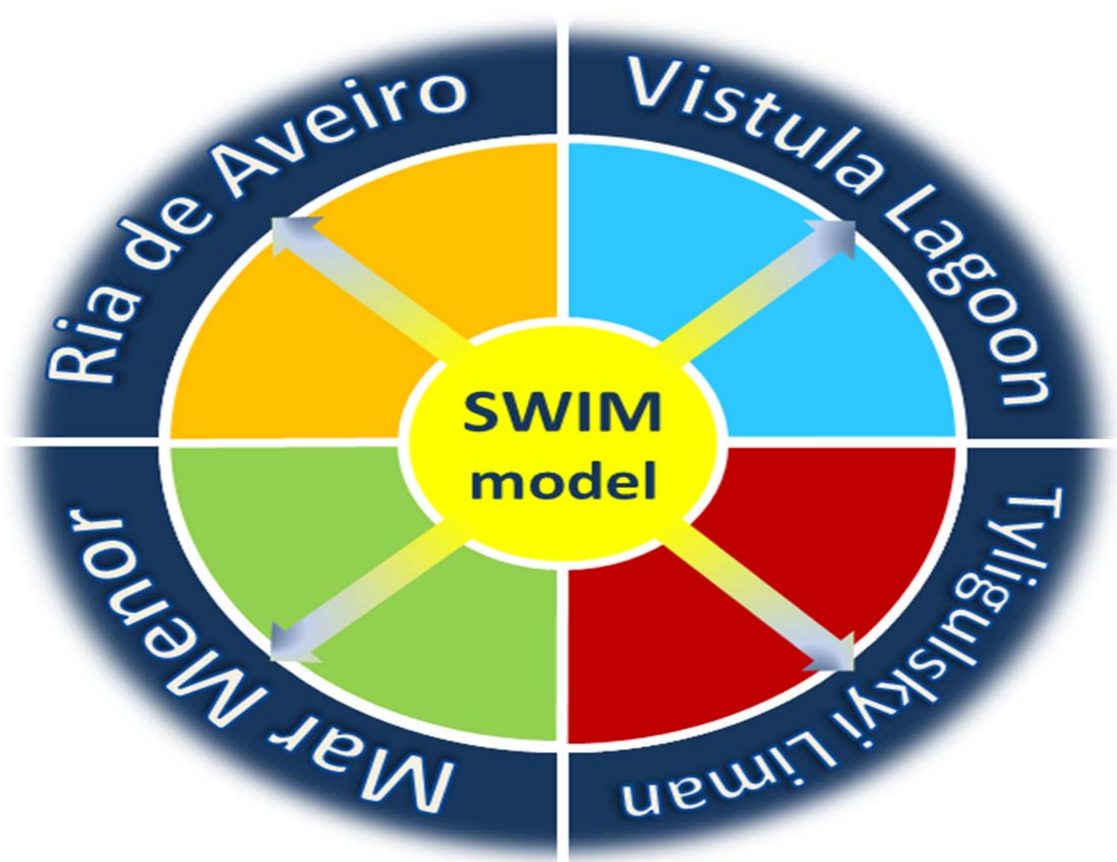
DELIVERABLE D5.1

Results of climate impact assessment

Application for four lagoon catchments



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Title Results of climate impact assessment – Application for four lagoon catchments
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Contents

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- ***Ria de Aveiro:***
  the Ria de Aveiro administration for water management, i.e., the Department for Planning, Information and Communication from the Portuguese Environment Agency – former ARHCentro in Portugal;

- ***Mar Menor:***
  the Regional Entity of Reparation and Waste water treatment of the Murcia region (ESAMUR) in Spain;

- ***Tyligulskyi Liman:***
  the Hydrometeorological Centre of Black and Azov Seas, the Odessa Regional Water Management Department, as well as the Chief Directorate of the State Agency of Land Resources of Ukraine in Odessa Region in Ukraine;

- ***Vistula Lagoon:***
  the Institute of Meteorology and Water Management - National Research Institute (IMGW-PIB), and the National Monitoring of the Environment (PMŚ) in Poland, as well as the Kaliningrad Provincial Center for Hydrometeorology and Environmental Monitoring (CHEM) in Russia.

Summary

The main objective of this study was to perform climate impact assessment for the catchment areas of four European lagoons: Ria de Aveiro, Mar Menor, Tyligulskyi and Vistula. For that, the eco-hydrological model SWIM (Soil and Water Integrated Model) was used. A commonly used technique for hydrological impact studies at the catchment scale is to use climate parameters provided by the Regional Climate Models (RCM) as input for hydrological models. In our case a set of 15 climate scenario data provided by the ENSEMBLES project was used. The reference period was 1971-2000 (p1), and climate impacts were evaluated for three future scenario periods 2011-2040 (p2), 2041-2070 (p3), 2071-2098 (p4).

Before applying climate scenarios for impact assessment, they were analysed and evaluated comparing long-term average monthly and long-term average annual temperature and precipitation in three future periods to those in the reference period. By that, so called climate change signals were estimated. The averaged over 15 climate scenarios climate change signals for temperature are similar for all four case studies. They amount to 1.05°C for period p2, 2.16°C for period p3 and 3.16°C for period p4 on average, while for the Tyligulskyi catchment the projected raise in temperature is slightly higher than for the other three cases. However, if to look on climate signals for 15 scenarios separately, there are significant differences between them: some models project higher increase in temperature, and other – lower than average.

Regarding precipitation, the projected signals are not so homogeneous in change direction, as for temperature, and the uncertainty in RCMs simulations is much larger. The agreement in change direction of precipitation is highest for the Aveiro (14 scenarios agree), followed by Vistula (13 scenarios agree), and lowest for the Tyligulskyi. Until the end of the 21st century, a more consistent increasing trend in precipitation is projected for the Vistula Lagoon catchment, while the decreasing trends are projected for the Aveiro and Mar Menor catchments. The strongest relative decrease in precipitation on average is projected for the Mar Menor. However, in the case of the Tyligulskyi there are largest discrepancies between scenarios from different climate models: some scenarios show decreasing trend, whereas the others produce increasing trend in precipitation, and there are also differences between three future periods. On average, only small changes in precipitation could be stated in this case. It is problematic to communicate such climate scenarios for the Tyligulskyi case to the stakeholders. The high diversity in scenario projections regarding precipitation for the Tyligulskyi case could probably be partly explained by the region coverage of the ENSEMBLES scenario data, where the Tyligulskyi Liman is located close to the border, destabilizing the climate simulation in the RCM applications.

