“Management of Transboundary Rivers between Ukraine, Russia and the EU – Identification of Science-Based Goals and Fostering Trilateral Dialogue and Cooperation”

Project acronym: ManTra-Rivers

WP C: Recommendations to improve the scientific basis for an IWRM

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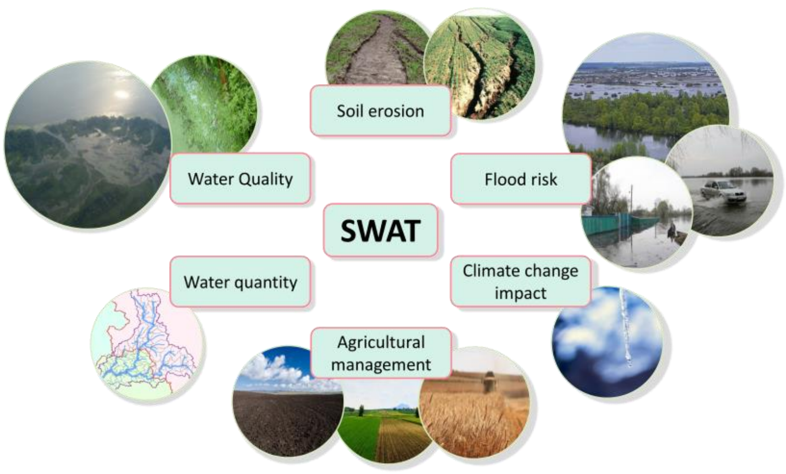

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1 Introduction

EU documents show the status and deficits regarding River Basin Management at the political, legal, governmental and technical level. Comparative documents for Non-EU-members are rare. Ukraine, having signed an Association Agreement with the EU, is on the way to collect necessary information. The effort to compile such documents for Russia is high and not affordable in this project.

From the analysis done in this project, we recognize that still a lot of work is needed at the technical level. This begins with the further development of the monitoring system for all relevant environmental variables, continues with the harmonization of data and methods and ends with an application or a further development of models that simulate hydrological and further relevant processes. This is a prerequisite for a profound scientific assessment of the status quo and the development of management options under possible changing conditions in the future.

These technical issues depict the focus of our work. In this report we give recommendations regarding monitoring (chapter 2), data handling (chapter 3), data bases and exchange (chapter 4), data analysis and models (chapter 5). We conclude with the dissemination of the project results (chapter 6).

2 Monitoring

Specific recommendations for the monitoring of environmental variables are presented for Western Dvina and Desna basins in the following sub-chapters. The chapter is completed with some general conclusions.

2.1 Western Dvina

In the project, a detailed up-to-date characterization of existing observational network in Western Dvina river basin was done. Hydrological gauging network in Western Dvina Basin consists of Russian, Belorussian and Latvian stations. Water level, temperature, discharge, ice regime and river hydromorphology are monitored. There is an evident discrepancy between gauging stations distribution between different countries (Table 1). Hydrological measurements in Western Dvina Basin have started at the end of XIX century (1906 in Latvia).

Table 1: Total number, parameters and period of station operation in Western Dvina Basin

River	***Western Dvina***		
Countries	**Russia**	**Belarus**	**Latvia**
Number of gauges in the catchment on the rivers	10	19	29
Parameters measured at gauge*	H, T, I, *Q*, *S*	H, T, I, *Q*, *S*	H, T, I, *Q*
Start of measurements	1878	1876	1906

* H-Water level, Q-discharge, T-temperature, I-ice thickness, S-snow depth, C-chemical compounds

Discharge is measured on approximately half of stations in Russia and Belarus. Latvia has more stations and all are operating (Figure 1). Belarus also has 5 stations at lakes with water level, temperature and ice thickness measurements. Latvian gauges also provide information about the situation of water objects.

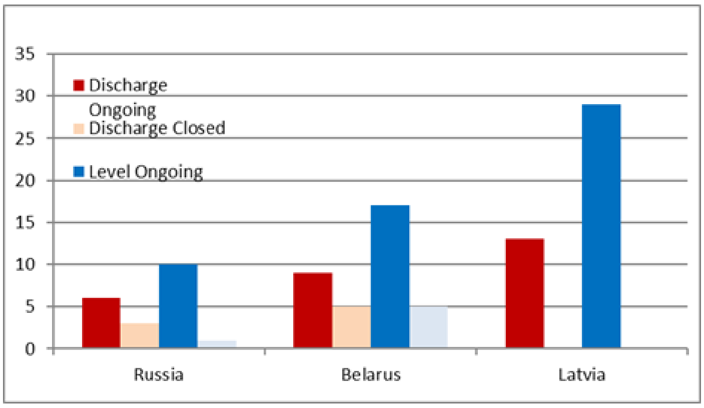


Figure 1: Number of ongoing and closed discharge stations

Water quality observations in Western Dvina Basin have been initiated in the middle of XX century. Most of these stations are located in Belarus (Figure 2). In Russia, four gauging stations exist, two of them monitor water quality at Russian outlet of Western Dvina and are situated upstream and downstream of Velizh town.

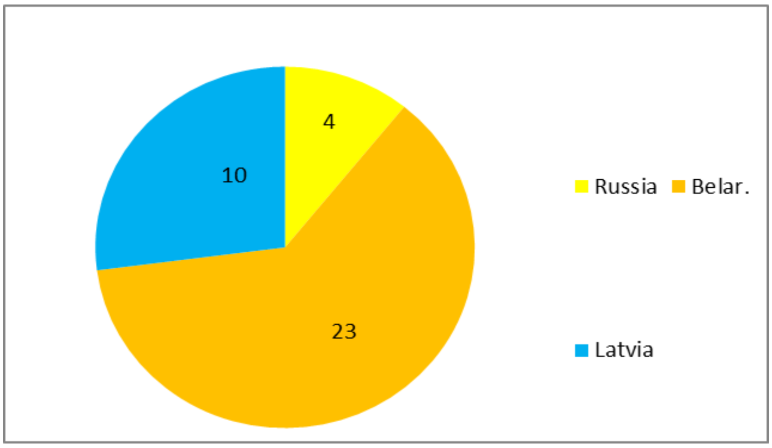


Figure 2: Number of water quality stations in Western Dvina Basin

Monitoring network in the Western Dvina basin is set up and operated according to Post Soviet type and to European type. According to monitoring purposes, Post-Soviet type includes regular, emergency and special types of monitoring. Regular monitoring of surface waters includes monitoring of hydrological parameters (water level and discharge, sediment concentration, temperature, ice phenomena and water quality), hydromorphology, water supply and use and conditions of water protection zones.

In Russian Federation, monitoring program is based on Water Code (2006) and State Monitoring of Water Bodies (part of the Federal Act on the Protection of Nature – 2001). The basin is characterized by an insufficient water quantity and quality monitoring, especially in the upper part of the Russian part of the catchment. Downstream areas have been intensively studied, e.g. based on Vitebsk and Polotsk gauging station located in Republic of Belarus.

Recently, some dams were constructed in Republic of Belarus. Special attention has to be paid on their impact on water resources, emphasizing the need for observations and tools to assess hydrological issues in the upper part of the catchment. In Belarus, observations of the state of the environment are conducted under the National Environmental Monitoring System (NEMS). Monitoring is coordinated by the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus.

In the downstream Latvian part, the Western Dvina falls under the jurisdiction of the European Union Water Framework Directive 2000/60/EC, whereas the water resources monitoring and management of the upstream part is regulated by a "Soviet-style system. In Latvia in 2010, a new monitoring program was approved by the Minister of Environment for 2009-2014. There are several monitoring systems coordinated by LEGMC, which include surface and groundwater as well as soil quality monitoring. These monitoring programs are determined by the National Environmental Monitoring Program (2002) and National Action Plan for Environmental Monitoring (2002). Hydrological observations are carried out at 70 hydrological stations on Latvian rivers, lakes and reservoirs.

One of the main differences between Latvian and Russian-Belorussian state of monitoring is the station density. Latvian LEGMC claims at its webpage that density of observation stations network is optimal to ensure a sufficient base for the analysis of lakes and rivers. In the Post-Soviet regions, it is obvious that station density is insufficient to obtain enough hydrological and water quality information.

Details of these approaches are shown in the Mantra-Rivers WP B Report. Hydrological and water quality monitoring should be optimized according to following principles:

- Monitoring periods and data should be harmonised to connect Soviet period data structure with Russian/Belorussian and absolutely different Latvian structure of data.
- Daily discharge data should be transferred to some kind of unified data centre e.g. GRDC (Koblenz, Germany). Data, which are obtained close to national borders, should be compared and harmonized.

- Measurements of suspended sediment concentration (SSC) at Velizh station show uncertainties which can be related to sampling location, sampling procedure and analytical methods. Regarding sampling, the significant drifts in the measured quantities may arise from to the absence of an integrating sampling technique, which do not allow to take a representative water within cross-sections of the rivers. The detailed study of the associated error is provided within Mantra pilot study at Velesa River. Uncertainties may reach 50% (Chalov et al., 2019). Another important methodological aspect is the type of filter used for sediment partitioning from dissolved load. According to Russian standard РД 52.24.468, filter with pore size 5 µm is used. Comparison with grain size distribution measured at Western Dvina tributary Velesa River indicate, that up to 12 % of the sediment load is associated with <5 µm fractions which can be lost during pumping through filters.

Russian water experts took part in a survey related to project results. The main goal was to assess the collective knowledge on impacts of transboundary river monitoring in the studied area, with the focus on Western Dvina catchment. Specifically, we developed an expert judgement protocol (Table 2), where each researcher has, for their respective field of knowledge, been requested to grade the experienced problem related to international water monitoring and management. This survey thus brings together experiences from both published and on-going research mostly from various research groups of Russia that is working actively with hydrological applications on transboundary rivers.

Respondents outline general problems, e.g. that Roshydromet monitoring is clearly insufficient, there is a deficit in monitoring data on petroleum pollutants; sharing of basic monitoring data may solve the problem of exchange between countries. Joint research needs to be developed. Many pollutants are generally not included in the list of measured indicators. Usually, intensive monitoring is very limited in periods and space. Most of the detailed data on hydrography and morphometry of the river network was collected more than 50 years ago and needs to be updated. The problem of comparison of hydrochemical data exists. The materials of long-term hydrological and hydrochemical observations from the database of Roshydromet and its regional divisions are required, management of water management systems in river basins requires comprehensive coordination, taking into account ecological and economic criteria.

Table 2: Questionnaire on transboundary river monitoring (where 1-completely agree, 10-completely disagree)

		Vsevolod Moreido Institute: Water problems institute, Russian Academy of Sciences Position: Research Assistant	Irina Danilovich Institute:Institute for Nature Management National Academy of Science, Belarus Position: Lead Researcher	Vladimir Shamov Institute: The Pacific Geographical Institute of the Far Eastern Branch of the Russian Academy of Sciences Position: Lead Researcher	Boris Gartsman Institute: Water Problems Institute, Russian Academy of Sciences Position: Lead Researcher	Aufar Gareev Institute: Bashkir state University Position: Professor	Leonid Korytny Institute: Institute of Geography, SB RAS Position: Senior Researcher	N. I. Koronkevich Institute: Institute of Geography, RAS Position: head of the laboratory of hydrology
1) Monitoring	The list of parameters measured at my institution is not enough to understand the hydrological system.	8	8	7	1	1	3	3
	The frequency of measurements at my institution is not enough to understand the hydrological system.	3	9	3	1	1	1	1
	On the country level there are deficits in monitoring of biological, hydro-morphological and other components.	5	5	2	1	1	5	5
	On the country level there are deficits in monitoring of toxic substances and of the toxicity and composition of discharged waste waters.	1	5	2	1	8	3	2

	There are problems with monitoring of transboundary rivers, such as harmonized sampling times, frequencies and techniques, as well as appropriate sampling sites.	5	10	2	1	1	-	6
	Joint inter-calibration exercises between national and transnational institutions are necessary to harmonize the data.	1	1	1	1	1	1	5
	An update of the sampling technique and laboratory equipment is necessary.	3	5	1	1	1	3	1
2) Data check, correction, harmonization	Hydrological data used by my institution are checked on plausibility.	2	1	3	1	5	2	5
	Hydrological data which is used by my institution are corrected	8	10	3	10	1	2	5
	Different sampling strategies (applied by different institutions) cause that the measured values are difficult to compare.	5	8	1	1	1	1	3

	For a transnational analysis, a harmonization of measurements is needed to overcome above mentioned problems.	5	5	1	1	1	1	1
3) Data collection and exchange	Data are collected in databases at my institute, which allow a quick and effective usage of the data.	1	1	8	4	10	5	3
	An intensification of the data exchange between riparian countries and between different national authorities is needed for a better system understanding.	1	5	1	4	1	1	1
	A specific data exchange protocol is needed, which regulates the format and amount of data.	8	5	8	1	1	3	8

According to the experts, the necessity to update sampling techniques and laboratory equipment and the necessity of joint intercalibration procedures are the most important aspects of the questionnaire. The other monitoring problems have approximately an equal weight (Figure 3).

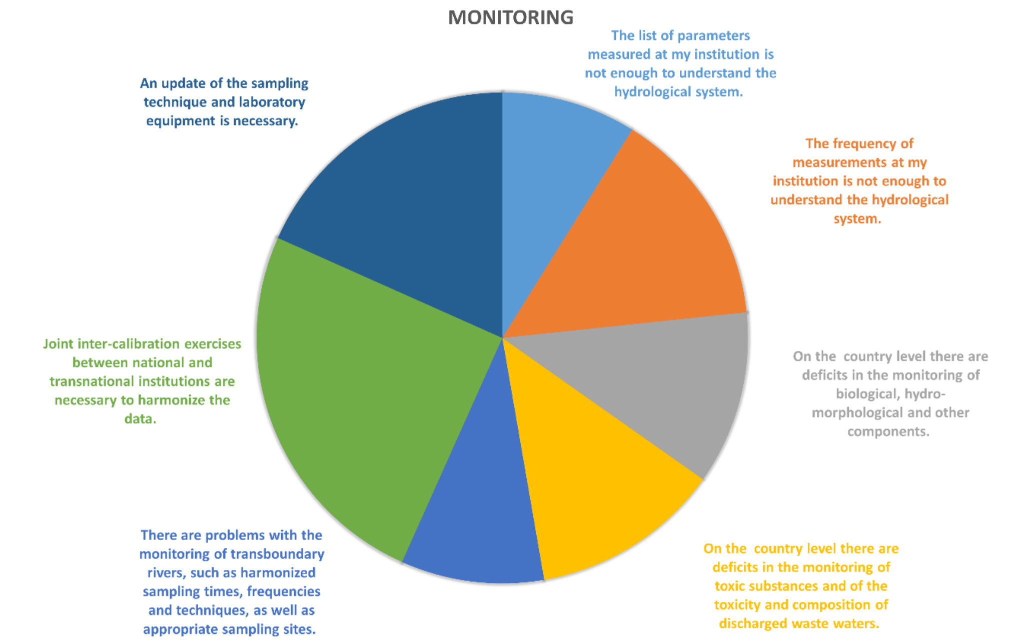


Figure 3: General monitoring problems percentage distribution

Majority of respondents proved that a harmonization of data is needed for a transnational analysis (Figure 4).

