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Challenges for transboundary river management in Eastern Europe – three case studies

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Abstract

The transboundary river basins shared between Russia, Ukraine and the European Union pose unique challenges for management because of differences regarding not only the legal framework but also related to monitoring practices and water utilization. Using the example of three river basins – the Desna (shared by Russia and Ukraine), the Western Dvina (shared by Russia, Belarus, Lithuania, Estonia and Latvia) and the Western Bug (shared by Ukraine, Belarus and Poland) – this paper provides an analysis of current challenges with respect to transboundary water resources management in Eastern Europe. This assessment is based on a comparison of similarities and disparities concerning the physical and human geography of the basins (and their national sub-basins) as well as specific problems related to water pollution caused by urban, agricultural and industrial water usage both in the recent past and today. All three catchments have a similar size, climate and hydrological characteristics. However, there are different challenges regarding up- and downstream sections of the respective basins: pollution input in the Western Bug originates primarily from upstream sources in Ukraine and Belarus, whereas ecological problems in the Desna and Western Dvina persist principally downstream, i.e.

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in Ukraine respectively Belarus and Latvia. Despite some differences between the basins, it is concluded that interstate cooperation is an important prerequisite for integrated water resources management (IWRM) in all of the studied basins. This analysis identified several key challenges related to start or continue with IWRM, including pollution mitigation, improved monitoring, appropriate governance, climate change and its effect on water balances in the catchments, capacity development and thorough system understanding.

Zusammenfassung
Die Bewirtschaftung der transnationalen Flusseinzugsgebiete im Grenzgebiet zwischen Russland, der Ukraine und der Europäischen Union ist insofern besonders anspruchsvoll, als erhebliche Unterschiede nicht nur hinsichtlich der gesetzlichen Rahmenbedingungen, sondern auch bezüglich des Monitorings und der Wassernutzung bestehen. Am Beispiel von drei Flusseinzugsgebieten – der Desna (Russland und Ukraine), der Westlichen Düna (Russland, Weißrussland, Litauen, Estland und Lettland) und des Westlichen Bugs (Ukraine, Weißrussland und Polen) – analysiert der vorliegende Beitrag gegenwärtige Herausforderungen in der grenzüberschreitenden Bewirtschaftung von Wasserressourcen in Osteuropa. Die Basis hierfür bilden neben der Betrachtung von Ähnlichkeiten und Unterschieden in den natur- und kulturräumlichen Ausgangsbedingungen der Einzugsgebiete (und ihrer nationalen Abschnitte) auch spezifische Wasserqualitätsprobleme, die durch die landwirtschaftliche, industrielle und urbane Wassernutzung in der jüngeren Vergangenheit und heute ausgelöst werden. Alle drei Einzugsgebiete ähneln sich hinsichtlich ihrer Größe, der Klimabedingungen und der Hydrologie. Es gibt jedoch unterschiedliche Problemstellungen bezüglich der jeweiligen Ober- und Unterlieger: Die Schadstoffeinträge im Westlichen Bug stammen vorwiegend aus den oberliegenden Staaten Ukraine und Weißrussland. In der Desna und der Westlichen Düna hingegen konzentrieren sich die Umweltprobleme flussabwärts, d.h. in der Ukraine bzw. in Weißrussland und Lettland. Trotz einzugsgebietsspezifischer Besonderheiten kann letztlich gefolgert werden, dass der zwischenstaatlichen Zusammenarbeit eine Schlüsselbedeutung für die Umsetzung eines integrierten Wasserressourcenmanagements (IWRM) in allen untersuchten Einzugsgebieten zukommt. Die vorliegende Bestandsaufnahme hat eine Reihe von Herausforderungen identifiziert, die zur Implementierung eines IWRM von Bedeutung sind. Dazu zählen die Verringerung von Schadstoffeinträgen, Verbesserungen in den Bereichen Monitoring und Governance, der Klimawandel und seine Auswirkungen auf die Wasserbilanz, Capacity Development und ein umfassendes Systemverständnis.

