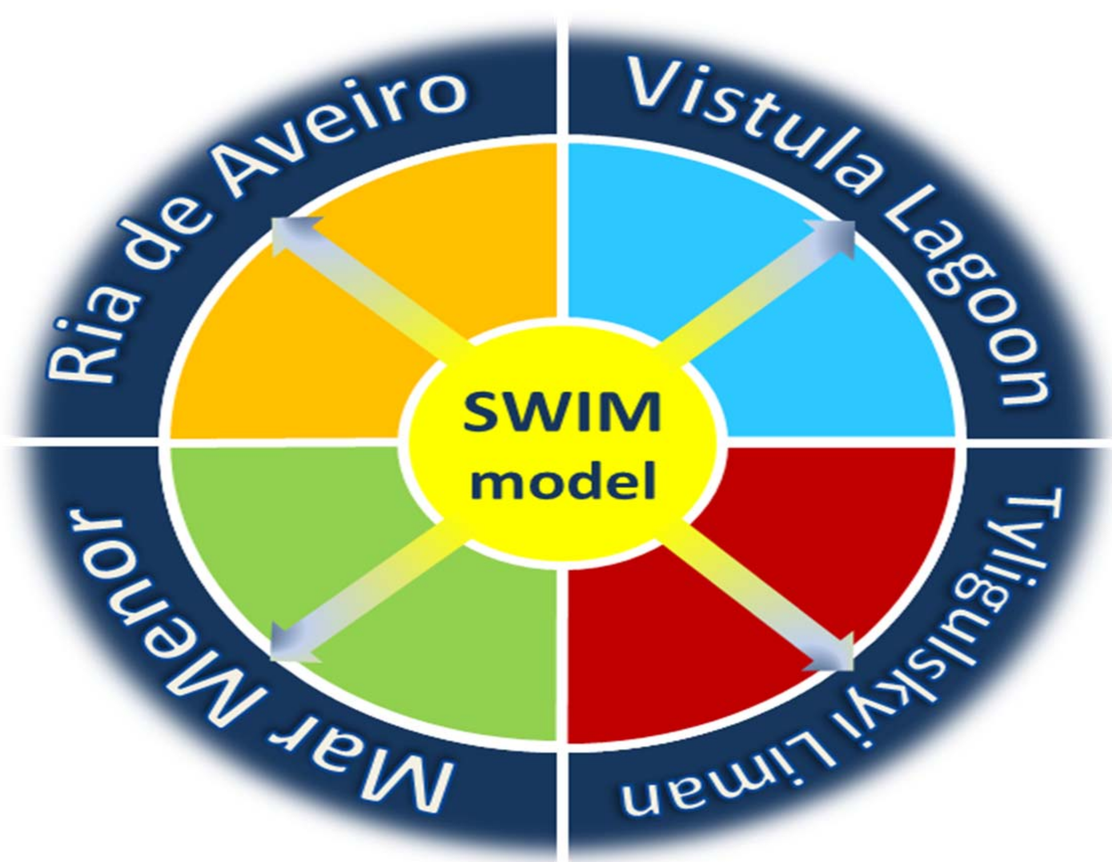
DELIVERABLE D5.1

# Results of climate impact assessment

## Application for four lagoon catchments

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| Title |
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| Results of climate impact assessment – Application for four lagoon catchments |
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[1] PU Public
PP Restricted to other programme participants (including the Commission Services)
RE Restricted to a group specified by the consortium (including the Commission Services)
CO Confidential, only for members of the consortium (including the Commission Services)

# 4. Mar Menor

## 4.1. Case study description and data preparation

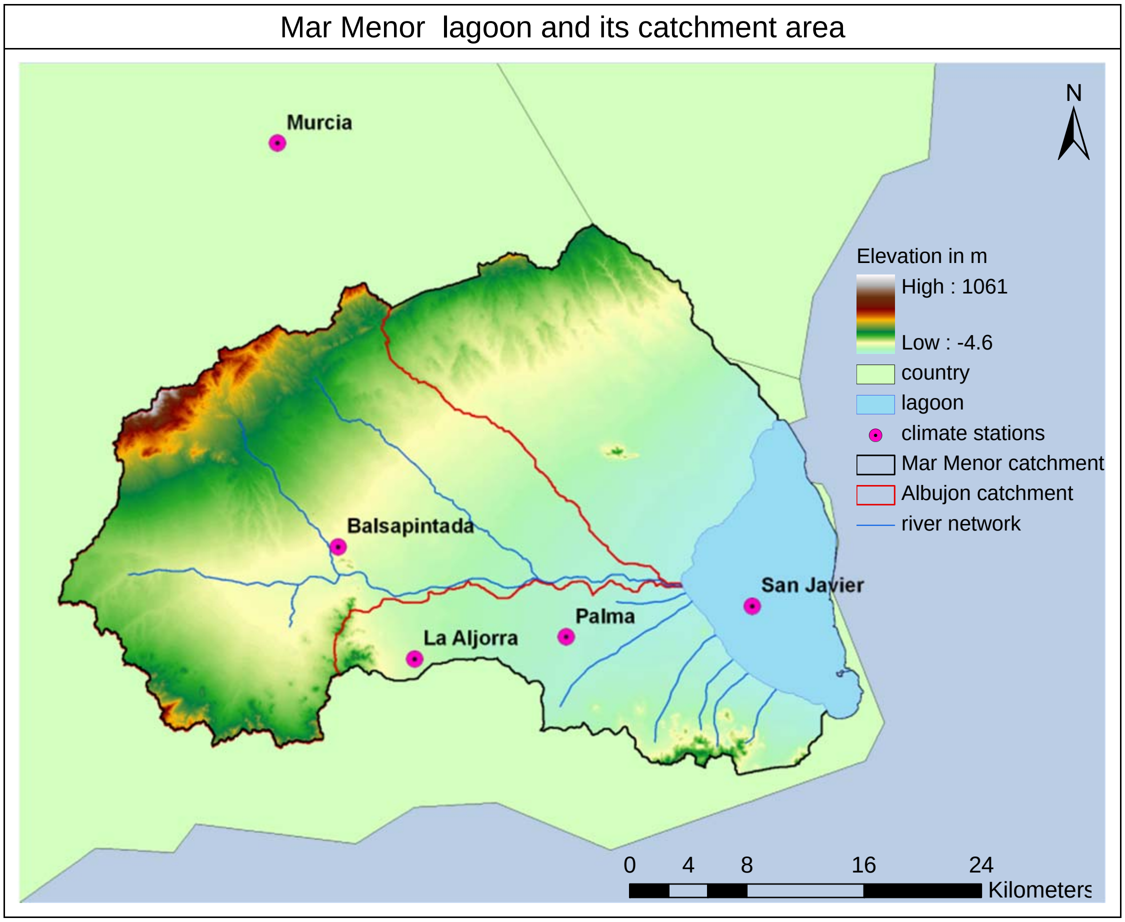



**Figure 4.1.1** Overview of Mar Menor lagoon and its catchment, showing the topography of the catchment, the lagoon, the catchment's boundaries, the river network and the catchment of Albujon wadi as well as available climate stations.

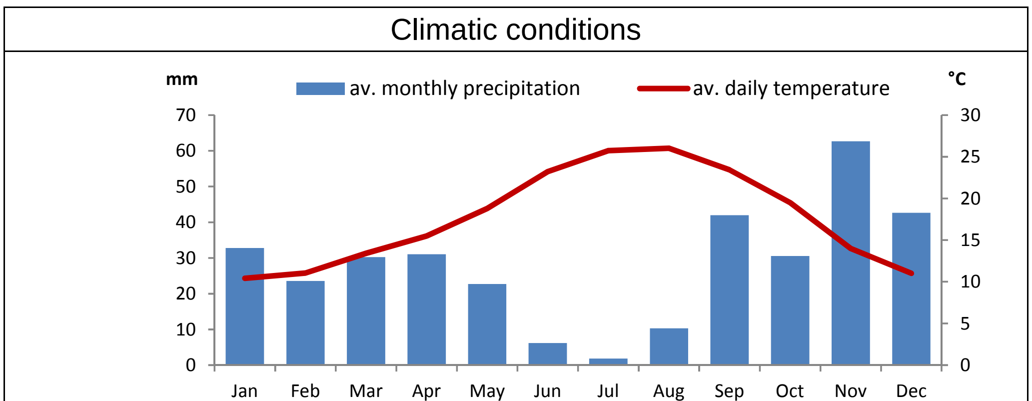
The total catchment area of the Mar Menor lagoon is about 1400km$^2$. The wide plain is also called "Campo de Cartagena". It is formed mainly by Quaternary material which is enclosed by mountains (Kretschmer et al., 2004). The altitude of the catchment ranges between -4.6 m a. s. l. in the east and 1061m a.s.l. at the very northwest. However most of the land is flat with an average elevation of 150m a.s.l..

