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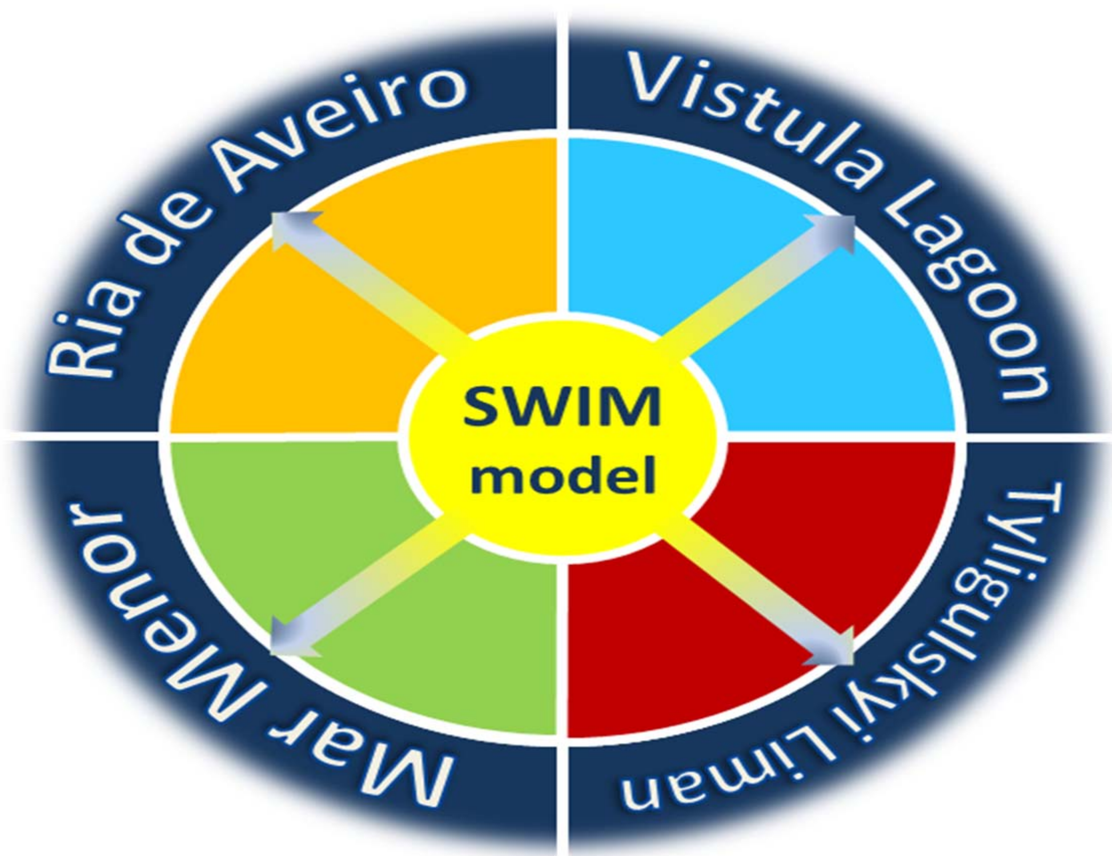
Results of climate impact assessment

Application for four lagoon catchments



Title Results of climate impact assessment – Application for four lagoon catchments
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5. Tyligulskyi Liman

5.1. Case study description and data preparation

Topography, land use, soils and climate characteristics

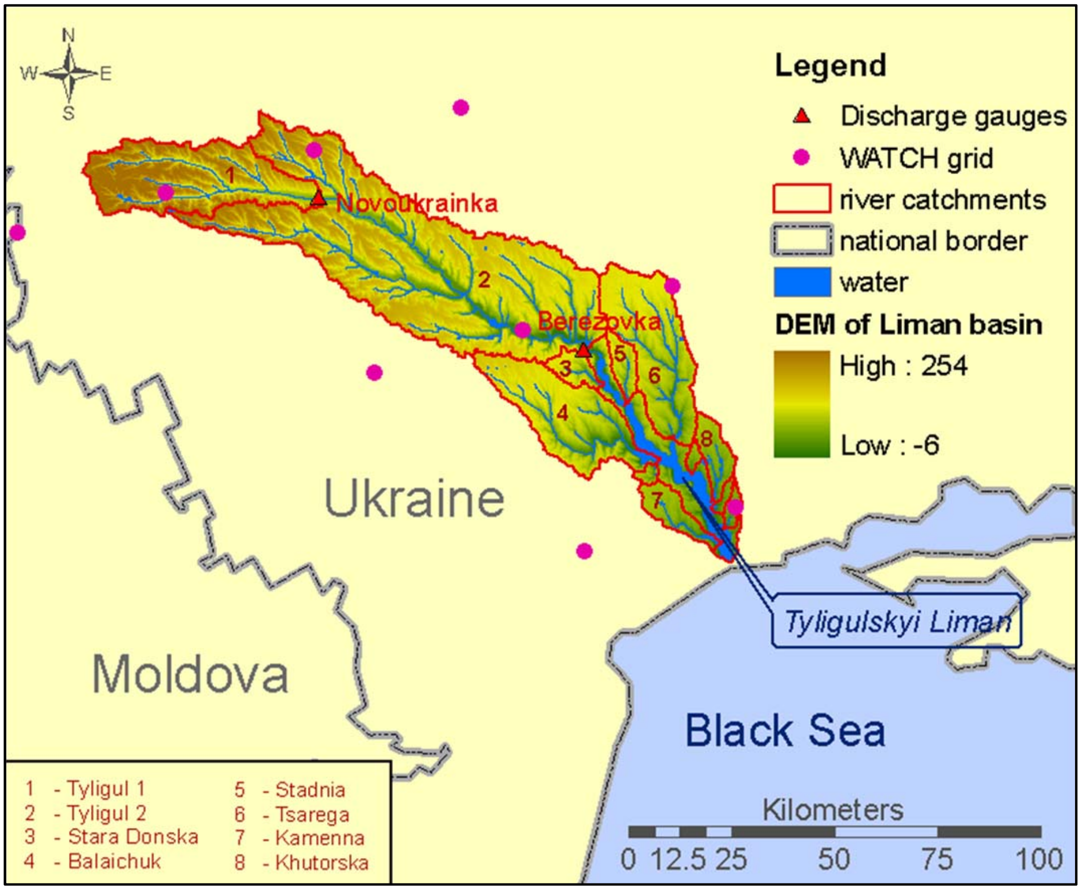


Figure 5.1.1 Overview of the Tyligulskyi Liman catchment: Digital Elevation Model (DEM), national borders, major sub-catchments (numbered), river courses, discharge gauges with available data, as well as WATCH grid points for climate interpolation.

The drainage basin of the Tyligulskyi Liman (local name for the lagoon) covers an area of about 5240 km^2 with an altitude ranging from -6 to 254 m a.s.l. according to the Shuttle Radar Topography Mission data (SRTM) (see Figure 5.1.1). 3550 km^2 of the total basin area form the basin of the main inflowing river Tyligul flowing from the Northwest. This river has a length of about 170 km. Other main water courses entering the lagoon are Balaichuk from the West and Tsarega from the East.

A large proportion of the total discharge of the rivers in this region is generated by spring flooding, but in August nearly all rivers dry out partially or completely (Jaoshvili, 2002). In general, it is quite usual to have no discharge in late summer in rivers of this district, and in most cases the duration of zero discharge increases with an increase in water collection area, as a considerable part of the discharge is expended along the river on evaporation and infiltration

and cannot be compensated by the runoff formed in the upper part of the basin (Shvets, 1961). Similar observations exist also for the rivers in the Tyligulskyi Liman catchment as mentioned by LAGOONS (2012a).

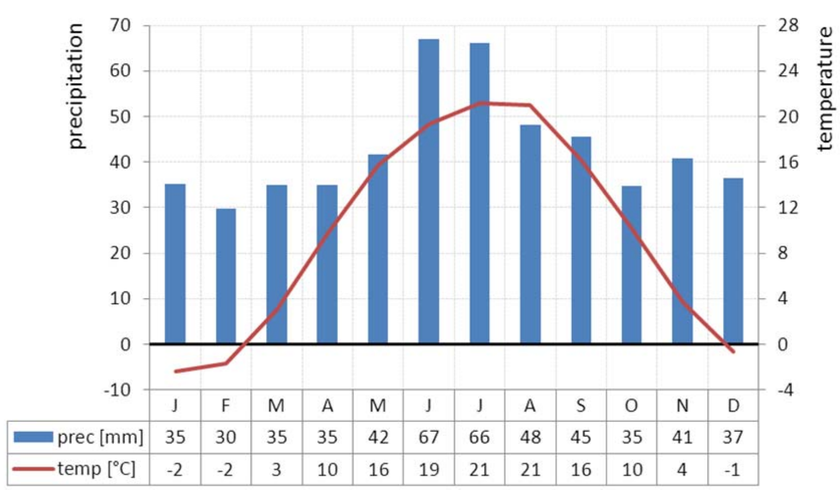
Measurements of river discharge within the Tyligul drainage area are available for two Tyligul discharge gauges located in the basin: Novoukrainka in the upstream part (only period 1984-1988) and Berezovka downstream the river, just before entering the Liman (periods 1984-1988 and 1998-2007). Data from these gauges also reveal this typical seasonal river behaviour as described above. While positive values of discharge are always measured in the upper gauge, the lower river part shows long time periods within a year with no flowing water (see Figure 5.1.5 left).

Watershed delineation by the GIS software MapWindow using the Digital Elevation Map (DEM) of SRTM created a map with 175 subbasins, which was used for the model set-up.

The density of climate stations with available climate measurements for the Tyligulskyi Liman catchment was very low (4 climate + 2 precipitation stations), and neither of them was located within the catchment of the Berezovka gauge. In addition, analysis of available real data showed only a weak conformance between measured precipitation at the stations around the river basin and observed discharge in the Tyligul river. Therefore, it was decided to use a GPCC-corrected WATCH climate forcing data set (WFDEI) covering the period 1979-2009 (Weedon et al, 2011; Schneider et al, 2013) to run the model for hydrological and water quality calibration and validation.

Figure 5.1.2 depicts monthly temperature and precipitation averaged for the whole basin. The winter months show temperatures below zero and moderate precipitation, the summer months are characterized by average temperature above 20°C and higher observed precipitation. On average, annual precipitation reaches 515 mm per year, and the average temperature is 9.7°C.