If a hydrological model is intended to be applied for climate impact assessment it should be first calibrated and validated for the case study catchments. Hydrological calibration of SWIM in all four catchments was a very challenging task. Firstly, this was due to often poor and inconsistent data available practically in all four cases, and, in addition, heterogeneity of spatial data for the Vistula Lagoon catchment. Especially for two catchments: Tyligulskyi and Mar Menor very important input data such as climate within the catchment, as in the first case, and time series of measured water discharge, as in the second case, were missing. So, it was decided to use WATCH data instead the missing observed time series for the Tyligul catchment, and to calibrate SWIM for the Albujon (Mar Menor case) in a quasi ungauged mode. Besides, water

quality data were insufficient in spatial and temporal dimensions almost in all cases to calibrate the model properly. Therefore, the model calibration for water flow and water quality variables was a very complicated task.

The model calibration was still done by collecting all possible data, and the support of case study partners in this regard is highly appreciated. After the standard calibration for the main rivers in the catchments, the SWIM model was set-up for the drainage areas of the four lagoons, and a comparison of water inflows and nutrient loads from all rivers using simulated data and data from literature and reports was done. Despite of all difficulties, the results of model calibration were quite satisfactory in all four cases, creating a sound basis for the climate impact assessment.

The results of climate impact assessment for our four case studies can be summarized as follows.

AVEIRO

The simulated results of climate impact on water discharge in the Aveiro show a moderate decrease in the 1st and 2nd future periods (-5 to -7%), which becomes higher by the end of the century (about -15% on average). Though the decreasing trend is very clear when average results driven by 15 climate scenarios are analysed, the uncertainty is high, and it is increasing with time from p2 to p4.

The increasing trend in water temperature, by 2°C at the end of the century is clear, and agreement between scenarios is high. Dissolved oxygen concentrations show a decreasing trend, which is consistent between scenarios, and rather small. All three studied nutrients: nitrate nitrogen, ammonium nitrogen and phosphate phosphorus demonstrate the decreasing trends in all three future periods varying between -5% and -9% for NO_3-N loads, between -3% and -7% for PO_4-P loads, and between -6% and -18% for NH4-N loads on average, but the level of agreement between scenarios varies between periods and components.

The conclusion for this case study is that water managers and stakeholders have to be ready to decreased water availability in the future, and the focus of adaptation measures should be in this direction, whereas water quality should not be a large problem if land use and current water management do not change drastically.

MAR MENOR

The impact projections for Mar Menor are similar to that of Aveiro, as the climate change scenarios in these two regions show similar trends. The results show a moderate decrease of average daily discharge to the lagoon by about 10% on average by the end of the century. For the 1st and 2nd future periods the scenarios do not agree on a common trend, and on average only a small reduction <5% can be stated. The uncertainty of projections becomes higher towards the 3rd future period.

The water temperature is steadily increasing, and by the end of the century an average increase of ca. 2°C is projected. Dissolved oxygen concentrations show a small decreasing trend. For nitrate nitrogen some increase is projected for the first scenario period, and a decrease of about 20% is simulated for the middle and end of the century (periods p3 and p4). The other two

nutrient components: ammonium nitrogen and phosphate phosphorus are decreasing, but very slightly.

The message for water managers and stakeholders is the same as in the Aveiro case: adaptation measures should focus mainly on water saving technologies. Water which is scarce already now, and water management requires water transfer from the other region, may become even more scarce in future. Besides, measures related to reduction of point source pollution and diffuse nutrient pollution from arable land should stay in focus of managers and stakeholders. Though the simulated average impacts do not show notably increasing nutrient loads, they reflect only long-term average dynamics, and hydrological extreme events in future may have negative consequences on water quality characteristics.

TYLIGUL

Climate projections for future derived from the ENSEMBLES climate scenarios are very divers for the Tyligulskyi catchment. Besides changes in temperature and precipitation in the future scenarios, also changes in solar radiation affect water discharge, and the resulting impacts should be interpreted by analysing all these parameters together. Besides, water inflow to the lagoon is strongly influenced by water management (ponds) in this catchment, and it was taken unchanged for the future in this study. Though changes in precipitation are minor on average in this case, river discharge as well as nutrient loads are expected to decline moderately in the scenario period p2, but to increase in the two last periods (p3 and p4) due to radiation influence. The loads show a similar behaviour as river discharge. Water temperature and dissolved oxygen are clearly connected to the air temperature dynamics. Rising temperature leads to an increase of water temperature and an accompanied decrease of dissolved oxygen concentration in the river waters. These trends are increasing with time, from period p2 to p4.

For this case, application of combined climate and land use change scenarios is important. Such extended study could provide useful information on how the ponds should be managed in future. In general, water availability seems to be a problem in this region, and further analysis of water management options together with climate change impacts would be very beneficial. For that, more consistent and reliable climate scenarios would be desirable for this region in order to reduce uncertainty of projections.

VISTULA

Climate scenario projections for the Vistula Lagoon indicate increasing trends for both temperature and precipitation. The results of climate impact assessment on water discharge in the Vistula lagoon catchment show a notable increase of water discharge by 7%, 21% and 18% on average in three future scenario periods.

The patterns of change in water temperature and dissolve oxygen are the same as in three previous cases. The increasing trend in water temperature, and decreasing trend in dissolved oxygen concentrations are consistent between scenarios.

Two nutrients: nitrate nitrogen and ammonium nitrogen demonstrate the decreasing trends in all three future periods varying between -2% and -6% for NO_3-N loads, and between -17% and -38% for NH4-N loads on average, but the level of agreement between scenarios varies between periods and components. On the contrary, phosphate phosphorus loads are expected to increase

slightly, according to the obtained results, by 2 to 9% on average. The uncertainty ranges are moderate.

Though expected changes in climate can be seen as beneficial for this region, one should not forget about water-related extreme events like floods and droughts, which were not investigated in this study. Therefore, adaptation to climate change is still needed, and measures related to water availability, flood protection, improved sewage treatment and better management practices in agriculture are still important, and should be considered for this region.

In total, the climate impact assessment provides some useful insights into possible future development in the four catchments of the lagoons. The results can be used by lagoon modellers in WP6 to evaluate climate impacts on the lagoon ecosystems.

1. Introduction

WP 5 of the LAGOONS project deals with quantitative drainage basin scenario modelling in the context of climate and land use changes. The objectives include:

- translation of the qualitative scenarios developed in WP4 to quantitative scenarios,
- evaluation of water discharge and nutrient (N, P) input from drainage basin areas under climate change and land use change scenarios as an input to quantitative lagoons modelling, and
- estimation of uncertainty in water discharge and nutrient input related to climate and land use change scenarios.

The simulation of climate and land use change scenarios should be performed for the drainage areas of four lagoons: Ria de Aveiro lagoon, Mar Menor lagoon, Vistula lagoon and Tyligulskyi lagoon located in different countries of Europe (Figure 1.1).

Deliverable 5.1, requested in month 24 of the project, is aimed in presenting the results of climate change impact assessments for the LAGOONS drainage areas characterised in Table 1.1.