Keywords IWRM, transboundary rivers, Eastern Europe, water pollution, Western Bug, Desna, Western Dvina

1. Introduction

Transboundary rivers are natural connections between different countries. Ukraine, Russia and the European Union share various river basins that cross one or more international borders (*Table 1*). The availability and quality of these water resources is the subject of constantly ongoing transnational negotiations of the riparian states. A joint management is only possible when all factors influencing water availability and quality are known. Sufficient and reliable data are indispensable for the understanding of characteristics of hydrological systems. Ideally, information would be collected and analyzed in a consistent manner. Different national regulations (regarding for example monitoring or water quality standards) and data scarcity can seriously impede a consistent system analysis (*Karthe* et al. 2015, 2017; *Ertel* et al. 2012). Moreover, the implementation of measures (e.g. conservation, technical and non-technical problem solutions) can be further complicated by institutional or political constraints (*Houdret* et al. 2013). Besides an assessment of the current situation, changing boundary conditions such as climate, land use or demographic changes can have enormous impacts on water resources and have to be considered.

In order to meet the manifold water demands of riparian states and to manage transboundary water resources in a sustainable manner, there is no way around a transnational system analysis and dialogue. International experience shows that the reasoning of riparian countries is not always rational but driven by political considerations or emotions. In such situations, water management concepts based on scientific evidence have the advantage of being acceptable to all parties involved because of their generally neutral and unbiased character. One of the most notable approaches is Integrated Water Resources Management (IWRM), which is defined as a "process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital (aquatic) ecosystems" (*GWP-TAC* 2000: 3). Particularly in developing and transition countries, IWRM has become the leading concept for water management (*Ibisch* et al. 2016). In this context, river basins are promoted as the relevant management units (*Dombrowsky* et al. 2014). In the case of the European Union (EU), the EU Water Framework Directive (EU-WFD) is a general framework for water resources monitoring and management that is implemented by all member states and at river basin scale. Even though countries outside the EU sometimes consider the EU-WFD as a role model, it was not designed for regions outside the EU (*Heldt* et al. 2017). Focusing on transboundary rivers shared between the EU and external countries, however, the directive becomes legally binding as soon as the river enters EU territory. Similarly, when a river leaves the EU and enters an external country, legal requirements may change at the national border. In both cases, transboundary cooperation is essential so that the interests of all riparian states can be met. Apart from some compromises, this at least requires a common understanding about environmental monitoring and data exchange. At the same time, new challenges must be integrated in IWRM due to transient conditions of global change, concerning economic, demographic, land use or climate changes (*Bernhofer* et al. 2016).

The aim of this review is to compile the current state of knowledge on the three transboundary catchments as a basis for further analyses as well as the development and implementation of site-specific measures in the future. For that purpose, this paper presents a comparison of similarities and differences regarding the physical and human geography of the basins as well as key challenges for IWRM across national boundaries.

Table 1 Basic characteristics of the transboundary catchments of the case studies[1]. Source: Own elaboration based on EEA (2003) and Chalov et al. (2017)

	Western Bug	**Desna**	**Western Dvina**
Basin size (km²)	37,757	89,003	85,964
River length (km)	772	1,130	1,020
Population	3,226,000	2,499,600	2,173,017
Prevailing ecoregions (% area) (*EEA* 2003)	Central European mixed forests (100%)	East European forest steppe (52%) Central European mixed forests (37%) Sarmatic mixed forests (11%)	Sarmatic mixed forests (96%) Scandinavian and Russian taiga (4%)
Continuous forest cover (% area)	32%	31%	65%
Countries sharing the basin and their administrative areas (province level)	**Ukraine** Lviv, Volyn **Belarus** Brest **Poland** Lublin, Mazovian, Podlasie	**Russia** Bryansk, Kursk, Kaluga, Oriol, Smolensk, Belgorod **Ukraine** Chernihiv, Sumy, Kyiv	**Russia** Tver, Smolensk, Pskov **Belarus** Vitebsk, Polotsk **Latvia** Zemgale, Vidzeme, Latgale **Estonia** Võru maakond **Lithuania** Utenos, Vilniaus