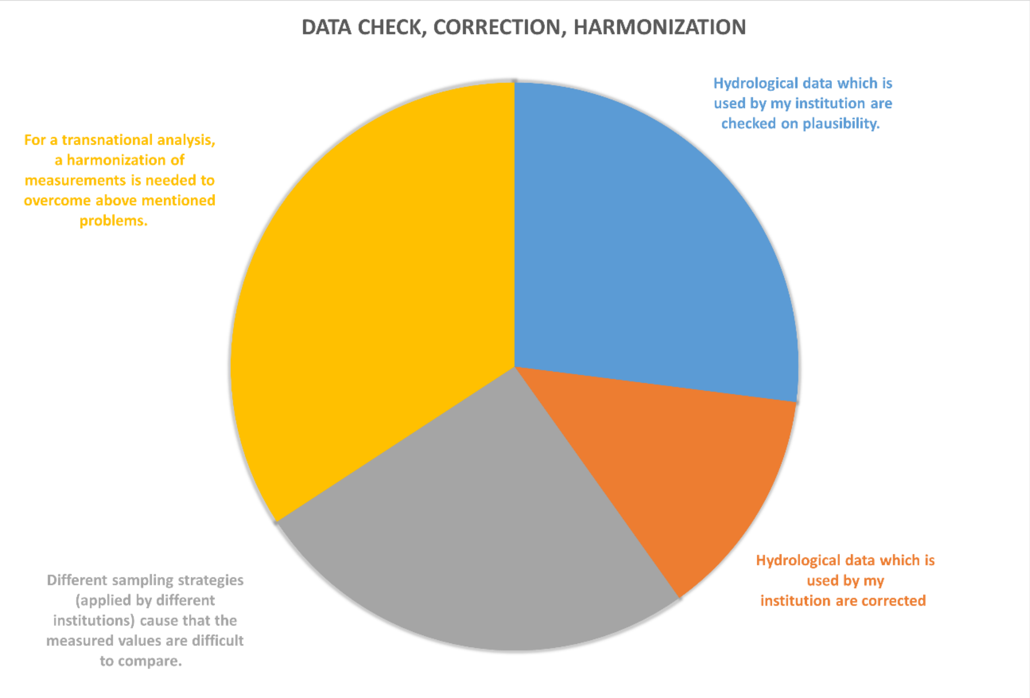


Figure 4: Data harmonization issues percentage distribution

More than half of the respondents voted for an intensification of data exchange between riparian countries (Figure 5).

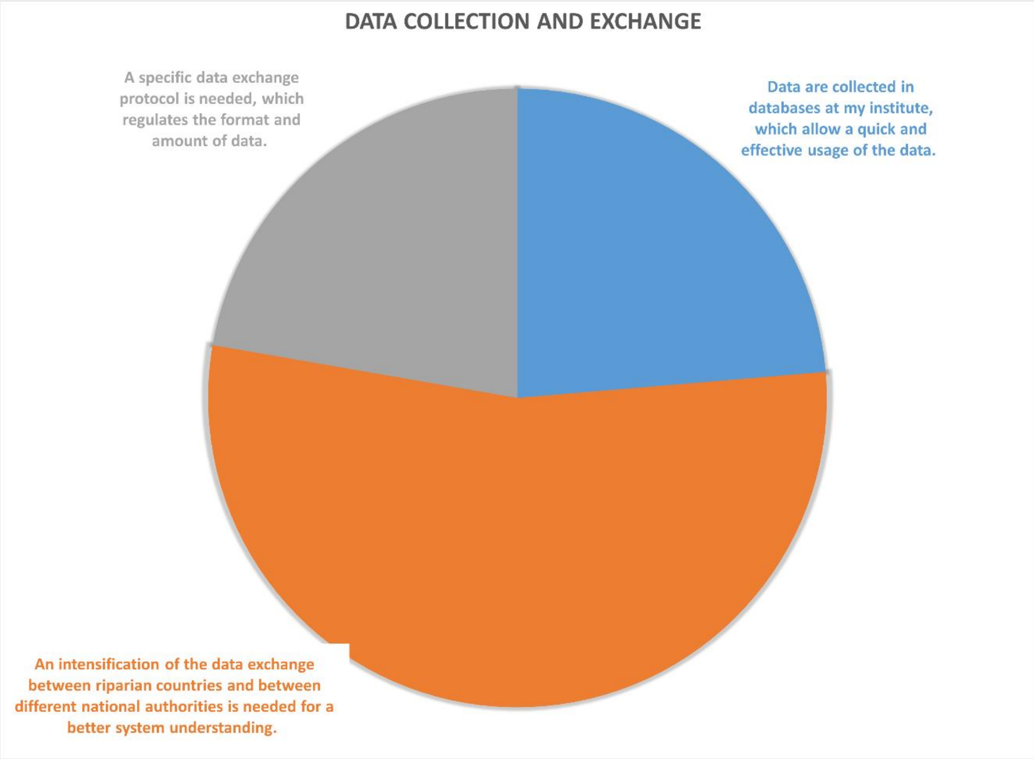


Figure 5: Generalized expert estimates as a percentage of their total

In general, the following issues were identified in the survey:

- All Russian experts note the insufficient frequency of observations in their organizations, whereas the expert from Belarus is highly satisfied with the frequency of observations;
- All experts recognize the lack of monitoring data (especially biological and morphometric indicators).
- Most experts recognize a shortage in water quality monitoring data and data on discharges and wastewater composition.
- All experts agree on the necessity to conduct joint research organized by national and international organizations.
- Only one expert states that hydrological data used by his organization has been corrected, he notes the need to collect them in databases for an effective work.

2.2 Desna

Signing the EU-Ukraine Association Agreement foresees the implementation of a series of EU strategies into various sectors of the Ukrainian economy and develops possibility of reforming Ukrainian national activities significantly in accordance with international norms and standards. One of the Ukraine-EU cooperation areas in the field of environmental protection is the improvement of the water quality and water resource management.

The Desna River Basin has been selected as region for the pilot study implementation aimed at detailed analysis of the current situation with surface water monitoring, river basin management and development of scientific based recommendations for Integrated Water Resources Management (IWRM).

Several problems were discovered in the Desna Basin during the previous stages of this project. One of the problems is related to surface water pollution by organic matter.

The positive moisture balance, plain ground, and high-water table favour the development of wetlands. The share of wetlands in the Desna basin is 10%, but in the Snov and Ubidy sub-basins it reaches more than 40%. Due to wetlands, more than 35% of organic carbon C_{org} is formed in the Desna Basin. Considerable amounts of organic matter of humic origin reach the surface water affecting its chemistry, e.g. sharply decreasing the dissolved oxygen content. Regular cases of fish mortality in winter and summer were noted in the Desna Basin.

The presence of a large amount of organic matter in water significantly increases the migration ability of water cations. Humic substances (HS) significantly complicate water treatment process, as during water disinfection they form secondary chlororganic compounds with carcinogenic properties.

Organic water pollution caused by the increased inflow of HS considerably aggravates the problem of providing high-quality drinking water for cities, for which the Dnipro River is the main source of drinking water. The water runoff stimulated HS leaching from the peat thickness. Fulvic acids (FA) dominated in the emission runoff, which is typical of natural waters. Their concentrations in the water runoff varies between 144-443 mg/l.

Another important water-ecological problem in the Desna Basin is identified as the anthropogenic pollution by *organic substances, biogenic elements (nutrients), and hazardous substances*. Waste waters of settlements and industrial enterprises contain high amounts if human and municipal wastes that are being decomposed by microorganisms leading to significant changes of river water chemical composition and causing unfavorable conditions for biological communities. In a case of large volumes of municipal waste waters entering surface water objects, the natural continuation of the processes in water is disturbed: water rapidly loses dissolved oxygen due to intensive oxidation. In some cases, it leads to critical oxygen concentrations in water and henceforth, the impossibility of hydrobionts life.

Spatial distribution of biodegradable organic matter (by BOD_5) in rivers of the Desna Basin is presented in Figure 6. It was noted that in small tributaries of the Desna River organic pollution is higher.

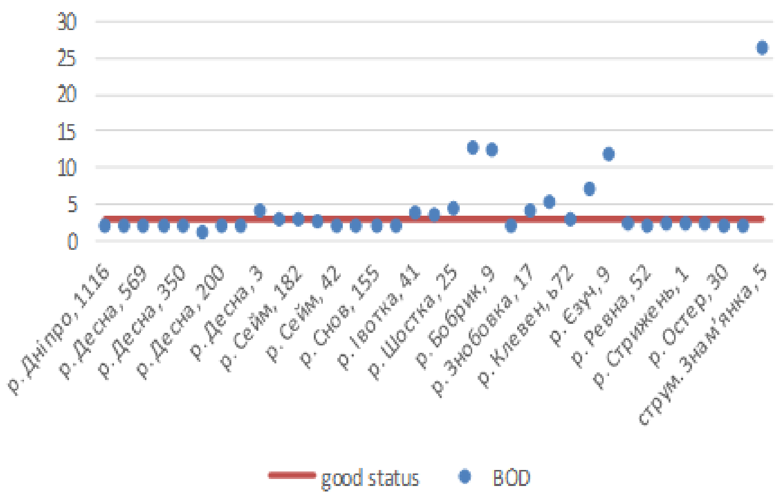


Figure 6: ***Spatial distribution of 90% percentile of BOD_5 (mg/l) values in the upper Dnipro River and the Desna Basin rivers comparing with the target value of the "good" ecological status (X- axis shows the names of the rivers).***

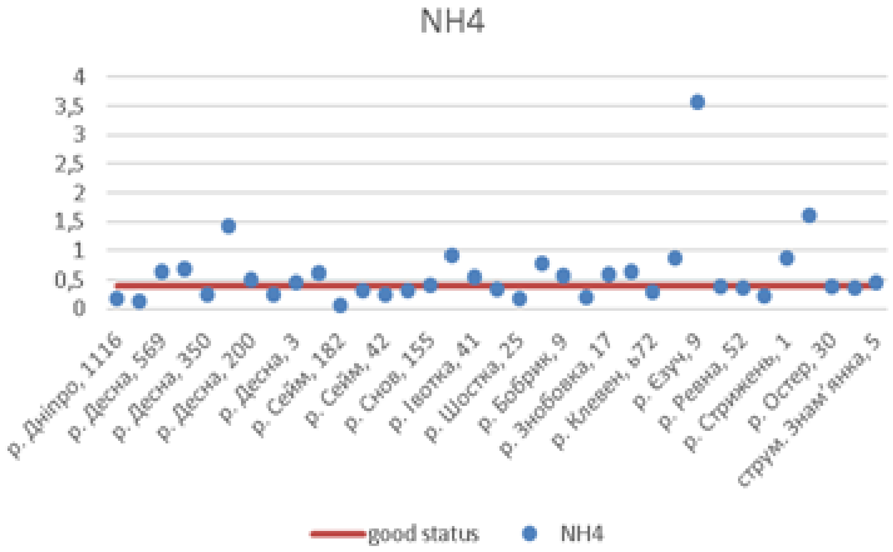
Setting up modern systems of urban agglomerations waste waters collection and treatment could be one of the ways to resolve the problem. Legal basis for such a solution is the implementation of Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment. According to this Directive, waste waters collection and treatment should be provided for all settlements with population equivalent or more than 2000. The use of up-to-date treatment technologies, especially of paper, paperboard, chemical and food industry as well as husbandry should be supported.

Pollution by biogenic elements

Municipal and wastewaters as well as polluted waters generated by agricultural activities stimulate algae development, promote eutrophication and sea pollution.

Pollution of surface water objects is caused as a result of municipal and industrial wastewaters and due to agricultural activities. It causes disturbances of the surface water ecological balance, damages of biodiversity, deteriorations of the state and quality of water. As worst case, this can lead to to the impossibility of water use for human needs.

The Desna Basin rivers pollution by ammonium and phosphates is illustrated in Figure 7.



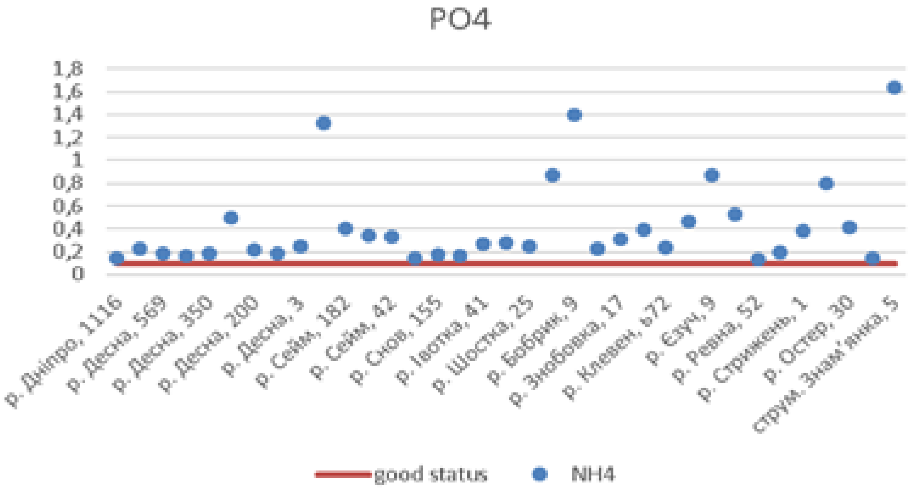


Figure 7: ***Spatial distribution of 90% percentile values for ammonia nitrogen (mg/l) and phosphates (mg/l) in the upper Dnipro River and the Desna Basin rivers comparing with the target value of the "good" ecological status (X-axis shows the names of the rivers).***

Modelling of the quantitative load of water objects by nutrients applying the SWAT model has shown that diffuse sources are the main sources of nitrogen incoming (Figure 8).

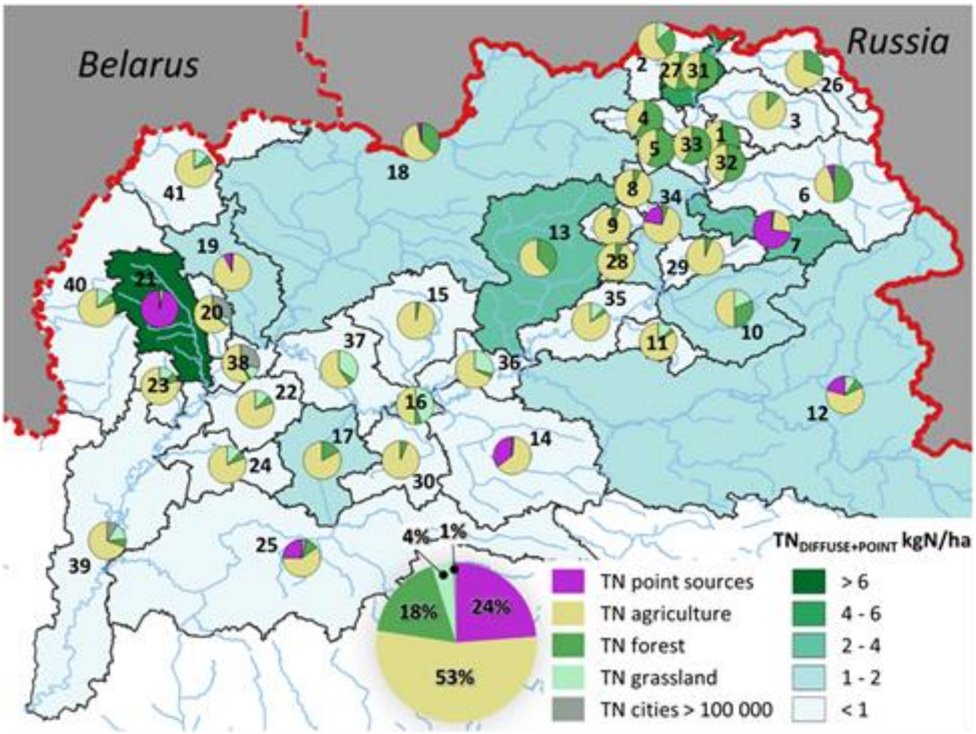


Figure 8: ***Nitrogen compounds emission in the Desna Basin (numbered circles represent the small sub-catchments).***

Phosphorus emission from the catchments is determined predominantly by diffuse sources (76% of phosphorous discharge). However, unlike for nitrogen, agricultural lands almost fully dominate in diffuse sources distribution. Phosphorous transport is mostly associated with erosion of particles (Figure 9).