There is only one water course with constant flow contributing to the Mar Menor lagoon, the Albujon wadi. Wadi is the Arabic term traditionally referring to a valley. In some cases, it refers to a dry (ephemeral) riverbed that contains water only during times of heavy rain or simply an intermittent stream. In the past the Albujon wadi used to be an ephemeral stream, which carried flow only after torrential rainfalls. Nowadays the baseflow of the wadi is fed by groundwater and there is a continuous flow throughout the whole year. However, the term "wadi" is still used. The catchment area of the Albujon (red borders in Figure 4.1.1) is about 630km$^2$. The average daily discharge of the Albujon wadi is very low, about 0.2m$^3$/s. Other ephemeral small streams or so called "ramblas" in the catchment are Rambla de Miranda,

Rambla del Miedo, Rambla de las Matildas, Rambla del Beal, Rambla de Ponce and Rambla de la Carrasquilla (in order of appereance on the map from the top).

In addition to the law preventing overexploitation of groundwater (usually for irrigation purposes), groundwater recharge has also risen due to changes in water management in the agricultural sector. Since the 1980's water for irrigation in this area is provided from the Tagus-Segura river system via a special water transfer channel. Part of this water is infiltrating through the soils and draining into aquifer, which leads to a continuous baseflow to the wadi even in very hot and dry summer time.

The climate in the catchment is semiarid Mediterranean (Figure 4.1.2). The average annual precipitation is around 340 mm. The driest months are June, July and August, with less than 20 mm rainfall in total on average. The average annual temperature is about 18°C, ranging from 11°C in December and January to 26°C in July and August.




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| precipitation [mm] | 33 | 24 | 30 | 31 | 23 | 6 | 2 | 10 | 42 | 31 | 63 | 43 |
| temperature [°C] | 10.4 | 11.1 | 13.4 | 15.5 | 18.8 | 23.2 | 25.7 | 26.0 | 23.4 | 19.5 | 14.0 | 11.0 |

**Figure 4.1.2** Climate chart showing average monthly precipitations and temperatures in the Mar Menor catchment based on data from available climate stations (2001-2011).

Most of the area (82%) in the Mar Menor catchment is occupied by arable land (see Figure 4.3), while horticulture (60%) is the most dominant land use. Other important land uses within the agricultural sector are citrus (30%), green houses (6%) and fruit trees (4%). After cropland heather has the 2nd largest share (11%) of land coverage, mostly occupying areas with higher elevations. The share of forested area is only 1%. Urban areas, especially settlements make up 3%. Along the northwest coast of the lagoon, most of the area can be identified as settlement (red colour). In this area tourism, which is of seasonal character, is strongly developed.

Industry does not play a very important role, and is hardly visible on the land use map (<1%) but its influence is still notable in regard of pollution of the Mar Menor lagoon. Mining for heavy metal extraction in the past has left over heavy metallic sediment wastes which can be transported to the Mar Menor through the ramblas draining to the lagoon from the south. However, modelling of heavy metals is not included in the current SWIM version. Therefore

pollution from industrial sites could not be considered in the modelling process, and it was not included in the project's objectives.

The main soils in the catchment are Cambisols (76%) occupying a bulk of the total area and Calcisols (10%) in the west. Cambisols are very characteristic soil types for the semi-arid Mediterranean regions. These soils are young soils with a continuous process of pedological maturation and mainly used for crop cultivation in the southern European region (JRC). Calcisols are more typical for arid regions. They are usually characterized by a good drainage and high calcium content which makes them relatively fertile.

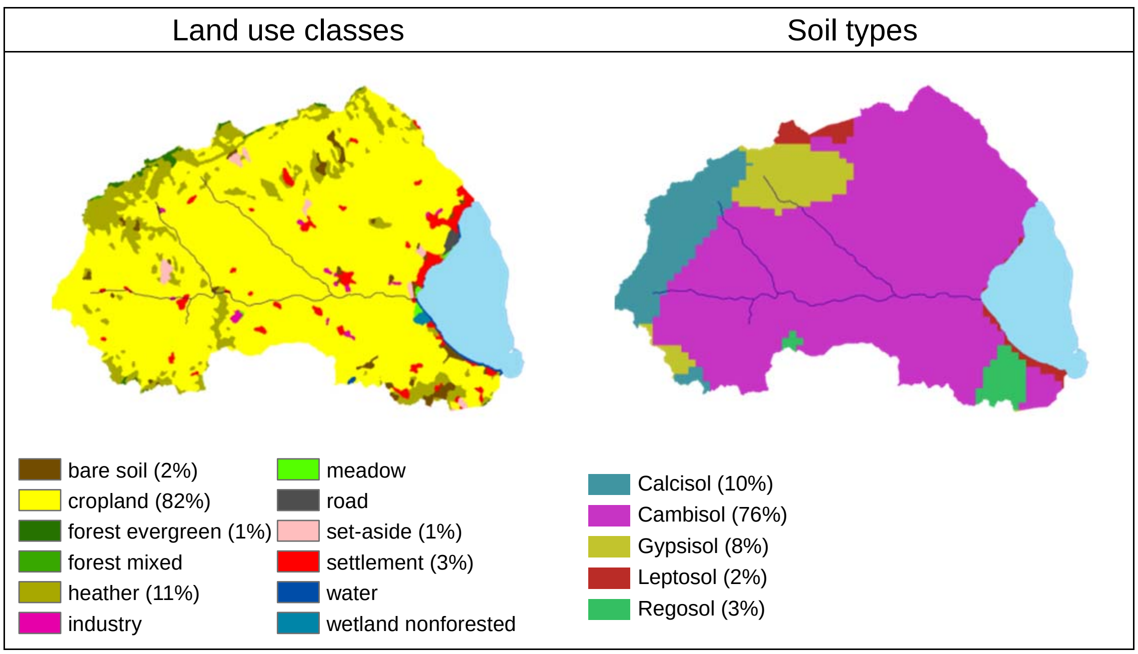



**Figure 4.1.3** Spatial distribution of land use classes and soil types within the Mar Menor catchment, as used for model set up.

Tourism is the main source of income for the local economy. During summer the population increases drastically, from 45.000 permanent inhabitants to 450.000 (LAGOONS, 2013), which causes problems not only in freshwater availability but also in wastewater management.

The major point source polluter in the catchment is the Urban Wastewater Treatment Plant (UWTP) of Los Alcazares, which serves most of the population along the north-western coastline. The UWTP is located very close to the lagoon. The effluents are discharged into a channel which flows into the Albujon wadi (<2 km). After two more kilometres from this point the Albujon drains into the lagoon.

The size and capacity of the plant were enlarged in the past, since large amounts of insufficiently treated wastewater were reaching the lagoon and causing devastating ecological effects every summer. The renewed and enlarged plant is in operation since 2008. About 56% of the effluent is reused for irrigation purposes. Figure 4.1.4 shows the location of the UWTP and total N and P inputs to the lagoon during the last years. According to the official numbers provided by the plant's operator, the average annual N load before modernisation was about 1000 tonnes per

year, and after the modernisation it decreased to about 100 tonnes per year, which means ten times reduction. The average annual P load decreased from about 300 tonnes to 60 tonnes per year, this makes a reduction to 20% of the former level.

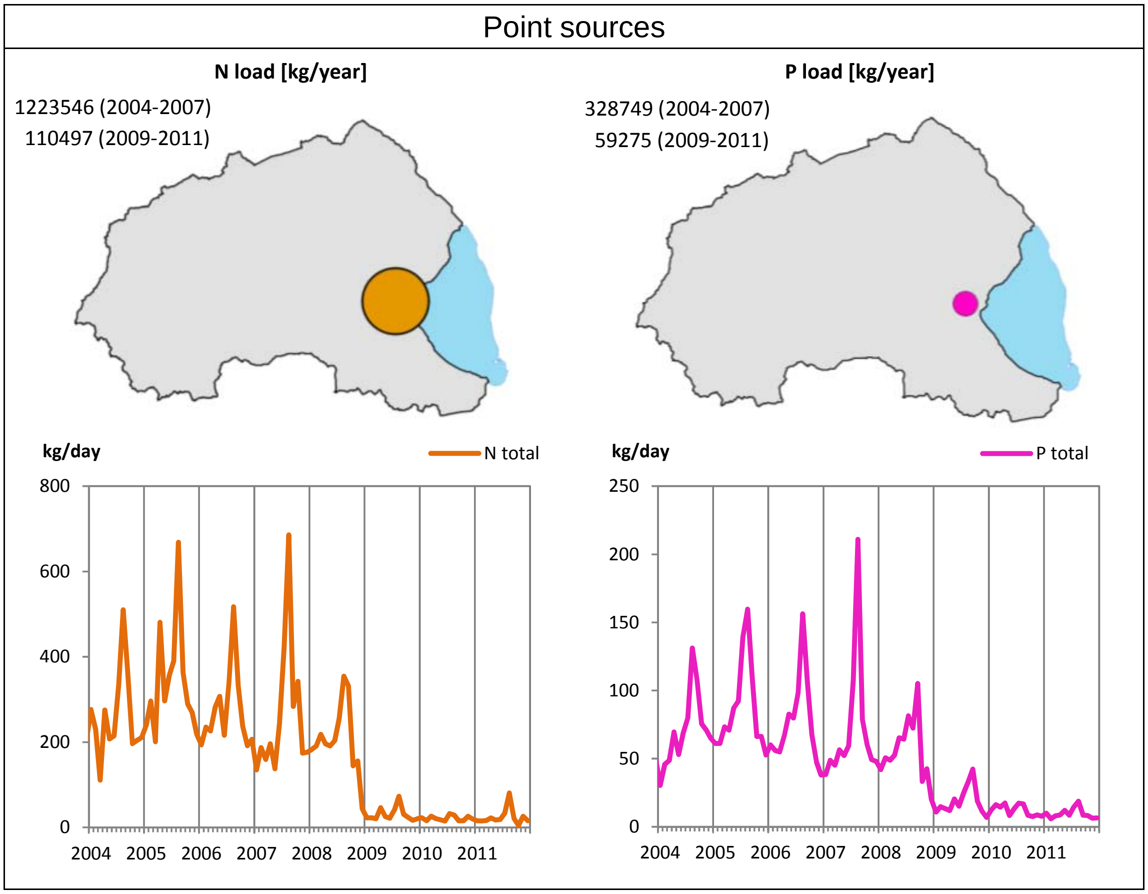



**Figure 4.1.4** Locations and amounts of point source emissions of total nitrogen and phosphorus, as implemented in the model.

