent of industrialization, people moved to urban areas, abandoning the land, leading to a dangerous afforestation, thus increasing the fuel buildup and storage [35]. Currently, in this area, forest fires affect approximately 450 thousand ha per year representing the 85% of the total burned area in Europe [4]. Portugal has one of the highest forest fire ranking in Europe, affected in the last decades by an increase of the number of ignitions and burned area [30]. Forest fire data for previous decades confirmed an increase in fire activity in the region. The 2017 fire season, which distinguished itself by destructive episodes, damaged a total area of 510 thousand hectares. Almost half of the burned area corresponds to forests and shrubland, pasture and unproductive land occupied the other large percentage, counting at the end for more than 90% of the total area affected by the fires. The relation between land uses and fire spread pointed out a higher probability of fires in shrublands, followed by forest [24], as confirmed by models of fuel accumulation which suggested a 20-40% increase in fuel when shrublands and forests enhance [21]. Portugal land use is characterized by 67% of forests and shrublands, which made the area predisposed to the advance of fires. Following a wildfire, runoff volume and sediment discharge have observed to increase over pre-fire conditions [31]. Also, the relation between the base flow and wildfires occurrence has been addressed, revealing an increase in volume in the following months [17] [2]. The change in curve number (CN) is a valuable tool to consider the effects of the fires. The increase of the number counts both for the loss of vegetation and changes in the soil [13] [3]. The main effect on the soil is the increase in its water repellency, which is the reduction in the rate of wetting and infiltration of water in the soil caused by the presence of a hydrophobic layer. When organic material burns, the volatilized material with hydrophobic properties can settle into the soil moving along the profile and condensing on cooler soil particles beneath the surface [7]. The enhance of soil water repellency goes from few months [16] [19] to years [12] [9] depending on the fire [32] [7] and soil characteristics. Increase in runoff can result in a greater soil erosion, which resulted to be enhanced by the loss of vegetation, which leads to a greater splash-erosion [29]. The equation commonly used to query soil erosion is the Universal Soil Loss Equation (USLE) which combines crop and vegetation with soil type, rainfall pattern, and topography [38]. The increase of suspended solids in the watershed after a fire event depends on the rainfall patterns, burned area extent, type [37] and fire severity, sediment sources, and watershed scale [33]. Among all the natural resources water is the most sensitive to vegetation and soil perturbation. The nutrient loads, particularly nitrogen and phosphorous, increase after the wildfires occurrence [33] [20]. Increasing nutrients are expected to increase the algae concentration. The increase in nutrients does not mean a sure increase in algae concentration. A study examined periphytic algae above and below burned sites in California and found essentially no difference, indicating that water quality changes did not exert any measurable effect on algae growth [15]. Wildfires were founded to affect also dissolved oxygen [1]. Water quality models are classified by the spatial dimension. 1-D models result effective in simulating processes that take place in the soil or in narrow streams. Such models lack the capacity of simulating hydrodynamics and water quality processes in larger water bodies, in which 2-D or 3-D computations are required.

Objective This work addresses the study of wildfire effects on the water quality of a reservoir where water is taken for human consumption. The models used assess both the land use changes caused by wildfires and the water quality changes in Castelo de Bode reservoir, located in the center of Portugal. The wildfire season considered in the study corresponded to the period between June and October 2017. Two different programs were used for the purpose: the Soil and Water Assessment Tool (SWAT) and the Hydrodynamic and Water Quality Model (CE-QUAL-W2). Mohid Statistical Analyzer was also used for calibrating the watershed model.

2. Methodology

2.1. Study area

The study area is located in the north region of Tejo watershed in the center of Portugal, approximately between 39° 30' and 40° 30' latitudes and 8° 30' and 7° 05' longitudes. The draining area is approximate of 3489.86 km^2 with a mean elevation of 508.45 m and a maximum one of 1900 m related to Serra da Estrela, where the spring is located. The area is covered by forests (36%), which are mainly characterized by Maritime pine, Eucalyptus, Pyrenean, and Cork oak, and by shrubland (40%). Even if the agriculture counts for approximately 20%, there are no significant urban agglomerations which end up counting for less than the 2% of the basin.

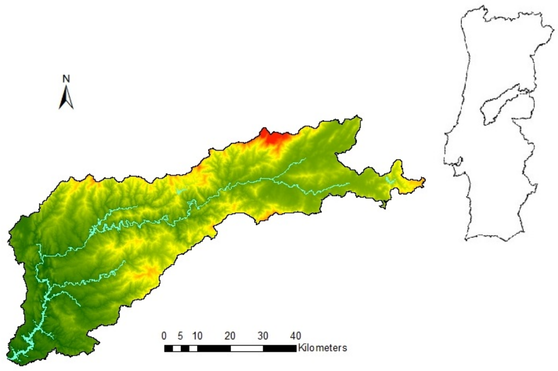


Figure 1: Location of the study area.