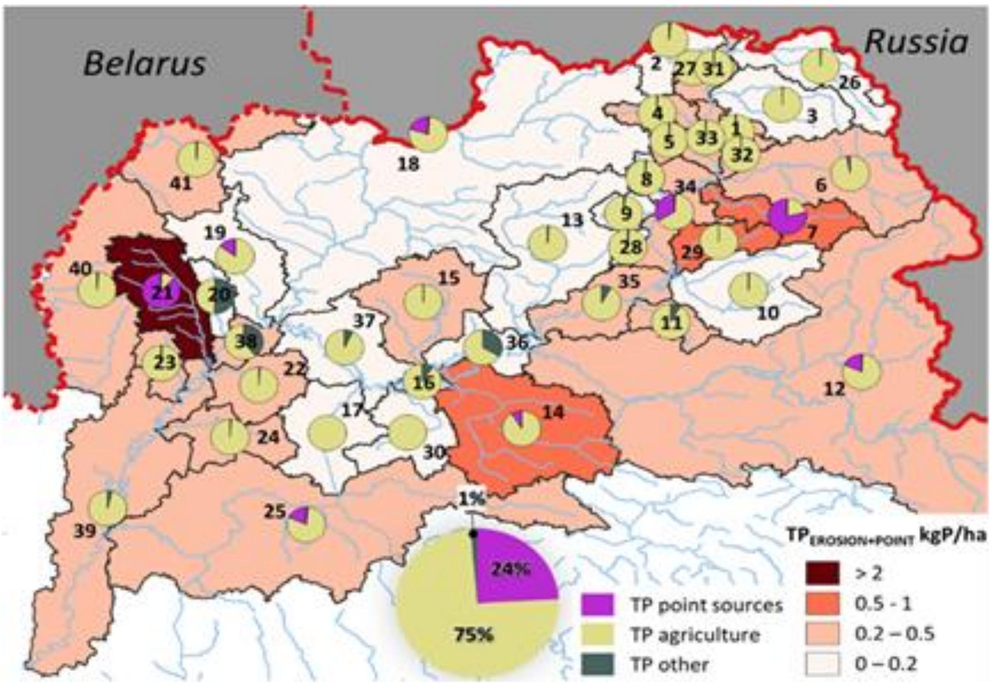


Figure 9: ***Phosphorous load in the upper Dnipro Basin and Desna Basin (numbered circles represent the small sub-catchments).***

To resolve the biogenic pollution problem, significant financial investments are necessary to provide a municipal wastewaters collection and treatment, an implementation of advanced (tertiary) removal of biogenic elements from wastewaters of big cities and in zones vulnerable to nitrate pollution, a limitation of phosphorus-containing detergents, and an improvement of agricultural practices. Advanced wastewater treatment should be provided for settlements of more than 100.000 inhabitants. All settlements with more than 2000 inhabitants should be provided with wastewaters collection and subsequent wastewaters treatment. Phosphates content in detergents should be limited legislatively.

An implementation of Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources allows controlling organic and mineral fertilizers application in agriculture.

Pollution by hazardous substances

Knowledge on quantitative parameters of Ukrainian surface water pollution by hazardous substances and on regularities of circulation paths in the environment is still limited. This requires high efforts in setting up of an appropriate water monitoring and related scientific researches.

Chemical polluting substances can enter natural water bodies by municipal and industrial wastewaters, as a result of agricultural activities, as a content of pharmaceutical and cosmetic products. There are 45 priority substances identified causing high risk´s for water ecosystems. Ecological standards ensuring the safe water use are established for such substances.

Solving the natural water pollution by hazardous substances problem is related to the implementation of safe industrial technologies, to the prevention of industrial accidents, and to the application of special methods for wastewater purification (introducing filters for dangerous and pharmaceutical substances sorption). Removal of dangerous substances from water and protection of humans and ecosystem health is possible by using relevant wastewaters purification methods. Using of the less toxic forms of agricultural chemicals should be stimulated; appropriate management and use of agricultural chemicals should be provided.

Conclusions

- Monitoring of nutrients in the Desna Basin should be coupled with modelling of nutrients transport and load in order to assess the possible influence of the Desna River pollution pathway downstream to the Kyiv Reservoir.
- Assessment of nutrients load should be performed for the Russian part of the Desna Basin that will allow obtaining a complete informational background for further drafting the River Basin Management Plan and elaborating of the Program of Measures.
- Monitoring of hazardous substances in the Desna basin should be established in order to identify the chemical status of the water bodies in the Desna Basin.

2.3 Conclusions

Very often, the frequency of observations is not enough for a profound process analysis. Nowadays, automatic gauging station for water quantity and quality parameters should be installed at critical points to understand the temporal dynamics and spatial variability. Having a sampling frequency for physical and chemical parameters of, e.g., once a year, can lead to misinterpretations.

Furthermore, the list of parameters should be extended to comprehensively assess the chemical status of water bodies.

To ensure correct estimations of the quantity and quality of water bodies, some general recommendations should be considered:

- Choice of appropriate measurement methods
- Operation by competent personnel
- Regular expert maintenance and servicing (calibration) of measurement devices
- Regular checking of the geodetic calibration of water level/ discharge stations
- Frequency of discharge measurements must ensure that the water level runoff relationship is valid (every three month, in different hydraulic conditions). Cross sections for the respective flow-off curve must be known.
- Intercalibration experiments and harmonization of monitoring practices are needed.
- Information and data exchange between national institutions and riparian countries to assess data and possibly correct and harmonize them

3 Check, correction, harmonization and handling of data

3.1 Data check and correction

Some measurement devices show a drift (e.g., the relative humidity sensor doesn't reach 100% anymore), or start-up speed of wind speed sensor increases over time. Exemplarily, a correction approach for hourly relative humidity observations is described (from Körner et al., (2020):

A period of two months was chosen to correct the drift of values below 100%. If in 1464 successive hours at no time a humidity of 99% is reached, a drift is assumed. The reason for using 99% is due to the fact that hygrometers can, even in the case of a drift, in exceptional cases have values of 100% relative humidity, e.g. when rain is blown into the climate hut or dew is deposited. For periods for which a drift was detected, a floating maximum (21 days) is then calculated. This is necessary to correct the humidity values in the following steps. Thus, it can be determined at any time how far the drift has progressed and which measured value corresponds to an actual humidity of 100%. A correction according to following formula is applied:

$$rH_{cor} = 100\% * rH_{meas}/rH_{max}$$

where rH_{cor} is the corrected, rH_{meas} the measured and rH_{max} the maximal value of relative humidity (which should be 100% in reality).

A visual inspection for outliers and suspicious data is recommended, because even quality proofed data can contain suspicious, e.g., repetitive data. An automatic check of data on physical meaningful thresholds, repetitive values and outliers should be performed. Recommendations are given for example in ECA&D (2013). Because tests which check only the interested station are often supercritical, a spatial outlier check using observations of surrounding stations is recommended for meteorological variables (Terskii et al. 2019).

Most precipitation measurements have an undercatch of precipitation due to wind and evaporation induced errors. A correction can base on site characteristics and further meteorological variables like temperature and wind speed (for details see 3.3)

Problems with the homogeneity of time series can arise from changes of the instrument, the measuring site, the closer surroundings, observation routines, calculation of daily values etc. The inhomogeneities often have the same order of magnitude as the climate change signal of the 20th century and obscure trends and the decadal variability. Various graphical and numerical homogeneity tests exist. Not only one of them, but various should be applied, because results can differ. Mostly, relative tests are applied, this means with the help of surrounding stations. Identified problems with the homogeneity of time series can be overcome. Exist homogenization approaches, but a cautious use is recommended, because the possibly unique statistic of the affected station could be disturbed. A non-consideration of the affected station maid be the better solution.

3.2 Bias correction of precipitation data

The amount of precipitation measured by any gauge is usually less than the amount of actual precipitation due to system errors related to the design of the gauge.

Tretyakov precipitation gauge (gauge O-1) with a wind shield is a main type of gauge across Ukrainian and Russian stations (Figure 10). Systematic errors are (in order of importance): wind induced undercatch (losses due to wind field deformation over the receiving set of the gauge), wetting losses on the internal surface of the receiving set, evaporation and condensation processes, and sweeping of snow cover during heavy snowstorms.

Figure 10: ***Tretyakov precipitation gauge***

Systematic losses differ according to the type of precipitation (snow, rain, mixed). Losses are larger for solid precipitation types. According to WMO report (Goodison et al., 1998), observed precipitation losses for shielded Tretyakov gauge are between 8 and 41% for snow and between 3 and 28% for rain at stations with average wind speed between 1.0 and 4.2 m/s.

Attempts to implement developed techniques for precipitation adjustment over a single measurement began on a mass network of USSR meteostations in the early 1970s and failed for two reasons. First, the methodology was too complicated for the observer despite simplifications of necessary calculations. Second, the simplification of the calculation scheme inevitably led to an increase in the random error of the corrected value of precipitation. As a result, it was decided to implement into the current data on precipitation a correction that compensates only wetting losses (Bogdanova et al., 2002). This wetting correction has been introduced since January 1, 1966 and is valid today at all weather stations in Ukraine and Russia. All other systematic errors so far remain unaccounted in current precipitation observations archives.

Several methodologies of wind induced undercatch exist for Tretyakov gauge but the most complex one as well as consistent with Ukrainian and Russian weather observation protocol was presented by Golubev (Goodison et al., 1998). The values of the correction coefficient are connected with the fall velocity of precipitation particles (equilibrium fall velocity in air) and dynamic characteristics of air flow during precipitation fall. Therefore, equations along with wind speed also includes wind direction, horizon shelteredness, air humidity, atmospheric pressure, and coefficient of precipitation types.

Unfortunately, in Ukraine, an official recommendation of precipitation correction due to wind induced undercatch doesn’t exist. In Russia this is regulated by Recommendations P52.08.657–2004 “Precipitation. Methodology of measurement of the O-1 gauge”. Efforts to establish a methodology for a correction of all errors should be undertaken in future.

3.3 Meteorological data alternatives

In the Western Dvina basin, density of climate stations is very low. Especially rainfall distribution within the catchment is not well represented with existing stations, because of very high spatial variability of rainfall (see low correlation between stations in Table 3).

Table 3: Correlation coefficients of daily precipitation between relevant stations (1979-2016)

Stat-ID	Name	Correlation coefficient				
26781	Smolensk	1				
26477	VelLuki	0.61	1			
26585	Beliy	0.31	0.21	1		
26578	Velizh	0.55	0.74	0.29	1	
26479	Toropec	0.60	0.56	0.48	0.57	1
		Smolensk	VelLuki	Beliy	Velizh	Toropec

Reanalysis datasets are valuable alternatives to observed station data. An atmospheric reanalysis is a meteorological and climate data assimilation project which aims to assimilate historical atmospheric observational data using a single consistent assimilation scheme throughout. The usage of reanalysis data must be taken with caution and should always be checked for the investigated region.

Reanalysis does fairly well regarding temperatures in Western Dvina basin, but tends to be more error-prone regarding precipitation. In many reanalysis projects, observed precipitation is not assimilated. It is simulated by the model and shows henceforth more uncertainty. At the same time, the data from meteorological stations are not always accessible or incomplete, and often contain outliers which require further corrections. Two meteorological station data sources were used:

- European Climate Assessment & Data (ECA&D) (http://www.ecad.eu);
- Global Surface Summary of the Day from the National Climatic Data Centre (GSOD NCDC/NOAA) (http://www.ncdc.noaa.gov/doclib).

The average annual precipitation is almost the same in the two datasets under consideration (723 and 725 mm for interpolated station data and reanalysis, respectively). There is a discrepancy between precipitation trends in the period 1981-2016. Reanalysis data show a downward trend whereas interpolated station data does not. Interpolated station data have lower values than reanalysis at the beginning and higher values at the end of the period. The reason for this discrepancy may be the decreasing number of station data over time. One of the trends in the region under consideration is the closure of stations recording comparatively low precipitation sums. Mean temperature values coincide very well, but daily minimum and maximum temperatures are underestimated by the reanalysis.

The relative humidity values of the reanalysis are slightly higher than interpolated station data. The wind speed values are about 33 % (or 1.38 m/s) higher for reanalysis in comparison to interpolated station data.

In the study area, solar radiation and sunshine duration are not measured; however, these solar characteristics are important for building a hydrological model. Based on the recommendations of the ERA-Interim developers (Dee et al., 2011), the use of sunshine duration is not recommended. Therefore, the reanalysis data of Solar Surface Radiation Downwards (SSRD) were used.

Because of mentioned uncertainties of reanalysis data, it is recommended to use station data for precipitation, temperature, humidity and wind speed.

3.4 Data alternatives using remote sensing data

Remote sensing applications are considered as alternative methods for monitoring of hydrological characteristics of rivers (water discharges and levels, turbidity, chemicals). It enables to obtain time-series of hydrological parameters for ungauged or of hardly accessible river reaches (e.g. boundary rivers). Nowadays, such data can be collected for all international rivers in the zone of national interests of Russia and neighbouring countries. Such information is provided by the commercial operation of UniScan™ stations, which receive, on the daily basis, information from satellites TERRA (DB), AQUA (DB), ENVISAT, RADARSAT_1, SPOT_4, SPOT_5, FORMOSAT_2, LANDSAT_5, EROS_A, and EROS.

As far as water quality was identified as the most poorly studied topic in the Western Dvina catchment, remote sensing monitoring of river water quality is discussed as a promising technology for observations in the reaches of international rivers. It is based on determining the relationship between the physical, chemical, and biological characteristics of water quality X and the optical brightness of water surface DN and its derivatives (spectral brightness coefficient Li and spectral albedo)

X = f (DN, Li)

In situations with limited possibilities of ground-truth observations in the basins, the calibration of such models can base on combining satellite data with episodic expedition surveys or data of measurements in the national part of the basin of an international river. But, formation conditions of water quality characteristic X should be uniform along the river. Exemplarily, we prepared a conceptual model for remote sensing applications to assess sediment concentrations (Figure 11) which is also can be used for specific chemical studies.

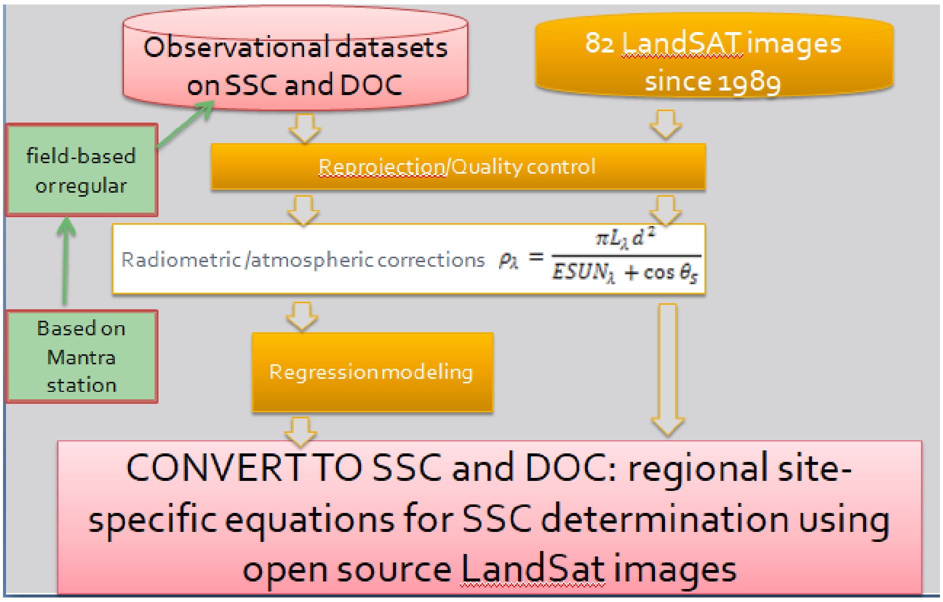


Figure 11: General workflow of the LandSAT image processing to determine SSC and DOC

3.5 Gap filling

Numerous approaches exist to fill gaps in the data series or to replace suspect values. A simple approach for small gaps (one or two days) of continuous data (e.g. temperature) is the linear interpolation between proceeding and successive values. For intermittent data (like precipitation) this method can’t be applied. Longer periods of missing values in time-series can result from financial shortcutting, from political changes (e.g. after 1991), etc. Autoregressive models were found suitable (Shahin et al., 2014). If measurements of adjacent sites are available, these can be used either by spatial interpolation (e.g. Hijmans et al., 2005) or by data-driven methods like nearest neighbour, linear or multiple linear regression (e.g., Ramos-Calzado et al., 2008), artificial neural networks (Reichstein et al., 2005) or the alternative machine learning method gradient boosting (Körner et al. 2018). Especially methods using information from surrounding stations were found to be very successful gap filling tools.