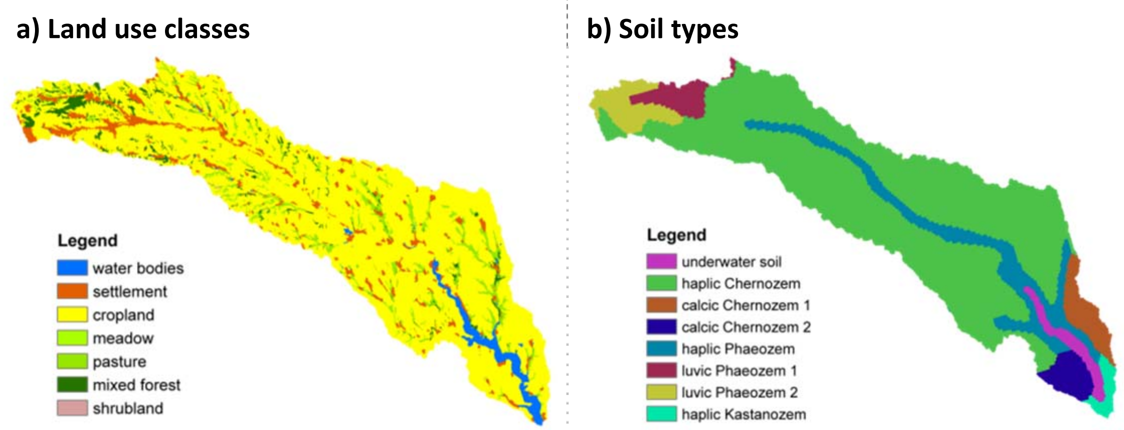
Figure 5.1.2
Climate chart for the Tyligulskyi Liman basin calculated as average monthly values using WATCH data for the period 1979-2009.



For setting up the SWIM model, two additional maps with spatial information are needed: distribution of land use categories and soil types (see Figure 5.1.3). As no general digital land

use map with sufficient resolution and information was available for the Ukrainian catchment, the land use map was digitized by PIK using a scanned paper map of this region delivered by the project partners from this case study area. This resulted in a map with a high percentage of agricultural area (89%), which corresponds to values on cropland percentage in this region mentioned in the LAGOONS report (2012). Only a small part of the basin is covered by forests (4%), and grassland occupies only 7% of the study area.

According to the analogue data source provided by the project partners from Ukraine, quite high share of the catchment area is assigned to settlements. Taking into account the economic and social conditions in this rural area, it was assumed that these settlements behave more like grassland and garden with a high water infiltration and evaporation potential, than like cities with a high share of impermeable soil cover. Most of the settlements are villages and recreation sites with a high proportion of garden area. That is why these areas were defined as grassland on the land use map for the modelling.



Land use category	[%]
Water	3.0
Settlement	7.1
Cropland	79.6
Grassland, extensive use (meadow)	0.03
Grassland, intensive use (pasture)	6.7
Forest mixed	3.5
shrubland	0.03

Main soil type	[%]
Underwater soil	2.4
Haplic Chernozem	70.2
Calcic Chernozem	6.5
Haplic Phaeozem	11.6
Luvic Phaeozem	7.7
Haplic Kastanozem	1.5

Figure 5.1.3 Spatial distribution of land use classes (a) and soil types (b) within the Tyligulskyi Liman catchment for the reference conditions. These maps were used for setting up the SWIM model and preparation of SWIM input files.

Soil map and soil parameterisation were derived from the HWSD data as described in section 2.2. In general, the catchment of the Tyligulskyi Liman is characterized by very fertile soils. Chernozems (77% of the total catchment area) as well as phaeozems (19%) belong to the most productive soil types in the world with surface layers rich in humus and available calcium ions bound in soil particles, resulting in a very permeable, well-aggregated structure. The chernozem surface layers can be two meters thick, with up to 16% humus (http://www.britannica.com). While chernozems occur in regions with annual rainfall of 450-600 mm, phaeozems are usually found in associated areas but with more than 550 mm rainfall per year. Accordingly, the most

common natural vegetation on chernozems is grassland (tall-grass or steppe), whereas forests can be naturally found on the phaeozem soil type. This pattern of soil, climate and vegetation conditions could also be detected in the Tyligulskyi Liman study area.

During SWIM model set-up spatial information on subbasin distribution, land use patterns and soil type composition has to be overlaid to form a hydrotope map. Hydrotopes are the smallest spatial units in SWIM modelling and are defined as sets of units within one subbasin with the same land use and soil class. It is assumed that they behave in the same way regarding hydrological, nutrient and vegetation processes. For the Tyligulskyi Liman catchment 920 hydrotopes have been delineated.

Land and water management (nutrient emissions, fertilization and water use)

As no detailed information on location and amount of single point sources within the catchment was available, anthropogenic nutrient inputs to the Tyligulskyi Liman catchment were calculated according to the average population density per administrative unit in the basin. The administrative data were extracted from the GADM database (www.gadm.org) and downloaded via internet. The population density values were found in the internet, too, (http://en.wikipedia.org/wiki/Raions_of_Ukraine) and are depicted in Figure 5.1.4 together with the calculated human induced nutrient emissions per day accumulated for administrative units (assuming of 5.5 g N/day and 1.2 g P/day per capita).

As mentioned in the LAGOONS report (2012a) the used water in the catchment is discharged into the Tyligul river without any treatment, hence 76% of the nitrogen emissions and 88% of the phosphorous emissions were assumed to reach the river network (HELCOM, 2012). For SWIM modelling these values were overlaid with the subbasin map to calculate the resulting nutrient loads per day for every subbasin to represent point source nutrient pollution in the catchment. As more detailed information on point source pollution was not available, these values were introduced to the model as constant values over the whole simulation period. According to these estimates, in total 750 kg N/day and 190 kg P/day are added by point sources to the Tyligulskyi Liman river network at the reference conditions. During the modelling the total nitrogen (TN) and total phosphorous (TP) values had to be divided into the different nutrient forms used in the model. It was done using the following assumptions: TN/3 → NO_3-N, TN/6 → NH_4-N, TN/2 → N_{org}; 0.6*TP → PO_4-P, 0.4*TP → P_{org}.

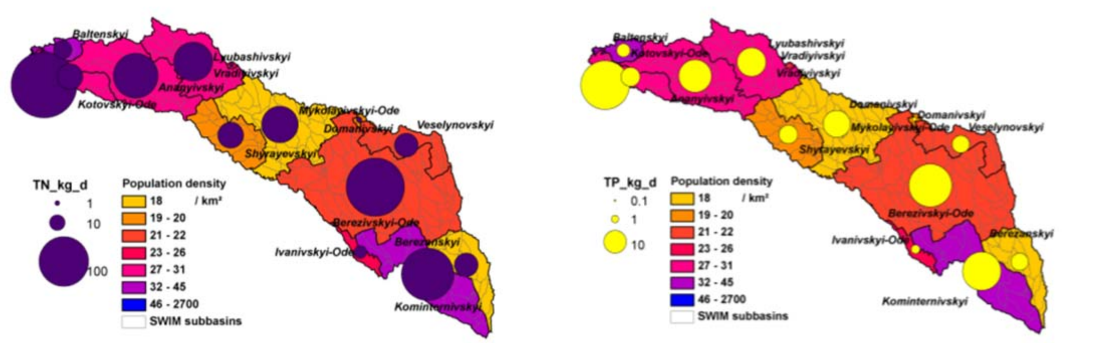


Figure 5.1.4 Estimated anthropogenic nutrient emissions (TN, TP) in the Tyligulskyi Liman catchment calculated using the average population density per administrative unit and their percental shares within the catchment.

To represent diffuse nutrient pollution influencing water quality in the river and in the liman crop management and fertilization data are important. As the standard version of SWIM allows only one crop species to grow on agricultural fields it was chosen to cultivate winter wheat, as it is the main crop in the region (LAGOONS, 2012a).

Nowadays, the amounts of used fertilizers in the Tyligulskyi Liman catchment are low, due to the naturally very fertile soils as well as high costs of mineral fertilizers and actual economic conditions in Ukraine (FAO, 2005). In general, livestock farming and applied fertilization amounts have been dramatically reduced after political reorganization around 1990 in this region (FAO, 2005, 2006), which can also be seen in water quality observations showing an obvious positive trend, especially for the nitrogen forms, and quite low nutrient concentrations in the beginning of the 21st century. Amounts of mineral fertilizers per hectare applied to different parts of the Tyligul river basin are listed in the LAGOONS report (2012a) and show an average value of 16 kg/ha in total, whereof 9.8 kg/ha nitrogen and 2.4 kg/ha phosphorous applied on arable land. Therefore, fertilizer amounts used for modelling the reference conditions in the Tyligulskyi Liman catchment with SWIM (Table 5.1.1) are relative small compared to other European regions and LAGOONS case studies.

Day	N_{min}	N_{org}	P_{min}
95	7	3	3
300	4	2	
Sum per year	**11**	**5**	**3**

Table 5.1.1
Fertilization dates and amounts (kg ha^{-1}) used for SWIM modelling in the Tyligulskyi Liman catchment.

The natural conditions of the Tyligul river are significantly influenced by water management measures. As described above, the measured discharge behaves quite unnatural: in low flow periods there is lower river discharge at the downstream gauge Berezovka than at the upstream gauge Novoukrainka. For quite long periods in summer the measured discharge at the Berezovka gauge is even $0 m^3/s$. Only during the high peaks observed at the downstream gauge during flood events the discharge downstream exceeds that measured upstream (Figure 5.1.5, left).

It can be assumed that a high share of naturally produced discharge “disappears” during the water passage through the basin. This is most likely due to a high evaporation potential of this region, but also due to intense water management measures implemented in the catchment. According to information from the case study partners, there are many small artificial reservoirs (ponds) constructed within the river network of the basin. They intercept the runoff working as huge evaporation basins (LAGOONS, 2012a), and are mainly used for the fish farming. The influence of the ponds on river discharge is more pronounced with the increasing river length, as can be seen by comparing the percental shares of average measured discharge, pond volumes and irretrievable use of the two drainage areas corresponding to the two gauges (Figure 5.1.5, right).

These quite unnatural discharge conditions and anthropogenic effects on natural hydrological cycle hinder standard hydrological modelling with SWIM, as well as with any hydrological model. Taken together with the quite poor availability of observational data:

- o measured discharge of the less influenced river gauge Novoukrainka is available only for the period of five years 30 years ago;
- o real measured climate data with many gaps and only outside of the basin;

the modelling of this catchment with SWIM was a very difficult task. The catchment has to be treated as almost an ungauged basin significantly affected by humans.