2. Material and methods

This paper presents a case study of three river basins in the border region between the eastern EU, Ukraine and Russia. Each river basin represents a different constellation, i.e. rivers shared by Ukraine, Belarus and Poland (Western Bug), by Russia and Ukraine (Desna) and by Russia, Belarus, Latvia, Estonia and Lithuania (Western Dvina) (*Fig. 1*). This work was done within the context of ManTra-Rivers, a trilateral project funded by the Volkswagen Foundation.

The literature review consisted of accessing various databases for scientific research. On the one hand, we identified previous projects that focused specifically on transboundary issues in these river basins, e.g. IWAS for the Western Bug River basin (*Kalbacher* et al. 2012). On the other hand, we looked for literature on specific features of the river basins, e.g. large cities like Lviv in Ukraine or the economic development in the respective countries. In addition, other sources including encyclopedias and legal documents were consulted. We compiled our findings on a shared server and categorized the available literature regarding their relevance for the topics water flow and climate change, water quality and river pollution, terrestrial ecosystems and land use change, and ecohydrology. In this paper, we focus on the most relevant findings.

For a comparison of long-term changes in hydroclimatic parameters between the three catchments, we compiled available datasets on precipitation and air temperature, water discharge and water quality from gauging stations located within the catchments. Data series were provided by the National Hydroclimatic Services. Regarding precipitation and air temperature, we compared the period 2001-2016 with 1980-2000 as reference period. In addition, we analyzed long-term fluctuations of the annual water discharge including trend and statistical uniformity of the time series. Trends in the datasets (annual and seasonal) were tested with the Mann-Kendall test (*Mann* 1945; *Kendall* 1975).