3.6 Harmonization

Examples of harmonization problems were reported in the second project report. Correction of affected values is well possible in some cases, in others, uncertain results arise. Three examples are mentioned exemplarily:

1) Differences in instrumentation often produce systematic errors which maid be corrected. If parallel measurements of, e.g. two temperature sensors, exist for a longer period (few years), a linear regression can be used, having one station as explanatory variables for the other one.

2) Analyses of water monitoring consistency along the transboundary river Western Dvina reveal important methodological problems, related to outdated methods applied at various gauging stations. Statistical approaches revealed that recently obtained datasets are not consistent both with current observations in the downstream part of Western Dvina basin (in Belarus and Latvia), as well as with historical datasets. The largest error can be related to the applied method, type of filters (<5 µm) and pumping procedure, as well as (possibly) insufficient sampling frequency. As far as Velizh station since 90th is the only station in Russian part of Western Dvina basin where sediment load monitoring is proceeded, the data demonstrate the basin-wide gap in the transboundary river monitoring. It also highlights the importance to check existing methods and techniques. This should be part of regular harmonization efforts of water monitoring.

3) Soil texture is different almost along the whole length of the national border between Ukraine and Russia although soil maps have the same scale 1 : 2500000 and soil groups classification, therefore, borders of the soil polygons match very well (Figure 12).

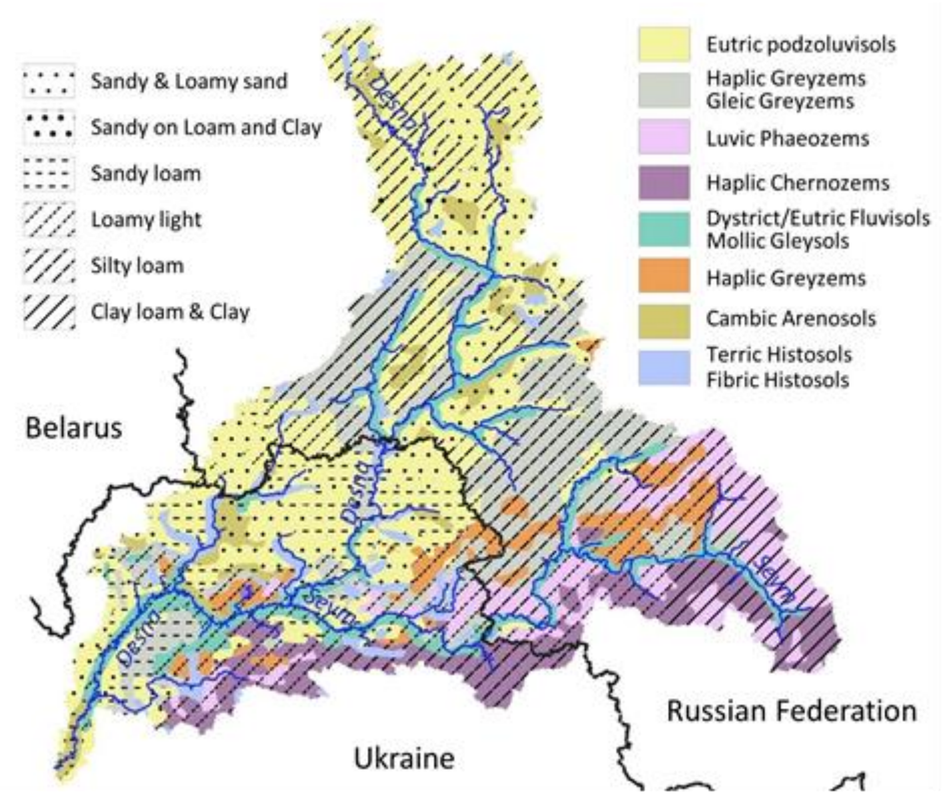


Figure 12: ***Soils types of the Desna basin according to FAO classification and texture according to Kachinsky classification.***

The main problem is that soil surveys, which were the basis for creation of maps, were conducted for the territory of Ukraine in 1957–1961 and for the Russian Federation approximately 20 years later – in the late 1970s. Therefore, the reason of texture discrepancy could be both methodological differences (field or laboratory methods) and transformations of physical properties under agriculture practices.

In the ‘Harmonized World Soil Database’, the whole area of the Eutric podzoluvisols across the Desna basin is attributed to Silty Loam according to USDA classification (Sand – 35%, Silt – 54%, Clay – 11%). Such generalization is too rough for hydrological modeling because filtration properties highly depend on soil texture, especially, for Eutric podzoluvisols. Therefore, soil properties have to be revised through field studies in the near future.

3.7 Data handling

To ensure a full reproducibility of the treatment of a dataset, the following approach is recommended. Raw data should be kept unchanged in the database and flagged for their quality (e.g.: 0=valid, 1= suspect, 9=missing value). Corrected and gap filled data should be stored separately and flagged for its treatment (e.g. 0=original value, 1=corrected, 2=filled, 9=no treatment possible).

Methods for data correction and filling should be made available for the user. This data storage and handling allows the user to follow the procedure and to develop and apply own algorithms.

Data should be kept in data bases in order to store large amounts of data efficiently, without contradiction and permanently and to provide subsequently required subsets in different, demand-oriented display formats for users and application programs. Widely used data base software is, e.g., ACCESS, MySQL and Oracle.

4 Databases and data exchange

Table 4, 5 and 6 give a nationwide overview of water quantity, quality and sediment data, their accessibility, availability, prices etc.

Current status in Ukraine

The surface water monitoring in Ukraine is regulated by two main normative acts.

1) Decree of the Cabinet of Ministers of Ukraine on approval of the "Arrangement of the state monitoring of water" # 758 dated with September 19, 2018. This document designates the Agencies responsible for water monitoring at national level and sets up different types of surface water monitoring according to EU Water Framework Directive. There is also a list of parameters to be monitored with monitoring frequency.

2) The Water Code amended in February 7, 2017 by related Law of Ukraine. This document sets up the state policy in water sector and has been modified according to EU Water Framework Directive requirements. Specifically, the term of "surface water body" is introduced as well hydromorphological monitoring etc.

According to Decree of the Cabinet of Ministers of Ukraine the main agency responsible for surface water monitoring is the Ministry of Ecology and Natural Resources of Ukraine (recently has been reformed in to the Ministry of Energy and Environmental Protection of Ukraine) acting via the State Agency of Water Resources of Ukraine (SWA). The second "player" in the surface water monitoring field is the State Emergency Service of Ukraine (SESU) acting via the Board of Hydrometeorology and supervising Hydrometeorological Centre, Central geophysical Observatory, Danubian Hydrometeorological Observatory, Ukrainian Hydrometeorological Institute and regional Hydrometeorological organizations.

It is stated in the Decree, that being the head agency providing practical activities the SWA collects all monitoring information and hosts the web-based geoportal presenting results of surface water bodies ecological and chemical status assessment and other relevant information (http://geoportal.davr.gov.ua:81/#waterSidebar.). Currently this geoportal is still under construction.

The above-mentioned SESU hydrometeorological organizations and institutions run their own databases which are not accessible publicly. Data exchange is being performed routinely according to the internal protocols. Ukrainian Hydrometeorological Institute runs the informational system developed in 1999-2005 and called AquaGuard (Figure 13).

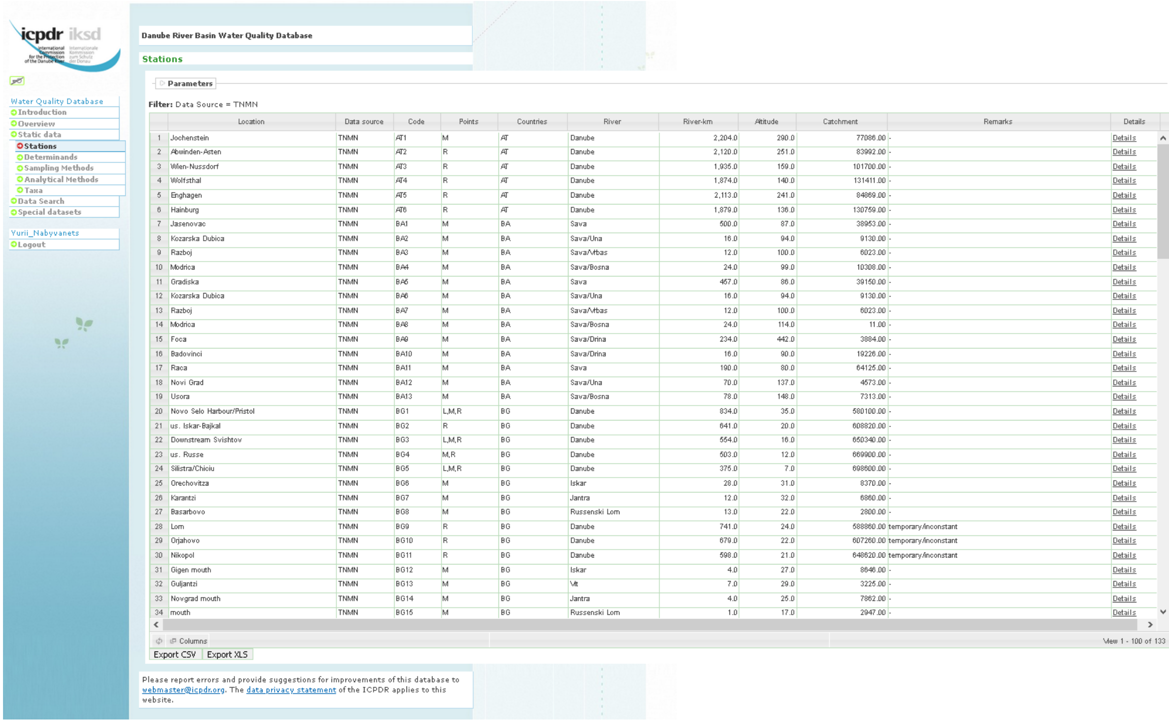
Figure 13: ***Starting page of AquaGuard informational system of the Ukrainian Hydrometeorological Institute***

This informational system contains water chemistry data of all national monitoring sites and provides possibility of data processing and visualization. This is a desk-top system being used for scientific purposes. The AquaGuard system is being updated annually by the mean of .dbf files provided by Hydrometeorological Centre upon request of Ukrainian Hydrometeorological Institute. The AquaGuard is also installed and used in the Central Geophysical Observatory.

For the time being, there are no inter-institutional protocols/agreements setting up the ecological data exchange. The information management component of the monitoring at national level is still under negotiation.

At the same time there is a positive example of monitoring data exchange at international level. Ukrainian Hydrometeorological Institute is responsible for surface water monitoring data providing to ICPDR within the framework of ICPDR Transnational Monitoring Network program. Data is sent annually (7 transboundary surface water monitoring sites in the Ukrainian part of the Danube Basin) in Excel format to Slovak Hydrometeorological Institute where data is processed and uploaded to ICPDR database DANUBIS (Figure 14). Access to the database is only for authorized persons.

Concluding, there is an urgent need of setting up the surface water monitoring data exchange between relevant agencies and institutions at national level in order to introduce the IWRM at full scale and provide support for the elaboration of the River Basin Management Plans.



icpdr iksd
International Commission for the Protection of the Danube River
Internationale Kommission zum Schutz der Donau

Water Quality Database
Introduction
Overview
Static data
Stations
Determinands
Sampling Methods
Analytical Methods
Taxa
Data Search
Special datasets

Yurii_Nabyvanets
Logout

Danube River Basin Water Quality Database

Stations

Parameters

Filter: Data Source = TNMN

	Location	Data source	Code	Points	Countries	River	River-km	Altitude	Catchment	Remarks	Details
1	Jochenstein	TNMN	AT1	M	AT	Danube	2,204.0	290.0	77086.00	-	Details
2	Abwinden-Asten	TNMN	AT2	R	AT	Danube	2,120.0	251.0	83992.00	-	Details
3	Wien-Nussdorf	TNMN	AT3	R	AT	Danube	1,935.0	159.0	101700.00	-	Details
4	Wolfsthal	TNMN	AT4	R	AT	Danube	1,874.0	140.0	131411.00	-	Details
5	Enghagen	TNMN	AT5	R	AT	Danube	2,113.0	241.0	84869.00	-	Details
6	Hainburg	TNMN	AT6	R	AT	Danube	1,879.0	136.0	130759.00	-	Details
7	Jasenovac	TNMN	BA1	M	BA	Sava	500.0	87.0	38953.00	-	Details
8	Kozarska Dubica	TNMN	BA2	M	BA	Sava/Una	16.0	94.0	9130.00	-	Details
9	Razboj	TNMN	BA3	M	BA	Sava/Vrbas	12.0	100.0	6023.00	-	Details
10	Modrica	TNMN	BA4	M	BA	Sava/Bosna	24.0	99.0	10308.00	-	Details
11	Gradiska	TNMN	BA5	M	BA	Sava	457.0	86.0	39150.00	-	Details
12	Kozarska Dubica	TNMN	BA6	M	BA	Sava/Una	16.0	94.0	9130.00	-	Details
13	Razboj	TNMN	BA7	M	BA	Sava/Vrbas	12.0	100.0	6023.00	-	Details
14	Modrica	TNMN	BA8	M	BA	Sava/Bosna	24.0	114.0	11.00	-	Details
15	Foca	TNMN	BA9	M	BA	Sava/Drina	234.0	442.0	3884.00	-	Details
16	Badovinci	TNMN	BA10	M	BA	Sava/Drina	16.0	90.0	19226.00	-	Details
17	Raca	TNMN	BA11	M	BA	Sava	190.0	80.0	64125.00	-	Details
18	Novi Grad	TNMN	BA12	M	BA	Sava/Una	70.0	137.0	4573.00	-	Details
19	Usora	TNMN	BA13	M	BA	Sava/Bosna	78.0	148.0	7313.00	-	Details
20	Novo Selo Harbour/Pristol	TNMN	BG1	L,M,R	BG	Danube	834.0	35.0	580100.00	-	Details
21	us. Iskar-Bajkal	TNMN	BG2	R	BG	Danube	641.0	20.0	608820.00	-	Details
22	Downstream Svishtov	TNMN	BG3	L,M,R	BG	Danube	554.0	16.0	650340.00	-	Details
23	us. Russe	TNMN	BG4	M,R	BG	Danube	503.0	12.0	669900.00	-	Details
24	Silistra/Chiciu	TNMN	BG5	L,M,R	BG	Danube	375.0	7.0	698600.00	-	Details
25	Orechovitza	TNMN	BG6	M	BG	Iskar	28.0	31.0	8370.00	-	Details
26	Karantzi	TNMN	BG7	M	BG	Jantra	12.0	32.0	6860.00	-	Details
27	Basarbovo	TNMN	BG8	M	BG	Russenski Lom	13.0	22.0	2800.00	-	Details
28	Lom	TNMN	BG9	R	BG	Danube	741.0	24.0	588860.00	temporary/inconstant	Details
29	Orjahovo	TNMN	BG10	R	BG	Danube	679.0	22.0	607260.00	temporary/inconstant	Details
30	Nikopol	TNMN	BG11	R	BG	Danube	598.0	21.0	648620.00	temporary/inconstant	Details
31	Gigen mouth	TNMN	BG12	M	BG	Iskar	4.0	27.0	8646.00	-	Details
32	Guljantzi	TNMN	BG13	M	BG	Vit	7.0	29.0	3225.00	-	Details
33	Novgrad mouth	TNMN	BG14	M	BG	Jantra	4.0	25.0	7862.00	-	Details
34	mouth	TNMN	BG15	M	BG	Russenski Lom	1.0	17.0	2947.00	-	Details

Columns   View 1 - 100 of 133

Export CSV   Export XLS

Please report errors and provide suggestions for improvements of this database to webmaster@icpdr.org. The data privacy statement of the ICPDR applies to this website.