Castelo de bode reservoir total capacity is 1095.00 hm^3 with a useful capacity of 902.50 hm^3. The flooded area is 3291 ha. Castelo de Bode reservoir presents a complex shape as it is formed by damming Zêzere river. This type of reservoir is usually divided into three longitudinal zones concerned them water quality [34]. The zones are called riverine, characterized by high suspended solids and nutrients concentration, transitional and lacustrine zone proceeding from upstream to downstream. The lacustrine zone is characterized by high light availability at depth and low nutrients levels. The zone is generally more oligotrophic than the rest of the reservoir. Besides the presence of Castelo de Bode reservoir, other two big dams are present in the area. Boucã reservoir, with a total capacity of 48.4 hm^3, and the upstream reservoir of Cabril, characterized by a total capacity of 720.0 hm^3. The watershed under study was hit by the fires several times throughout the fire season 2017. The most destructive events take place in June, with a burned area of 47992.18 ha, in August, with 47779.16 ha burned and in October, with 37779.69 ha. Forest and shrublands, of which the unproductive land is also part, resulted the most affected ones corresponding respectively to the 47% and 44% of the total burned area.

2.2. Models overview

Two different models were implemented, one to obtain the flow and concentrations values at the inlet of the reservoir, and a second used to model the flow and decay of those components inside the lake. The SWAT (Soil and Water Assessment Tool) is a continuous-time, semi-distributed, process-based river basin model. It divides a watershed into multiple sub-basins which are then subdivided into hydrologic response units (HRUs), characterized by homogeneous land use, soil, and slope characteristics. The SWAT hydrology is based on the Soil Conservation Service (SCS) equation expanded to considered also soil and groundwater movement [23]. Erosion is calculated using the Modified Universal Soil Loss Equation (MUSLE). Considering nutrients, the model tracks their movement and transformation, simulating their removal from the soil through runoff, sediments, and leaching. Pesticides movement through the stream network and soil profile is modeled using GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) which examines the interactions between pesticide properties, soil characteristics, management variables and climate [18]. CE-QUAL-W2 is a two-dimensional, longitudinal and vertical, water quality and hydrodynamic model. Assuming lateral homogeneity, the model gives better results when applied to relatively long and narrow waterbodies. CE-QUAL-W2 divides the waterbody in a main part in which several branches or tributaries can flow. The mesh is made by longitudinal segments of length Δx and vertical layers of height Δz. The model predicts water surface elevations, velocities and temperatures and any combinations of constituents can be included or excluded by the simulation. The governing equations perform a mass and momentum balance of the fluid phase in a control volume, considering lateral and layer averaging.

2.3. Data for the implementation of the models

2.3.1 Watershed modeling

Watershed and HRUs data. From the use of the digital elevation model (dem) provided by the European Environment Agency, the basin and water channel network characteristics were delineated, resulting in 14 sub-basins. The HRUs were implemented using Corinne land use map (2012) and the Soil database provided by the European Soil Data Center (ESDA) [25]. With a threshold of 10% in the soil type and the slope and 0% in land use, the total number of HRUs resulted equal to 773.

Weather data. Weather data were provided by the National Centers for Environmental Protection (NCEP). Precipitation, wind, solar radiation, and relative humidity data were available divided into 15 stations for a period of 36 years, between 1st of January 1979 and the 31st of July 2014.

Point source discharges, fertilizer, and nitrogen in rainfall. Wastewater treatment plants (WWTP) inside the basin were considered as point sources, which data were provided by INSAAR (Inventário Nacional de Sistemas de Abastecimento de Água e de Água residuais). The concentrations considered are the emission limit values (VLE) dictated by the Decreto-Lei n.o 236/98. The point source discharges were added through the monitoring points located at the end of each sub-basins. In order to correctly estimate the nitrogen concentration in the watershed, the presence of nitrogen in rainfall and in fertilizers were taken into consideration. Literature provides the wet concentration of Nitrate in Europe, more specifically for Portugal, where the range results being between 0.2-0.4 mg/l in measures made both between 2000-2002 and 2005-2007 [36]. In this study, an average value of 0.3 mg/l was considered. The fertilizer considered is Urea, a form of nitrogen fertilizer with a NPK (nitrogen-phosphorus-potassium) ratio of 46-0-0. The fertilization is added every year for all the month of May two times per day. The total amount of fertilizer added each year is 170 kgN/ha.