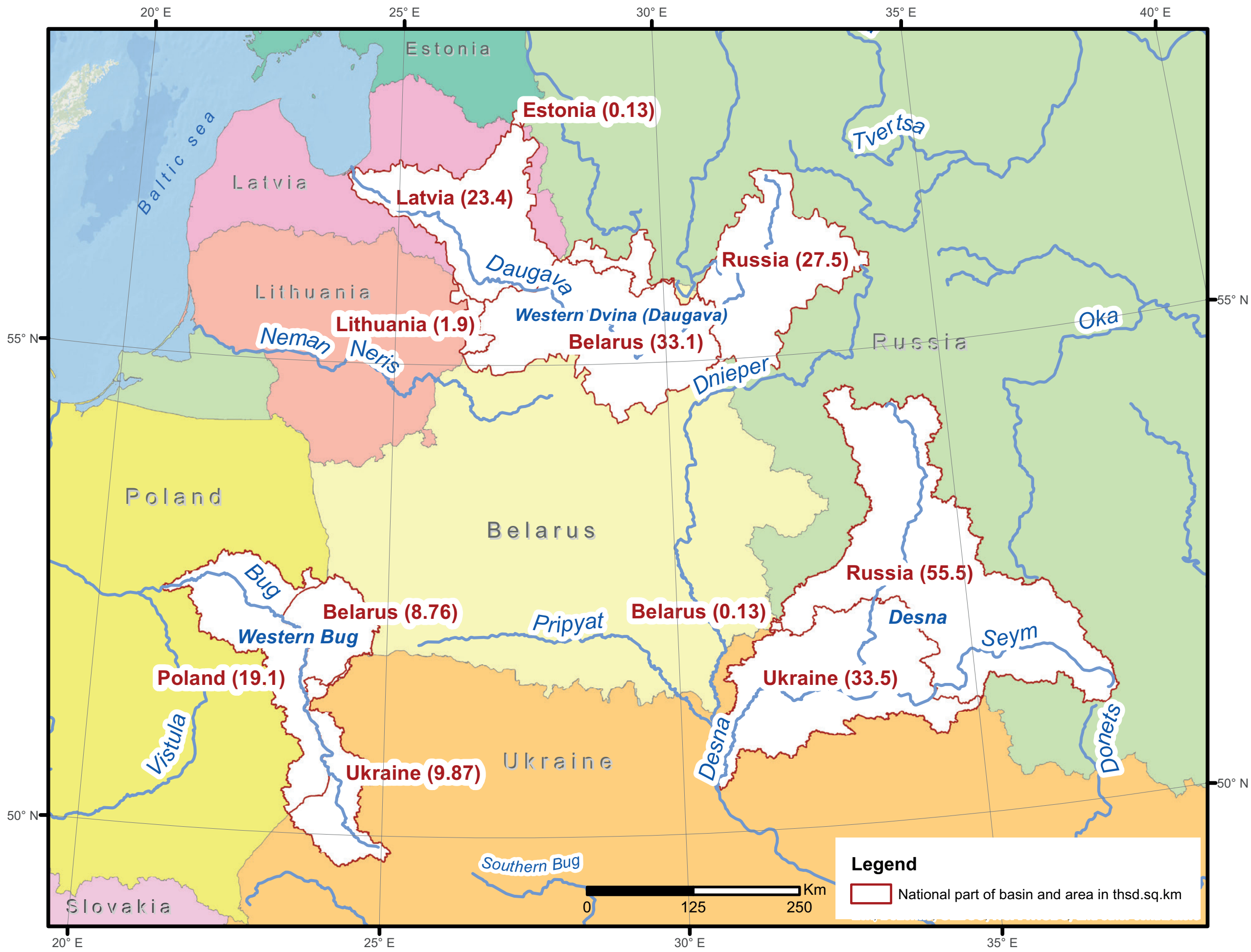

Fig. 1 *Location and subdivision of the transboundary basins of the Desna, Western Dvina and Western Bug into national sectors. Source: Own elaboration based on Esri, DeLorme, GEBCO, NOAA NGDC. Cartography: Pavel Terskii*

Uniformity (stationarity) of the time series data was checked by the application of the Student's *t*-test and the Fisher's *F*-test. The *t*-test was made to check whether mean values of two periods differ significantly. The Fisher's *F*-test provides an estimate of the uniformity of the time series with respect to the variance. Since the Fisher's *F*-test is designed for time series that follow the normal distribution, the coefficients of skewness (Cs) and autocorrelation (r1) were considered in the analysis (*Evstigneev* and *Magritskiy* 2013; *Rozhdestvensky* et al. 2010). For all tests, the level of significance was set to 0.05, and the time series length had to be at least eight years. The following text mentions only significant changes.

Comparative analyses of the geodata available for the case study areas with regard to specific local geodata were performed and relevant applications were done for environmental and hydrometeorological features of the river assessment. Global datasets of reanalysis simulations were assessed, which contain grids of numerous climatological elements. The most suitable datasets for the project are ERA-Interim and NCEP-CSFR[2]. Land use parameters were estimated for each national sector of the studied rivers according to Globcover LU Type (Globcover LU code) (*CEOS* n.d.).

The literature and data review were performed in order to

1. assess the current availability of published literature and data and identify knowledge gaps;
2. characterize the current state of knowledge relevant for river basin management in the three basins with a focus on the following topics:
   a. Hydrological trends and their drivers (climate variability and change, land use change, water abstractions);
   b. water quality (problems, gradients, identification of main pollution sources);
   c. aquatic ecology (state of ecosystems, known impacts of pollution, assessment methods used in different countries/scientific studies);
   d. technical measures (with a focus on municipal wastewater collection and discharge into the rivers);
   e. institutional and geopolitical challenges for water management beyond the above-mentioned problems (differences regarding legislation and water governance structures; obstacles and options for transboundary cooperation).