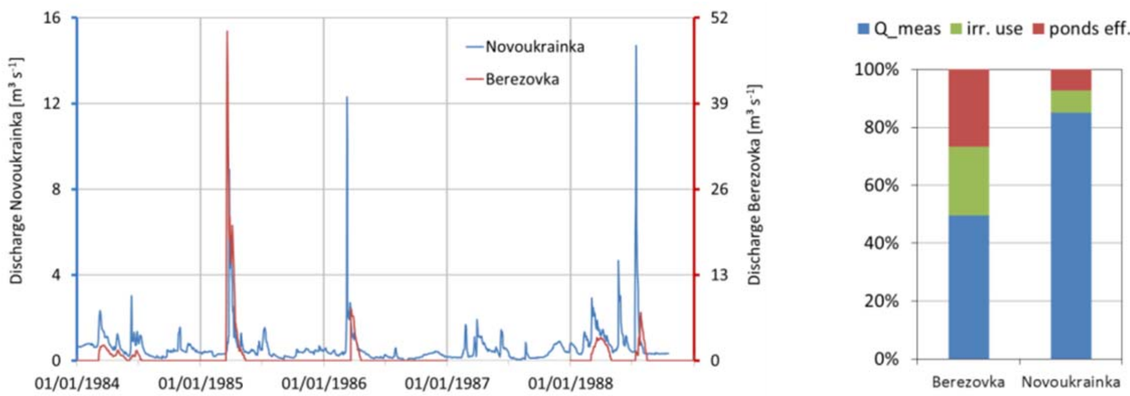


Figure 5.1.5 Analysis of observed discharge data at two Tyligul river gauges: comparison of daily measures discharge in the period 1984-1988 (left), and average data on discharge, irretrievable use and effective pond volume upstream of the two gauging stations in percent of their sum for the period 1984-1988 (right).

Table 5.1.2 Water management data used for setting up the SWIM model to calculate hydrological reference conditions in the Tyligulskyi Liman catchment. Data for the Tyligul river basin were delivered by the LAGOONS project partners, data on three additional rivers flowing to the Liman (1, 3, and 10) were calculated by using information found in the LAGOONS report (2012a). Management zones were assumed according to the river kilometres indicated in the data set. The data were calculated per km² for every management zone and then used to calculate the specific management impacts per subbasin as a part of the management zone.

	Management zone *River (km)*	Area *km²*	Irretrievable use *1000 m³ y⁻¹*	Ponds eff. volume *1000 m³*
1	Balaichuk	584		1925
2	Dubova	193	400	825
3	Khutorska	112		429
4	Liman	729		
5	Lipetska (0-11)	124	100	
6	Lipetska (11-38)	153	120	300
7	Melanka	208	1050	500
8	Slipukha	183	550	480
9	Tartakai	143	600	1280
10	Tsarega	622		2963
11	Tyligul (0-47)	530	3216	4000
12	Tyligul (47-84)	262	1436	117
13	Tyligul (84-104)	212	1848	2600
14	Tyligul (104-145)	378	1379	824
15	Tyligul (145-159)	103	125	1300
16	Zhuravka (0-12)	157	554	
17	Zhuravka (12-44)	288	117	100
18	Zhuravka (44-93)	256	310	970

It would be impossible to simulate the observed discharge at the Tyligul gauge Berezovka reasonably without adjusting the model code and implementing the massive management measures in the basin. The irretrievable use of water listed per river section of the Tyligul river and its main tributaries was delivered by the project partners (see Table 5.1.2) and could be considered via simple water extraction from ground water resources in the model. The amount of subtracted water per subbasin was calculated by the ratio of subbasin area to previously defined management areas. The calculated water abstraction per km^2 and management zone can be found in Figure 5.1.6 (left).

Even more difficult was the implementation of the pond volumes and their management in the catchment. As a first step, it was done in a similar way as described before by calculating the share of pond volumes per subbasin located within the special management zone. The pond's effective volumes per square kilometre of every management zone are shown in Figure 5.1.6 (right). The ratio of subbasin area to management zone area defines the final effective pond volume per subbasin. Then it was assumed that flowing water in the subbasin firstly fills the ponds. Then the difference between the actual water amount in the subbasin and the defined effective pond volume of the same subbasin was used to calculate water flow to the next downstream river reach. Stored water in the ponds is subject to evaporation and seepage, so that the ponds could be filled again in the case sufficient discharge water is available. When the actual pond volume is below the defined effective volume, the discharge to the next river reach is set to zero.

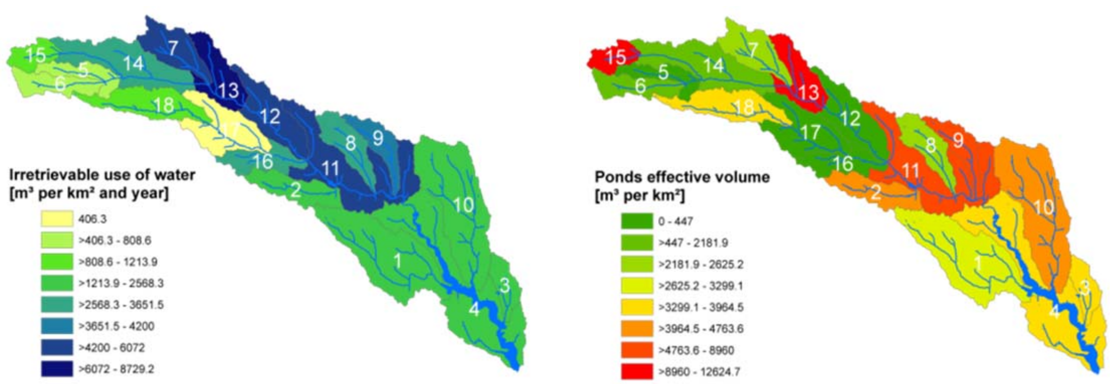


Figure 5.1.6 Water use and management per management zone as implemented in SWIM for the reference conditions of the Tyligulskyi Liman catchment. The values per km^2 were used to calculate the management effect per corresponding SWIM subbasins. The numbering of the management zones can be found in Table 5.1.2.

Such massive water storage in the basin also influences nutrient loads transported by the river. In case all water was filled to a pond without any outflow, the nutrient loads were set to 0, too. In times of partial outflow from the ponds to the downstream reaches, the nutrient loads were diminished accordingly by keeping the previous nutrient concentration.

There were some regions around the Tyligulskyi Liman where no information about irretrievable water use or pond volume per square kilometre was available. For these regions the average value of all other defined regions was assumed.

5.2. Hydrological calibration and validation

As a first step of hydrological calibration of SWIM in the Tyligulskyi Liman catchment the simulated potential evapotranspiration was calibrated and compared to measured values delivered by our Ukrainian project partners from Odessa. In contrast to the standard SWIM version (where the Priestley-Taylor-method is used) potential evapotranspiration *PET* for the Tyligulskyi Liman catchment was calculated using the Turc-Ivanov approach as a function of temperature (*T*) and solar radiation (*Rad*) for temperatures above 5°C, and temperature (*T*) and air humidity (*Hum*) for temperatures lower than 5°C (Wendling and Müller, 1984):

$$PET_{turc} = 0.0031 * omega * (Rad + 209.4) * T / (T + 15) \qquad (T > 5°C)$$

$$PET_{turc} = 0.000036 * (25 + T)^2 * (100 - Hum) \qquad (T \leq 5°C).$$

The term *omega* describes monthly correction factors, which were slightly adjusted, compared to those correction factors derived for middle Europe and found in literature (Glugla, 1989). The potential evapotranspiration values calculated in this way were then multiplied by a land-use specific correction factor *corn* to get the final values:

$$PET = corn * PET_{turc}$$

Correction factors used for SWIM in the catchment under study are listed in Table 5.2.1.

With this method it was possible to reproduce the measured long-term mean monthly evaporation data originating from the surface of a reservoir located close to the study area. The observed evaporation data cover the period 1960-2007, and were compared with the monthly averages of SWIM-simulated potential evapotranspiration for the case study site within the period 1979-2009. The average monthly evaporation values could be reproduced by the model. The observed maximum value in July as well as the minimum in winter were simulated quite well (Figure 5.2.1). After this calibration of the evaporation process in the basin no changes in evaporation correction parameters were made during the further hydrological calibration process.

Table 5.2.1 Monthly correction factors (*omega*) used for calculating the potential evapotranspiration according to the method of Turc-Ivanov found in literature (Glugla, 1989) and those finally used in the hydrological modelling of the Tyligulskyi Liman catchment with SWIM (above), as well as correction factors on land use (*corn*) implemented in SWIM (below, only land use classes used in the Tyligulskyi Liman catchment are listed).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
omega_Lit	0.70	0.85	0.95	1.05	1.25	1.15	1.05	0.95	0.90	0.80	0.75	0.70
omega_SWIM	0.70	0.85	0.95	1.05	1.05	1.10	1.15	1.25	1.05	1.00	0.75	0.70

Land use class	Water	Settlement	Cropland	Meadow	Pasture	Mixed forest	Shrubland
corn	1.3	1	0.9	1	1	1.14	1

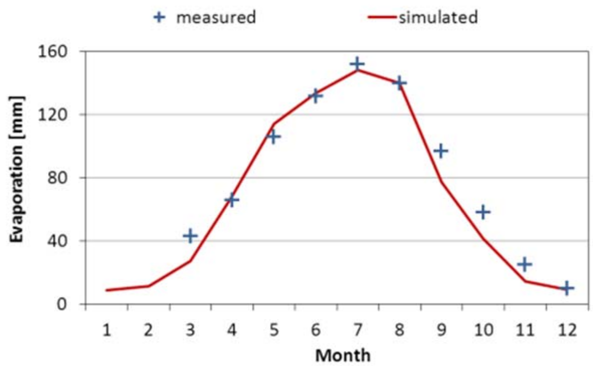


Figure 5.2.1
Comparison of measured and simulated evaporation (mm) for the Tyligulskyi Liman catchment (measured: monthly mean evaporation from surface of a fresh water reservoir 1960-2007, simulated: monthly mean potential evapotranspiration in the catchment averaged for 1979-2009).

During the hydrological calibration of the SWIM model data from both gauges located at the Tyligul river, Novoukrainka and Berezovka, were used for comparison of the measured and simulated data, with more emphasis on the last gauge Berezovka, which is most important for the assessment in this LAGOONS case study region.