Post-fire scenario. The post-fire scenario considers the same weather conditions and point sources as the scenario without fires. The scenario starts in October, considering all the fire events at once. The choice is supported by the secondary succession, which takes place when a community that previously existed has been removed by a major disturbance such as a fire or a flood. Thus, following its type steps, grasses and perennials start to grow after 1-2 years, the bushes after 4-5 years and the pines between 5 and 150 years. Oaks and Eucalyptus are resprouting after a wildfire, restoring in 1.5 years [26]. This means that no plant has the time to grow or restore in a period over 5 months. Two different parameters were changed. To correctly modified those parameters, the severity of the wildfires that hit each area has to be known. Areas characterized by a burned area between 10% and 32% were considered affected by low-severity burns, while areas with a burned area bigger than 50% were considered affected by high-severity burns. Between 32% and 50%, the area was characterized by moderate-severity burns [13]. To consider the effect of the fires in the soil, the curve number (CN) was altered to take into account the water repellency enhances by the fires. By increasing the CN value, the runoff potential is increased. The curve number (CN) was increased by 5, 10 and 15 for low, moderate and high severity respectively [14]. To consider the loss of vegetation, the C factor in the Universal Soil Loss Equation (USLE) has been modified. The vegetation C factor is usually around 0.001 and 0.003. Since a value of 1 means no vegetation, while a value of 0 means dense forest, a value of 0.02, 0.16 and 0.3 for low, moderate and high severity respectively were considered. After this, three different scenarios with fires were considered, characterized by different precipitation trends following the event, divided into dry, wet, and normal trends based on the total rainfall, the number of dry days and statistical parameters such as the average and the median. The average was calculated in a year range, in the winter, and in the summer period.

2.3.2 Reservoir modeling

Bathymetry. The reservoir is imagined to be formed by three branches, where one corresponds to the main channel. A total of 77 sections were created, all with different width, length, and angle. To validate the bathymetry generated for the Castelo de Bode reservoir, the volumes corresponding to each quota were calculated and the cumulative volume curve was determined and compared with the "elevation-volume" graph provided by SNIRH.

Flow and water temperature. The inflow was provided by SWAT, while the outflow was provided in first place by SNIRH and after shaped until the correct water surface level was found. An output structure was located at 70 m under the average water surface level. The emergency spillway started to work when the water level was reaching the maximum high of full reservoir, equal to 122.0 m. The water temperature data was calculated using the following equation:

$$T_w = 0.7 \cdot T_{A-1} + 7.71 \tag{1}$$

where T_w is the water temperature and T_{A-1} is the air temperature of the day before.

Initial concentrations. Initial concentrations of total suspended solids (TSS), nitrogen dioxide (NO_2), nitrate (NO_3) and dissolved oxygen were directly provided by the SWAT outputs. A stoichiometric constant of 60 was used to convert chlorophyll a to algal biomass dry weight OM (i.e., algae = chlorophyll a/60) [28]. SWAT model outputs time-series algae dataset in its entirety (as a single algae group), whereas CE-QUAL-W2 simulates various species/groups of algae based on their specific characteristics. The amount of algae given by SWAT was divided into diatoms, greens, and cyanobacteria. The organic matter (OM) was estimated using the stoichiometric ratio between organic nitrogen and OM and organic phosphorous and OM. In the case of fresh water in continental Portugal, the limiting nutrient was found been phosphorous [8]. For this reason, the constant value was considered being the organic-N to OM ratio. Published literature and model default value suggested a typical value of 0.08 (8% of OM is organic-N [ORGN]) for the stoichiometric ratio between OM and organic-N [11]. The fraction of organic-P [ORGP] in OM was estimated using the following equation:

$$\frac{ORGN}{ORGP} = \frac{\sum organic - N}{\sum organic - P} \tag{2}$$

The CE-QUAL-W2 model accepts the OM in its four different forms:

- LDOM, labile dissolved organic matter;
- RDOM, refractory dissolved organic matter;
- LPOM, labile particulate organic matter;
- RDOM, refractory particulate organic matter.

When sediment concentration is less than 100 mg/l, 40% of the OM will be in particulate form. With a concentration greater or equal to 100 mg/l, 75% of the OM is assumed to be in a particulate form [8]. In order to divide the OM in labile and refractory, it was assumed that the majority reaching the reservoir (75%) is in a refractory form [10].

3. Results and discussion

The results are divided into two different parts. In the first one, the calibration and validation of the watershed and reservoir models are implemented. The observed data used for the calibration of the reservoir model are provided for a 14-year range, from 01/10/1986 to 01/01/2000. Two stations were considered for the flow calibration, Cabril and Castelo de Bode. For nitrate calibration, Pedrinha water quality station, located in the North-East part of the watershed, was used, with observed data between 25/05/1987 and 19/06/2017. The observed data used to calibrate and validate the water level and the surface temperature in the reservoir model go from 01/01/1988 to 01/01/2000. The observed data for the component concentrations are given by SNIRH for a period of time that goes from 1989 to 1992.