Information about the chemical composition of the effluent from the UWTP in Los Alcazares was available for the peiod 2004 – 2011 on a monthly basis. As visible in the graphs (Figure 4.1.4, lower graphs) N and P loads usually increase during summer. Before the operation of the new UWTP the average daily N loads in August could reach 700 kg/day, while outside the touristic season they were about 100-200 kg/day. Differences in the emissions between the tourist season and off-season of 15-30% also aplly to the total P loads of the effluent. After 2008 the highest loads of summer effluent were reduced to 73 kg N/day and 42 kg P/day. During the off-season the average loads are 16 kg N/day and 8 kg P/day.

Some hydrological and water quality data for calibration were available for Albujon for the period 2002-2006. However, only sporadic measurements were available in this period, and the SWIM model had to be run and calibrated for this period practically as in ungauged mode. Besides, discharges from the UWTP were available only from 2004 onwards. Therefore, two

additional years (2002-2003) of effluent loads were constructed artificially, using an average year of the period 2004-2007. For the assessement of climate impacts another artificial year, an average of 2009-2011 was assumed as "typical" for the whole reference period, and accepted also for three future periods to evaluate climate change impacts.

Besides nutrients pollution from point sources, diffuse pollution from agricultural areas was simulated by SWIM. Two of the main horticultures grown in the catchment are water melons and lettuce. The recommended fertilizer amounts are between 150-265 kgN/ha for water melons and 60-180 kg N/ha for lettuce depending on the irrigation type (drop or traditional). No recommendations about P fertilizer were availbale. In the model a simplification of the agricultural management was assumed. Only two of the variuos horticultures were implemted: water melons and lettuce. Further, it was assumed that cropland is covered by plants during the whole year. Water melons are grown from March until September and fertilized at the beginning of the growing season with 150 kg N/ha and 60 kg P/ha (see Table 4.1.1). Lettuce is grown from September until February and is fertilized with 120 kg N/ha and 50 kg P/ha.

**Table 4.1.1**
Fertilization dates and amounts (kg/ha) in the Mar Menor catchment as applied in the model

| Day | $N_{min}$ | $N_{org}$ | $P_{min}$ |
|---|---|---|---|
| 61 | 100 | 50 | 60 |
| 274 | 100 | 20 | 50 |
| **Sum per year** | **200** | **70** | **110** |

Water management in the catchement has two major components: irrigation and UWTP effluents. The effluent from the UWTP in Los Alcazares is discharged, and about 56% of the water is used for irrigation of arable land. The irrigated area is about 41000ha. The amount of water used for irrigation varies from year to year depending on several factors. Most of the water for irigation is delivered by the Tagus-Segura water diversion (122 $hm^3$). About 13.2 $hm^3$ are reused effluents from UWTPs, 4.2 $hm^3$ are diverted directly from the Segura basin and another 2.2 $hm^2$ from desalination plants (CRCC).

Weather conditions have significant influence on water demand and availability for irrigation. In dry years less water from the Tagus river basin can be diverted to the irrigation areas in the Mar Menor catchment area. In order to overcome this kind of irregularity 1300 ponds with a total capacity of 21 $hm^3$ exist in the area, which are used for irrigation as well. Therefore it is difficult to state the exact amount of water used for irrigation every year.

In the model the estimated average amount of water, 141.6 $hm^3$, was assumed to be applied to the irrigated areas every year during the model calibration, as well as for climate impact asesement in future. Since subbasin and hydrotope delineation was already finished when information about water management became available, the exact extent of the irrigated fields could not be implemented into the model. The amount of water for irrigation had to be distributed on a larger area (652 $km^2$) than the actual one (400 $km^2$). Hydrotopes within the red boundaries (see. Figure 4.1.5) having cropland as land use class were irrigated on a daily basis in the period between March and September with 1.02 mm daily.

The second important component of water management in the catchment is the discharged effluent from the UWTP in Los Alcazares. The UWTP was added to the model with monthly constant values as shown in the above graph (Figure 4.1.5). An artificial year was calculated as

an average from the available data for 2004-2007 and used as input data for 2002-2003. For climate impact assessment an average year representing the discharges of the new UWTP was calculated and used. The effluent was added directly to the Albujon wadi, about two kilometers away from the mouth.

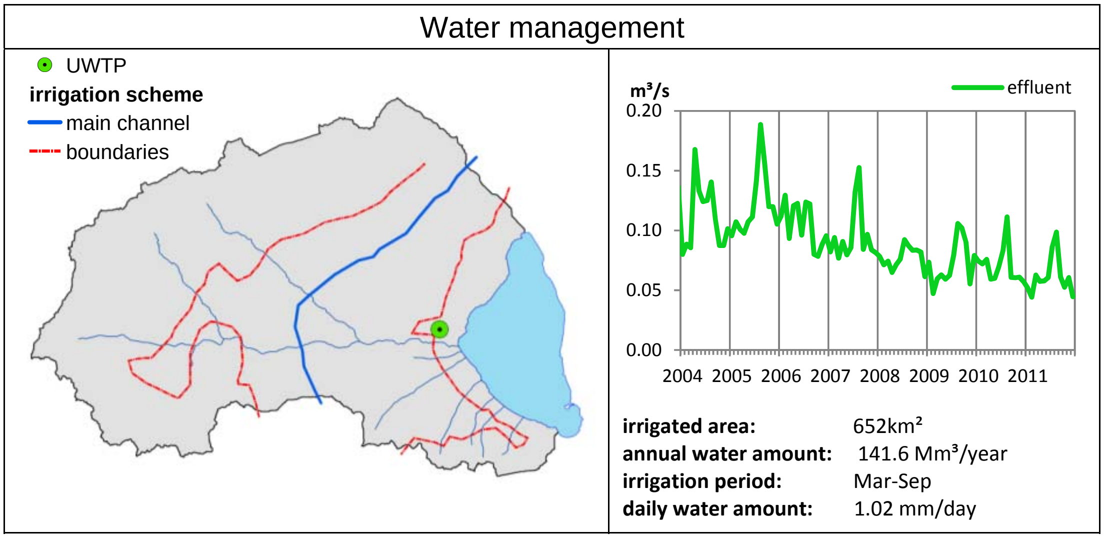



**Figure 4.1.5** Location and amounts of water discharged from the UWTP, as well as irrigation scheme and amounts as implemented in the model.

The following table (Table 4.1.2) provides an overview of most relevant data and sources, used and implemented in the SWIM model of Mar Menor.

**Table 4.1.2** Data as used and implemented in the model and their sources.

| Data and sources | | | |
|---|---|---|---|
| **Spatial and attributed data** | **DEM:** 90x90m raster (SRTM[1]), source: http://srtm.csi.cgiar.org/<br><br>**Albujon wadi,**<br>**Albujon catchment,**<br>source: University Murcia (UM) | **Landuse:** shape file (CLC2006[2]), source: http://sia.eionet.europa.eu/CLC2006<br>**Crop parameters**, source: SWIM database<br>**Crop management**, source: literature review, UM | **Soil:** 1kmx1km raster(HWSD[3]), source: http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/<br>soil parameters, source: HWSD and German pedological mapping guidelines 2005 |
| | | | |
| **Time series** | **Climate:**<br>5 stations (4 in watershed),<br>period:2000-2011,<br>source: University Murcia | **Q gauges**: NO gauges<br>estimated seasonal dynamics for 2003, source: Garcia-Pintado et al. 2006<br>24 survey measurements for period 09/2003-06/2006,<br>source: UM | **WQ gauges**:<br>No gauges,<br>24 survey measurements of NH4-N, NO3-N and PO4-P concentrations for period 09/2003-06/2006,<br>source: UM |
| | | | |
| **Additional** | **Point sources:**<br>1 UWTP, monthly total N and P concentrations (mg/l) for 2004-2012<br>source: University Murcia | **Water management**:<br>Irrigation with water diverted from the Tagus river, annual amounts and irrigated area,<br>source: WP2 Deliverable D2.1c | **Water discharge**:<br>1 UWTP, monthly flow (m³/month), for<br>2004-2012<br>source: UM |

## 4.2. Hydrological calibration and validation

Hydrological calibration in the Mar Menor catchment was done in a quasi ungauged mode. The reason is that there were no time series of river flow observations available, but only some sporadic measurements collected during several surveys in the time period between 2002 and 2006. In addition, the calibration with a biweekly time step for the year 2003 was performed using estimated discharge from Gracia-Pintado et al. (2006). An additional difficulty was that contributions to the total flow of the Albujon wadi from the UWTP for the year 2003 were not available and had to be estimated from the following years.