Figure 5.2.2 shows daily river discharge simulated at gauge Berezovka for all time periods with available measured data. After implementation of all water management measures according to the method described in the previous section, the SWIM model was able to reproduce the measured discharges quite satisfactory. At least, times without observed discharges were also simulated, and two large observed peaks resulting from snow melt processes in the basin could be matched as well. Looking at the long-term average daily discharge at the gauge Berezovka (Figure 5.2.2, right) one can see that the model results with the Nash-and-Sutcliffe efficiency of 0.86 and the deviation in discharge balance of 0.1% are acceptable.

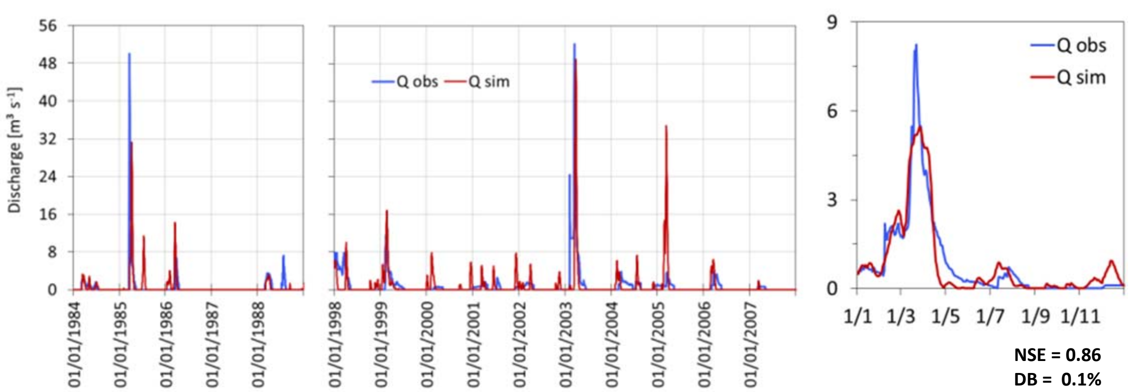


Figure 5.2.2 Comparison of observed and simulated daily (left) and long-term average daily discharge (right) at gauge Berezovka achieved with SWIM model after implementation of available water management information.

A comparison of the observed and simulated monthly average discharges at the gauge Berezovka can be seen in Figure 5.2.3. Here again, most of the months with the observed water discharge could be matched by the model sufficiently well.

It is interesting to see the influence of the implemented management measures on the model results. For this reason the model was additionally run two times: 1) without the implemented ponds and 2) without any management (ponds and irretrievable use) by using the same

calibration parameter set. The comparison of results can be seen in Figure 5.2.3, too. In case no water management is considered during the modelling, there are no periods without discharge, and the river discharge is notably higher than that with water management. The influence of ponds on water discharge is obviously more significant than the consequences of irretrievable water use. As it is hardly possible to estimate real natural discharge flowing to the Tyligulskyi Liman, it is difficult to decide whether this strong influence of implemented pond management meets the real conditions or whether those management impacts are overestimated by the model.

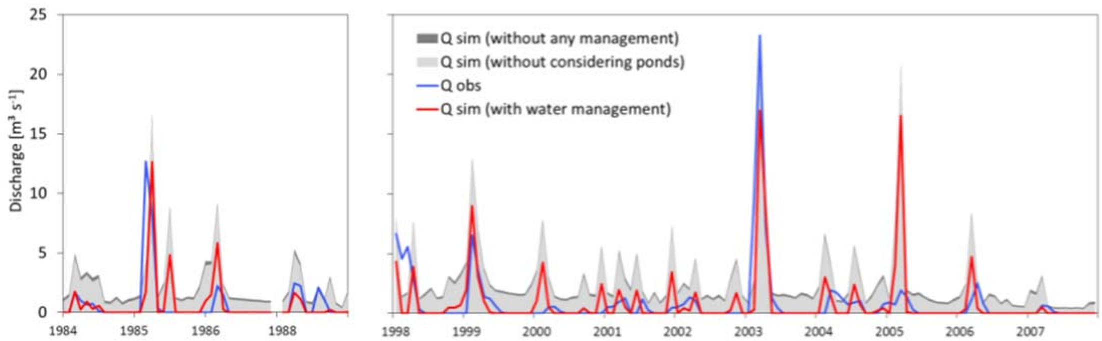


Figure 5.2.3 Observed (blue) and simulated (red) monthly average discharge at gauge Berezovka with implemented water management data (irretrievable use and ponds), and simulated discharge in the conditions when one or both management measures are switched off (grey areas).

In addition, the long-term monthly average simulated and observed discharges were compared for both gauges, Berezovka and Novoukrainka, also in comparison with two options when management is switched off (Figure 5.2.4). Results in terms of model performance show a good agreement of the modelled and observed seasonal discharge dynamics, with some better results at the downstream gauge. It can also be seen, that the influence of water management measures is higher in the downstream part than in the upstream part, which corresponds to literature and data described in section 5.1.

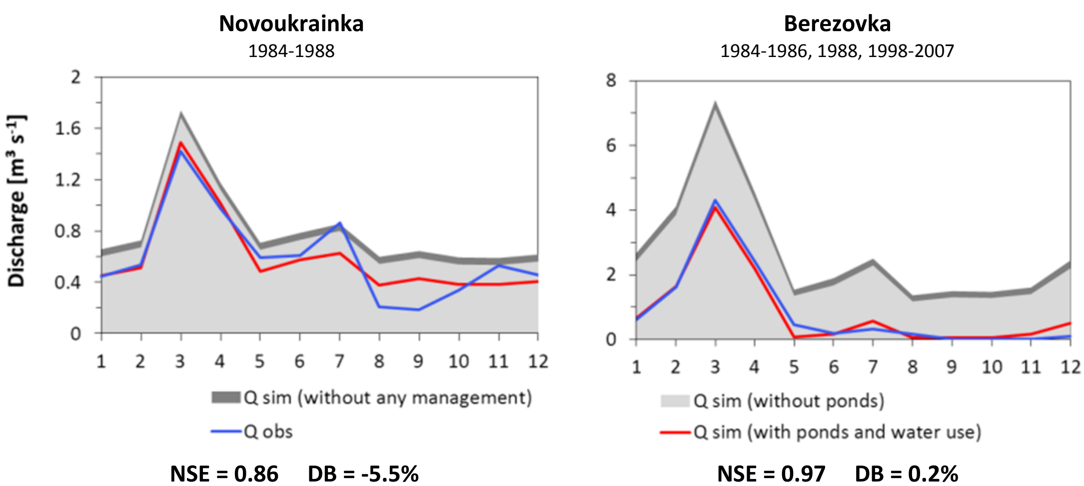
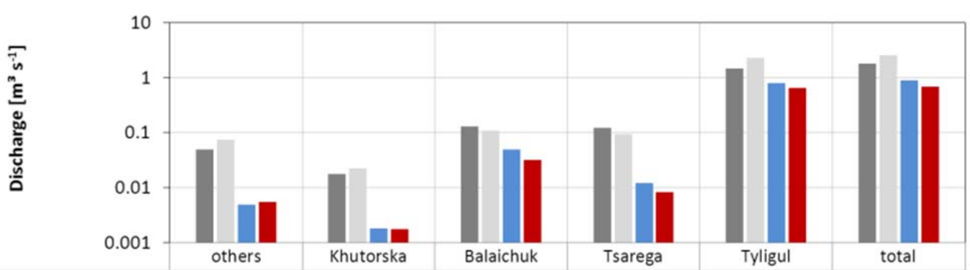


Figure 5.2.4 Comparison of the observed (Q obs) and simulated (Q sim) long-term average monthly discharges at the gauges Novoukrainka and Berezovka averaged for time periods with available measured discharge data. Grey areas show the potential influence of implemented water management on the simulated results. The model performance was calculated only for the fully managed monthly discharges.

As last step for hydrological calibration of the Tyligulskyi Liman catchment, a comparison of simulated and average literature discharge values was performed for the four larger rivers flowing to the Liman and the total inflow. The literature values were taken from the LAGOONS report (2012a), where some information on recent real and estimated natural discharges expectable for rivers of this area without anthropogenic impacts on the water cycle was found. The data are given for the total inflow to the Liman as well as for the separate inputs from the Tyligul, Tsarega, Balaichuk and Khutorska rivers to this water body. The natural flow values cited in literature were compared with the SWIM model results achieved without implemented water management measures, and the mentioned above long-term average real inputs of the period 1953-2007 were compared with the average SWIM values for the period 1980-2009.

Figure 5.2.5 (using the logarithmic scale) shows the results of this analysis. It can be seen that a bulk of water input to the Tyligulskyi Liman comes from the Tyligul river. The measured real average discharge values of this river (blue) could be reproduced satisfactorily by application of the calibrated SWIM model with implemented water management measures (red). However, slight discrepancies can be detected when comparing the reported estimated natural discharge with the SWIM-simulated discharges without considering water management. SWIM seems to slightly overestimate the water amounts in undisturbed environment. This could be resulting from a lack of right intensity definition or description of water consumption processes induced by environmental characteristics, causing a higher natural loss of water during its passage through the catchment as assumed during the modelling. But it is also possible that the influence of pond management in the catchment was assumed to be higher than in reality as a consequence of the equal distribution of pond volumes over all subbasins located within one management zone. On the other hand, natural inflow from the two smaller rivers discharging to the Liman is underestimated, possibly as a result of underestimated management impact during hydrological calibration. Nonetheless, the simulated human influenced water discharges perfectly meet the level of the real observed values reported in literature.



	others	Khutorska	Balaichuk	Tsarega	Tyligul	total
Q natural (literature*)	0.05	0.02	0.13	0.12	1.46	1.78
Q sim (without management)	0.07	0.02	0.11	0.10	2.27	2.57
Q obs (literature*)	0.005	0.002	0.05	0.01	0.79	0.89
Q sim (with management)	0.005	0.002	0.03	0.01	0.65	0.70

* Deliverable D2.1d LAGOONS project (LAGOONS, 2012a), page 7

Figure 5.2.5 Comparison of the mean inflows to the Tyligulskyi Liman (1953-2007) found in literature and SWIM-simulated average inflows for 1980-2009. Q natural (dark grey) means Q value calculated by using the water-heat balance approach assuming no economic activity. It can be compared with the SWIM results (light grey) achieved without considering irretrievable water use and pond management. The estimated value of discharge in current real conditions (blue) was taken from literature or calculated assuming certain percentages of water loss. These values can be compared with the SWIM-simulated average discharges (red) taking all management information into account.