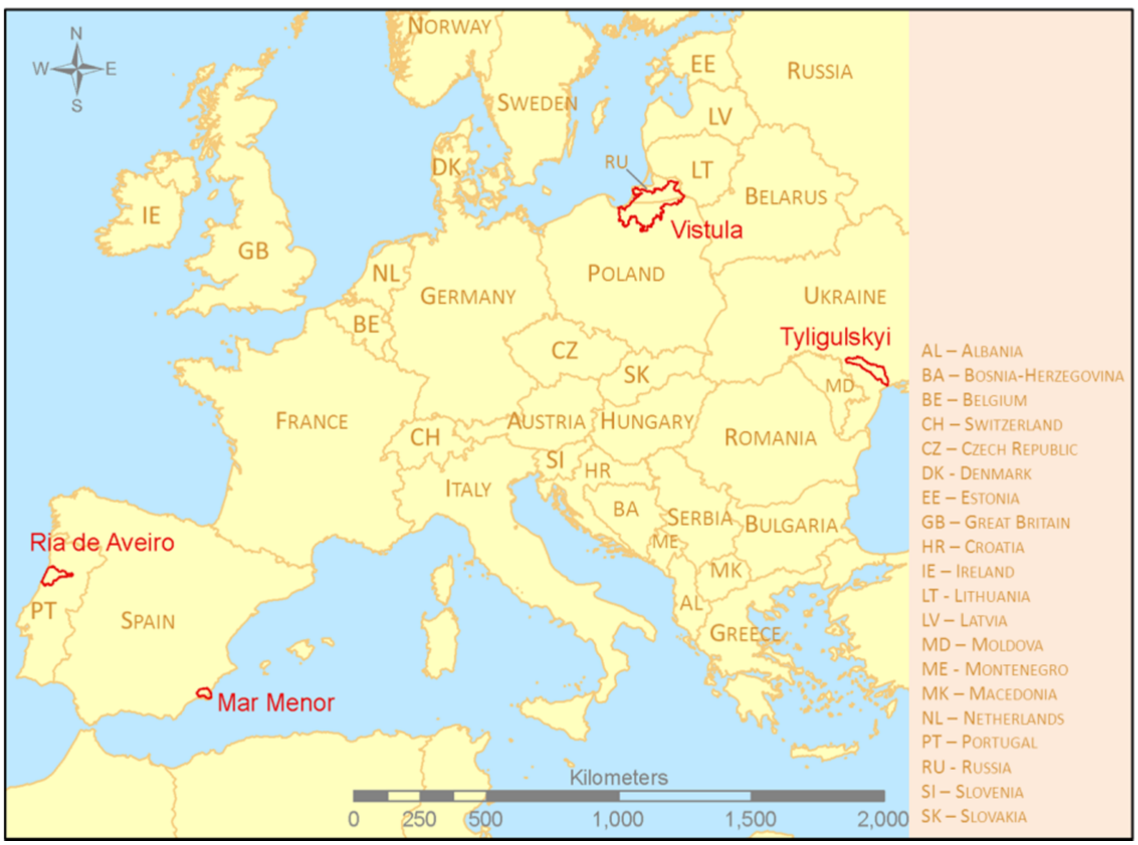

Figure 1.1 Catchments of the four European case study lagoons investigated in the LAGOONS project.

The Ria de Aveiro lagoon is situated in northern Portugal on the Atlantic coast. Its catchment area is about 3600km^2. The major river flowing into the lagoon is the Vouga. The average altitude of the drainage basin is 363m. The climate in the catchment can be characterized as humid and temperate with an average annual precipitation of 1100mm and an average temperature of 14°C. Most of the land is covered by forest (56%) and agriculture (29%).

The catchment of the Mar Menor lagoon is the smallest among all case studies. It has an area of about 1247km^2. It is situated in the south of Spain on the Mediterranean Sea and is characterized by very hot and dry summers. The average annual precipitation in the catchment is about 337mm, while the average temperature is 25°C. Agriculture is the major land use (82%) in the catchment. Forest accounts for less than 1%. The main water course draining to the lagoon is the Albujon wadi.

The Tyligulskyi lagoon is situated on the Black Sea coast in Ukraine. The catchment area is about 5240km^2 with an average altitude of 102m. The main river flowing to the lagoon is the Tyligul river. The climate in the catchment area can be described as warm temperate in the south and continental towards the north with an average annual precipitation of 515mm and an average temperature of 9.7°C. Similar as in the Mar Menor catchment, agricultural land occupies about 80% of the total area, while forest accounts only for 4%.

The largest of all four case study areas is the catchment of the Vistula lagoon with a size of about 20730km^2. The Vistula lagoon catchment is also the only transboundary case study in this project, as it is located on the territories of both Poland and Russia. The main rivers draining to the Vistula lagoon are Pregolya, Pasleka and Elblag. Most of the land is occupied by agriculture (67%) and forest (25%). The average annual precipitation is about 750mm, while the average temperature is about 7.7°C.

Table 1.1 Characteristics of the four case study areas investigated in the LAGOONS project.

	unit	Aveiro	Mar Menor	Tyligulskyi	Vistula
Catchment area	km^2	3556	1247	5240	20730
Country		Portugal	Spain	Ukraine	Poland/Russia
Sea		Atlantic Ocean	Mediterranean	Black Sea	Baltic Sea
Main rivers		Vouga	Albujon	Tyligul	Pregolya Pasleka Elblag
Av. altitude	m a.s.l.	363	100	102	82
Av. temperature	°C	14	25	9.7 *	7.7 *
Av. annual precipitation	mm/y	1100	337	515 *	750 *
Major land uses	%				
Agriculture		29	82	80	67
Forest		56	1	4	25

* WATCH climate data interpolated to the entire catchment and averaged for the period 1979-2009

2. Methods

2.1. Soil and Water Integrated Model (SWIM)

The eco-hydrological model SWIM (Soil and Water Integrated Model, Krysanova and Wechsung, 2000) was developed based on two models: SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989). The model is suited for the modelling of hydrological processes, vegetation, erosion and nutrients in meso- to macroscale river basins with an area ranging from 100 km^2 up to 200,000 km^2. A conceptual diagram of SWIM is presented in Figure 2.1.1. SWIM is a semi-distributed, process-based eco-hydrological model that includes mathematical descriptions of physical, biogeochemical and hydro-chemical processes and includes some conceptual and semi-empirical elements (Krysanova et al., 2005).

SWIM has a three level disaggregation scheme: basin - subbasin - hydrotopes, with hydrotopes as sets of units within one subbasin that have the same land use and soil type. It is assumed that those hydrotopes are characterized by uniform process behaviour concerning hydrology, vegetation and nutrients. These processes are first calculated at the hydrotope level on a daily time step before they are aggregated at the subbasin level. Climate parameters are assumed to be homogeneous on the subbasin level. Like the management data, they are external drivers for the model.