The next graph (Figure 4.2.1) shows the simulated by SWIM water discharge at the mouth of the Albujon wadi, and the existing sporadic measurements of discharge. Due to insufficient observed data no statistical measures for evaluation of model performance could be calculated. Nevertheless, the visual graph fitting method resulted in satisfactory results.

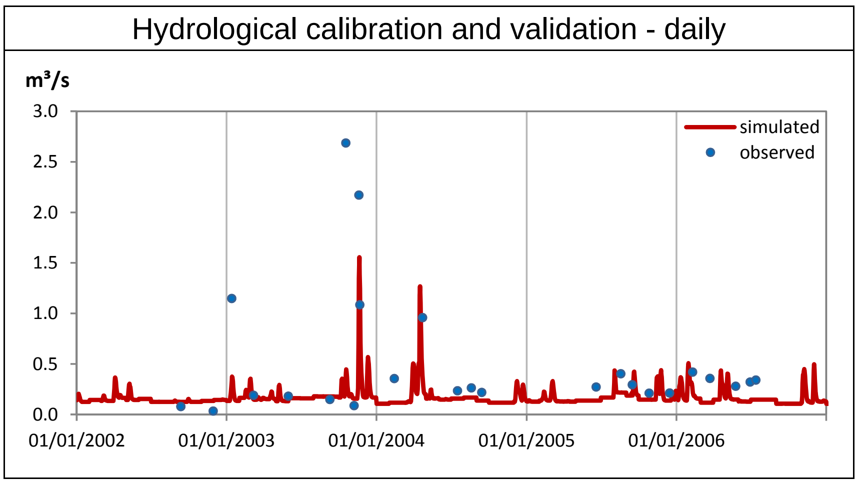



**Figure 4.2.1** Graph showing the simulated daily water flow of the Albujon wadi (red line) and some sporadic discharge measurement (blue points) at the outlet.

The calibration results for the period 10/2002 – 02/2004 using the estimated discharge from Garcia-Pintado et al. (2006) are presented in the next figure (Figure 4.2.2). In the upper part the totals of monthly precipitation for 10/2002 – 02/2004 are shown. The lower graph is showing the simulated by SWIM biweekly discharge for the same period at the mouth of the Albujon wadi, and the discharge curve adopted from the graph published in the paper by Garcia-Pintado et al. (2006).

Both curves show very similar flow dynamics. In August the simulated discharge is missing one peak. This peak must have its origin in the discharge coming from the UWTP since almost no rainfall was recorded for this month (see upper graph). The actual contribution from the UWTP for 2003 was not available and hence the model cannot reproduce the observed peak. Nevertheless, the average simulated discharge for 2003 is 0.20 $m^3/s$, which is very close to the one estimated by Garcia-Pintado et al., 0.24 $m^3/s$.

Another indicator of model performance that can be used when NSE or DB cannot be calculated is the runoff coefficient of the catchment (the percentage of precipitation that appears as runoff

as the long-term average value). This value gives an impression of how much rainfall over a catchment is actually contributing to the total runoff. In the case of Mar Menor, which has a catchment area of 632km$^2$, the runoff coefficient for 2003 estimated by using the model outputs is only 2.52%. Taking into account that in addition to the total annual precipitation about 217mm (irrigation water) are added to the catchment, the actual runoff coefficient is even lower than two percent (1.6%).

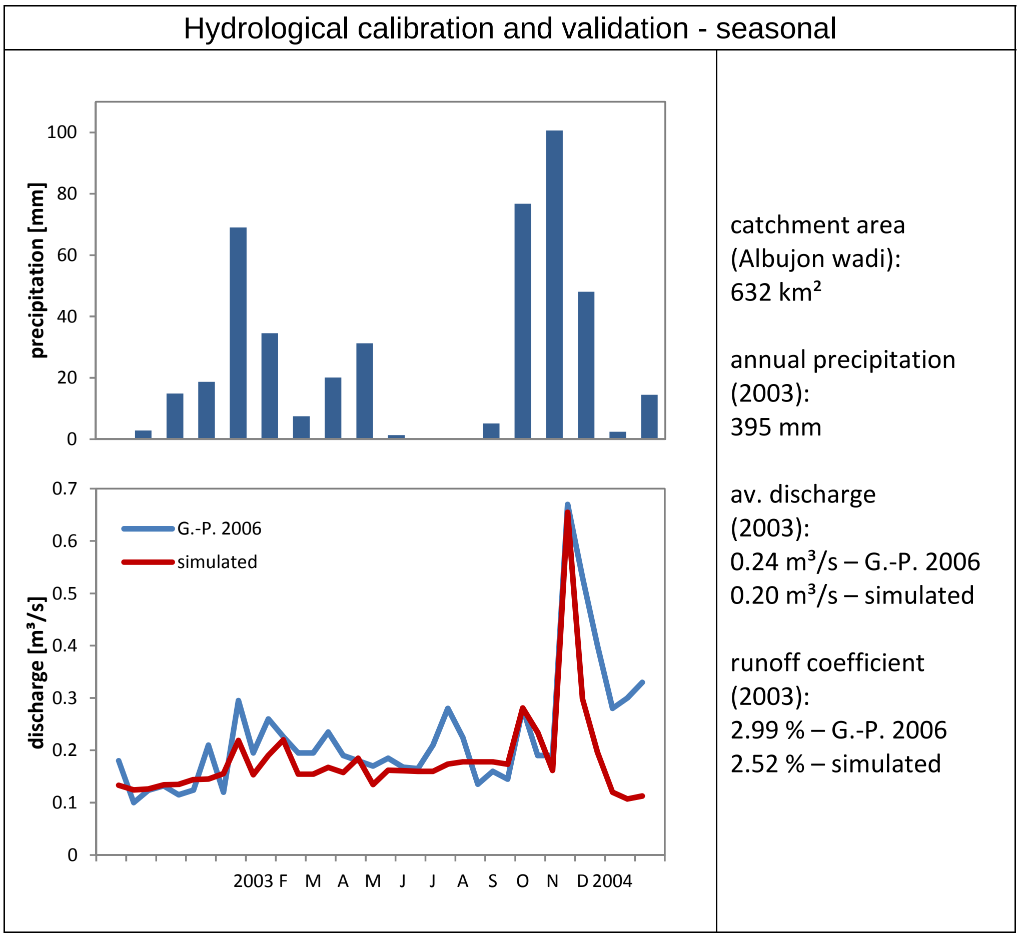



**Figure 4.2.2** Monthly sums of precipitation (upper graph), discharge curve adopted from Garcia-Pintado et al. 2006 (blue line) and simulated discharge (red line) for the same period.

The following figure (Figure 4.2.2) shows the spatial patterns of precipitation (interpolated input data) and three simulated major water fluxes in the catchment: evapotranspiration, runoff and groundwater recharge as average values for the period 2002 – 2011.

In the Mar Menor catchment precipitation ranges from 300 to 372mm per year, this means that rainfall distribution in the catchment is relatively homogeneous. Nevertheless it can be stated that most of the rain falls at the edge of the mountains in the south-eastern part of the catchment.

In general, evapotranspiration is higher in areas with higher precipitation. However in the case of the Mar Menor catchment evapotranspiration is also higher on the territory of irrigation area. This is because more water is available for evapotranspiration due to additional water input to the system. The average actual evapotranspiration rate in this region is about 300mm/year, while some parts even reach values of 600 mm/year.

Runoff generation in the catchment is also influenced by the irrigated land. It ranges between 0-14 mm/year at the western borders of the catchment and 41-175 mm/year in the irrigated region. On areas categorized as settlements runoff rates are higher than in the surroundings, as water cannot infiltrate through the sealed grounds.

Groundwater recharge is almost of the same magnitude as runoff, a bit lower on average. It ranges between 0-13 mm in the mountainous northern part of the catchment and 47 -162 mm/year in the irrigated region. Within the irrigated region lowest rates of groundwater recharge can be found on areas categorized as settlements, which are characterized by poor infiltration.