SWIM calculates all hydrological processes at the hydrotope level, and is able to deliver average annual outputs of all important water flow components per hydrotope. Spatial patterns of hydrological flow components often reflect the precipitation amounts, soil type distribution or land use pattern of the area under study. This can also be seen for the catchment of the Tyligulskyi Liman (Figure 5.2.6). The highest precipitation is in the north-western part of the catchment, causing higher runoff values, evaporation rates and groundwater recharge amounts in this sub-region. This is the only part of the basin containing some forested area. Such areas are usually characterized by lower runoff and groundwater recharge but higher evapotranspiration rates due to higher leaf area index. In general, permanent vegetation cover types (as grassland or forest) show similar patterns of the hydrological components. Agricultural fields usually generate higher amounts of runoff than less intensively used areas, but the runoff patterns may additionally reflect distribution of precipitation amounts and soil types.

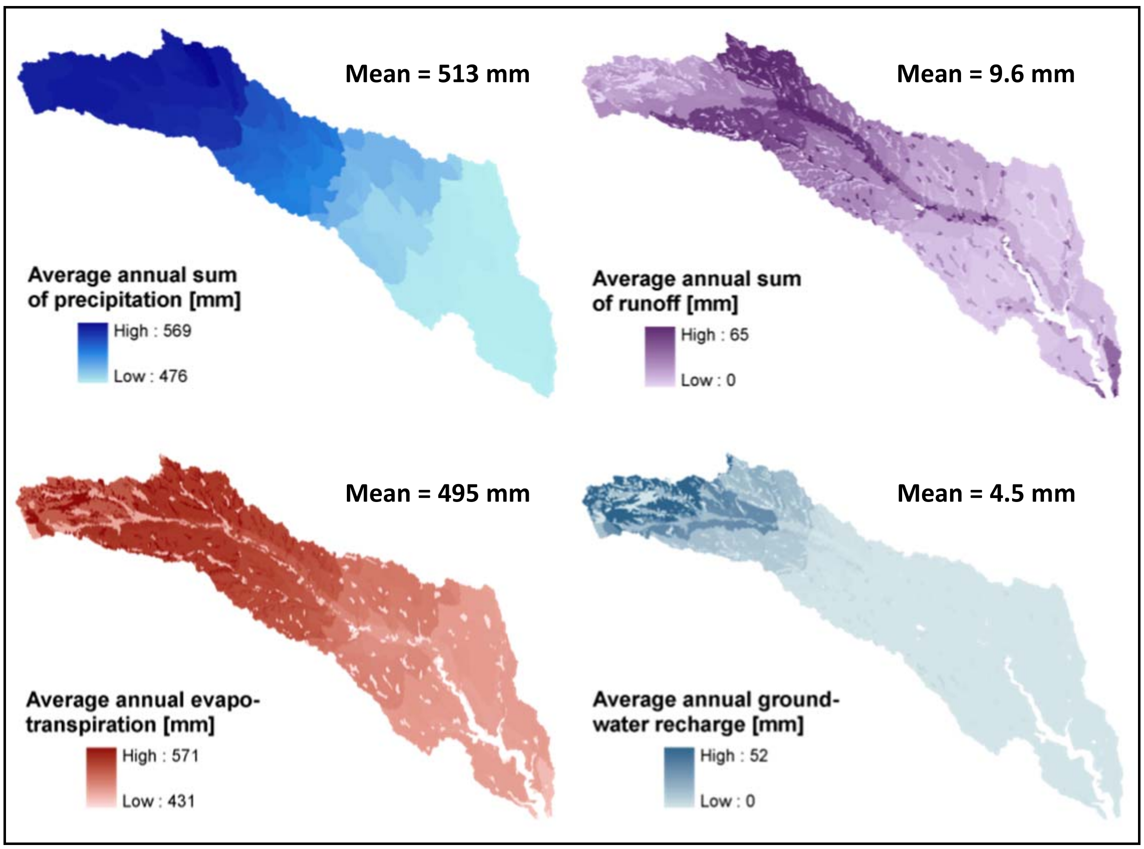


Figure 5.2.6 Spatial patterns of water cycle components in the Tyligulskyi Liman catchment averaged for the time period 1980-2009.

Looking at the spatial patterns of water components one can clearly see that water movement and behaviour strongly depend on soil characteristics. According to description of chernozem properties, these soils are usually very thick with many arable layers and high rooting depth. Such parameterization resulted in quite high evapotranspiration rates on agricultural fields with chernozem soil types, in case the precipitation amount allows high evaporation. Soils with

lower rooting depth and smaller number of arable layers usually have a higher potential for groundwater recharge and runoff, but lower evapotranspiration rates. Land use patterns are reflected as well (e.g. highest evapotranspiration amounts in forested areas and lowest in settlements, or higher runoff and lower groundwater recharge on populated land). The large number of implemented ponds within the Tyligulskyi Liman catchment increases the overall sum of water evaporation in the basin and leads to massive loss of water, but this relationship was not implemented in the code directly, because exact mapping of pond surface areas on the hydrotope level was not possible. Therefore, spatial patterns of evapotranspiration (Fig. 5.2.6) do not include this sub-component.

5.3. Calibration and validation of water quality

Water quality in the catchment of the Tyligulskyi Liman was calibrated for the variables nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), phosphate phosphorous (PH_4-P), and dissolved oxygen (DOX) using available data from three observation gauges around the downstream station Berezovka, which were only rarely sampled during the last 30 years. These three observation stations were treated as one gauge and data were averaged in times when more than one measurement were available. As no information on water temperature was available, this parameter was not calibrated.

Available measurements of nutrient concentrations in the river obviously show a decreasing trend after 1990, especially for the nitrogen forms. This is a consequence of closing several cattle farms and reduction of livestock in the area after political reorganization, and a strong decrease in fertilized areas in the region, as well as lower fertilizer amounts applied to arable land due to economic reasons (FAO, 2005, 2006). This development caused a strong decrease in organic fertilization amounts in the region, lowering measured ammonium concentrations in the river from around 2 mg/L to very low average values of about 0.05 mg/L. The same trend can be seen in the nitrate nitrogen concentrations. However, no trend is visible in the measured phosphate phosphorous concentrations. This can be explained by the following: phosphate phosphorus is emitted by more or less constant point sources during the whole period. Due to the detected trends in nutrient concentrations in the river it was decided to use data only from the recent period 2001-2007 for calibration.

Water quality calibration was complicated by the fact that there are many periods with zero measured discharge at the Berezovka gauge. In some cases it even occurred, that concentration measurements were available on days when zero discharge was detected. This is quite unrealistic nutrient behaviour, which can hardly be reproduced by a model which calculates nutrient concentrations as the ratio of loads to discharge. Therefore it was decided to firstly compare the observed and simulated nutrient loads in the basin.

The measured loads were derived by calculating the product of observed concentrations and discharges on the same day ($L=C*Q*86.4$). The results of the comparison of these calculated loads with the SWIM-simulated loads are shown in Figure 5.3.2 for nitrate and ammonium nitrogen as well as phosphate phosphorous. Simulated nutrient loads occur only in times with simulated discharges. Ponds not only lower the amounts of discharging water but also the transported nutrient loads. In times of no simulated discharge, no loads are simulated, and diminished discharges result in diminished nutrient loads. By this method, a few points of

calculated observed nutrient loads could be reproduced by the model quite well. However, it is also visible that the real model calibration with so rare measurements is a very difficult task.

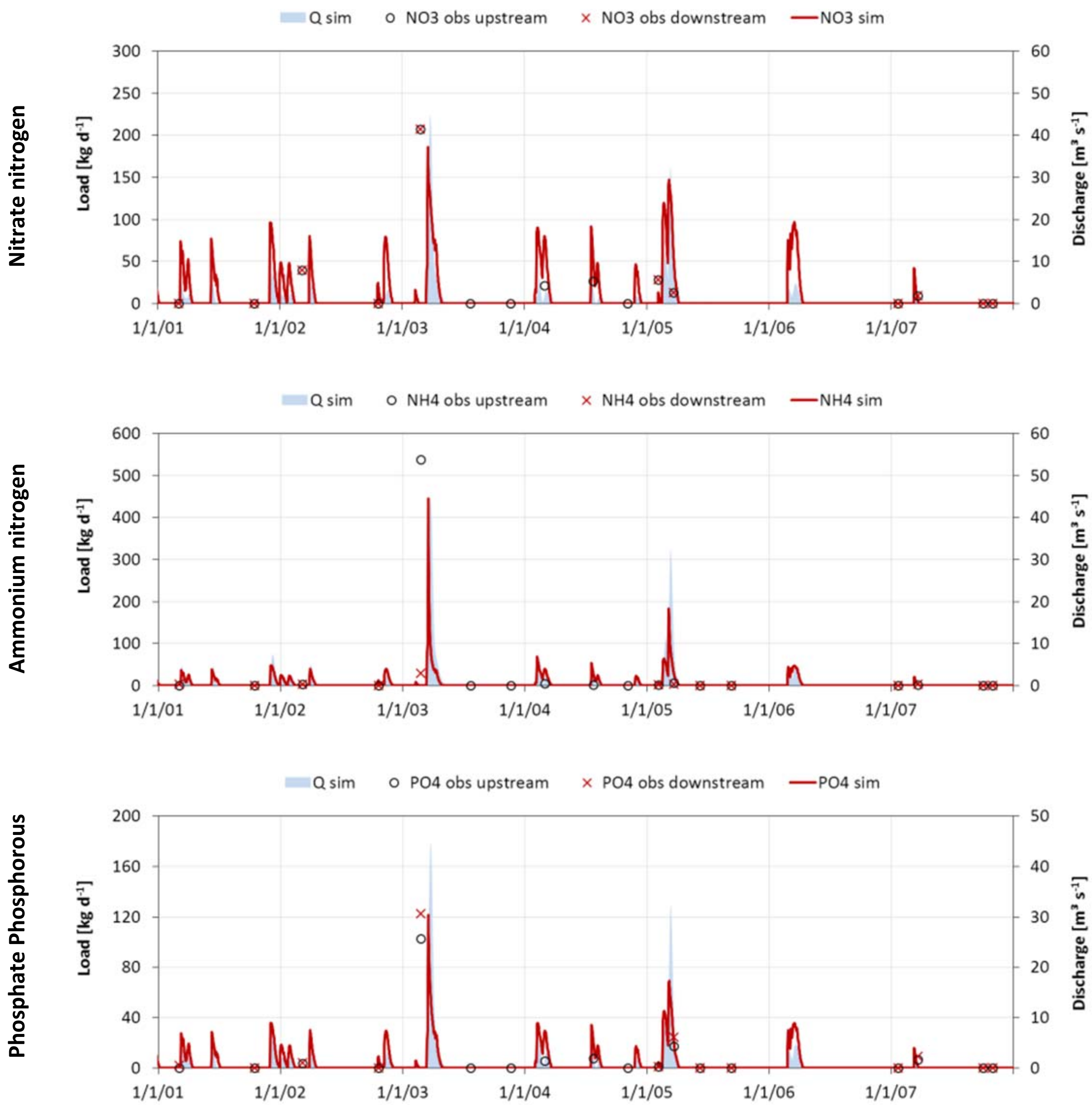
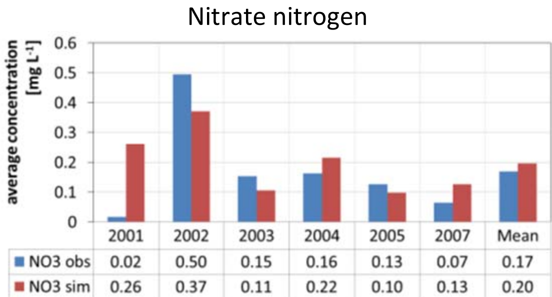
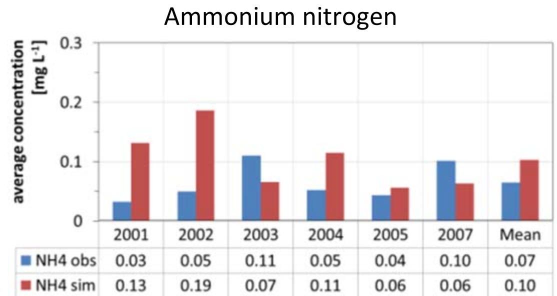