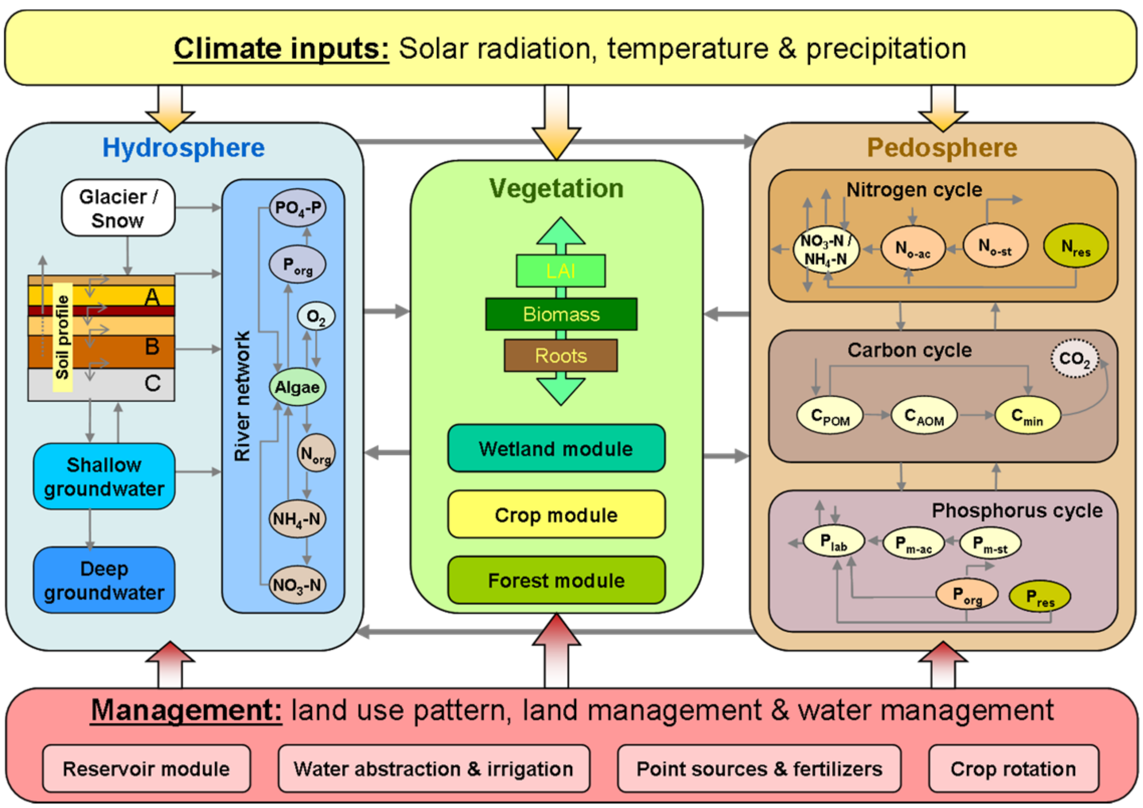

Figure 2.1.1 Scheme of the SWIM model illustrating different model compartments and considered processes, drivers and feedbacks.

Due to its spatial resolution as well as climate and land use considered as boundary conditions, the model allows the analysis of the impacts of climate and land use change on the major model output variables.

The use of SWIM is mainly restricted to associates of the Potsdam Institute for Climate Impact Research (PIK) and their project partners. The model's ability to adequately simulate hydrological processes, nutrient dynamics, crop yield and erosion has been thoroughly tested validated in many river basins over the last 15 years. SWIM is still being developed further as new modules are introduced to the model (for example, a glacier module), other modules are enhanced in order to simulate processes better (e.g. in-stream transport, crop growth or wetland dynamics), and water management measures are implemented (e.g. irrigation, ponds or reservoirs) in accordance to the particular research need or specific case characteristics. SWIM has been applied for several catchments of different sizes firstly in Germany, and later in other European countries, as well as for river basins in Africa, Asia and South America. Most of the results in terms of modelling performance were satisfactory (Krysanova et al., 2013).

Hydrological processes in SWIM

Hydrological processes in SWIM are based on the water balance equation starting from soil water content:

$$SW(t+1) = SW(t) + P - Q - ET - PERC - SSF$$

where SW(t) is the soil water content on the day t, P - precipitation, Q - surface runoff, PERC - percolation and SSF - subsurface flow (or interflow). Melted snow is treated as additional precipitation (Krysanova and Wechsung, 2000).

Surface flow is calculated by a non-linear function of precipitation and a retention coefficient which depends on land use and soil type, on management and on the actual soil water content. Subsurface flow and percolation are calculated simultaneously and separately for each soil layer. If in one layer percolation exceeds field capacity, subsurface flow occurs. This is of particular importance for layers with lower permeability than in the layers above. The number of soil layers is defined depending on available soil parameterization for the catchment. SWIM is able to consider up to ten different soil layers. Percolation from the bottom soil layer leads to a recharge of the shallow aquifer from where water can rise again to the soil profile by capillary rise. Other processes in the shallow aquifer are lateral flow and percolation to the deeper aquifer (Krysanova et al., 2013). From the deeper aquifer water cannot rise up again.

Snow processes are simulated using the method of Gelfan et al. (2004). Snow melting is calculated with a degree-day-factor. Water outflow from the snowpack depends on the following parameters: snow depth, content of ice and liquid water and snow density. The process of refreezing of melting water and snow metamorphism are also considered (Huang, 2012).

Potential evapotranspiration is calculated on the basis of solar radiation, daily mean temperature and elevation using the method of Priestley and Taylor (1972). The actual evaporation is calculated separately for soil and plants as functions of potential

evapotranspiration and the Leaf Area Index (LAI), while soil evaporation is reduced when its accumulated amount exceeds 6 mm. The limited soil water content leads to decreased plant transpiration (Krysanova and Wechsung, 2000).

Vegetation processes in SWIM

The crop and vegetation module represents an important interface between hydrology and nutrients. SWIM distinguishes the characteristics of 74 different plant types containing crops and natural vegetation (Krysanova et al., 2013). The crops (e.g. summer barley, potatoes, maize, or winter wheat) and natural vegetation (e.g. grass, pasture, or broadleaf forest) are described in SWIM by such parameters as maximum leaf area index, maximum plant rooting depth, optimal nutrient content parameters, and harvest index dependent on accumulated heat units.

The vegetation growth is calculated in SWIM using a simplified EPIC approach (Williams et al., 1984). The increase in biomass is calculated on the basis of solar radiation, the LAI and a specific plant parameter for converting energy into biomass. The estimation of LAI is based on a function of biomass and daily heat unit accumulation. The latter is calculated from daily maximum and daily minimum temperature (Krysanova and Wechsung, 2000).

Plant growth in the model can be influenced by the four potential stress factors: temperature, water, nitrogen content and phosphorus content. The degree of discrepancy between potential and actual increase in biomass due to stress factors is calculated as a function of difference between the optimal and actual values of potential stress factors. Plants grow until physiological maturity is reached or, in the case of crops, until they are harvested (Krysanova and Wechsung, 2000).