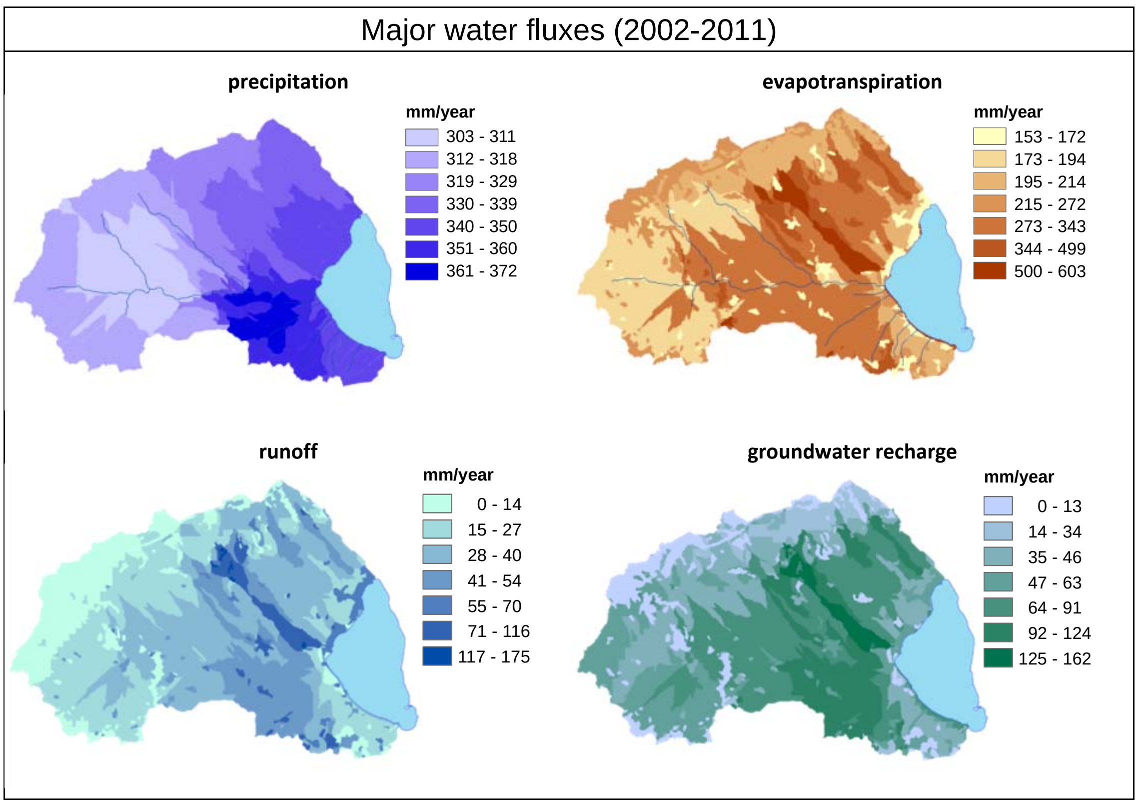



**Figure 4.2.3** Spatial patterns of major water cycle components in the Mar Menor catchment averaged over the period 2002 – 2011.

## 4.3. Calibration and validation of water quality

Water quality calibration for the Mar Menor catchment was done using data for the outlet of the Albujon wadi. A number of samplings that have been carried by Velasco et al. in the period

11/2002 – 06/2006 were made available for calibration of the model. In total, 24 for measurements of $NO_3$-N, $NH_4$-N and $PO_4$-P concentrations could be used. They were converted to daily loads by multiplying the concentrations of the samples by the discharge measured during sampling.

The following three graphs (Figure 4.3) show the results of the water quality calibration. At this point it should be recalled that real data on point source pollution from the UWTP was only available from 2004 and input data on point source pollution for the model for 2002 and 2003 had to be estimated from the available data. Due to the small number of observations it was not possible to calculate any statistical indicators neither to consider seasonal dynamics in the calibration process. Nevertheless, the model was able to reproduce the levels of all three variables, and also some peaks of the observed nutrient loads.

The 1st graph in figure 4.3 shows the simulated daily and measured loads of $NO_3$-N at the mouth of the Albujon wadi. It is clearly visible that loads are higher during winter, when precipitation and also runoff are higher. This observation leads to the conclusion that $NO_3$-N loads are mainly caused by diffuse pollution from the arable land. The model is able to reproduce high peaks, as the ones in November 2003 or April 2004 but also lower ones as in winter 2005/2006. The lowest values of $NO_3$-N for both simulated and observed loads occur during summer, when runoff is at its minimum and nutrients are barely washed away from the fields.

Ammonium loads (2nd graph in figure 4.3) do not show any influence by weather conditions, however the simulated outputs and observed data show a clear seasonality. The ammonium ion has a positive charge and is strongly attracted by negatively charged soil components and organic matter. Therefore, in contrast to $NO_3$-N, $NH_4$-N can hardly be washed away from soil. Due to this fact it can be assumed that most of the ammonium contamination in the Albujon wadi comes from the effluent of the UWTP. Depending on the stage of treatment (primary, secondary and tertiary) and the effectiveness of treatment, the $NH_4$-N share can vary between 5 and 75% of the total N concentration of the effluent. In some years (e.g. 2004) the estimated $NH_4$-N input from the UWTP matches pretty well with the observed loads. In others (e.g. 2005) it is slightly below the observed peaks during summer season. In October 2003 the model misses a winter peak, which must not necessarily be related to diffuse pollution. During storm events high amounts of waste water are transported to the UWTP. Small plants must then release the effluent untreated because the volume often exceeds their capacity. Therefore the winter peak in 2003 can have its origin in the effluent disposal as well.

Phosphate phosphorus shows a similar behavior as ammonium nitrogen. The observed loads are high during summer and low in winter. This is indicative for $PO_4$-P pollution mainly from point sources. The estimated input from the UWTP in Los Alcazares matches pretty well with the measured $PO_4$-P loads.

In conclusion it can be said that two of the three modelled water quality variables, $PO_4$-P and $NH_4$-N depend mostly on the point source input data from the UWTP, while $NO_3$-N loads depend mainly on wash-off from the fertilized cropland.

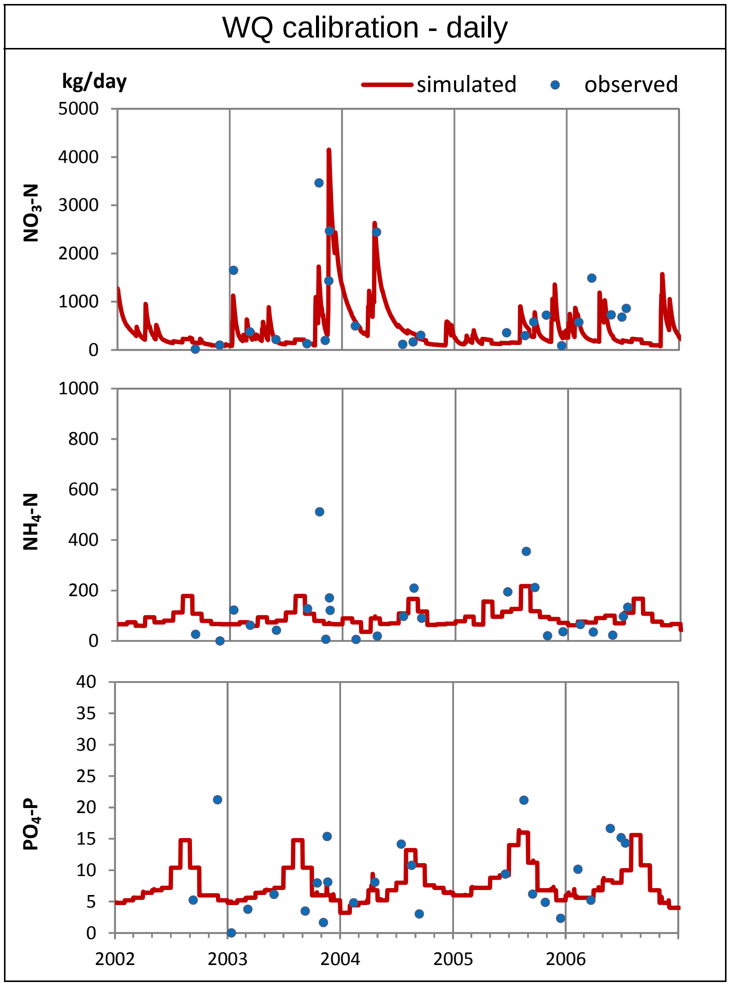



**Figure 4.3** Graphs of water quality calibration showing daily dynamics of simulated (red line) and observed loads (blue points) of $NO_3$-N, $NH_4$-N and $PO_4$-P

## 4.4. Climate impact on water flows

The impacts of climate change on water flows can be seen in the next figure (Figure 4.4.1). The upper three graphs show the average daily discharge dynamics for each of the three future periods, and the lower three graphs show differences in total water discharge between these three periods and the reference period as mean monthly values. The discharge is given as the sum of the Albujon wadi and the other six ramblas flowing into the Mar Menor lagoon. The average values of total discharge from all simulations driven by 15 climate scenarios are shown for three future scenario periods (black lines) and can be compared with the average values of the simulated Q values driven by 15 climate model runs for the reference period 1971-2000 (red lines). The outer uncertainty band (light grey) is defined by the maximum and minimum values of all the results driven by 15 climate scenarios, while the inner range (dark grey) is defined by the 25$^{th}$ and 75$^{th}$ percentiles of all the results.

During 2011-2040 the total average maximum daily discharge reaches values of 3m$^3$/s, while the maximum flow decreases to less than 2m$^3$/s for the other two future periods. The

magnitude of these numbers is of the same order as of the peak flows during the calibration period. In all three periods the highest flow can be observed during autumn-winter, from September until December. This also agrees with the seasonality observed during the calibration period. The curve of average daily dynamics for each of the scenario periods is quite similar to that in the reference period. The curve of average daily dynamics driven by the "best fitting" scenario S3 is as well quite similar to the average curve driven by 15 scenarios. The inner uncertainty band is also hardly visible in the graphs, as it is very small and close to the average curve. Therefore, differences between three periods are only visible in the winter months, when runoff clearly decreases.