Figure 5.3.2 Comparison of calculated measured and model-generated simulated nutrient loads at Berezovka site near to the confluence of the Tyligul river to the Tyligulskyi Liman in the time period 2001-2007.

Another comparison of the observed and simulated water quality was performed using average annual values of nutrient concentrations (calculated from a few available samples). The results are shown in Figure 5.3.3. The comparison was done per year as well also for the total period 2001-2007 ("Mean" in the graphs). During the calibration an attempt was made to catch the calculated mean values as good as possible, and generally they are well comparable, although some discrepancies between the observed and simulated annual nutrient concentrations are still obvious.





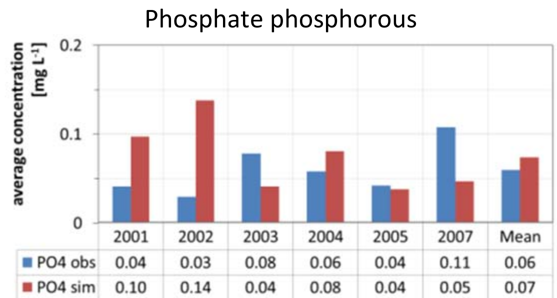


Figure 5.3.3
Comparison of annual mean observed and simulated nutrient concentrations at the Berezovka gauge (Tyligul river).

As the last step in water quality calibration the measured and simulated concentrations of dissolved oxygen where compared (Figure 5.3.4). Quite unusually, no seasonal dynamics of the measured dissolved oxygen can be observed. This could partly be caused by a very inhomogeneous distribution of sampling dates over the months (grey bars in the graph).

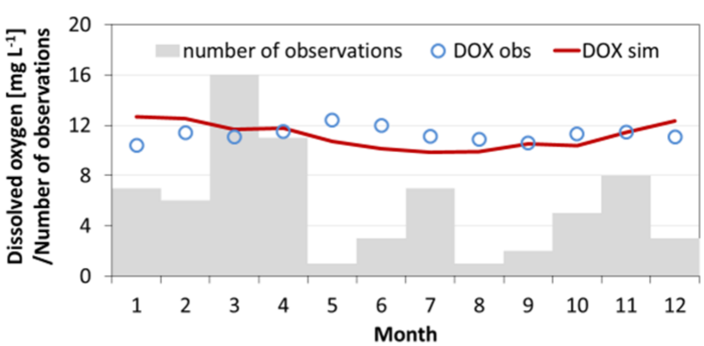


Figure 5.3.4 Seasonal dynamics of dissolved oxygen concentrations in the Tyligul river (station Berezovka): Comparison of average monthly values calculated using all available observed data in the period 1984-2008 (total number of observations per month indicated with grey bars) with long-term monthly average values simulated with SWIM in the period 1980-2009

5.4. Climate impact on water flows

Average daily dynamics and seasonal changes

After calibration and validation of the SWIM model for river discharge and water quality in the Tyligulsky Liman catchment, assessment of climate change impacts was performed. Figure 5.4.1 shows the long-term average daily discharges for three scenario periods (upper graphs) as well as seasonal differences in the total water inflow to the Tyligulskyi Liman between the three scenario periods and the reference period simulated by SWIM under a set of ENSEMBLES

climate scenarios. The average values of total discharge from all simulations driven by 14 climate scenarios are shown for three future scenario periods (black) and compared to the average values of the simulated discharge values driven by the climate model runs for the reference period 1971-2000 (red). The uncertainty bands are included in the picture as well, showing the 90/10-percentile range (light grey) of all results driven by the entire ENSEMBLES climate scenario set. The dark grey inner uncertainty bands illustrate the 25/75-percentile range of the projected total discharge to the lagoon, which can be likely expected in future.

Besides, the average models outputs driven by the whole set of 14 climate scenarios can be compared with the outputs driven by S10 scenario in the same periods (blue). This climate scenario was detected as the “best fitting” one in the reference period.

Looking on precipitation change signals of all 15 ENSEMBLES scenarios calculated for the Tyligulskyi Liman catchment during evaluation (see Table 2.5.3), no clear trends in future precipitation could be identified. However, the mean signal of all scenarios shows no trend for p3, or precipitation tends slightly to decrease in p2 and p4. Resulting average discharges simulated under these climate scenarios show an increase in January and February, decrease in March and April and no significant changes in the remaining months. It seems that snowmelt peaks in spring are going to be decreased in future as a result of increasing temperature and lower snow amounts. This is accompanied by higher winter discharges than in the reference period due to more precipitation falling as rain in the warmer winter months. The summer months with long lasting low flow conditions remain nearly the same during the future periods.

It should not be forgotten that the climate impact assessment was performed by using the calibrated SWIM model with all water management measures included. The influence of the implemented pond equations on the modelled river discharge could interfere with the impacts of a changing climate, as a part of discharge in the summer months is absorbed by the ponds. The undisturbed water volume could be different throughout the future periods, but due to the pond influences, it cannot be seen. Only in times, when the available water volume exceeds the effective pond volume in the catchment, and the evapotranspiration effects on water cycle are low, changes in discharge in future periods can be observed.

The highest uncertainty in the scenario outputs can be seen during winter and spring periods with some increase in overall uncertainty towards the end of the century. Maximum monthly negative changes account for March and April (about -2 m^3/s), maximum positive changes can be seen in January and February with amounts around 1 m^3/s.

Model results driven by the “best fitting” scenario S10 (blue) are quite different from the average results driven by the whole set of climate scenarios. During the first six months of the virtual year of all periods, SWIM results driven by S10 show lower levels than SWIM results averaged for all scenarios, but with several high peaks. The trends of seasonal changes for S10-driven simulations correspond to the climate change signals for precipitation calculated for this scenario during the scenario evaluation.

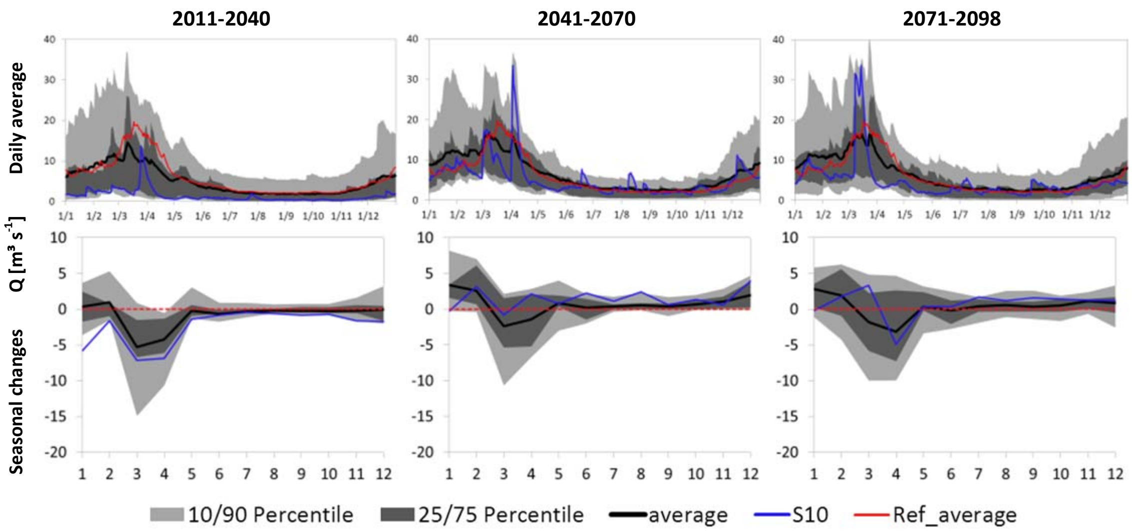


Figure 5.4.1 Average dynamics of total water inflow to the Tyligulskyi Liman averaged for simulations driven by 14 ENSEMBLES climate scenarios (excluding the outlying scenario S8): long-term average daily discharges with percentile bands compared to the daily average discharge simulated in the reference period (above) and absolute differences in monthly average discharges for three future periods compared to the reference period 1971-2000 (below).

Changes in water fluxes – spatial patterns

Climate change impacts on water flow components were analysed also with regard to the spatial patterns on the hydrotope level. The average differences for precipitation and three variables runoff, evapotranspiration and groundwater recharge were calculated between the three future periods and the reference period per hydrotope and presented on the maps. The resulting maps are depicted in Figure 5.4.2.

Due to the fact that no continuous trend in precipitation could be recognized from period p2 to period p4, spatial patterns of changes in three periods are quite divers. While the first future period is characterized by decreasing precipitation mainly around the Tyligulskyi Liman, the second period shows unchanged or only little precipitation decrease also around the lagoon, followed by the last simulated future period with the highest decrease in precipitation. This decrease is higher in more upstream regions of the catchment and reaches values around -30 mm per year.

All other water component patterns follow this precipitation behaviour, and are also influenced by soil type and land use class distributions. Runoff mainly decreases in areas with decreasing precipitation. The highest decreasing trends can be observed in areas with permanent vegetation (grassland) due to higher evapotranspiration values in these hydrotopes.