In addition to the water-specific aspects, we collected information on the general geography of the basins in order to account for resulting differences between the three basins. The following case studies are therefore structured into three subsections each, dealing with (1) the physical environment, (2) the population, economy and political geography as well as (3) the resulting challenges for river basin management. Obviously, differences exist regarding the information available for each basin, and between countries or even regions within a specific basin. Nevertheless, a systematic analysis of the three exemplary river basins helped to gain a better understanding of the general challenges for transboundary river basin management in the border region between Russia, Ukraine and the countries of the eastern EU.

3. Case study: Western Bug

The Western Bug River originates in Ukraine, then becomes a border river with Poland and later with Belarus. It drains into the Zegrze Reservoir of the Narew River, a tributary of the Vistula. This reservoir provides drinking water for roughly one million Warsaw residents (*DREBERIS* and *Stadtentwässerung Dresden GmbH* 2008). 49.2% of the watershed is located in Poland, 23.4% in Belarus, and 27.4% in Ukraine (*Mioduszewski* et al. 2012).

3.1 Physical environment of the river basin

The basin's topography is primarily flat except for some hills in the upper reaches of the river. The climate is temperate and moderately continental (*Herenchuk* 1972, 1975) with an annual mean temperature of 7.0-7.6°C and yearly mean precipitation of 650-700 mm (*Lipinskyy* et al. 2003; *Pavlik* et al. 2014). On average, snow cover lasts from late November to mid-March (*Kasprowicz* and *Farat* 2010), leading to a runoff peak in spring from snowmelt, in contrast to a low discharge in fall (*ICWS* 2001). The predominant soil classes are sod-podzolic soils, such as luvisols, podzoluvisols, and podzols (*Nachtergaele* et al. 2009).

Our analysis of discharge measurements of the Ukrainian gauging station Lytovezh and the two Polish stations Wlodawa and Wyszkow indicated a positive trend in the period 1983-2014. This contrasts with the other two investigated basins but also with the Ukrainian Western Bug sub-basin at the gauging station Kamianka Buzka, where a slight decrease in runoff was observed.

So far, only the Ukrainian part of the river basin has been well investigated with coupled hydrological and water quality models (*Kalbacher* et al. 2012; *Tavares Wahren* et al. 2012). The results demonstrate that the water quality along the river course changes significantly. On the 7-point chemical water quality scale developed by the German Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA), quality along the river ranges from a value of 3, denoting moderate pollution, to 7, excessive pollution. Areas with excessive pollution are the Poltva River, a main tributary, as well as the Western Bug itself directly downstream of the confluence of this tributary. In these sections of the river system, all but one water quality variables fail to meet both Ukrainian and European water quality standards; the only exception being acceptable nitrate levels. The headwaters preceding this confluence contain the only section of the river system with moderate pollution, whereas the remaining headwaters are in a state of critical pollution. Downstream, the remaining sections of the river are either critically, heavily, or very heavily polluted (*Hagemann* et al. 2014). The lower section is less polluted because of self-purification and sedimentation processes (*DREBERIS* and *Stadtentwässerung Dresden GmbH* 2008). The Dobrotvir Reservoir, "a river dam unintentionally serving as an oxidation pond" (*Ertel* et al. 2012: 1471), contributes significantly to this positive change in water quality.

The morphological state of the river system is another factor facilitating water quality improvements. Apart from the Dobrotvir Reservoir, which is the single biggest outlier, "the river's hydromorphology is mainly in a low to moderate degradation state" (*Hagemann* et al. 2014: 2439). Downstream, forests and swamp areas covering the river bank serve as buffers shielding the river to a certain degree from further pollution (*Hagemann* et al. 2014).