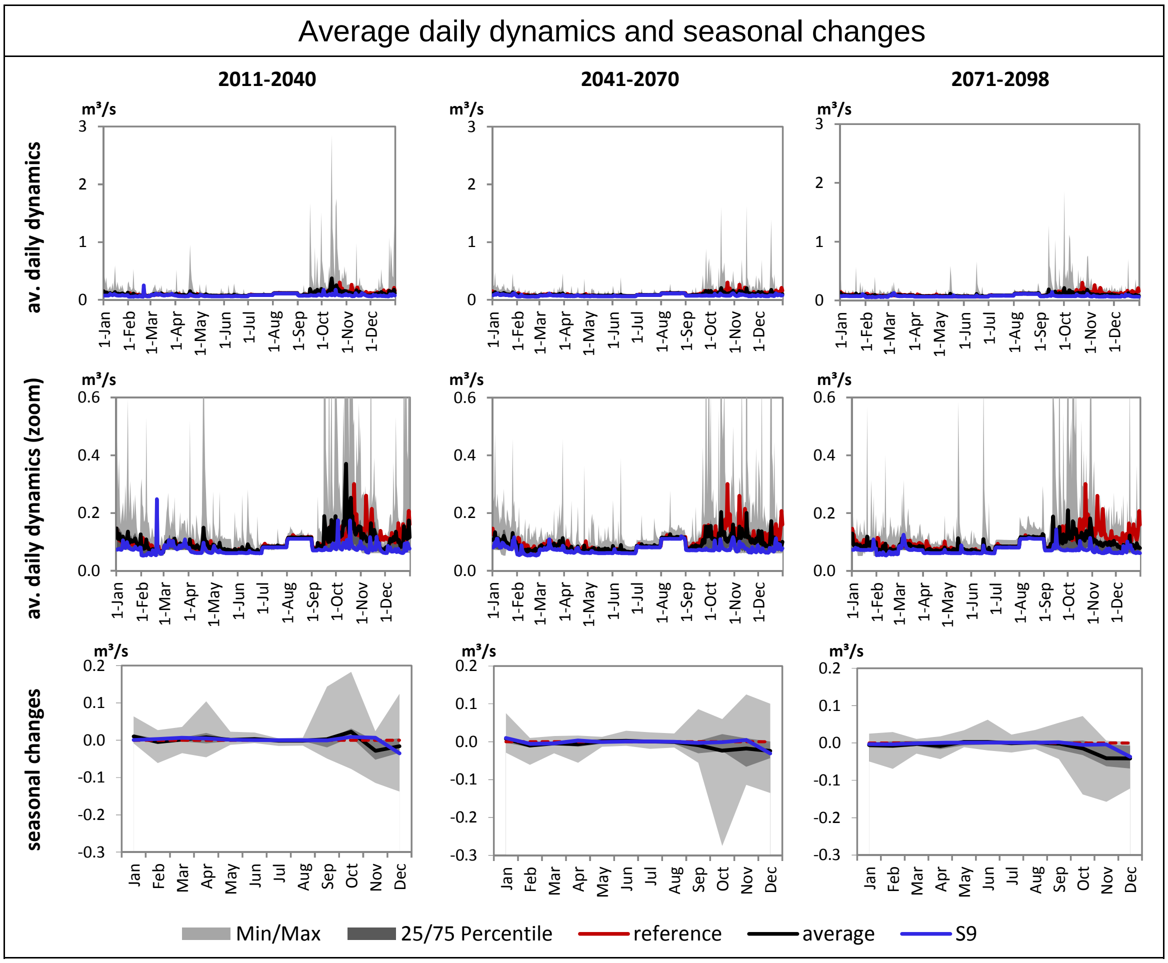



**Figure 4.4.1** Average daily dynamics and absolute changes of monthly averages for the total water inflow to the Mar Menor lagoon analysed for all 15 climate scenarios and three future periods compared to the reference period 1971-2000.

Changes in runoff become clearer when looking at the lower three graphs in figure 4.4.1. For all three periods there are scenarios which project an increase as well as a decrease in average monthly flow. For the first future period there is even a slight increase of discharge (see average curve) simulated for October. The maximum and minimum uncertainty band in September to December ranges from $0.2m^3/s$ to $-0.1m^3/s$, while for January until April it only varies between

0.1m$^3$/s and -0.5m$^3$/s. The best fitting scenario shows no visible changes for this period, except of some minor discharge reduction (<0.05m$^3$/s) in December.

For the second future period (2041-2070) more scenarios agree on a decreasing trend. The maximum projected decrease in discharge reaches -0.27m$^3$/s in October. On average a reduction of about 0.02m$^2$/s for the period October until December can be observed. The simulation driven by S9 scenario shows a small increase of discharge in January (<0.01m$^3$/s) as well as a decrease of 0.02m$^3$/s in December, and during the rest of the year no visible changes can be seen.

In the last future period (2071-2098) the uncertainty band is reduced, ranging only from 0.05m$^3$/s to -0.15m$^3$/s. The average decrease in discharge for November and December is higher than in the previous period (-0.04m$^3$/s instead of -0.02m$^3$/s).

The next figure (Figure 4.4.2) shows the spatial patterns of projected changes in precipitation, evapotranspiration, runoff and groundwater recharge in the Mar Menor catchment between the future scenario (p2, p3, p4) and reference (p1) periods. In the first step the model outputs for each scenario (S1 - S15) were averaged over the four simulation periods of 30 years. Next, a mean of all 15 simulation outputs was calculated for the reference and the three future periods. From these, differences in water fluxes between the future periods and the reference period were derived and mapped.

Average annual changes in precipitation show that projected rainfall will decrease about -5 to -14mm in the first future period (2011-2040), compared to the reference period. The decrease for the 2$^{nd}$ scenario period is about -15 to -30mm, while for the last period the decrease can reach -53mm. As the area of the catchment is relatively small and only few grid cells of the climate scenarios are situated inside the catchment the overall decrease in precipitation shows a quite homogenous pattern.

Along with a decrease in average annual precipitation there is also a decrease in average annual evapotranspiration. During the first future period in most parts of the catchment the decrease is very little, not more than -4mm. In some places there might even be a slight increase of not more than 5mm. In the second and third future periods the decrease becomes more visible. It is not so strong in the irrigated areas as water used for irrigation counteracts the reduction of precipitation. In the last period precipitation above the Mar Menor lagoon increases up to 65mm, while it decreases up to -59mm in the catchment.

The average annual runoff for 2011-2040 is almost the same as for the reference period. A reduction in runoff is hardly visible. The changes range only between 1 and -1mm/year. In the second and third future periods the average decrease of runoff in the irrigated area is about -2 to -4mm. There are almost no changes in the western part of the catchment, since this area was already one of the driest during the reference period and had nearly zero runoff. The strongest decrease in runoff can be observed on areas categorized as settlements (up to -13mm). This is due to the fact that these areas had the highest runoff during the reference period and thus a significant decrease in precipitation could result in a stronger reduction in runoff.

Groundwater recharge seems to be a bit more sensitive to climate change than runoff. A reduction in groundwater recharge of up to -4mm is already visible during the first future

period. Similar to runoff, a stronger decrease can be observed in areas where recharge was relatively higher during the reference period. On average, for the last period maximum changes of -21mm could be reached.