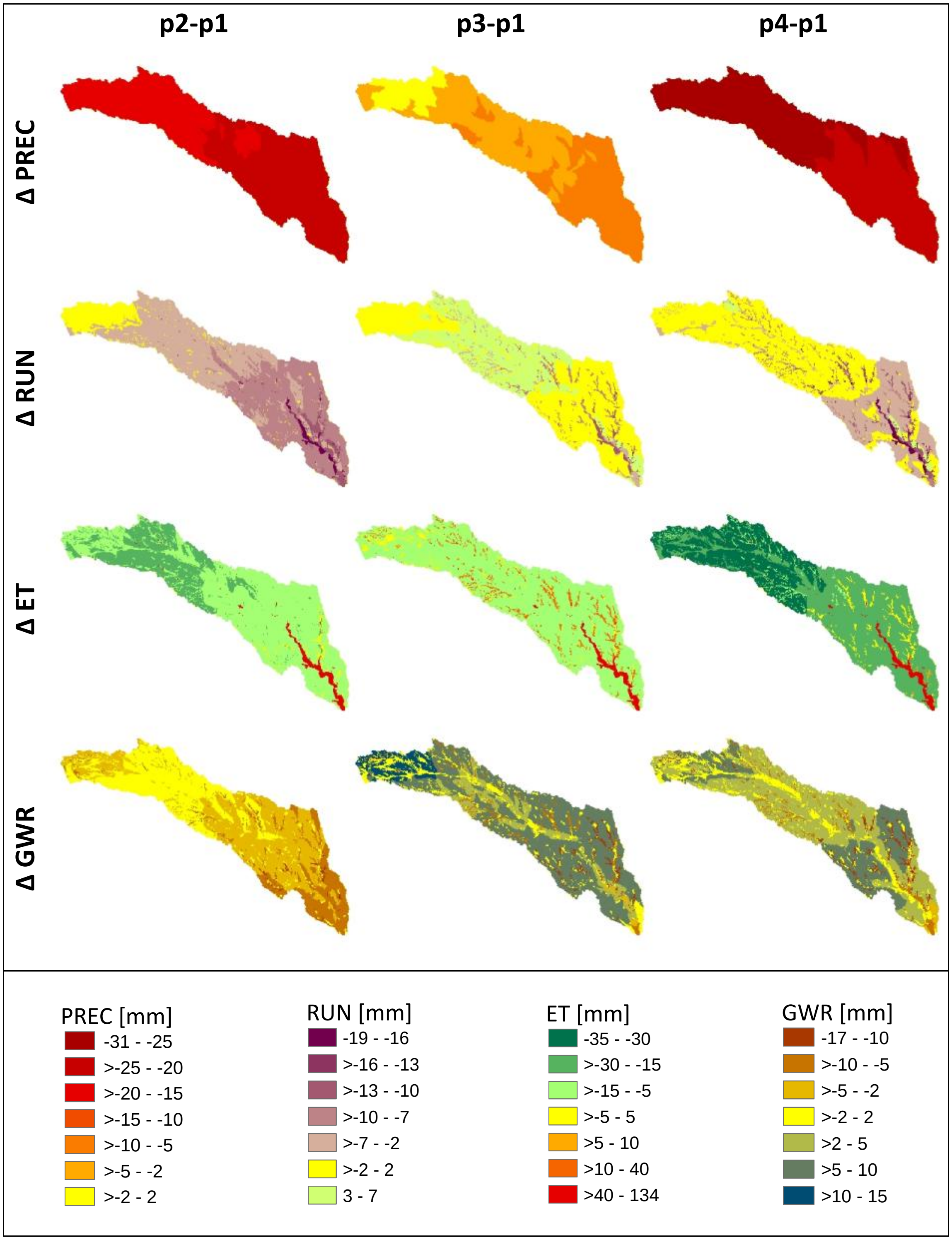


Figure 5.4.2 Spatial patterns of average annual changes in precipitation (PREC), runoff (RUN), evapotranspiration (ET) and groundwater recharge (GWR) in the Tyligulskyi Liman catchment under the ENSEMBLES of climate change scenarios (future periods p2, p3, p4 compared to the reference period p1): the model outputs were averaged over all years per period and all simulations driven by 14 climate scenarios (excluding S8).

Water losses by evapotranspiration decrease with decreasing precipitation due to less available water for transpiration. In all periods changes in evapotranspiration show higher values on grassland than on agricultural fields due to the higher leaf area index of the vegetation there. The area of the Tyligulskyi Liman causes evaporation values which are as high as the potential evapotranspiration, which increases in the future periods by up to 127 mm/y due to a strong increasing trend in temperature generally projected by all 15 climate scenarios.

Groundwater recharge is projected to increase in the second future period with less decreasing precipitation and remains more or less stable or decreases in dryer periods. The highest decrease in groundwater recharge can be detected under grassland with higher evapotranspiration potential due to rising temperature.

5.5. Climate impact on water quality

During climate impact assessment the influence of changed climate on water quality variables was analysed as well. Figure 5.5.1 shows the seasonal changes of the average monthly water temperature and dissolved oxygen concentration for the three future periods with regard to the average monthly values in the reference period 1971-2000. The model outputs were averaged over 30 years and are presented with uncertainty bands describing the heterogeneity of the simulations driven by 15 ENSEMBLES scenarios. Strong trends are obvious: water temperature increase and dissolved oxygen decrease to later scenario periods.

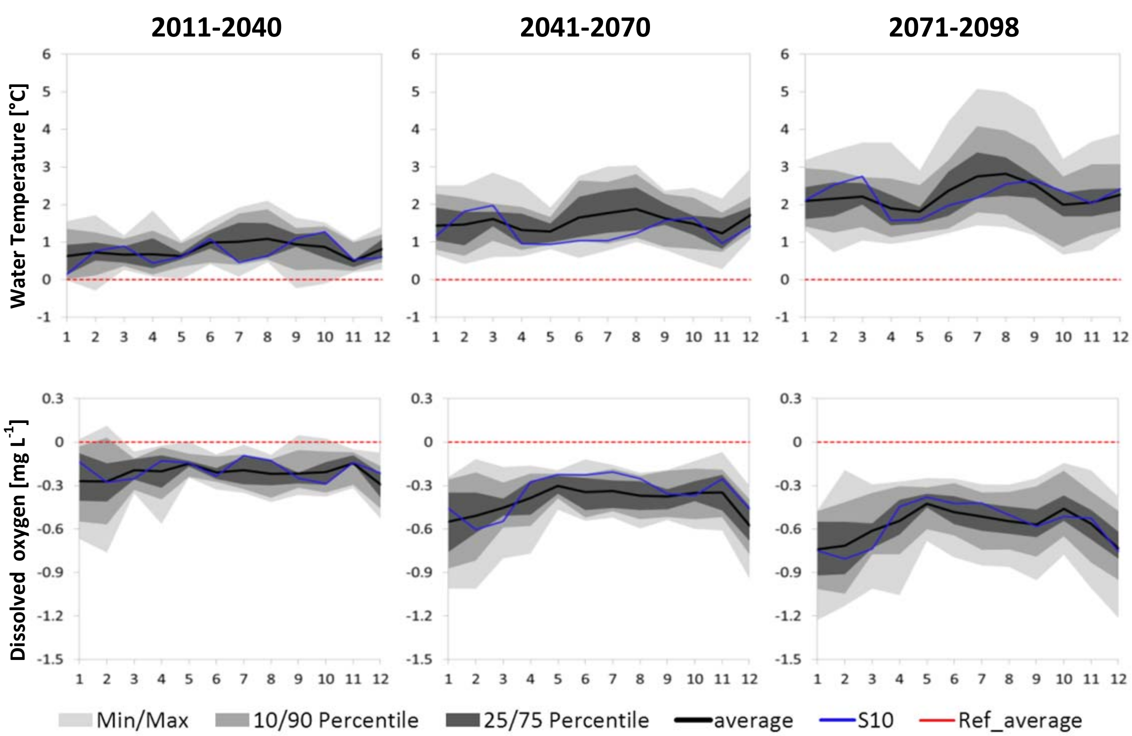


Figure 5.5.1 Average seasonal changes of water temperature and dissolved oxygen concentrations in rivers flowing to the Tyligulsky Liman under a set of 15 climate scenarios. The monthly values are calculated as the difference between the average values per month of one of the future periods compared to the same averages in the reference period.

The trends for both variables can be clearly connected to the projected changes in average temperature in the case study area. Dissolved oxygen concentrations in river water are calculated via the saturation concentration, which is a function of water temperature. The best fitting scenario S10 demonstrates similar behaviour as the average of all 15 scenarios and is almost always located within the 25/75 percentile uncertainty band.

In general, uncertainty increases to the end of the century due to increasing diversity of climate scenario parameters in the future.