In order to adjust the modelled crop growth to future climate conditions with potentially shorter growing season as a consequence of higher temperatures, the SWIM model code was altered to allow the harvesting date to be adjusted to the crop-specific maximum accumulated heat units.

Vegetation growth plays an important role in the hydrological cycle as transpiration and evaporation both depend on the LAI. Besides, the surface runoff is influenced by a cover-specific retention coefficient (Krysanova et al., 2013).

Plant growth processes influence nutrient dynamics in the catchment as well. Nutrient uptake by plants diminishes nutrient availability in soil; mineralisation of crop residues and soil organic matter increases nutrient amounts in soils. Nutrient uptake is described in SWIM based on a supply and demand approach. Nutrients can be uptaken from all soil layers that have roots, starting from the upper horizon and proceeding downwards until the daily demand is met or until all nutrients are depleted. The daily nutrient demand is calculated as a function of the optimal to the already accumulated nutrient contents in the crop biomass at a specific growth stage.

Nutrient processes in SWIM

The SWIM model simulates nitrogen, phosphorous and carbon cycling in the soils of the basin. As this study deals with nitrogen and phosphorous concentrations measured at the outlet of the catchments, only these processes and their model implementation are shortly described here.

The *nitrogen module* for the soil layers includes several pools: nitrate nitrogen, active and stable organic nitrogen, and organic nitrogen in plant residues, as well as the flows: fertilization, mineralization, denitrification, plant uptake, input with precipitation, wash-off, leaching, and erosion. Two different pools are assumed to be sources for nitrogen mineralisation: crop residue and soil humus. The stable organic nitrogen pool is not subjected to mineralisation. Organic nitrogen flow between the stable and active pools assumes that the active pool fraction at equilibrium is 0.15. Nitrogen decomposition rate of residue is a function of the C:N and C:P ratios, soil temperature and water content. Denitrification occurs in periods of oxygen deficit, which usually is associated with high water content in soil, and is a function of soil temperature and carbon content. The amount of nitrogen lost from soil with surface, subsurface and groundwater flows is calculated daily and defined as the product of actual nitrogen concentrations in soil layers and total water loss of the day (Krysanova and Wechsung, 2000).

To describe nitrogen soil processes in more detail, the ammonium nitrogen pool was added to the nitrogen cycle (Hesse et al., 2012) taking into account decomposition, mineralization, nitrification, volatilization, leaching, erosion, and plant uptake processes. In contrast to nitrate nitrogen the ammonium nitrogen leaching is influenced by its high adsorption potential to soil particles.

The soil *phosphorus module* is simulated in a similar way and includes the pools: labile phosphorus, the active and stable mineral phosphorus, the organic phosphorus and phosphorus in the plant residue, and the flows: fertilization, sorption and desorption, mineralisation, plant uptake, erosion, and wash-off. The flows between the different phosphorous pools are governed by equilibrium equations (Krysanova and Wechsung, 2000). In contrast to the standard SWIM version the soluble phosphorous in this study is allowed to leach also vertically through the soil profile as a function of phosphorous concentration, the amount of leaving water and of the ratio between the phosphate phosphorous concentration in the soil to that in soil water (Hesse et al., 2008).

While passing the soil layers nitrogen and phosphorous are added to the corresponding lateral water flows (interflow and base flow). Then nitrogen and phosphorus are transported with surface, subsurface and groundwater flows to the river network. During their passage through the catchment nutrients are subject to retention and decomposition processes in the soils, whose intensity rate and time are described by specific parameters. After that nutrients are transported to the basin outlet defining the resulting water quality characteristics there.

Water temperature and dissolved oxygen in rivers

Water temperature of the rivers flowing into the lagoons was requested by the project partners and therefore implemented in the SWIM model code. Furthermore, the water temperature is necessary to calculate the concentration of dissolved oxygen in the river water. Both

components were included by using some simplified forms of equations taken from the in-stream nutrient module developed for SWIM by Hesse et al. (2012).

To simulate water temperature the same approach as in the SWAT model (Neitsch et al., 2002) was used, which is taken from Stefan and Preud'homme (1993):

$$T_{wat} = A + B \times T_{av}$$

where T_{wat} is the water temperature of a subbasin for the day in °C, and T_{av} is the interpolated average air temperature of that day for the according subbasin centroid in °C. A and B are the site specific constants. The equation assumes that the lag time between air and water temperatures is less than one day, which could be wrong, especially for large rivers. Additionally to air temperature the water temperature could also be influenced by other environmental parameters such as solar radiation, wind speed, water depth, ground water inflow or impoundments along the stream network, but these factors were neglected in this study. In case air temperature is lower than 0°C, water temperature was defined to be 0.01 °C.

Stefan and Preud'homme (1993) mention the possibility to alter the constants A and B within certain ranges for rivers in different geographical and climatic regions. This was also done in this study even with varying values of A for summer and winter time. The numbers used per case study area are listed in Table 2.1.1.

Table 2.1.1 Numbers used to calculate river water temperatures per case study basin.

	Aveiro	**Mar Menor**	**Tyligulskyi**	**Vistula**
A (summer/winter)	6/3	6/3	2/7	5/2
B	0.75	0.75	0.66	0.75
Summer days	120-300	120-300	90-270	90-270
Winter days	301-119	301-119	271-89	271-89

Dissolved oxygen concentration in the rivers is the difference between the saturation oxygen concentration and the oxygen consumption. The saturation oxygen concentration describes the amount of oxygen that can be dissolved in water and is a function of temperature, concentration of dissolved solids, and atmospheric pressure. In a simplified form the saturation concentration of dissolved oxygen can be calculated by the equation:

$$Ox_{sat} = \exp\left[-139.34410 + \frac{1.575701 \times 10^5}{T_{watK}} - \frac{6.642308 \times 10^7}{T_{watK}{}^2} + \frac{1.243800 \times 10^{10}}{T_{watK}{}^3} - \frac{8.621949 \times 10^{11}}{T_{watK}{}^4}\right]$$

with Ox_{sat} representing the equilibrium saturation oxygen concentration at 1 atm in mg L^{-1}, and T_{watK} being the water temperature in K (273.15 + °C) (Neitsch et al., 2002).

In the current SWIM version used for this study the saturation oxygen concentration level could be slightly altered by a correction coefficient used for calibration. Then dissolved oxygen concentration was calculated as a function of oxygen reaeration processes, the oxygen demanding ammonium concentration in the river, as well as the oxygen demand of the river sediment derived from the channel depth. Reaeration, nitrification and sediment oxidation processes can be calibrated by defining their specific rates at 20 °C.

2.2. Soil parameterization

Spatial distribution, texture and layering of soils are important features describing the modelled catchment area. They strongly influence water and nutrient cycling in the catchment, as well as vegetation growth. Therefore, soil characteristics are very essential SWIM input parameters.