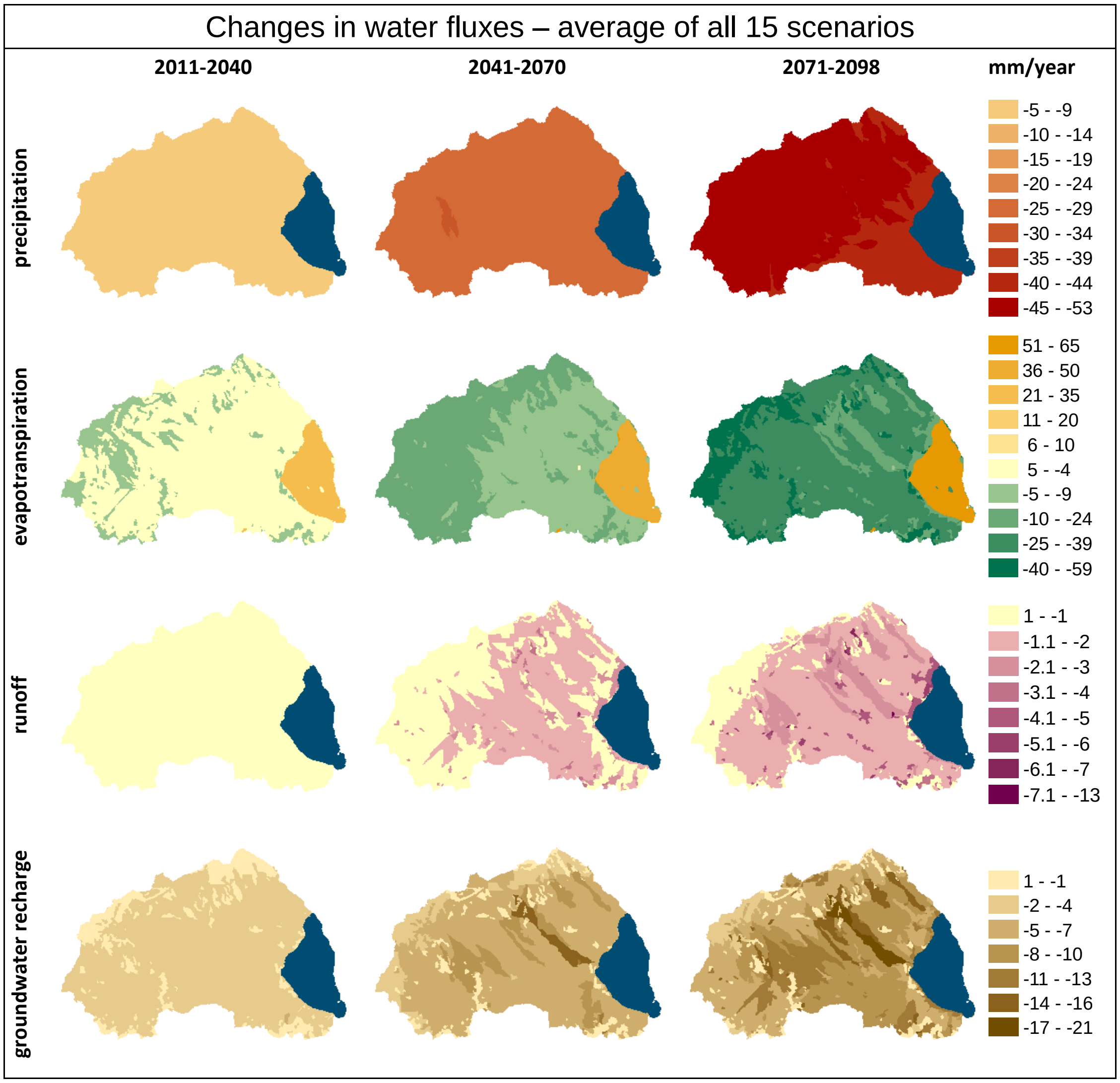



**Figure 4.4.2** Average annual changes of major water cycle components in the Mar Menor catchment calculated for the means of all 15 climate scenarios for each future period compared to the reference period.

## 4.5. Climate impact on water quality

The results of climate impact assessment on water quality are presented in next figure (Figure 4.5.1) showing the average daily dynamics of total daily nutrient input to the Mar Menor lagoon as well as average DOX concentrations and water temperatures of Albujon wadi and all ramblas draining to the lagoon for three scenario periods.

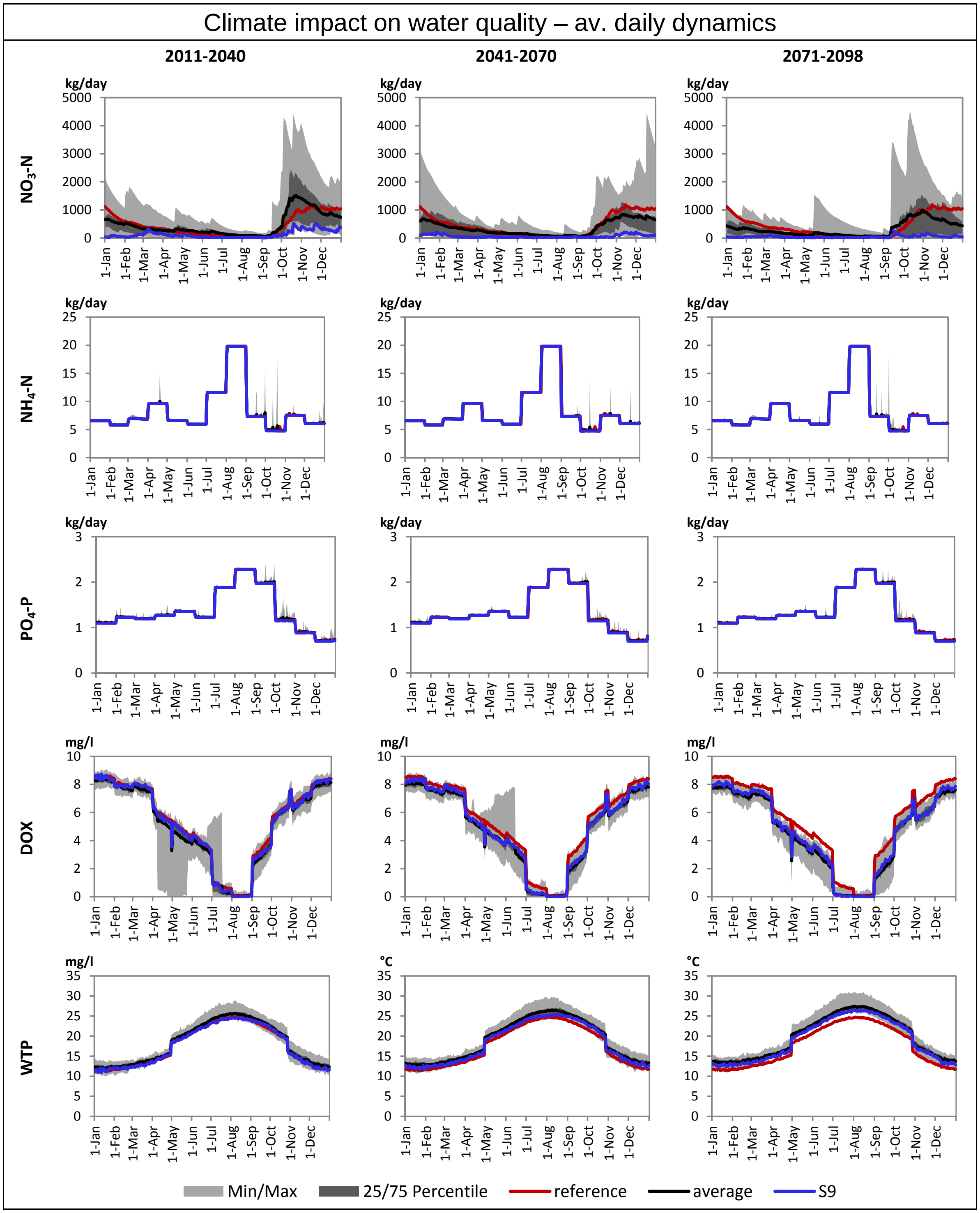



**Figure 4.5.1** Average daily dynamics of water quality parameters for each future period.

On average, total daily input of nitrate nitrogen to the lagoon for 2011-2040 is likely to increase during October compared to the same time of the reference period (compare first graph). This observation corresponds to higher average daily discharge observed for the same period during

the hydrological impact assessment. Maximum values of about 4000kg N/day could be reached, while the maximum average of all scenarios is about 1500 kg N/day. The simulation driven by S9 scenario projects very low daily loads, below the average and even below the 25$^{th}$ percentile. During the second and third future periods nitrate loads decrease compared to the reference period and the average maximum value does not exceed 1000 kg N/day.

The average daily dynamics of ammonium nitrogen and phosphate phosphorus do not show any notable changes. Both variables mostly depend on the input data from the UWTP and hardly on the climatic conditions in the catchment (only via effects on water discharge).

Changes in dissolved oxygen concentrations and water temperature should be interpreted with caution since neither of both was calibrated for the catchment. The average daily dynamics of DOX reveal that concentrations could drop down to 0.01mg/l during summer. This value is the result of very high ammonium concentrations during the summer season, which in a sense is logical but still unrealistic. The average daily dynamics also show that all scenarios agree on decreasing concentrations for the last future period.

Looking at the average daily dynamics of water temperature one can see that it stays nearly constant during 2011-2040. An increase can be observed for the two next periods. The increase as well as the uncertainty range regarding the maximum values is higher during summer than during winter.

The following figure (Figure 4.5.2) shows the average seasonal changes of total monthly nutrient inputs to the Mar Menor as well as changes of average monthly DOX concentrations and water temperatures calculated as means for all lagoon tributaries for three scenario periods compared to the reference period.

Average changes of monthly $NO_3$-N loads to the lagoon are mostly visible during the rainy season and less during summer. For 2011-2040 monthly loads may increase by max 2500 tonnes in October, while the average increase for this month is only about 300 tonnes. In December and January there is a slight decrease of -300 tonnes. During the rest of the year, no changes in monthly loads are visible. For 2041-2070 and 2071-2098 most scenarios agree on the decreasing $NO_3$-N loads to the lagoon as winter precipitation also decreases. On average Ammonium nitrogen and Phosphate phosphorus show almost no changes for any of the future periods. However for $NH_4$-N some scenarios project changes of +/- 10% for the months September – December. The maximum changes in $PO_4$-P loads for the same period vary only between +/-5%. For the last future period there is even a clear decrease by an average value of 2% during September – December.

The changes in DOX concentrations increase with each scenario period as temperature rises. The changes in summer are the smallest or close to zero, since during this time simulated concentrations are also close to 0. Water temperature increases by a bit less than 1°C during the 2011-2040. The uncertainty band becomes thicker for the second and third future periods with changes ranging between 1 and 4°C. Most of the time the changes of the simulation driven by S9 scenario are lower than the average changes, but still within the 25$^{th}$ and 75$^{th}$ percentiles band of all scenarios.