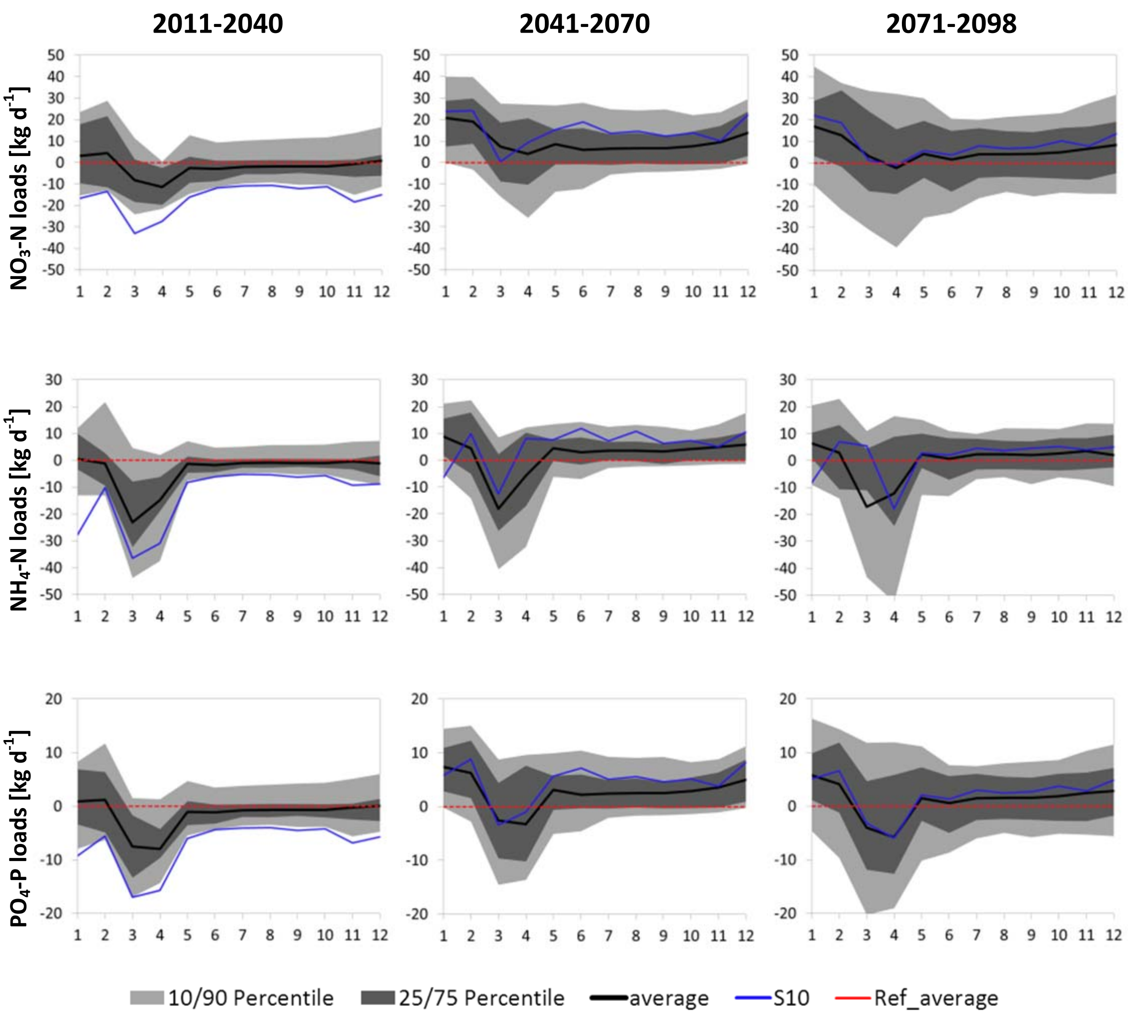


Figure 5.5.2 Impact of ENSEMBLES climate scenarios on seasonal changes of the sum of all nutrient loads flowing to the Tyligulskyi Liman as average of 14 climate scenarios (excluding scenario S8). The changes were calculated as differences between the monthly average values in the future periods to the average value in the reference period.

Climate impacts on the sum of all nutrient loads introduced to the Tyligulskyi Liman are similar to the impacts on water discharge. Figure 5.5.2 depicts seasonal changes of nitrate nitrogen, ammonium nitrogen and phosphate phosphorous loads coming to the Tyligulskyi Liman for all three future periods. A decrease can be detected during the snow melt period, whereas a slight

increase is visible in the two first winter months in the year. For the remaining months from May to December almost no change in nutrient loads can be seen on average. For the second future period 2041-2070 with an overall projected increase in precipitation, the nutrient load level during the low flow period is higher than in the reference period due to higher available discharge enabling transport of nutrients.

In general, the nutrient loads behave similar as the water discharge. This is partly the result of the influence of ponds implemented in the model. They are defined not only to take the inflowing water but also the nutrient loads coming with them. Therefore, nutrients can only reach the lagoon with the rest water coming to the river outlet.

As a result, it is not possible to get information on real climate influences on nutrient processes looking only on the loads entering the lagoon. Possibly changed nutrient processes due to changes in precipitation or higher temperatures are not distinctly reflected in the resulting nutrient model output, as the nutrient processes are interfered with the ponds influence.

5.6. Summary and conclusions

Climate projections for future derived from the ENSEMBLES climate scenarios are very divers in the Tyligulskyi Liman catchment. While a strong increasing trend in temperature can be expected in the basin, and it is projected by all 15 ENSEMBLES scenarios, the future trends in precipitation do not show a common pattern. Looking at the mean climate change signals for precipitation (compare Table 2.5.3) as an average of all 15 scenarios, a decreased precipitation is projected for the periods p2 and p4, whereas the period p3 shows a slightly increased precipitation level.

Figure 5.6.1 summarizes the effects of changed climate on water quantity and quality variables. After applying the set of 15 climate scenarios, percental changes of total inputs to the Liman were calculated for every scenario and every future period with regard to the reference period of the same scenario. The average values as well as the uncertainty ranges of all models outputs from simulations driven by 15 climate scenarios are presented in the figure.

Two different patterns can be detected:

a) Water temperature and DOX are clearly connected to the air temperature in the case study area. 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.

b) River discharge as well as nutrient loads are expected to decline in the nearer future (p2), but to increase in the two last periods (p3 and p4), with a bit higher increase in p3 than in p4. The loads show a similar behaviour as river discharge. This is partly due to the impacts of the pond’s water and nutrient storage potential as described in the previous section.

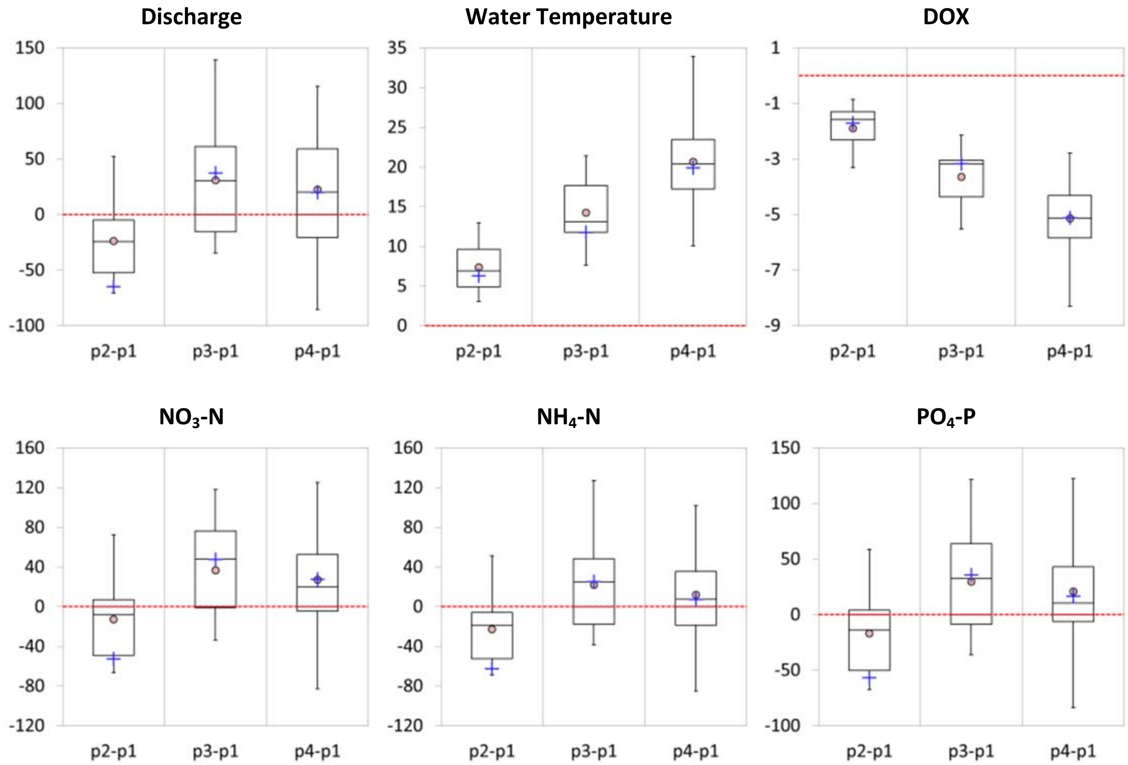


Figure 5.6.1 Ranges of the percental changes of total input to the Tyligulskyi Liman from its catchment area simulated by SWIM driven by 15 ENSEMBLES climate scenarios (future periods (p2, p3, p4) were compared to the reference period (p1) of the same scenario run). The box plots visualize the following ranges: min/max, 25/75-percentile, median and average (dots) as well as the value for the S10 scenario (blue cross).

Curiously, the discharge's response to climate changes is not clearly and directly connected to the mean precipitation change signal calculated as an average of all 15 scenarios (compare Table 2.5.3). For period p2 a decrease in average precipitation is detected and followed by a decrease in discharge, an opposite behaviour can be seen for p3 with increasing precipitation and discharge, but for p4 an obvious decrease in precipitation compared to the reference period results in higher average discharge as simulated for the reference period.

To explain this strange behaviour, not only changes in precipitation and temperature have to be analysed for the climate scenarios but also that in solar radiation. This climate parameter highly influences model results via evapotranspiration. Figure 5.6.2 illustrates the average changes of climate parameters in comparison with the resulting change in discharge. One can see that the discharge always behaves oppositely to the solar radiation. Even in periods with unchanged or decreasing precipitation the discharge may increase due to reduced solar radiation and resulting lower water loss by evapotranspiration in the catchment.

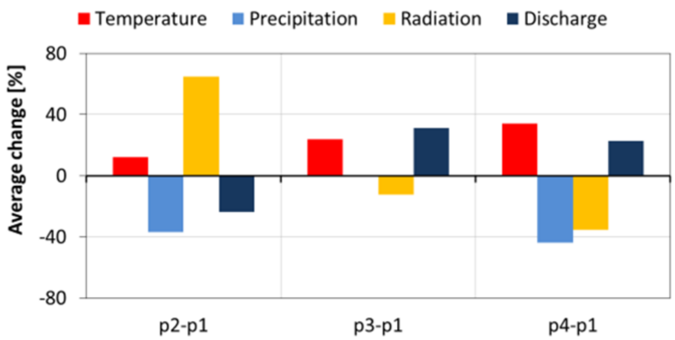


Figure 5.6.2 Average changes of temperature, precipitation and solar radiation as well as the resulting change in average discharge simulated with SWIM for the three future periods p2, p3 and p4 compared with the reference period p1 (precipitation change is scaled by factor 10, and radiation change by factor 100)

Climate change impact assessment performed for the Tyligulskyi Liman catchment reveals the limitations and constraints of this method. The eco-hydrological catchment model driven by various climate scenarios, which have different directions of change in precipitation and radiation, generates quite heterogeneous model results with high uncertainty ranges, and a clear conclusion for future development is difficult to produce. As the modelled discharge is highly influenced by implemented anthropogenic water management measures in the region, the ecosystem responses due to climate change only become hardly detectable. Nevertheless, the model application and scenario assessment help to identify direction of potential changes in water quantity and quality and deliver first impression about a possible future of the catchment.

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