For this study, information about location of soil types and their parameterization were derived by using two different spatial data sets: the Harmonized World Soil Database (HWSD; FAO et al., 2012) for regions outside of the European Union (Russia and Ukraine) and the European Soil Database (ESDB) with the Soil Geographical Database of Eurasia (SGDBE) covering case study areas located in Portugal, Spain and Poland. These maps have different resolutions: the HWSD is provided in a 1km x 1km raster, while the ESDB is delivered as a shapefile providing the best (and favourable) spatial resolution, because data may be lost during raster creation process especially in case where the soil properties are harmonized. Particularly, delivered information about soil depth and layering is not very precise but is needed for parameterization.

Table 2.2.1 Soil characteristics derived from the Harmonized World Soil Database (HWSD) and/or the Soil Geographical Database of Europe (SGDBE) to estimate soil parameterization needed for SWIM modelling.

	HWSD/SGDBE → → →	**SWIM soil parameterisation**
Layering	Topsoil 0 – 30 cm Subsoil 30 – 100 cm	T1: 0 – 10 cm T2: 10 – 30 cm *(with topsoil parameters)* S1: 30 – 60 cm S2: 60 – 100 S3: 100 – rooting depth S4: rooting depth – 200 cm *(with subsoil parameters)*
Texture	Sand, silt, clay content	Sand, silt, clay content Soil type/texture
Soil parameters	Bulk density	Bulk density
	Texture + bulk density	Rooting depth Saturated conductivity
	Texture + bulk density + organic C content	Porosity Available water capacity Field capacity
	Organic C content	Organic C content Organic N content
	Gravel content + organic C content + texture	Erodibility factor

With the two soil data sources mentioned above it was possible to get information about horizon nomenclature, depth of upper and lower soil layer, particle size fractions (clay, silt and sand percentages), organic carbon content and bulk density. Using this information alone and in combinations, together with rules and tables found in a German manual of soil mapping guidelines (AG Boden, 2005), additional parameters needed for SWIM could be derived. Table 2.2.1 gives an overview about soil input data needed for SWIM modelling and parameters used for their estimation according to general relationships listed in literature.

2.3. Climate interpolation

Climate parameters are important external drivers of the SWIM model. They are delivered with a spatial distribution to the model according to information of real climate stations located in and/or around the case study area. These real climate measurements are interpolated to the centroids of all subbasins of the simulated case study area (created by watershed delineation of the catchment using a GIS tool) by an inverse distance method taking altitude information into account. Every subbasin gets daily information about minimum, maximum and average temperatures [°C], precipitation amount [mm], solar radiation [J/cm^2] and relative air humidity [%] assuming constant climate parameters within one subbasin.

In general, a density of real climate stations not lower than one station per 100 km^2 is recommended. Data from as many stations as possible within the catchment under study is needed to be sure that the spatial heterogeneity of precipitation data is captured. It is hardly possible to achieve sufficiently good modelling results in areas with a small number of available climate stations. In case of missing information about precipitation amounts reaching the catchment area, it is nearly impossible to match the measured discharge dynamic.

2.4. Evaluation of model results

Nash and Sutcliffe efficiency (NSE)

The non-dimensional efficiency (Nash and Sutcliffe, 1970) is a measure to describe the squared differences between the observed and the simulated values and can be used to illustrate the quality of the simulated model results. Its value is based on the dispersion of values around the line of equal values. The equation can be written as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(obs_i - sim_i)^2}{\sum_{i=1}^{n}(obs_i - obs_{av})^2}$$

where *NSE* means the efficiency, obs_i defines the observed value, sim_i means the corresponding simulated value, and the variable obs_{av} is the mean value of the observed parameters for the whole simulation period. Unlike R^2, the NSE is sensitive to additive and proportional differences; however like R^2 it is oversensitive to extreme values because of squared differences (Legates and McCabe, 1999). The efficiency can vary from minus infinity to 1 and should be as near as possible to 1. If NSE < 0, the observed mean obs_{av} is a better predictor than the model

(Wilcox et al., 1990); if NSE = 0, the observed mean obs_{av} is as good a predictor as the model; and if NSE > 0, the model is a better predictor of observed data than the observed mean (Legates and McCabe, 1999). Usually, the NSE values above 0.7 are considered as corresponding to satisfactory, and above 0.8 as to good modelling results.

Deviation in balance (DB)

Another criterion of fit to describe the quality of simulated model results is the relative difference in balance, which shows the long-term differences of the observed values against the simulated ones for the whole modelling period:

$$DB = \frac{sim_{av} - obs_{av}}{obs_{av}} \times 100$$

DB means the deviation in balance in percent, obs_{av} is the mean value of all observed data for one parameter and sim_{av} is the average of the corresponding simulated data. For best model results the deviation in balance should be as near as possible to 0. Usually, the deviation in balance below 5% is considered as good.

2.5. ENSEMBLES climate scenario data and evaluation

Runoff simulations provided directly by climate models are considered not be reliable as comparisons between observed discharges and model outputs for the 20th century show that the models cannot simulate runoff satisfactorily (IPCC, 2007a). Therefore, a commonly used technique for doing hydrological impact studies on the catchment scale is to use climate parameters (e.g. precipitation and temperature) provided by climate models as input for hydrological models (Teutschbein and Seibert, 2010). As global climate models are too rough for regional eco-hydrological studies some downscaling is needed to get reliable input data for the hydrological models. The downscaling scheme for simulated climate data from global to catchment scale using the dynamical downscaling method and applying those downscaled climatological data as input for a hydrological model is shown in Figure 2.5.1. The ENSEMBLES climate scenario data used in this study were produced in a similar way and will be described in the following section.

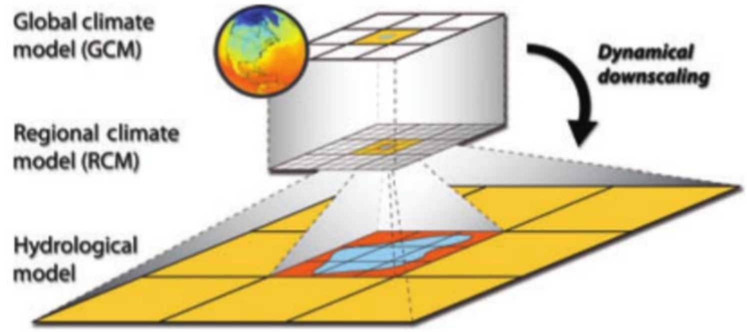

Figure 2.5.1 Downscaling scheme for simulated climate data from global to catchment scale.

Source: Teutschbein and Seibert (2010)

ENSEMBLES scenario data description

A set of climate scenario data for climate impact studies in Europe was provided by the ENSEMBLES project (van der Linden and Mitchell, 2009). This project aimed to produce projections for the future European climate by running an ensemble of regional climate models. Such a multi-model approach leads to improvement of the quality of projections because uncertainties in simulations of future climate can be assessed.