3.2 Population, economy and political geography

The Western Bug river system is subject to the EU-WFD because the river flows through Poland and discharges into the Baltic Sea. As opposed to Poland, the upstream riparian countries Ukraine and Belarus are not EU member states. River management and protection fall under the respective national legislation, which also means that they do not benefit from EU financial support mechanisms to improve their water infrastructure and management (*DREBERIS* and *Stadtentwässerung Dresden GmbH* 2008).

Despite its relatively small size, 47.4% of the affected population lives in the Ukrainian part of the catchment, followed by 36.3% in Poland, and 16.3% in Belarus. As such, the Ukrainian part is the most densely populated, in particular because of Lviv, a city on the Poltva River with a population of 0.76 million (*Mioduszewski* et al. 2012). The second largest city is Brest, Belarus, with 0.34 million inhabitants. The Polish sector has the lowest population density with a number of smaller towns (*Skurbilowicz* 2014).

Human activity in the catchment differs depending on the country. The Ukrainian part features the most development, including agriculture, industry, coal mines, and the Dobrotvir power plant. In Belarus, there are larger farms exceeding 1,000 ha (*Mioduszewski* et al. 2012). In Poland, there are no large industrial sites, merely small farms. In addition, 5,739 km^2 of the sub-basin consists of protected areas (*IUCN* 2017).

Prior to Ukrainian independence in 1991, the water management sector benefited from governmental subsidies, allowing for a satisfactory infrastructure in the Soviet Union. Afterwards, companies in this sector became municipal properties, bringing about deterioration because of financial shortages. An important reason for this is that Ukrainian water companies charge comparatively low water use fees. However, the situation has been improving since 2006 due to fee hikes. Further fee increases remain a key task for improving the situation (*DREBERIS* and *Stadtentwässerung Dresden GmbH* 2008).

Until recently, Ukraine had a highly centralized administrative structure consisting of many small territorial communities with little political power. In addition, there was a distinct lack of horizontal cooperation, for example between the Ministry of Regional Development, Construction and Communal Services and the Ministry of Agrarian Policy, despite a shared responsibility for water management in rural areas. However, a 2015 reform unified the large number of small municipalities into larger entities, improving their capacity for infrastructural improvements (*Verkhovna Rada Ukrainy* 2015). Still, the Ukrainian sector of the basin suffered from inefficient water management. Another problem is a lack of specific instructions for the implementation and enforcement of policies, such as water management on a river basin scale as per the 1995 Water Code of Ukraine (*Hagemann* et al. 2014). Adoption of the new version of the Water Code of Ukraine by the Law of Ukraine

№ 1830-19 has in general resolved the problem by harmonizing requirements to water management with those put in practice in the EU (*Verkhovna Rada Ukrainy* 2017).

3.3 Resulting challenges for river basin management

The Western Bug suffers from water quality problems caused by outdated or overloaded wastewater treatment plants, agriculture, industry and coal mining (*Ertel* et al. 2012). For large sections, the river features well-functioning water-land connectivity and a sufficient structural variability (*Scheifhacken* et al. 2012). Nevertheless, the upper Western Bug is strongly affected by human interventions generating severe environmental impacts and health issues. Both point-source and diffuse pollution contribute to these issues (*Helm* et al. 2012). Point source pollution primarily stems from outdated, deteriorating, and overburdened – or even non-existent – wastewater treatment plants (WWTPs), particularly in the city of Lviv on the Poltva River, but also in further cities downstream (*Malynovsky* et al. 2011). None of these WWTPs, dating back to the 1960s through the 1980s, can sufficiently reduce nutrients in the water. In addition, only about 24% of the rural population in Ukraine is connected to central WWTPs (*DREBERIS* and *Stadtentwässerung Dresden GmbH* 2008). The Poltva River is the most significant source of organic pollution. Among other pollutants, it exhibits high levels of chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), phosphorus, bacterial abundance, and antibiotic resistance (*Ertel* et al. 2012). Diffuse pollution originates from both agriculture and industrial waste, particularly associated with mining. Estimates on pollution sources contribution vary widely (*Helm* et al. 2012). A study by *Mioduszewski* et al. (2012) estimates that roughly half of the total nitrogen and phosphorous pollution load in the Western Bug is emitted by agriculture. Following a surge of privatizations of formerly collective farms after 2000, large-scale application of fertilizers and pesticides left nitrogen, phosphorus, and other, persistent chemicals in the natural environment (*Hagemann* et al. 2014). Finally, land-use and land-cover changes, such as an increase in man-made surfaces, i.e. soil sealing, to 12% of the Ukrainian area of the basin in 2010, affects the water balance while "causing reduced infiltration and enhanced overland flow" (*Hagemann* et al. 2014: 2441).