The second section addresses the study of the scenarios used to understand the effects on the water quality of wildfires on a sub-basin, catchment, and reservoir level. The results presented refer to the following year to the fires, characterized by the dry rainfall scenario. The choice on the dry conditions was because it poses the higher risk. A one year simulation period was implemented, considering that is the time necessary for the rebirth of vegetation. The comparison of the effects on the water for dry, wet, and normal rainfall year was implemented only on a reservoir level.

3.1. Calibration and validation of the models

3.1.1 SWAT

The calibration and validation of the model implemented in ArcSWAT were carried out using Mohid Statistical Analyzer tool. To calibrate the model, properties governing water movement into and out of the aquifers needed to be changed. For this purpose, the GW_DELAY, which represents the water delay time, the ALPHA_BF, which is a direct index of groundwater flow response to the change in discharge, and the GWQMIN, which is the threshold depth in a shallow water aquifer, were modified. The results of the Statistical Analysis are shown in Tables 1 and 2.

Parameters	Castelo de Bode		Cabril	
	Monthly	Daily	Monthly	Daily
Obs. Average	60.91	60.81	39.12	39.03
Mod. Average	75.73	75.55	42.68	42.57
R2	0.69	0.28	0.83	0.52

Table 1: Statistical analysis of monthly and daily observed and modeled flow data.

Parameters	Nitrate (mgN/l)
Observed average	2.544
Modeled Average	2.549
R2	0.045

Table 2: Statistical analysis of observed and modeled nitrate data.

3.1.2 CE-QUAL-W2

Water level and temperature. A R^2 value of 0.979 characterize the comparison between the observed and modeled data for the water level (Figure 2.a).

Parameters	Modeled (m)	Observed (m)
Min	100.57	100.84
Max	121.99	121.59
Average	115.40	113.42

Table 3: Minimum, maximum and average values for modeled and observed water level data.

Modeled data for surface temperature present the same seasonal pattern as the observed data (Figure 2.b). The minimum and the maximum modeled surface temperature result equal to 27.2℃ and 10.5℃, complying with the observed values, respectively equal to

27.0℃ and 11.0℃. In Figure 3 the summer and winter stratifications, which characterized big waterbodies as a reservoir, are presented. The typical summer thermal stratification is characterized by higher temperatures in the more superficial layer (epilimnion), and a gradual decrease with increasing depth (metalimnion), leading to lower temperatures at the bottom layers (hypolimnion) (Figure 3.a). In the winter period, the waterbody is no longer stratified along the depth but results mixed (Figure 3.b).

Water quality components. The thesis focuses on studying four different water quality components, such as the main nutrients, nitrate and phosphate, chlorophyll-a, which take into account the algae concentration, and the dissolved oxygen. Figure 2.c and Figure 2.d present the comparison between modeled and observed concentration of phosphate and chlorophyll-a respectively. Modeled data for the phosphate present an average of 0.023 mgP/l, with a standard deviation of 0.013 mgP/l. The observed data are characterized by an average of 0.022 mgP/l, with a standard deviation of 0.0078 mgP/l. Chlorophyll-a modeled concentration has an average of 1.302 μg/l, with a standard deviation of 1.139 μg/l. Observed data present an average of 2.083 μg/l, with a standard deviation equal to 1.763 μg/l. Considering nitrate, the averages result equal to 0.602 and 0.545 mgN/l, respectively for modeled and observed data. The standard deviation, thus the variation from the average, results in 0.261 mgN/l for modeled data and 0.291 mgN/l for the observed ones. Dissolved oxygen modeled data present an average of 7.617 mg/l, with a standard deviation of 1.738 mg/l. Maximum and minimum values are, respectively, equal to 11.510 mg/l and 1.321 mg/l. Two types of observed data are provided for dissolved oxygen, field and laboratory analyzed ones. Observed data analyzed in the field present an average and a standard deviation of, respectively, 7.968 mg/l and 1.713 mg/l. Observed data analyzed in the laboratory have an average of 9.586 mg/l with a standard deviation of 0.914 mg/l.

3.2. Effects of fire

3.2.1 Effects on a sub-basin level

To study the effects on a sub-basin level, one of the most affected sub-basin in the 2017 season was considered. This sub-basin has a total burned area of 16016 ha, equal to the 71% of the sub-basin area and to 15% of the total burned area of the watershed. Shrubland and forests result the most affected ones, counting respectively for the 53% and 44% of the total burned area. The post-fire scenario is characterized by an enhancement, mostly located in the peaks. Considering the runoff, the maximum value increases of the 100% moving from 8.043 mm to 16.752 mm. The total runoff in the year following the fire results equal to 58.283 mm while in the scenario without fire results 17.887 mm. Figure 5 shows the difference in sediment concentration in the reach that crosses the sub-basin. The maximum moves from a value of 23124.01 mg/kg to 34594.13 mg/kg enhancing of 50%. The total sediment concentration flowing in the reach results 367249.7 mg/kg compared with the 124019.4 mg/kg of the scenario without fires, increasing of almost 200%.