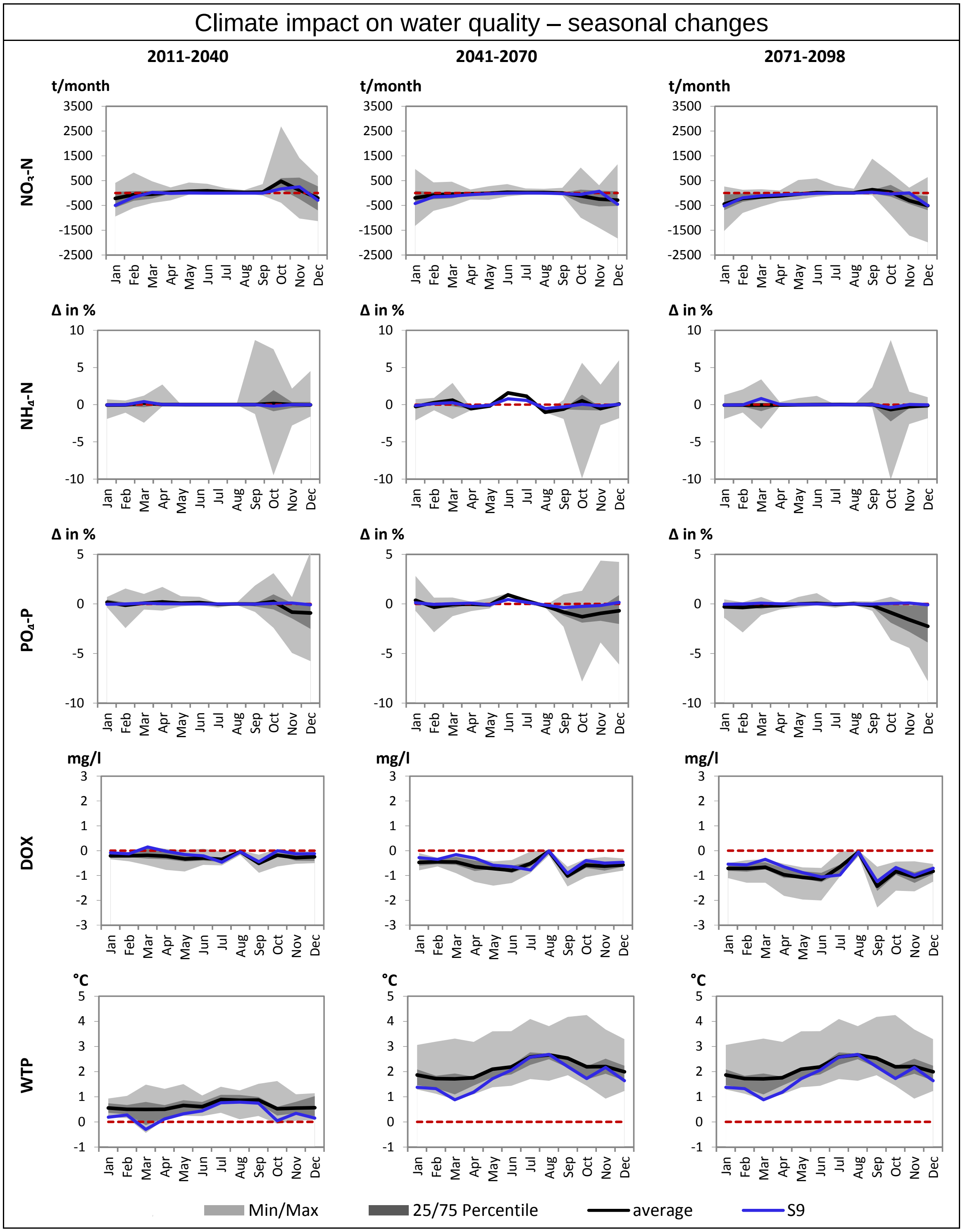



**Figure 4.5.2** Average seasonal changes of water quality parameters for each future period compared to the reference period.

## 4.6. Summary and conclusions

In conclusion we can state that the average projections for Mar Menor driven by 15 scenarios (Figure 4.6) show a moderate decrease of average daily discharge to the lagoon by 5% during

the last three decades of the century. For the near future (1st and 2nd future periods) the scenario do not agree on a common trend. An increase of 2 to 7% goes along with a reduction of -5 to -12%. The uncertainty towards for the 3rd future period becomes higher, however most scenarios project a reduction up to -18%. Although the uncertainty of results driven by 15 climate scenarios for each period is quite large on average, a clear decreasing trend in daily discharge can be observed.

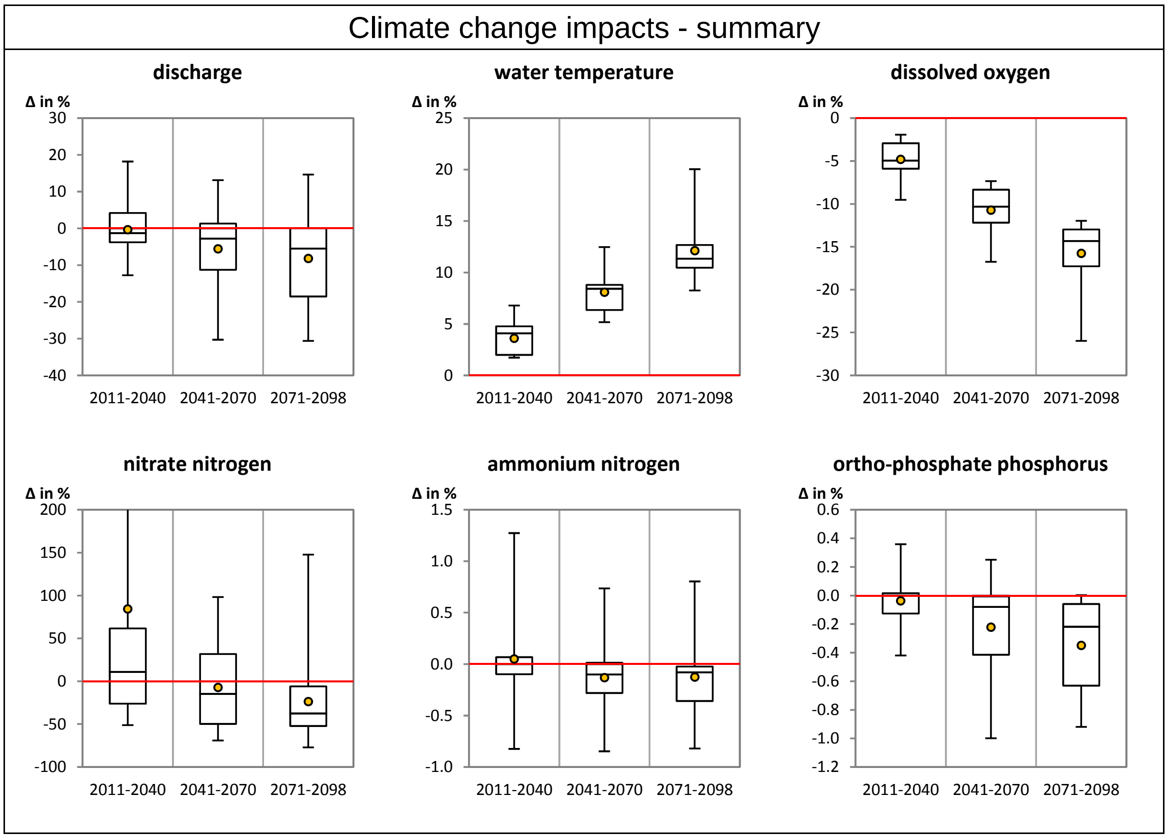



**Figure 4.6** Relative changes of average daily total discharge and nutrients input to the lagoon, as well as of average water temperatures and DOX concentrations for each of the three future periods compared to the reference period.

The trend in water temperature is even clearer. All scenarios agree on increasing temperatures. Towards the end of the century an average increase of ca. 2°C is projected.

Dissolved oxygen concentrations show a decreasing trend. A decrease of - 15% towards the end of the century means in real values a change of only -0.1mg/l.

Average daily $NO_3$-N loads show a different picture. During the first future period an average increase of about 15% is projected. Some scenarios cause increases of about 50%, and one scenario is even responsible for changes up to +800%. This increase is caused by single occurrence of very high winter precipitation, which leads to a strong effect of diffuse pollution from fertilized soils. The disagreement between scenarios becomes smaller for the 2nd and 3rd future periods, where most scenarios project a decrease in daily loads of about 20%.

On average, ammonium nitrogen is getting reduced only very little. During the first period most scenarios even agree on minor changes between -0.1 and 0.05%, which on average means no changes at all. For the second and third periods an average reduction of $NH_4$-N loads of about 0.2% is projected.

The relative changes in phosphate phosphorus are the smallest of all variables. Similar to $NH_4$-N loads on average there are no changes of $PO_4$-P daily loads during the first future period. There are some little changes of -0.06 and -0.2% for the 2$^{nd}$ and 3$^{rd}$ periods, and also the uncertainty increases in these two periods.

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