In the ENSEMBLES project a set of Regional Climate Models (RCM) was run using the boundary conditions that were produced by different General Circulation Models (GCM) before. However, not all possible combinations of RCMs with GCMs were run (due to high costs of simulations and time limit). All models were driven by the A1B emission scenario which assumes an increasing world population until 2050 up to 8.7 billion people and decrease of population afterwards. The economy is projected to be globalized and marked-orientated with a balanced use of fossil and non-fossil energy resources (Bates et al., 2008). For this scenario the best estimate of projected temperature rise on a global scale is 2.8°C with a likely range between 1.8 and 4.4°C until the end of the 21st century (IPCC, 2007b).The A1B emission scenario can be referred to as an intermediate one concerning projections for increasing atmospheric CO_2 concentration and temperature.

The combination of GCMs with RCMs resulted in different climate scenarios. The resolution of the scenarios is 25 or 50 km and the simulated period is either 1951 – 2050 or 1951 - 2100. In this study only the scenarios with a resolution of 25 km and those that were run until 2100 were considered as this resolution fits better to the scale of our catchment areas and the aim is to simulate changes in runoff and water quality until the end of the 21th century. The resolution of climate input data is very important for eco-hydrological modelling in meso-scale catchments. Therefore, taking into account the size of the LAGOONS case study catchments a resolution of 50 km for climate data was regarded as too rough.

Table 2.5.1 GCM/RCM combination matrix used in this study for climate impact assessment in the LAGOONS case study catchments.

GCM / Institute_RCM	HadCM 3Q0	HadCM 3Q3	HadCM 3Q16	ECHAM5-r3	BCM	ARPEGE
C4l_RCA3		S1	S5			
HC_HadRM3Q0	S2					
HC_HadRM3Q3		S3				
HC_HadRM3Q16			S4			
ETHZ_CLM	S6					
KNMI_RACMO				S7		
SMHI_RCA				S9	S8	
MPI_REMO				S10		
CNRM_Aladin					S11	
DMI_HIRHAM				S13	S14	S12
ICTP_REgCM				S15		

There are 15 climate scenarios in the ENSEMBLES climate data set that fulfil these requirements. They are referred to as "S1" to "S15" in this study. The selected scenarios were run by nine European institutes that used six different GCMs to drive eleven different RCMs (Table 2.5.1). Though all the selected scenarios were run until the end of the century, not all parameters needed for this study are available until the year 2100. As in the most of the cases all necessary data are completely provided only until the year 2098, the end of our scenario periods was set to this year.

In order to use the climate scenario data as input data and driving force for the SWIM model, the following six parameters are needed: the minimum, maximum and average temperature, precipitation, air humidity and solar radiation. These parameters were interpolated from the RCM grid points to the centroids of the subbasins in every case study area by using an inverse distance method. All grid cell centres situated within the catchment boundaries or within a maximum distance of 10 km around the case study basins were used for climate interpolation.

As it is a common method in climate impact research to use averages of 30-year-periods for analysis of climate behaviour, trends and possible impacts, the scenarios S1 to S15 were divided into four scenario periods for further climate studies within the LAGOONS project. The periods were defined as follows:

- Reference period: 1971-2000 (p1)
- 1. Future period: 2011-2040 (p2)
- 2. Future period: 2041-2070 (p3)
- 3. Future period: 2071-2098 (p4)

ENSEMBLES scenario data evaluation

Before applying the ENSEMBLES scenario data to the case study areas they were analysed in detail considering changes in temperature and precipitation from the reference period to the future scenario periods. Besides, a comparison with the observed climate at 1-2 real climate stations in the reference period was done for getting an impression about the RCM-simulated climate "reliability" in the case study areas.

The first task was realized by calculating climate change signals, which describe the absolute differences of mean climate parameter values between the reference period and the future periods. In case this signal is positive the climate parameter (e.g. temperature T or precipitation P) is projected to increase in future, whereas a negative signal value indicates a decreasing trend. Climate change signals were calculated and compared for all 15 scenarios to get an impression about the overall projected climate trends. The values were calculated as the mean of all grid cells located in and around the lagoons catchments. Climate signals were evaluated for annual mean values of all three future periods compared to the reference period as well as for seasonal dynamics of these parameters and periods. The results of this evaluation are summarized in the next subsection.

The second task realized a comparison of the climate model outputs simulated for the historical period with real measured data within the lagoon basins to find the "best fitting" scenario (i.e. having the smallest weighted difference). The choice of such scenario was necessary especially for the project partners from WP 6 (lagoon modellers), as their 3-dimensional models with fine resolution cannot be run for all 15 scenarios.

For the second task the observed precipitation and daily mean temperature from selected real climate stations in the catchments were compared to the climate model data of the corresponding nearest grid cell for the same period. For each LAGOONS catchment, one or two stations were chosen for the comparison. These stations are listed in Table 2.5.2 together with the periods analysed, which were different due to availability of the observed data. For the station 'Gafanha de Nazare' in the catchment of the Ria de Aveiro only precipitation data were compared due to lack of temperature data, and for all other stations both climate parameters were compared.

Catchment	Climate station	Time period	Number of years
Ria de Aveiro	Gafanha de Nazare	1991 - 2000	10
	Viseu	1998 - 2010	13
Mar Menor	Balsapintada	2000 - 2011	12
Tyligulskyi Liman	Liubas	1998 - 2007	10
Vistula Lagoon	Chernyakhovsk	1993 - 2011	19
	Olsztyn	1993 - 2011	19

Table 2.5.2
Climate stations used for evaluation and comparison of climate model outputs with real measured climate data to find the "best fitting scenario".

During this evaluation differences in seasonal dynamics of temperature and precipitation between the observed climate data and simulated climate data S1 to S15 were compared. For that, mean monthly temperature and mean monthly precipitation for the studied periods were firstly calculated from the observed and simulated data, and then average monthly differences were estimated and compared between the scenarios. In order to identify the "best fitting" scenarios for each parameter (T, P) and each station, the average of the absolute values of monthly differences was chosen as an appropriate method. For precipitation this value was normalized by dividing the monthly difference by the mean monthly observed precipitation and expressed in percent. Using this method, finally15 values were obtained for precipitation and 15 values for temperature, which can be used for choosing the climate scenarios, which are closest to the observed mean monthly T and P in the reference period, and in that sense could be treated as "the best fitting " scenarios. The following scenarios were identified as "best fitting" ones: S3 for the Aveiro catchment, S9 for Mar Menor catchment, and S10 for Tyligulskyi and Vistula case.

Summarized results of the scenario evaluation

Climate change signals were calculated as differences in long-term (30 years) average temperature and precipitation between three future periods p2, p3 and p4 and the reference period p1. The results are listed in Table 2.5.3. This Table shows climate signals as average values for all 15 scenarios as well as for the "best fitting" scenario detected for every case study

by comparing climate model outputs with the real measurements during the historical period 1971-2000.