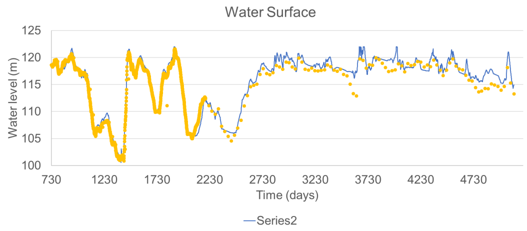
3.2.2 Effects on catchment level

The total inflow to the reservoir results equal to 12200.09 m^3/s, while in the scenario without fire it results in 997.55 m^3/s. On average, the picks of the fire scenario result 1.3 times bigger than the one without. Figure 4 shows a sharp increase in the concentration of the main nutrients. The concentration of phosphate reaches a maximum of 3.67 mgP/l in the fire scenario, more than twice the value if the fires had not occurred. Even the average doubles, moving from 0.138 mgP/l to 0.358 mgP/l. The maximum nitrate concentration for the fire scenario results equal to 50.94 mgN/l, while the scenario without fire is characterized by a maximum of 16.88 mgN/l. The average moves from 1.70 mgN/l to 4.86 mgN/l. The greatest difference between the two scenarios is present at the end of the hydrological year that follows the fire event when the both of the nutrients present a sudden increase in concentration. Considering the changes in the sediment concentration, the average moves from 392.27 mg/l to 395.77 mg/l in the scenario with fire. The maximum value moves from 1001.10 mg/l to 1083.20 mg/l. The main difference is found to be in the base sediment inflow concentration: the minimum in the scenario with fire results equal to 56.27 mg/l, 50% higher than 36.61 mg/l, the minimum of the scenario without fire.

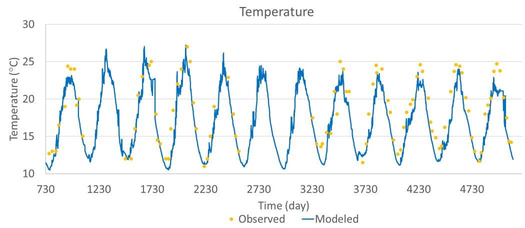
3.2.3 Effects on reservoir water quality

Considering the water surface level, the difference between the two scenarios is on average equal to 1.25 m with a maximum difference equal to 1.89 m. Both the nutrients enhance in the fire scenario. The average increases by 32% and 38% for nitrate and phosphate respectively. The maximum and minimum values of nitrate enhance of 33% and 32%. Considering the phosphate, the minimum and maximum values increase, respectively, of 19% and 45%. Chlorophyll-a presents a sharp increase at the peaks level after the fire. The average has a relative enhance of 36%, moving from 0.544 mg/l to 0.739 mg/l in the fire scenario. The maximum value increases by 24%, while the minimum results decreased by 10%. The dissolved oxygen presents slightly lower values than the scenario without fire. the fire scenario presents an average value of 3% lower than the scenario without fire. The maximum and minimum values are 1% and 10% lower than in the scenario without fire.

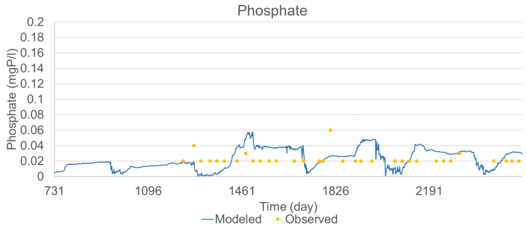
Water quality changes for different meteorological scenarios. The comparison between the different effects in reservoir water quality for dry, wet and normal rainfall year following the fires was studied. The dry scenario results to have the most marked effects with respect to the increase in nutrients. The nitrate average value relative increases by 32% in the dry scenario, while in the wet and normal scenarios it enhances by 18% and 7%, respectively. The maximum value relative increases by 33%, 20% and 0% for dry, wet and normal rainfall scenario respectively. The minimum value