Figure 14: ***ICPDR DANUBIS database.***

Table 4: Nationwide information concerning water quantity data;

Abbreviations: Roshydromet- Russian Federal Service for Hydrometeorology and Environmental Monitoring; Ukr. Hydrometeor. Centre - State Emergency Service of Ukraine; LEGMA - Latvian Environment, Geology and Meteorology Agency; Belhydromet - Republican Center for Hydrometeorology, Control of Radioactive Contamination and Environmental Monitoring; IMiGW-PIB - Polish Institute of Meteorology and Water Management -National Research Institute

Country	**PL**	**UA**	**RU**	**LV**	**BY**
Holders of hydrological data (agency)	IMiGW-PIB	Ukr. Hydrometeor. Centre	Roshydromet	LEGMA	Belhydromet
Open hydrological data available (source)	-1956-1983 published in Yearbooks -1984-2016 with costs - free since 2017	Data not open.	Since 2008 daily, monthly and annual datasets are published https://gmvo.skniivh.ru/ http://meteorf.ru/	https://www.meteo.lv/en	Data request at: http://www.belgidromet.by/ru/
Type of available open datasets	water level, discharge, temperature, ice phenomena	Data not open.	2008-2019 Discharge, water level, temperature, sediment concentration (sparse)	Variable; some stations with discharge, water level, temperature, water object situation, including ice events	water level, discharge, temperature, ice phenomena; different time-series length; monthly data free
Not open-access hydrological data	IMiGW-PIB - https://dane.imgw.pl/	Excel tables, information on water level, discharge. Time series vary depending on hydrological station.	Central Department of Hydrometeorological services http://www.ecomos.ru/kadr22/uslugiGidrologija.asp	calculated components	Belhydromet http://www.belgidromet.by/ru/
Existing protocol of hydrological data exchange	By special order	Does not exist	Agreement for the commercial data obtain	By special order	Agreement for the commercial data obtain

Table 5: Nationwide information concerning water quality data

Country	PL	UA	RU	LV	BY
Holders of data	Chief Inspectorate for Environmental Protection GIOŚ	Hydromet. Centre, Central Geophysical Observatory, Ukrainian Hydro-meteorological Institute	Hydrochemical Institute Smolensk CGMS Tver CGMS	LVGMC	Belhydromet
Open data available (source)	Annual review published: quality of surface waters	Not available	Annual review published: quality of surface waters		Annual review published: National environmental monitoring system of the Republic of Belarus
Type of available open datasets	Average, maximum, minimum for the year	Not available	Average, maximum, minimum for the year and basin averages (2010-2018)	Average, maximum, minimum for the year and basin averages	Average, maximum, minimum for the year. (2006-2018)
Not open-access data	3-4 time a year: Phytoplankton, Chlorophyll "a", Temperature, Total slurry, Dissolved Oxygen, BOD5, TOC, Oxygen saturation, Conductivity at 20°C, Dissolved Substances, Sulfates, Chlorides, Calcium, Magnesium, Total hardness, PH, Ammonium nitrate, Kjeldahl nitrogen, Nitrate, Nitrite, Total nitrogen, , Total phosphorus, various heavy metals	Excel tables containing information on hydrochemical parameters concentrations. Time series depend on the rank of monitoring site.	t^0, pH, O2, % O2, BOD5, Suspended solids, colorness, transparency, smell, CO2, Conductivity (uS/cm), Dichromate oxidation (COD), suspended substances, Stiffness common, Total nitrogen, Ammonium nitrogen, Nitrogen nitrite, Nitrate nitrogen, Phosphate, Total phosphorus. nickel, Zinc, Copper,Cadmium, Lead, Nickel, Manganese, Iron total, Phenols total, Mineral oils. (1-6 times a year)		12 times a year: indicators of physical properties and gas composition of water, BOD, COD, nitrogen-containing and phosphorus-containing substances, metal content, Oil and oil products in dissolved and emulsified state, Synthetic surfactants anionic 7 times a year: mineral composition 1 time a year: mercury, arsenic 2 times a year: phytoperiphyton, macrozoobenthos
Protocol of data exchange	By special order, signing bilateral agreements separately each time	Does not exist	Quality of surface waters of Russian federation (annual review)		National environmental monitoring system of the Republic of Belarus (annual review)

Table 6: Nationwide information concerning sediment data

Country	**PL**	**UA**	**RU**	**LV**	**BY**
Holders of data	Chief Inspectorate for Environmental Protection GIOŚ	No sediment monitoring	Hydrochemical Institute Smolensk CGMS Tver CGMS	-	Belhydromet
Open data available	http://www.gios.gov.pl/pl/stan-srodowiska/monitoring-wod	-	Since 2008 10 days and monthly averages of sediment concentrations: https://gmvo.skniivh.ru/ http://meteorf.ru/	-	
Not open-access data	Suspended load concentration 3-4 time a year http://www.gios.gov.pl/pl/stan-srodowiska/monitoring-wod	-	Central Department of Hydrometeorological Services http://www.ecomos.ru/kadr22/uslugiGidrologija.asp	-	Belhydromet http://www.belgidromet.by/ru/
Existing protocol of data exchange	Quality of surface waters (annual review)	-	Quality of surface waters of Russian federation (annual review)	-	National environmental monitoring system of the Republic of Belarus (annual review)

Current status in Russia

Based on the survey and reviews implemented within a project, the following problems of water management data processing in Russia were identified: (1) insufficient network density of gauging stations, (2) limitations in data access, and (3) outdated methods applied for the data collection.

(1) The density of the hydrological network has decreased by more than 1.5 times, on small rivers even more than 3 times since 1990. Small rivers are the most vulnerable to human activities and hydrological observations are vital for ecological conditions, water supply and quality. The comparisons show that in averages there are 1000-times smaller density of sediment observational network in Russia compared to EU countries (Figure 15). For adequate comparison of water resources distribution and variability in transboundary catchments it is necessary to organise a denser gauging network in Russia and manage observations of water discharge, sediments and quality.

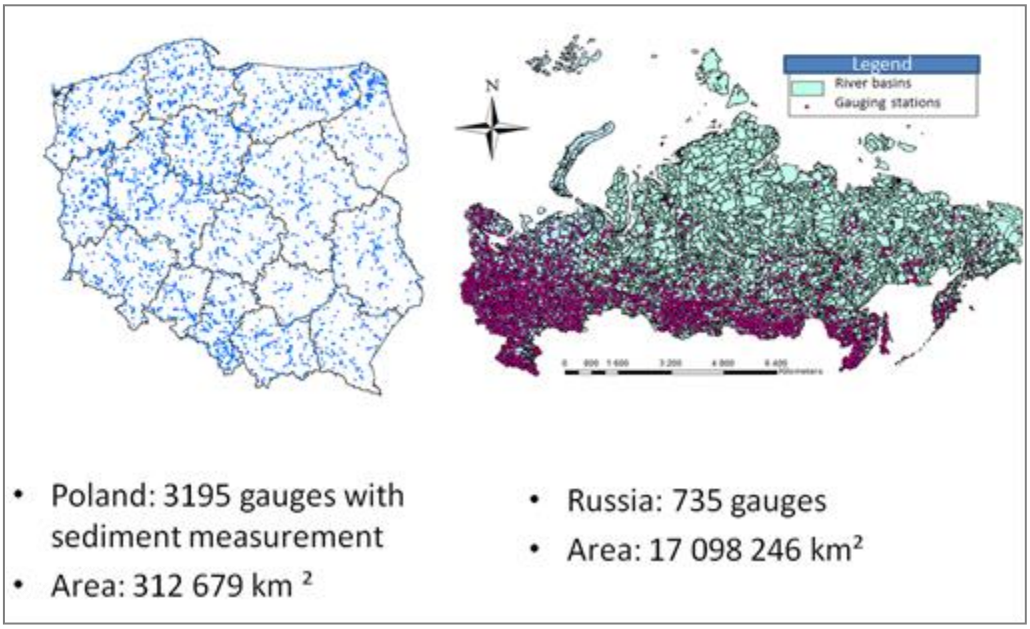


Figure 15: Comparative representation of gauging network

(2) Limitations in data access are mostly concentrated on data availability and data format for different periods of time. Until 1988 all daily hydrological data (water levels, discharge, sediments and partly quality) was published in Hydrological Yearbooks (issued by State Water Cadaster), which are freely accessible for academic users. Some data were digitalized and collected by Roshydromet, but it is very expensive. Between 1989 and 2007 the data is published in Yearbooks as well, but information is closed and subject to a fee. Since 2008, the main source of daily information is the Automated Information System of State Monitoring of Water Objects (AIS GMVO) (Figure 16). It is the official collection center of hydrological monitoring information, which is provided by North-Caucasusian scientific and research institute of water management under the Federal Agency of Water Resources. It includes all corrected data since 2008. Main Russian agencies in the sphere of water resources which are involved in data provision, are Roshydromet, Rosnedra, Federal Agency of Water Resources and Regional Departments of Water Management.

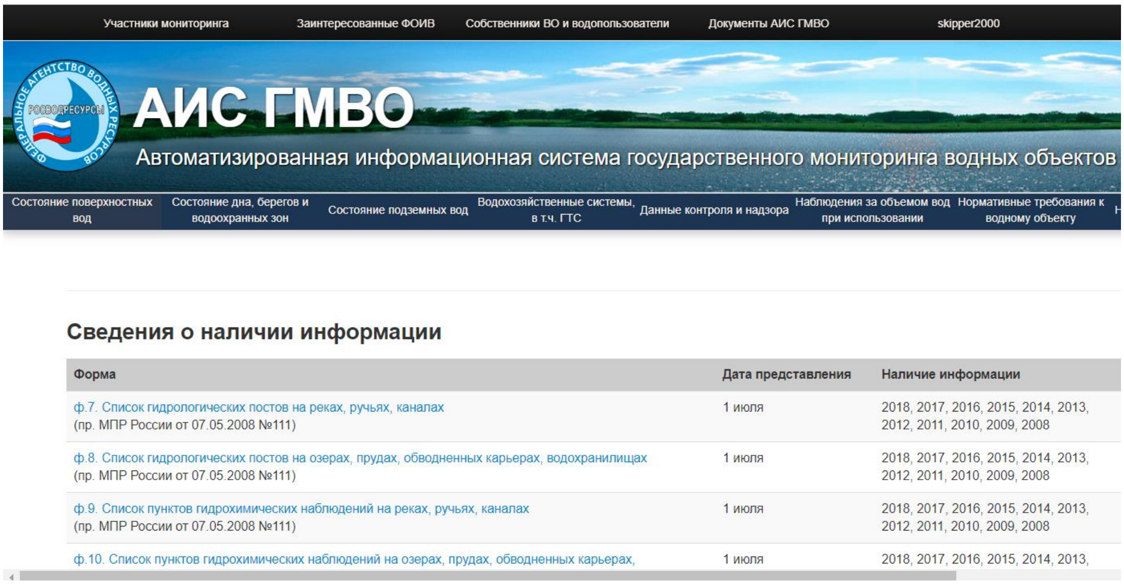


Figure 16: Title web-page of AIS GMVO system

Stored datasets are not complete, but include a lot of information, such as:

- The list of hydrological, chemical and biological gauging stations on different water bodies,
- The list of ground water bodies, monitoring stations and data on ground water resources and pollution,
- Daily, monthly, annual and extreme water levels and discharge,
- Suspended sediment data,
- Water quality state and some data,
- Ice regime and events,
- State and condition of hydrotechnical structures,
- Data on bedload sediment pollution,
- Data on water protection zones and regime of its usage,
- Limits and norms of water resources usage.

Concluding, to compile long-term hydrological data, a lot of financial resources have to be planned and a lot of work has to be invested into data checks, corrections and harmonization. It results, that no consistent database is used by different scientist, because preparation is neglected or differ between groups. Henceforth results are difficult to compare. It is strongly recommended that this work is done once properly by the data holding organizations, including digitalization of data, to set up a consistent database for all users.

(3) There are big errors in hydrological data processing due to insufficient maintenance of the gauging network. The uncertainties associated with discharge determination significantly change from year to year and strongly depend on computational methods used and frequency of discharge measurements (Shiklomanov & Lammers, 2009). Furthermore, sediment concentration measurements base on poor outdated filtering techniques, which are not capable to catch the whole range of particles transported by rivers.

Another problem is the assessment of mean and extreme hydrological characteristics for ungauged catchments. Process based and statistical methods were developed by experienced hydrologists in 1970s (http://docs.cntd.ru/document/1200035578). Since that times the density of runoff observation points has decreased. Furthermore, changes in climate cause also changes in water balance components and their interactions (e.g. changes in the inter annual distribution of evapotranspiration, water discharge due to higher temperatures and altered precipitation regime). Changes in statistical characteristics and probability distributions are the consequence. We recommend a modernization of the methodology of runoff calculation for ungauged catchments, which can base on observed data, expedition data, remote sensing technology, and indirect methods such as modelling and statistical approaches.

Freely available European data

WISE is the Water Framework Directive Database (https://www.eea.europa.eu/data-and-maps/data/wise-wfd-3) and contains data from the first and second River Basin Management Plans reported by EU Members States. There is information about surface water bodies (number and size, water body category, ecological status or potential, chemical status, significant pressures and impacts) and about groundwater bodies (number and size, quantitative status, chemical status, significant pressures and impacts). The information is presented by country, river basin district (RBD) and river basin district sub-unit (where applicable). But, no observed values/ timeseries are available.

Climate data at European level are available from European Climate Assessment & Dataset ECA&D (www.ecad.eu). These are station and gridded observation data. A further source are gridded re-analysis datasets (https://reanalyses.org/). At the national level, only some countries provide data free of charge, e.g. German Wether Service (https://opendata.dwd.de/climate_environment/CDC/).

A Global Runoff database is held by the German Bundesanstalt für Gewässerkunde (https://www.bafg.de/GRDC/EN).

Remote sensing data provide a multitude of data usable for water management tasks. Spatial and temporal resolution and accuracy have to be checked carefully, as they are no direct measurements. The European COPERNICUS initiative (https://land.copernicus.eu/pan-european) provides a large set of spatial data:

- CORINE land use data are updated every 6 years since 1990 and have a resolution 25 ha resp. 100 m.
- Furthermore, exist High Resolution Layers (HRL) for imperviousness, grassland, forest, water and wetlands (resolution 20 or 100 m) as well as a monitoring of riparian zones and an urban atlas.
- Asset allocation is done with the BEAM (Basic European Assets Map), which can be used for the analyses of flood damage potential.
- Water quality data such as turbidity, total suspended matter, chlorophyll-a or harmful algae blooms exist, for example: WasMon-CT (https://www.eomap.com/portfolio/wasmon-ct/)

5 Data analysis / models

Statistical data analysis aims at an understanding of temporal development of a variable (timeseries at a certain station) or its spatial distribution (of various stations at a certain timestep) or its combined spatial-temporal development. Also, dependencies to other variables or the separation of water or sediment sources are of interest. Applied methods are trend analysis, cluster analysis, principal component analysis etc.

One step further is the setup of models which simulate the interdependencies between interested variables considering further environmental variables and boundary conditions. Goals of modelling are:

- Process understanding: spatial and temporal development, importance and origin of water balance components, sediments and contamination sources (diffuse, point) under current and past conditions
- Future conditions: test of management options for agriculture and forestry, cost benefit analysis of possible measures to improve water quality (land use change, water treatment etc.)

There is a great variety of model types, starting with purely data driven models (e.g. applying Artificial Neuronal Networks), empirical, physically based and combined models. They differ in their data requirements, their explanatory power, their applicability for changed conditions etc. Mostly, data are required from topography or cross sections of the river or lake, land use, soil, climate data, management data, calibration data (discharge, water quality measurements) etc.

With the help of two examples typical tasks during data analysis and model application are presented and discussed.