The average climate change signals for temperature are similar for all four case studies. They amount to approximately 1°C for the period p2, ca. 2°C for p3 and ca. 3°C for p4, while for the Tyligulskyi Liman catchment the simulated raise in temperature is higher than for the other three catchments.

Regarding expected changes in precipitation, the signals are more diverse among the catchments. Until the end of the 21st century, an increasing trend in precipitation is projected for the Vistula Lagoon, while the precipitation trend is decreasing for the Aveiro and Mar Menor catchments. The strongest relative decrease is simulated for the Mar Menor catchment. For the Tyligulskyi catchment only very small changes in precipitation are projected on average.

However, these are only averaged over 15 climate scenarios results. If single scenarios are analysed, large differences in precipitation signals between the single scenarios are notable (see Figure 2.5.2). While some simulate an increase in precipitation, others project a decreasing trend. This uncertainty is especially large for the Tyligulsky catchment area.

Table 2.5.3 Annual climate change signals for the average of all 15 selected ENSEMBLES scenarios, as well as the "best fitting" scenario in each catchment for the parameters temperature and precipitation.

Catchment		temperature (°C)			precipitation (%)		
		p2 – p1	*p3 – p1*	*p4 – p1*	*p2 – p1*	*p3 – p1*	*p4 – p1*
Ria de Aveiro	*average*	+1.03	+2.10	+3.09	-5.6	-7.5	-15.6
	S3	+1.2	+2.16	+3.08	-3.6	-6.6	-11.1
Mar Menor	*average*	+0.88	+1.97	+2.97	-1.6	-10.7	-18.3
	S9	+0.48	+1.56	+2.6	-5.2	-8	-28.9
Vistula Lagoon	*average*	+1.05	+2.18	+3.12	+4.3	+10.5	+9.7
	S10	+0.79	+1.83	+2.8	+3.8	+12.1	+8.9
Tyligulskyi Liman	*average*	+1.24	+2.39	+3.46	-1.5	+0.8	-4.1
	S10	+1.11	+2.02	+3.4	-8.7	+2	-3.2

ENSEMBLES scenario data application

After hydrological and water quality calibration all 15 chosen climate change scenarios from the ENSEMBLES project were applied to the calibrated SWIM model in four case study areas. The land use and management input data of the reference period were unchanged in the future periods in order to evaluate impact of climate change only.

The climate scenario impacts on water discharge and water quality variables were analysed as an average of all 15 scenarios on the long-term average daily, seasonal and annual basis for the total discharge and nutrients loads flowing to the particular lagoon. To get an impression on the ranges of uncertainty of future projections, different percentiles of the scenario results as well as minimum and maximum values were shown in addition.

For the analysis the four time periods mentioned above were used. Each of the three future scenario periods was analysed with regard to the reference conditions simulated by the same

scenario set. Additionally to the analyses of the averages of all 15 scenarios, an analysis for the "best fitting" scenario with regard to the historical data is shown separately in all cases.

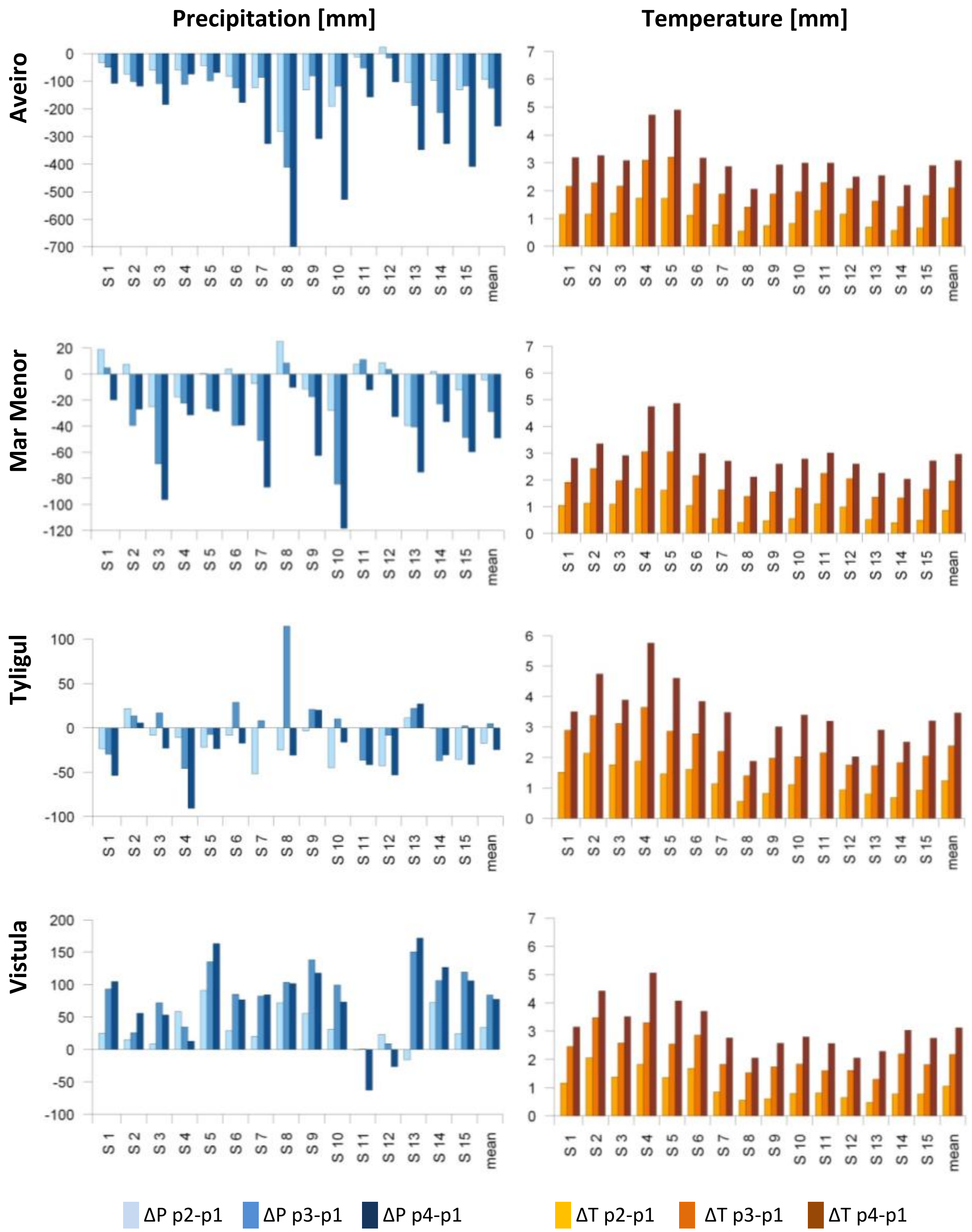

Figure 2.5.2 Climate change signals for all 15 ENSEMBLES scenarios and on average calculated as the difference between the average annual precipitation and temperature, respectively, of the three future periods (p2, p3, p4) to the annual values of the reference period (p1) of the same scenario.

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