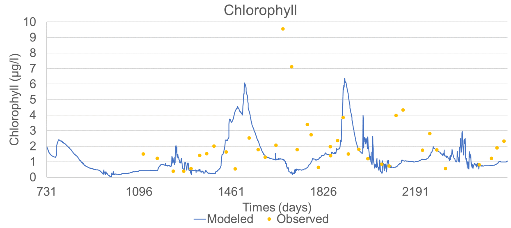
(a) Water level



(b) Surface temperature

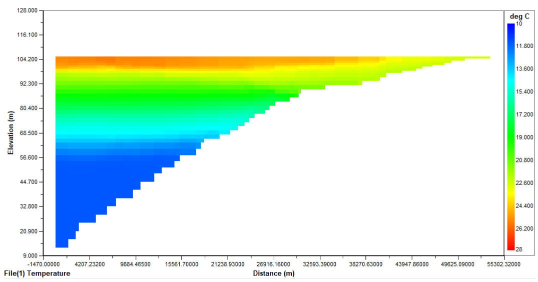


(c) Phosphate

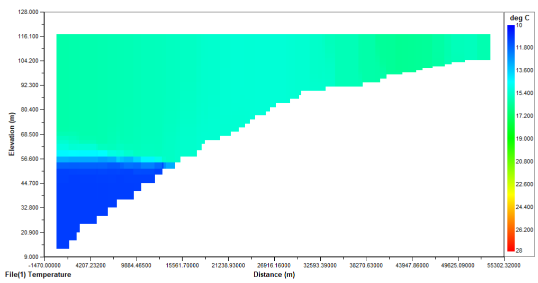


(d) Chlorophyll

Figure 2: Comparison between the modeled data and observed ones.



(a) Water temperature contours lines - Summer.



(b) Water temperature contours lines - Winter.

Figure 3: Water temperature contours lines - Difference between summer and winter.

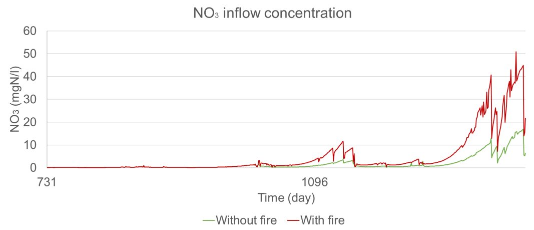
results to have a relative increase of 32% in the dry and normal scenario, while in the wet one it results 5%. The same behavior is found in the phosphate concentration, where the most accentuate increase is related to the dry scenario. The maximum, minimum and the average value relative increase results, respectively, of 45%, 19%, and 38%. In the other two scenarios, the maximum and average value relative increase are lower than 10% and 25%, respectively. More uniform changes are found when considering the chlorophyll-a enhance. The dry scenario presents still the highest relative increase values for maximum and average, being 24% and 36% respectively. The minimum value results to increase more in the other two scenarios, counting for 35% and 39% relative increase for the wet and normal scenario. In the dry scenario, the minimum does not increase with respect to the scenario without fires. The dissolved oxygen results to have lighter changes in comparison to the other components. The most important changes happen in the wet scenario, were the minimum and the average values have a relative increase of -99% and -6% respectively. In the other two scenarios, the relative increase of the minimum does not exceed the -20%, while the relative increase of the average results -3% for both dry and normal scenario. The relative increase of the maximum results lower than -2% for all the three scenarios.

3.3. Discussion

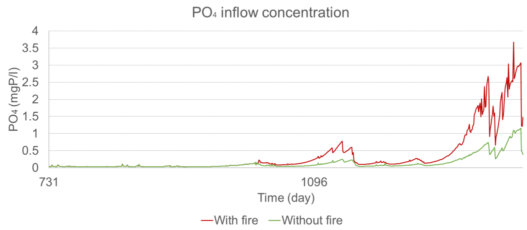
3.3.1 Validation of the watershed model

Flow validation. The Pearson Product – Moment correlation (R^2) is a parameter to validate model results. It measures the strength of a linear association between two variables. From Table 1, monthly values of 0.83 mm and 0.69 mm are equivalent to a strong relationship between the data. When considering daily values, the comparison at the level of Cabril reservoir has provided an acceptable R^2 value, equal to 0.52 mm. A weak, almost moderate, strength of relationship turned out from Castelo de Bode daily comparison. During the calibration, it was reached a point in which, even if the parameters were further changed, the results were worsened.

Validation of nitrate concentration. The calibration and validation of the nitrate concentration did not lead to satisfactory results considering the R^2 parameter (Table 2). The average of the observed data and modeled data matches up to values of 10^{-3} being equal to 2.544 mgN/l and 2.549 mgN/l respectively. One of the main reasons for the low correlation could be the different location of the observed and modeled data place. Modeled data can be extrapolated only from the monitory points located at the end of each sub-basin. The water quality station of Pedrinha, used in the analysis, is located inside the sub-basin. Moreover, data relating



(a) Nitrate inflow concentration.



(b) Phosphate inflow concentration.

Figure 4: Nutrients inflow concentrations comparison between with and without fire scenario.