5.1 Example 1: Climate change and impacts on hydrology

Climate change impact on water flow as well as on other water balance components was assessed using hydrological models of the Desna, Western Bug and Western Dvina basin. The Soil Water Assessment Tool (SWAT, Arnold et al., 2012) was independently set up, calibrated and validated for each basin (Fischer et al., 2014; Osypov et al., 2018; Pluntke et al., 2014; Terskii et al., 2019). These models can now be applied for alternative boundary conditions as for example climate change scenarios.

Data

Climate Projections are taken from recent climate downscaling projects EUROCORDEX (https://euro-cordex.net/), and ReKliEs-De (http://reklies.hlnug.de/home/). In EUROCORDEX, seven Global Circulation Models GCM were downscaled with 6 Regional Climate Models RCM, having a spatial resolution of 12 km (0.11°). From this suite of climate projections, six were chosen to show the bandwidth of possible climate developments (Table 7). Two representative concentration pathways (RCP) were chosen to analyse the uncertainty that arises from the global development of greenhouse gas emissions. The RCP 2.6 scenario represents a global warming which does not reach the level of 2°C at the end of the 21st century. Under the RCP 8.5 scenario, an approximately three times higher primary energy consumption is assumed. It represents the upper end of climate change. Global climate developments in the last years seem to follow the RCP 8.5 path. Therefore, the focus was set here, choosing four RCP 8.5 projections.

To cover the uncertainty that derives from different GCMs two GCM were chosen:

1) Max- Planck- Institute Earth System Model (MPI- ESM) and
2) European community Earth-System Model. We used the model runs of two RCM that downscale the two chosen GCM: REMO and RCA4

Hydrological simulations of Western Bug basin until Reservoir Dobrotvir were used here from a past project for comparison to Western Dvina and Desna. The model was driven by an alternative climate projection: GCM ECHAM5 under the SRES emission scenario A2, which represent rapidly growing emissions. The GCM was downscaled with COSMO Climate Limited-area Model (CCLM 4.8) with a horizontal resolution of approximately 7 km (Pavlik et al., 2012).

Table 7: Chosen climate projections

GCM	*RCM*	*RCP*
MPI-ESM R1I1P1	REMO	RCP2.6
MPI-ESM R1I1P1	RCA4	RCP2.6
MPI-ESM R1I1P1	REMO	RCP8.5
MPI-ESM R1I1P1	RCA4	RCP8.5
EC Earth-R12I1P1	REMO	RCP8.5
EC Earth-R12I1P1	RCA4	RCP8.5

Climatic conditions

Analysis of the climatic conditions in the future is based on indices. The focus was set on indices that provide information about the average water availability, extreme precipitation and dry conditions in the region (Table 8).

Table 8: Analysed indices.

Index	*Abbrev.*	*Explanation*
Precipitation	pr	Precipitation sum [mm]
Potential Evapotranspiration	pet	Potential Evapotranspiration sum [mm]
Climatic water balance	cwb	Difference between precipitation and potential evapotranspiration [mm]
Occurrence of heavy rainfall	pr95oc	Occurrence of precipitation events over the 95th percentile [ ]
Amount of heavy rainfall	pr95am	Precipitation sum of events over the 95th percentile [mm]
Occurrence of extreme rainfall	pr99oc	Occurrence of precipitation events over the 99th percentile [ ]
Amount of extreme rainfall	pr99am	Precipitation sum of events over the 99th percentile [mm]
Dry days	dd	Number of days with precipitation less than 1 mm [ ]

The results from GCM and RCM often biased, because of limited process understanding and model inherent shortcomings such as spatial resolution, process description etc. It is necessary to reduce such errors before applying the data for impact modelling. Applying an empirical quantile mapping (using the r-package 'qmap'), we corrected precipitation and temperature data.

Spatial distribution of the mean yearly temperature *tas* and yearly precipitation *pr* sum, as well as for derived variables potential evapotranspiration *pet* and climatic water balance *cwb* of the period 1971-2000 is exemplarily shown for the model combination MPI_REMO (Figure 17). There is a clear yearly mean temperature gradient in the investigation area with lower values in north-east and higher values in south-west. The temperature range from below 3°C until 10°C seems to be too extreme in comparison to observations: 1985-2014, Moscow: 5.9°C, Kiev: 8.6°C, Warsaw 8.5°C (https://climatecharts.net/). Precipitation mainly shows a different gradient with high values in north-west (Baltic Sea) and low values in south-east. Modelled high values up to 1200 mm seem too high in comparison to observations (Riga: 656 mm). But, direct observation over sea are very scarce, therefore a validation is hard to do. Higher precipitation sums are modelled at the south-west corner of the investigation area. They are plausible, because by the Carpathian Maintains. Both factors, elevation and distance to the Baltic Sea and North Sea determine the distribution of precipitation. Potential evapotranspiration, which is based in the applied approach on mean temperature und sunshine duration, shows a clear north-south gradient. Increasing temperatures towards the south lead to increasing *pet* rates. Climatic water balance reflects the regional distribution of *pr* and *pet*. Higher *pr* sums and lower *pet* rates in the north result in a positive *cwb*, with up to 225 mm water surplus and more. Contrasting conditions can be found in the south, where *pr* sums are lower and *pet* rates are higher, which results in a negative *cwb* of -200 mm and more. From a climatic point of view, there is a deficit of water.

The other three model combinations show only slightly different climatic conditions.

For the analysis of future climate conditions, the two most contrasting projections regarding their magnitude and spatial distribution were depicted from the suite of six analysed projections. The climate signal is presented, i.e., future values refer to values of the reference period. Climate signal are independent of model errors and are well suited for comparisons.

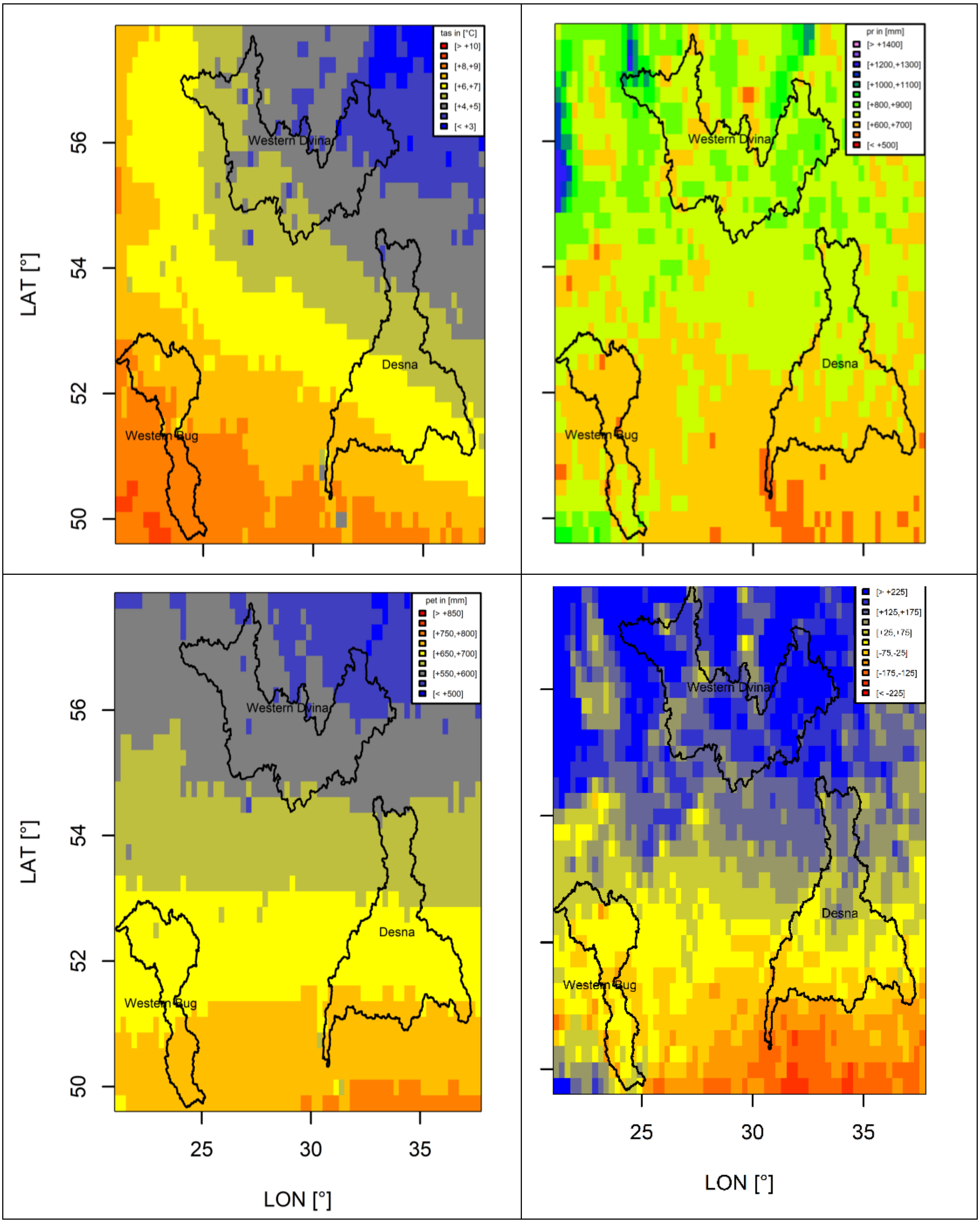


Figure 17: Climate conditions of the past (1971-2000) for the three basins modelled with MPI_REMO for emission scenario RCP 8.5. Up left: mean temperature, up right: precipitation, bottom left: potential evapotranspiration, bottom right: climatic water balance

Precipitation is projected to increase in nearly the whole investigation area (Figure 18). Changes are minor for the near future (NF, 2021-2050) and mayor for the far future (FF, 2071-2100). No clear gradient of the changes is projected for the NF. But, a clear south-north gradient becomes apparent for the FF, with an increase of more than 200 mm in the north and a decrease between 25 and 75 mm in the south. A weaker gradient of increasing precipitation sums is projected by ECEARTH_RCA4_RCP85. For the RCP 2.6 scenarios no or only slight positive and negative changes are projected.

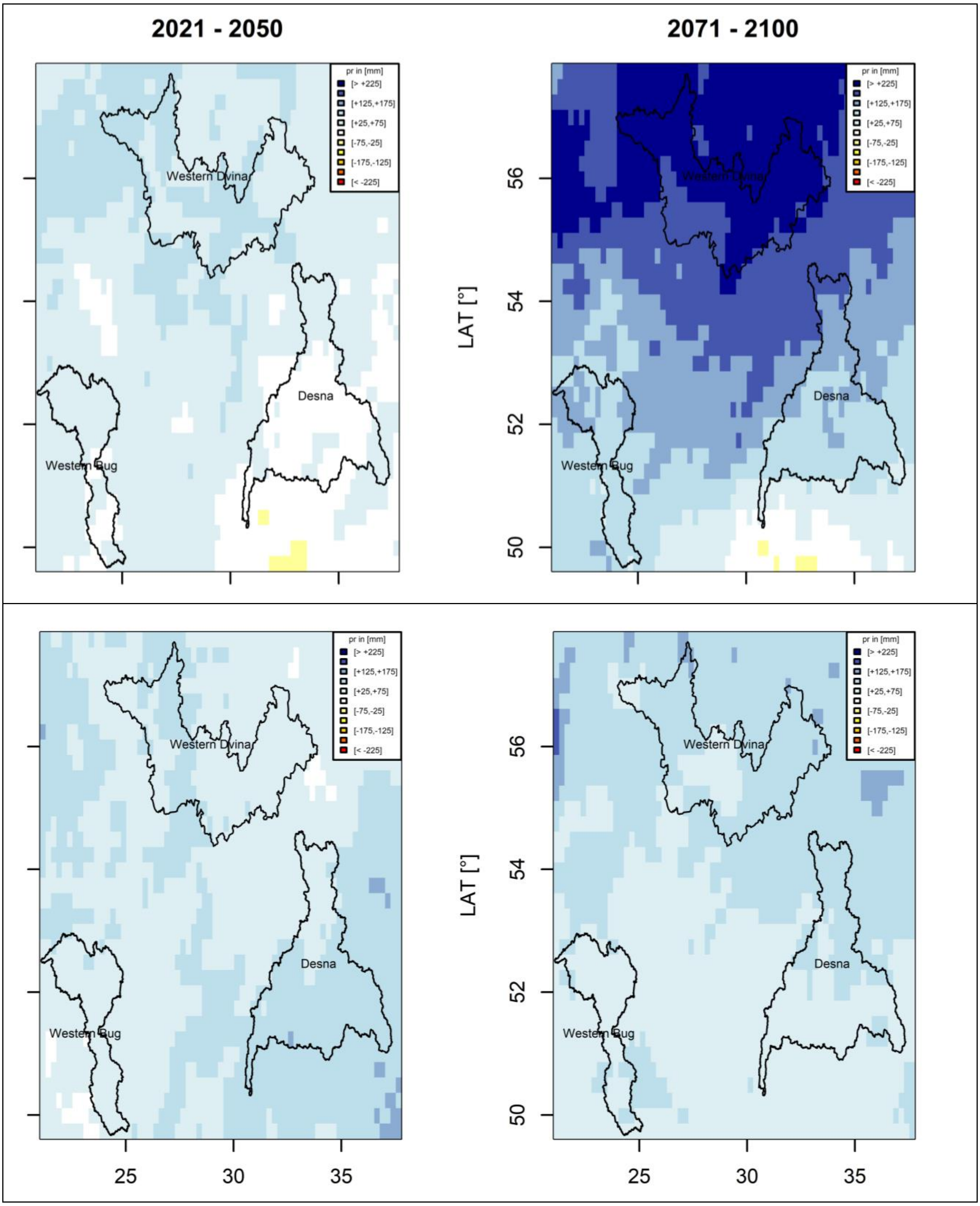


Figure 18: Climate signals of precipitation for two climate projections. Above MPI_RCA4_RCP85 and below ECEARTH_RCA4_RCP85

Only slight increases of Potential Evapotranspiration are projected for the south in the NF (Figure 19), but they become more concise in the FF. A north-south gradient of *pet* is projected by the MPI driven models, whereas the ECEARTH driven models show a more homogeneous increase in the investigation area. The reason for these trends is increasing temperature of up to 5°C until 2100 (ECEARTH). Global radiation is projected to decrease for the RCP 8.5 and remain nearly unchanged for the RCP 2.6 scenarios (not shown here). Although global radiation also has a positive influence on *pet*, its influence is less dominant in comparison to temperature.

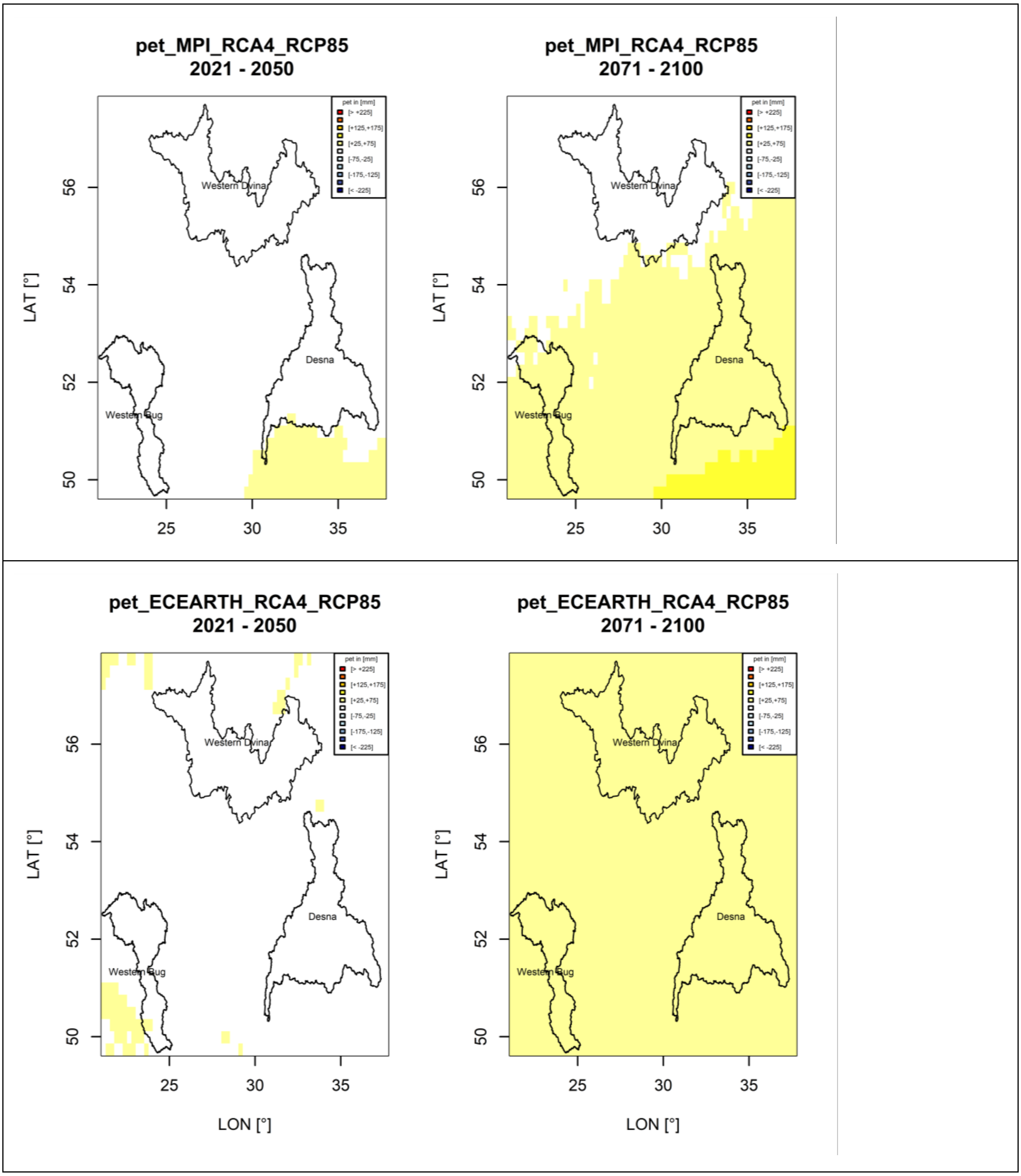


Figure 19: Climate signals of potential evapotranspiration for two climate projections.

Future changes of <u>Climatic Water Balance</u> result from spatial distribution of *pr* and *pet* (Figure 20). In the north, where *pr* - as an input of water - significantly increases (up to more than 200 mm per year) and at the same time *pet* increases – as a loss of water – (up to 75 mm) results a positive *cwb.* This means, from a climatic point of view, a surplus of water is projected for Western Dvina basin (between 50 and 200 mm for ECEARTH and MPI, resp.). For Western Bug only minor increases of *cwb* are projected. In the Desna basin, a gradient with positive changes of the *cwb* in the north and no, and spatially very restricted negative changes in the south evolve.

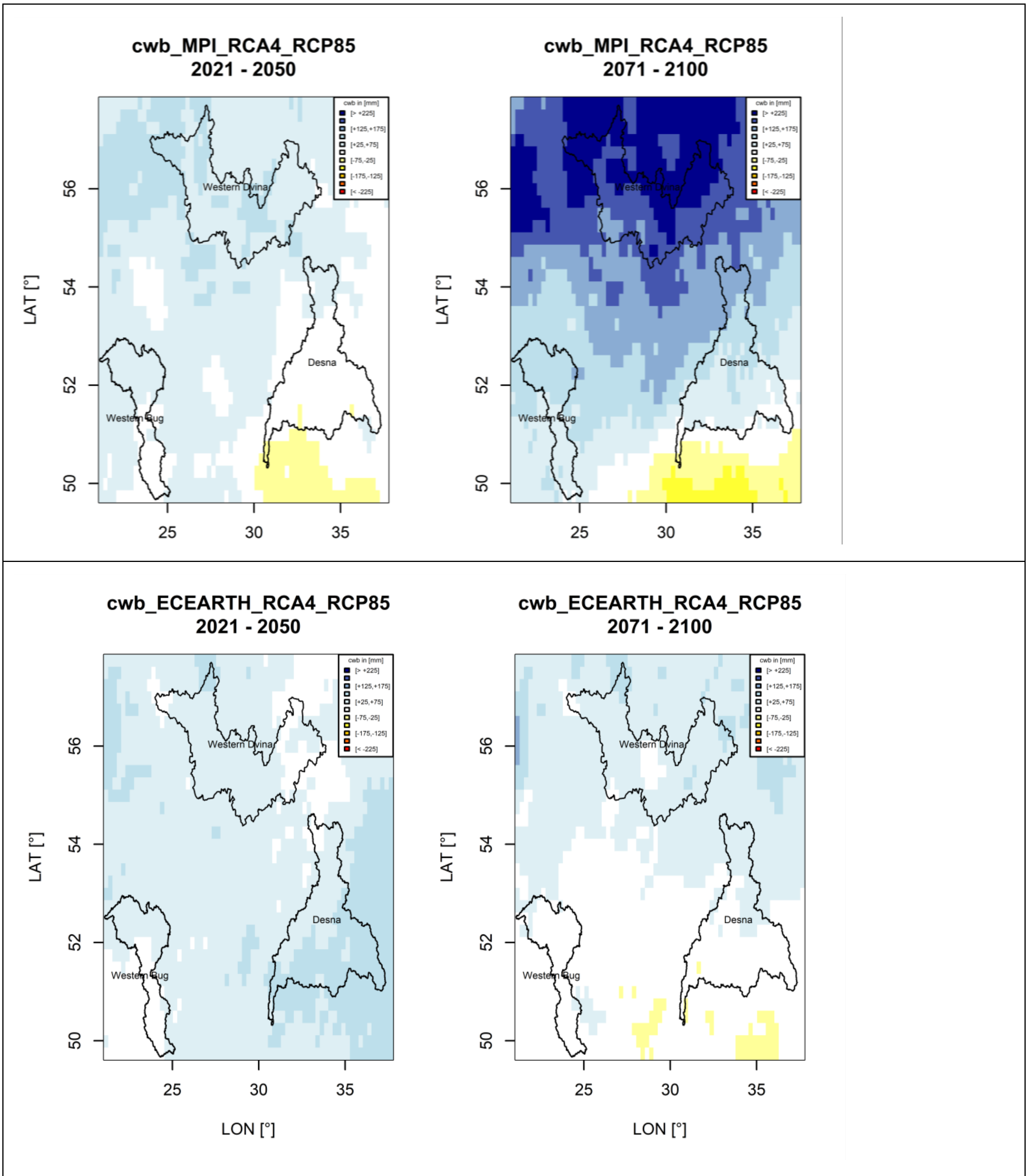


Figure 20: Climate signals of climatic water balance for two climate projections.

For the characterization of climate conditions also indices concerning climate extremes such as heavy precipitation and drought events were analysed. The occurrence of heavy precipitation events (RR95p) and precipitations amounts during those events in the past was lowest in Desna basin (south-east) and highest in Western Dvina basin (north-east) (see: left column in each basin plot of Figure 21). All four model combinations show the same result. Large-scale atmospheric circulation is a strong influencing factor for the climate of Northern Europe (Klavins and Rodinov 2010). Avotnice et al. (2010) showed that cyclonic circulation patterns from western and northern orientation, and cyclonic patterns directly over the region, often cause extreme precipitation events. This could explain the observed extreme precipitations gradients in the investigation area.

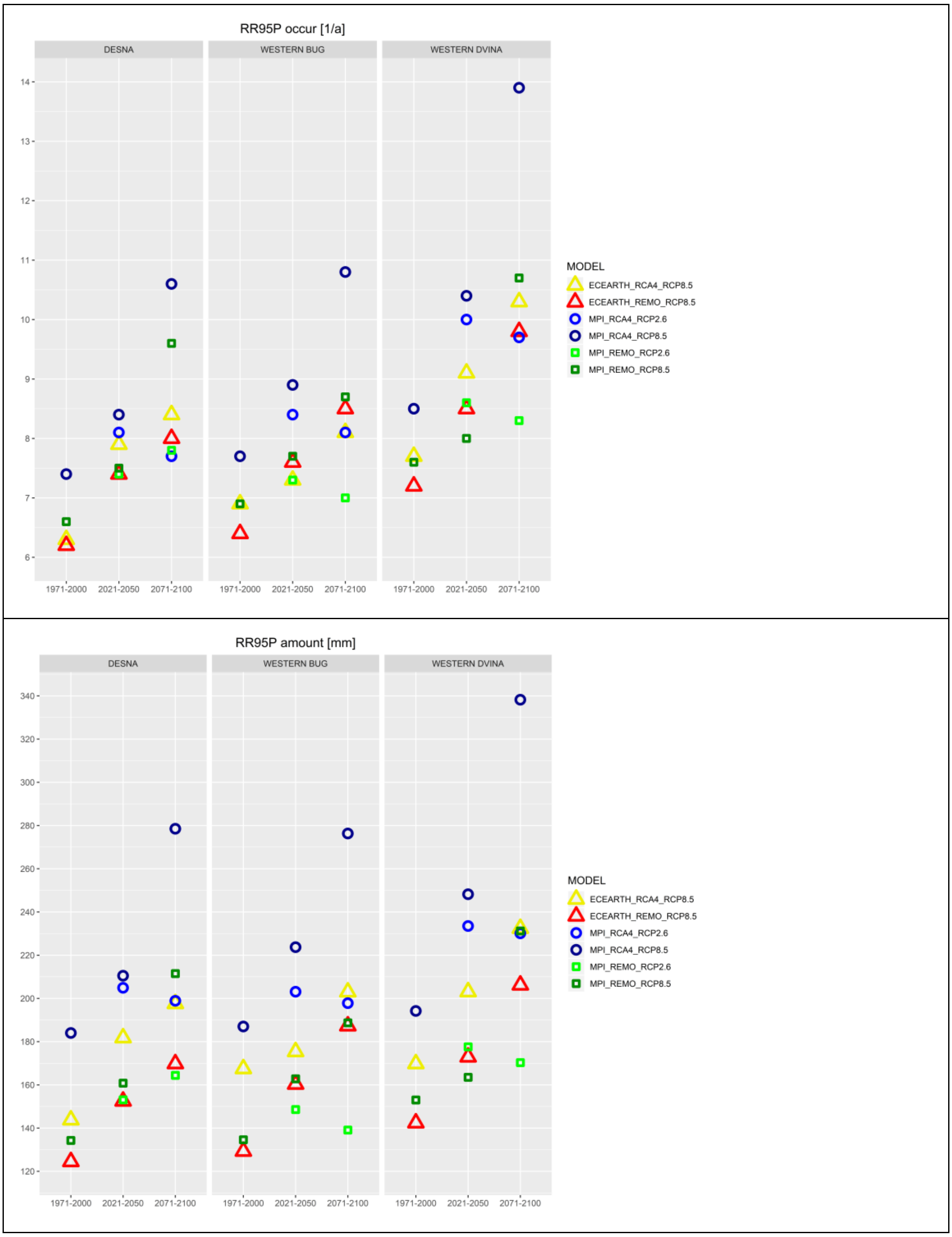


Figure 21: Occurrence and amount of precipitation over the 95th percentile for the three regions for the past as well as for the near and far future

Occurrence of heavy precipitation is projected to increase in all basins for NF (Figure 21). Further increases are simulated for FF under RCP85, contrasting the decreases under RCP26. Results are widespread especially for Western Dvina, e.g., between 10 and 14 heavy precipitation events are simulated under the RCP85 scenario. Patterns are similar for the amount of water during heavy precipitation with one exception. MPI_REMO_RCP26 shows also increasing amounts for FF in Desna basin, although the occurrence is slightly increasing. An intensification of precipitation is the consequence. Stronger precipitation events (RR99p) occur naturally less frequent, but future changes are very similar.

Consistent with the distribution of precipitation sums and heavy precipitation events are the dry conditions. Lowest number of dry days (<1 mm) were simulated for Western Dvina Basin, the highest number in the Desna basin (see left column in each basin plot of Figure 22). Models exhibit quite different results for the number of dry days. The two ECEARTH models project a decrease of dry days in NF and an increase in FF. MPI simulations under RCP85 show decreasing trends of dry days. Under RCP26, dry days seem to be reduced in NF but increase again in FF. Overall, changes of dry days are not dramatic, some days only. The most prominent change is the reduction of dry days between NF and FF for Western Dvina from 195 to 183 days. Because of the nearly overall increasing precipitation sums, drought is of no concern at the yearly level.

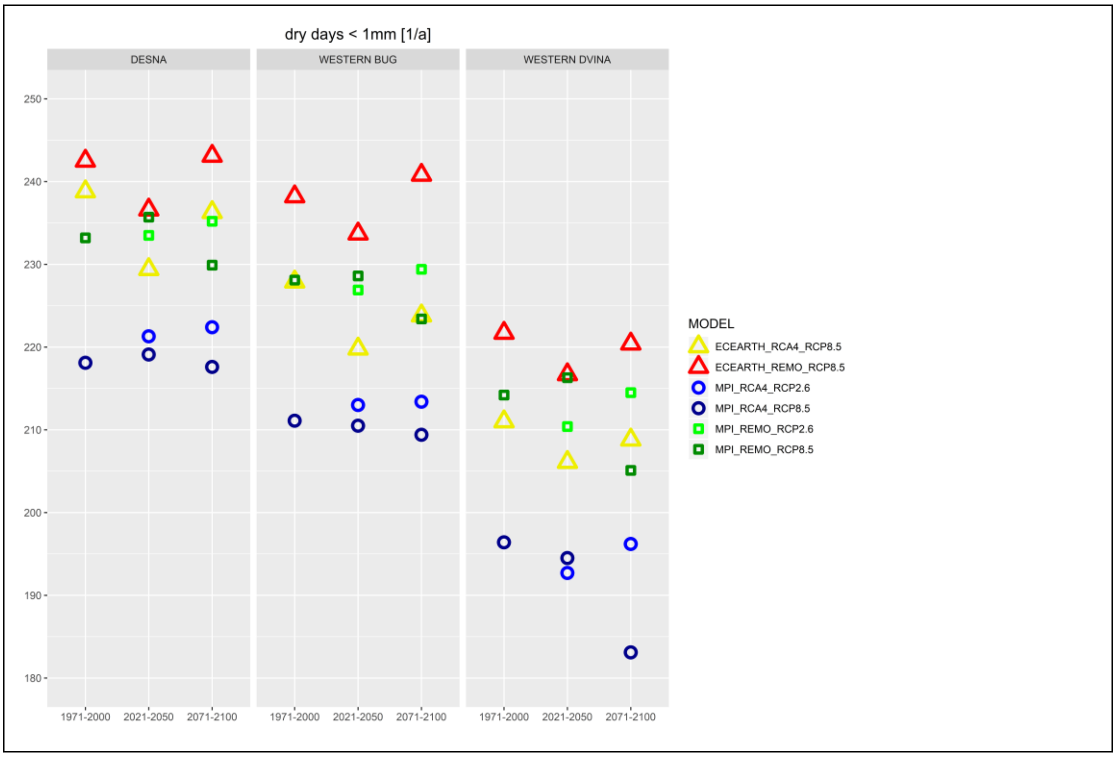


Figure 22: Number of dry days for the three regions for the past as well as the near and far future

Hydrological impacts

Here, focus was set on high impact scenarios (RCP85 for Desna and Western Dvina and A2 for Western Bug), because recently we are on the path of a strong global temperature increase. Table 9 resumes the results of the main water balance components for the three basins. Figure 23 visualizes the changes of the yearly cycles of the water balance components in 2071-2100 (far future FF) compared with a reference period in the past.