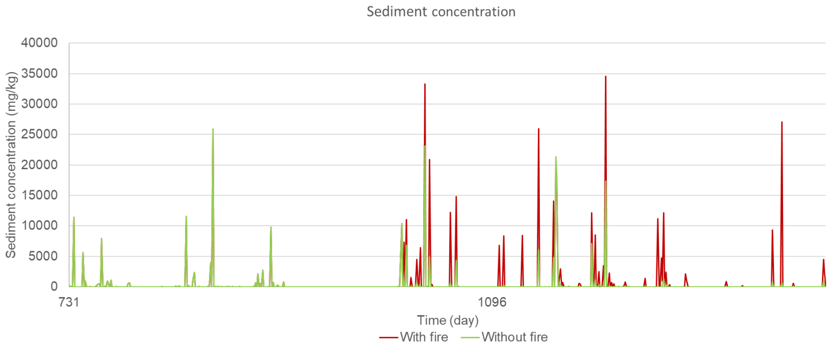


Figure 5: Sediment comparison with and without fires scenario.

to the WWTPs can be inserted into the model only at the monitory points of the sub-basin in which they are present. In general, a good correlation between the observed and modeled data is found when the calibration and validation period of the model is limited [6]. A poor correlation is usually found when the calibration and validation period is very extensive, in the order of decades [39].

3.3.2 Validation of the reservoir model

Water surface level and surface temperature. The file concerning the outlet flow has been modified until a satisfactory water level was obtained. The modeled data are satisfactory, correctly simulating level trend (Figure 2.a) and a value of R^2 equal to 0.979 reveals a strong correlation between observed and modeled data. Modeled data for surface temperature shows that the model is able to represent the seasonality of the data (Figure 2.b), the summer stratification and the winter mix (Figure 3). The parameter that most influence the water temperature resulted being the wind speed measurement height, i.e. the height at which wind speed measurements were taken. A slight change in this parameter leads to significant changes in the surface temperature.

Water quality components. The modeled data show the occurrence of higher nutrients values following wet months, associated with drainage basin inflows, followed by a decrease due to consumption by primary producers during spring (Figure 2.c for phosphate). The order of magnitude of the modeled data is the same as the observed one, even if they do not show the same trend. The temporal series of observed chlorophyll data presents a considerable variation during the year, not presenting a seasonal trend (Figure 2.d). This variation may be associated with the discharges of the dam for the production of energy, since they determine the residence time of the water in the dam, thus conditioning the growth of algae. Dissolved oxygen modeled data level generally allows aquatic life, except for a short period where the value falls below 5-4 mg/l. A marked seasonal variation was found, with high values in dry periods and low values during the wet ones. In the wet months, the organic load that flows to the reservoir explains the lower values, as a consequence of the oxygen consumption due to organic mineralization processes, revealing that the model is able to reproduce the dynamics of the production and breathing processes that occur in the system.

3.3.3 Wildfires effects

Sub-basin level. A notable increase in both runoff and sediment concentration has been seen in the study of the effects of fires at a sub-basin level. Not only will there be an increase in runoff, but the runoff will present double the sediments, reducing its transparency and increasing the presence of nutrients, such as phosphate, which is transported with them. High concentration of sediments affects the light penetration and habitat quality of a waterbody. Particles provide attachment places for pollutants, such as metals and bacteria, and can also provide nutrients for pathogens decreasing the water quality. An area with the same area and land uses but with different fire severity, i.e. with changing in CN and C USLE values, give quite different runoff and sediment yield. For example, an olive area affected by a high fire severity presents 96.845 mm of total runoff and 0.653 ton/ha total sediment yield the year following the fire event, while an olive area affected by a moderate fire severity presents a total runoff and sediment yield of respectively 62.101 mm 0.153 ton/ha. Comparing the changes in sediment concentration at a sub-basin level and at the Castelo de Bode inflow, it was found that the concentration is more likely to change at the sub-basin level. It can be explained by the higher settling velocity that the burned particles present compared to the unburned ones [5]. Even if the concentration of sediments is higher at the sub-basin level, this does not significantly influence the concentration at the entrance of the reservoir as the sediments have traveled a major route within the watercourses.

Catchment level. The inflow discharge in Castelo de Bode reservoir results having an increase in both peaks and baseflow. The increase of baseflow, which is the amount of water that flows in a river when no precipitations occur, results to be more relevant than the increase in the peaks. Considering the nutrients, phosphate and nitrate concentrations, a sharp increase is present in both of them (Figure 4). The phosphate concentration in the fire scenario (Figure 4.b) clearly exceeds the 0.4 mgP/l threshold given by the World Health Organization (WHO), classifying the water quality as bad. High and increased, from the reference condition, concentration of phosphates represents a risk to the normal operation of river ecosystems, causing eutrophication, oxygen deficiency in the bottom substrate and reduced biodiversity. In the fires scenario, the nitrate concentration exceeds the limit stipulated by the WHO for drinking water, which is less than 10 mgNO_3-N/l (Figure 4.a). High concentration of nitrates represents a risk both for human health and for the aquatic one, by stimulating excessive growth of algae and causing oxygen deficiency in the bottom waters reducing the biodiversity.

Reservoir level Differently from what is happening in the river scale, the effects on the reservoir in the year following the fires do not result as significant. The water surface level increase on average of 1.25 m. Both the nutrients concentrations slight increase in the fire scenario. In the study case, this increase does not seem to compromise the quality of water. Comparing with the sub-basin and the inflow, the concentration in the reservoir does not change considerably. In this particular study, the increase in concentration does not seem to be a threat to the water quality at the end of the reservoir, where the water tower owned by EPAL is located. Castelo de Bode reservoir is one of the largest in the country. Both for its size and shape, the high concentration of nutrients and of the other components present in the inflow is dissolved and distributed along the lake. Even if, in this particular study, the wildfires have not significant effects on the quality of water used for human consumption in Castelo de Bode reservoir, they can have in other situations. If the relative increase in concentration is considered, the wildfires result to affect considerably the nutrients and the chlorophyll concentrations.

Weather scenarios. When considering the weather scenarios, both the nutrients present a most accentuated increase in the dry scenario if considering the average value. The reason could be the presence of a more wet summer period than in the other two scenarios. Since the fertilizer is sprinkled in the month of May and the dry scenario presents greater rainfalls in summer, the concentration of the nutrients could results higher. The mutual enhance in nutrients concentration could lead to a serious eutrophication problem. A waterbody extremely affected by eutrophication, in addition to producing bad smells, then impoverishing the quality of the place, is unusable as drinking water. With dry conditions, the average values of the nutrients result 32% and 38% higher for nitrate and phosphate respectively. The maximum increases of 33% for nitrate and 45% for phosphate. The average and the maximum value of chlorophyll result 36% and 24% higher than the scenario without fire. Therefore, if the wildfires occur at a time when there is already a high concentration of these components, their increase could be a threat to water quality. Considering all the three different meteorological scenarios, none of them differs in a particular way from the other for the increase in concentrations compared to the scenario without fires. Increases in concentration occur, but none of them significantly changes the quality of the water. This means that different meteorological events do not affect the quality of the water at the end of the reservoir in an alarming way. If the reservoir under study had been smaller, the effects of the various scenarios would have been greater. Considering that the quality of the incoming water is considerably damaged by fires, presenting high and alarming levels of nutrients, the water present at the end of a smaller reservoir would probably have been more degraded.

4. Conclusions

The results obtained from the calibration of the two models used in this study confirm the validity of the complementary use of both of the programs to assess the quality of water inside a reservoir. For the purpose of the study, ArcSWAT proved to be a potential tool for the implementation of the fires. It was possible to geolocalize the burned areas and change the land use characteristics. CE-QUAL-W2 has proven to be able to model the concentration of the elements in an excellent manner throughout the entire length of the reservoir. The examination of the effects in the reservoir basin and the effects on the inflow concentrations was a non-negligible part to correctly study the changes in the reservoir. From the simulations, a considerable increase was found at the sub-basin and inflow level. Not so much the runoff levels as the levels of the components which results worrisome. Both nutrients, nitrogen and phosphorus, exceed acceptable quality limits, resulting in a risk both to the aquatic ecosystem and to human health. It has also been found that the sediments concentration after a fire is much higher at the sub-basin level than at the inflow level to the reservoir. As regards the effects on Castelo de Bode reservoir, an increase was found both in the water surface level and in the concentration of the components. The water level is increased up to 2 m, resulting in a more frequent use of the spillway in case of heavy rains. In this study, the increase of concentrations does not result alarming, probably due to the vastness of the waterbody. If the relative increase is considered and if the fires occur when there is already a high components concentration, such as nutrients and chlorophyll, the fires results to be a threat to the quality of water intended for human consumption. The results from the study of the various meteorological scenarios do not point out any particular scenario with respect to the others. It seems that the concentration trends, in the section close to the dam, are not strongly dependent on the rainfall conditions following the fire, probably due to the vastness of the waterbody. To support this statement are the alarming effects present at the entrance to the reservoir, i.e. at the end of water courses, alarming concentrations which disappear along the lake. With the increasing risk of fires occurrence, it is important to use available modeling tools to simulate the possible effects in the water quality. This work can contribute to implementing water quality changes for different scenarios after the occurrence of a phenomenon that leads to land changes.

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