Table 9: Mean water balance for RCP85 and A2 (Western Bug) scenarios

	Western Dvina						Desna						Western Bug					
	1974-2000		2021-2050		2071-2100		1971-2000		2021-2050		2071-2100		1963-1990		2021-2050		2071-2100	
Precipitation (mm)	835		882		989		643		710		747		676		672		672	
Evapotranspiration (mm)[*1]	341	41%	372	42%	412	42%	480	75%	511	72%	543	73%	426	63%	433	64%	440	65%
Surface runoff (mm)	99	12%	92	10%	91	9%	29	5%	37	5%	32	4%	5	1%	5	1%	5	1%
Lateral flow (mm)	5	1%	6	1%	7	1%	32	5%	37	5%	41	5%	11	2%	11	2%	10	1%
Tile drainage (mm)	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	55	8%	54	8%	54	8%
Percolation (mm)	390	47%	412	47%	479	48%	102	16%	125	18%	132	18%	179	26%	170	25%	163	24%

[*1] value in percent relates to precipitation

In recent past, the investigated basin of Western Dvina (WD) had an average precipitation of 835 mm per year. For the FF a yearly increase of 154 mm/a is projected - most pronounced in spring (see also Figure 23). A share of 41% of precipitation evaporated. Elevated temperature in FF lead to an increase in evapotranspiration. There is enough water in the soil available throughout the year, no water depletion occurs. 12% of precipitation became surface runoff, projections show decreasing rates, having an increase in March (earlier snowmelt) followed by a pronounced decrease in April/May. Nearly half of precipitation turned into groundwater, this share rises a bit in FF having a dynamic related to earlier snowmelt.

Precipitation in Desna basin was 643 mm/a. Projected increase is 30%, less than in WD, whereby most projections show a summerly deficit. Evapotranspiration share is much higher than in WD (75%). Although there will be an increase in absolute evapotranspiration rate in the future, the share reduces slightly. High temperature lead to high evapotranspiration in winter and spring, followed by summerly decrease, because soil water is depleted. Only 5% of precipitation turned into surface runoff; a slight yearly increase is projected showing a similar snow-driven dynamic as in WD, but far less prominent in absolute values. Lateral flow behaves very similar to surface runoff. The share of percolation into groundwater is much lower than in WD (16%), and projected increases for FF are not pronounced.

Western Bug had a precipitation of 676 mm/a. No changes at the yearly basis are projected, but looking into seasons an increase in the colder months and a pronounced decrease between June and September shows up. A high share evaporated (63%). Increasing evapotranspiration rates are projected between January and June and a decrease in August-September, because soil water is depleted. Only a very small share turned into surface runoff, which seems not to change in the future. Results are similar for lateral flow, but slight decreases in FF are possible. Western Bug is the only basin where tile drainage plays a major role (8% of precipitation), showing a slight decrease in FF. A fourth part of precipitation turned into groundwater, showing reductions for the FF.

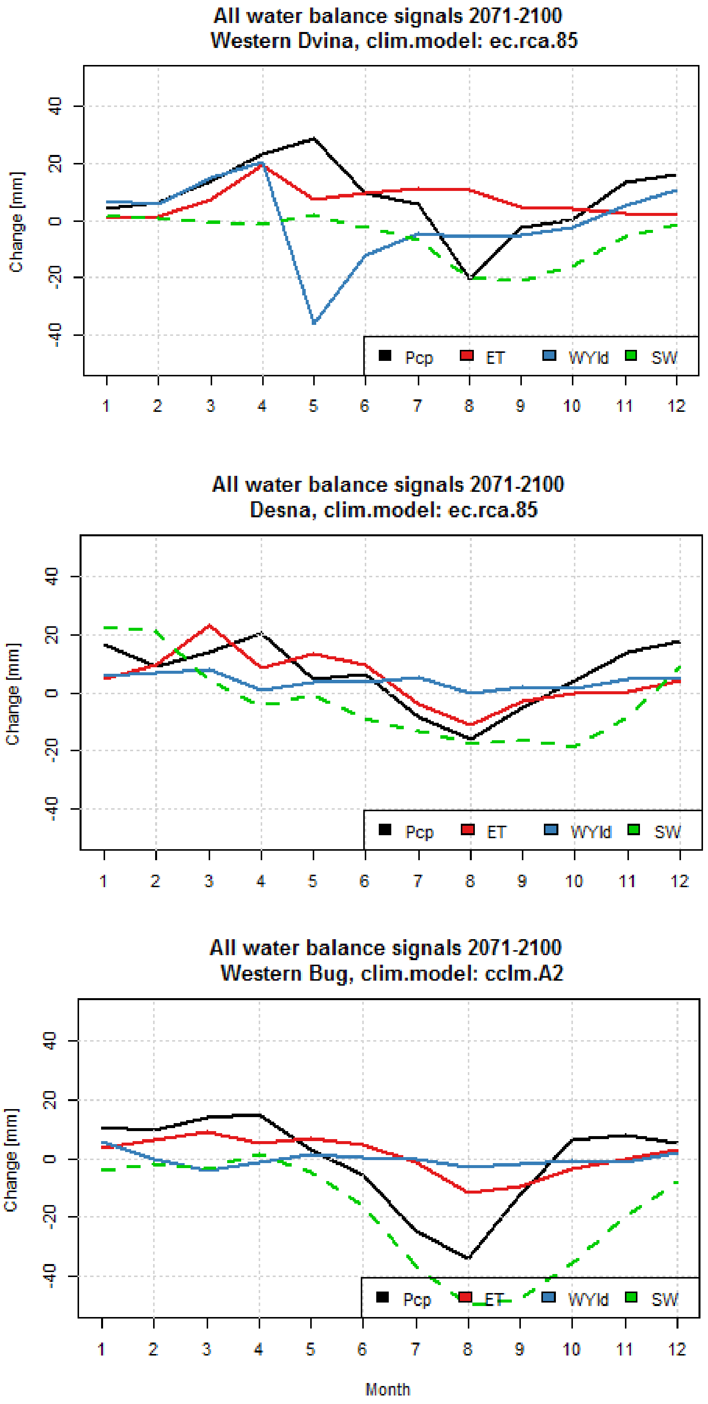


Figure 23: Water balance components (Pcp=precipitation, ET=Evapotranspiration, WYld=Water yield, SW=soil water) of Western Dvina (above), Desna (centre) and Western Bug (below) for one exemplary climate projection of the period 2071-2100. Shown are the signals, i.e. future minus reference values.

Overall, remarkable differences appear between the basins. One reason could be that the applied climate projections differ: for Western Bug an older scenario was used, which is still valid but not completely comparable. Furthermore, an older GCM version of the MPI model and a different RCM were used. Another reason are historic climate gradients, having more precipitation and lower temperatures in the north compared to the south. And these trends seem to aggravate in the future. The northerly situated basin WD seems not to run into water management problems from the quantitative point of view, because increasing precipitation rates are projected. In Desna this increase is smaller, in Western Bug not existent, therefore increased evapotranspiration can lead to water shortages in summer and fall months. In the future, the balance of precipitation shifts from snow to rainfall which produce higher surface runoff. Moreover, higher winter temperature prevents soil freezing which induce higher infiltration into soil profile, consequently, higher lateral and groundwater flows. Lower snow cover and unfrozen soil lead to earlier and less pronounced spring floods.

A flow duration curve shows the frequency of monthly discharges and its changes in the future. Exemplarily Figure 24 shows it for runoff of Desna at the gauge Chernihiv. The median runoff (50%) of NF and FF exceeds the current runoff by ~ 70 m^3/s (30%). No changes are expected during low flow (>90%) and slightly increase during high flow conditions (<10%). A comparable analysis at Western Bug (Fischer et al., 2014) revealed a completely different picture: decreases at all flow levels, which are remarkable under low flow and neglectable under high flow conditions.

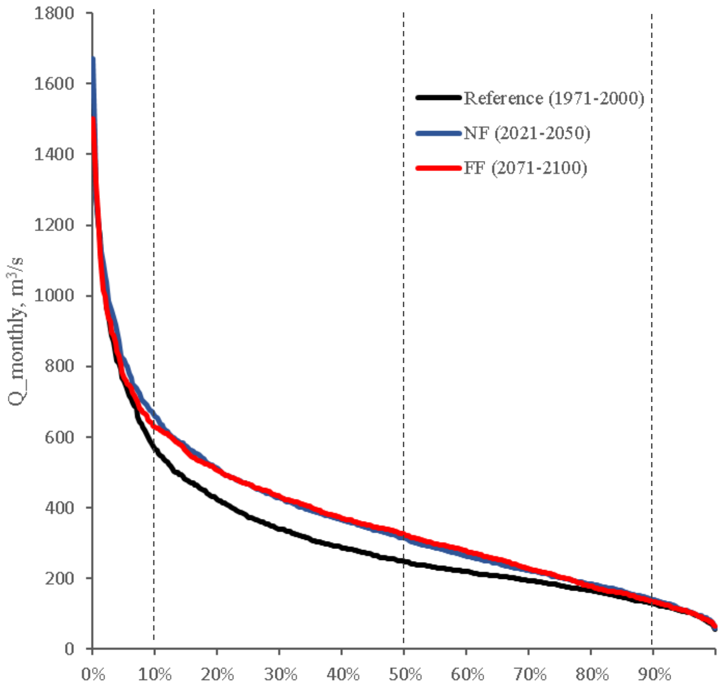


Figure 24: ***Average monthly flow duration curve for Desna (outlet Chernihiv). Reference, NF, FF is an average of four RCP 8.5 scenarios.***

Recommendations

A sustainable water management should consider changes in the boundary conditions of the hydrological system. One of the major challenges nowadays are climatic changes. Observed trends to more extreme dry and wet events have to be considered in the planning (floods, droughts). Climate projections which base on scenarios of greenhouses gas emissions are available for the globe and for regions (applying GCM and RCM). Uncertainties of this modelling approach have to be considered. This means an ensemble of climate projection using a set of GCM and RCM should be analysed and further used for impact modelling. A further uncertainty source stems from hydrological model. Differences in model structure, its parametrisation and calibration approach lead to differences in the hydrological output. If resources allow, also a set of hydrological models should be applied.

Bias correction of the climatic input is of great concern for hydrological modelling. Before an application, climate data should always be checked on a bias. But bias correction has to be examined carefully. Different approaches should be tested having in mind the consistency between climate variables as well.

5.2 Example 2: Pilot study Western Dvina

A pilot study within a Russian sub-catchment of WD aimed at a novel establishment of a measuring and modeling concept to investigate water and sediment transport in transboundary river basins. Intensive monitoring campaigns (snapshot and regular) and the use of different models were the applied methods to quantify flows of water, sediment and other substances along the Russian part of WD. A further study point was to estimate accuracy and precision of water quality components accounting types of river material (suspended particulate matter, nutrients, heavy metals), of the sampling strategies, of the reporting period and of the seasonal variability (the role of transport regime). Additionally, the study is devoted to understand the mechanisms of runoff and pollutants formation based on hydrochemical analyses. Details can be found in the second report of the project[1] and in Chalov et al. (2019).

In particular, a water quality monitoring station was installed and further upgraded to improve sediment monitoring and enable a detailed system analysis.

To enable a deeper system understanding regarding the matter flows in a river basin and to enable the evaluation of measures to improve water quality, a hydrological model was developed. For a Russian sub-basin of Western Dvina the Soil and Water Assessment Tool (SWAT) (Arnold, D. N. Moriasi et al., 2012) was set up (Terskii et al., 2019). With these models, water flows can be temporally and spatially assessed. This is a pre-requisite for further simulations of matter flows (nutrients, pesticides, sediments). An integrated approach for the apportionment of water and sediment sources and pathways for ungauged territories was developed (Chalov et al., 2019) and applied to Western Dvina River Basin. The approach comprises various elements such as SWAT, a statistical assessment of regular discharge data, the discrimination of runoff sources using end-member mixing analysis (EMMA), the apportionment of sediment sources using fingerprinting technique and sediment concentration and water discharge hysteresis rating curves analyses.

Based on the work done in the pilot study in Western Dvina basin, we formulated the most urgent challenges for further transboundary management:

- Expansion of the comprehensive hydrological monitoring tools to the whole Western Dvina basin, including all riparian countries
- Development of new observational tools to consistently predict water and sediment loads as well water quality parameters with a particular focus on remote sensing application as a surrogate for direct measurements

[1] https://tu-dresden.de/bu/umwelt/hydro/ihm/meteorologie/forschung/forschungsprojekte/projekt-mantra-rivers?set_language=en

6 Dissemination of the project results

Russian project results considering Western Dvina (WD) catchment were presented at various scientific conferences and workshops. The main discussed conclusion concerns insufficient monitoring data and transboundary collaboration. The system, how hydrological information is obtained, processed and stored strongly differs from country to country in WD basin. The structure of generalization of hydrological information in Russia does not take into account approaches mentioned in the EU-WFD. But, modern methodological procedures, such as hydrological modeling and indirect sediment load calculations can strongly level out these inconsistencies. Modeling issues were discussed during some special [2], and thematically broader conferences in Russian Federation [3] and in the EU[4].

The results of the project were presented to experts from water sector of Russian Federation (Table 10). The experts were introduced to the main outputs of the study, as well as to further plans. The experts gave their recommendations regarding the formulation of main project achievements.

The project outcomes were presented to Ukrainian experts in surface water monitoring and to representatives of related agencies. The feedback was, that the project in principle covers all aspects of national surface water monitoring including monitoring networks, monitoring protocols, etc. It was highlighted that reorganization of current monitoring system finally will result in compliance with WFD requirements as well as with requirements laid down in other water related EU Directives. However, taking into account the time frames of Directives implementation at the national level, work has to be accelerated. Furthermore, it was noted that financial support at national level is insufficient. Most of the work was done with support of EU funded projects. Special attention was paid to the information management component. It was emphasized, that there is still no explicitly displayed will of organisations/agencies to share monitoring information even under conditions of establishing the SWA geoportal. This problem requires intervention at the top administrative level.

[2] International SWAT Conference, Warsaw, Poland, 26-30 June 2017

[3] XIV all-Russian scientific and practical conference and exhibition "Perspectives for the development of engineering in the construction in Russian Federation" in Moscow,

The second international young scientists’ forum on soil and water conservation and ICCE symposium «Climate Change Impacts on Sediment Dynamics: Measurement, Modelling and Management». Moscow, 2018

Third Vinogradov readings. Saint-Petersburg, 2018;

II Russian Conference on Hydrometeorology and Ecology: achievements and development prospects Saint-Petersburg, 2018

[4] 2nd Baltic Earth conference “The Baltic Sea region in transition”. Helsingor, Danmark, 2018

Table 10: List of experts involved into the study

Name	Place of employment	Status	Current position
Vsevolod Moreido	Water Problems Institute Russian Academy of Sciences	phD	Research Assistant
Vladimir Shamov	Pacific Geographical Institute of the Far Eastern Branch of the Russian Academy of Sciences	Dr. habil.	Leading Researcher
Boris Hartsman	Water Problems Institute Russian Academy of Sciences	Dr. habil.	Leading Researcher, Head of Water Modeling Laboratory
Aufar Gareev	Bashkir State University	Prof. Dr. habil.	Head of Hydrology Department
Leonid Korytny	Institute of Geography SB Russian Academy of Sciences	Prof. Dr. habil.	Senior Researcher
N. I. Koronkevich	Institute of Geography Russian Academy of Sciences	Prof. Dr. habil.	Head of the Laboratory of Hydrology

Project results regarding nutrients load were presented during the workshop of the EUWI+ project (December 10, 2019). There were 5 presentations given by Ukrainian team and covering all problematic aspects in the Dnipro Basin and Desna Basin as a sub-basin. International experts appreciated work done underlining the importance of results from the point of view as a significant step forward in river basins management.

Ukrainian team at EUWI+ project' workshop

Cross basin wide issues were presented at the 8th International Water Resources Management Conference of the International Commission on Water Resources Systems (ICWRS), Beijing, China in 2018. During a workshop organized by the Volkswagenstiftung (in Radebeul, Germany, May 2019), results were discussed between participants of the same funding initiative. Furthermore, a specific dissemination workshop of this project took part in Wyzkow, Poland, in October 2019. Results and perspectives for a participation of our project consortium in a new UNDP project under Polish leadership were discussed.

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