As per the 2014 Association Agreement between the EU and Ukraine, the latter has to approximate its environmental legislation to EU standards until 2025 (*European Council* 2014). Currently, there are two main players in surface water monitoring: the State Emergency Service of Ukraine and the State Water Agency of Ukraine. These organizations refer to 'maximum allowable concentration' (MAC) values for assessment of water quality. However, MAC values are different depending on the type of surface water use, i.e. fish farming, on the one hand, or drinking water supply and recreation, on the other hand. The chemical MAC values for the former are prescribed by the so-called OBRV guideline (transliteration: Orientiryentovno Bezpechni Rivni Vplyvu; translation: approximate secure impact levels of pollution in water bodies with fish industry; applied outside of cities), whereas the latter are prescribed by the SaNPiN guideline (transliteration: Sanitarni Pravyla i Normy; translation: sanitary rules and norms; applied in urban areas). This division sometimes causes misunderstanding and misinterpretation of monitoring data, especially when reports do not specify which guideline they adhere to. In general, however, the current MAC values are quite close to the target value which corresponds with 'good' water quality according to EU-wide standards. The problem of competing standards is exacerbated by the fact that data are unavailable or inaccessible in many cases (*Blumensaat* et al. 2012). Furthermore, monitoring is often insufficient (*Pluntke* et al. 2014).

Climate constitutes one of the major boundary conditions for hydrologic processes. Future climate projections indicate decreasing water availability during the summer half-year (*Pavlik* et al. 2014), which might have serious implications for water quality and agriculture (*Fischer* et al. 2014). In these two works it was found that for the period 2071-2100, temperatures are projected to rise throughout the course of the year, particularly in the winter months, leading to a decrease of cold events along with an increase of warm events like heat waves and tropical nights. Reduced precipitation and altered precipitation patterns are projected to lead to more dry days. Both declining precipitation and rising temperatures are projected to cause a decrease in the annual climatic water balance. This means that, e.g. in late summer, potential evapotranspiration exceeds precipitation. Hydrologic modeling showed less surface runoff and soil water content, an increased number of low-flow events, and less snow accumulation. The projected socioeconomic consequences of such developments are diverse. Beyond serious impacts on water quality and agricultural as well as silvicultural yields due to water scarcity, the energy sector, water management, and human health are projected to suffer. Potential hazards include increasing air pollution and an increased occurrence of pests, pathogens, and diseases (*Schanze* et al. 2012). On the other hand, climate change also brings opportunities for agriculture: increased growing seasons due to higher temperatures, in combination with increased CO_2 concentrations which stimulate growth in some crops[3], including wheat and sugar beets, may result in higher yields. However, this opportunity also depends on sufficient irrigation (*Fischer* et al. 2014).

4. Case study: Desna

The Desna River originates in Russia and is the longest tributary of the Dnieper River, which, then again, is the largest river in Ukraine and the third largest in Europe. It serves as a drinking water source for large regions of Ukraine and is one of the main drinking water sources for the capital city Kyiv (*Khrystyuk* et al. 2017; *Luzovitska* et al. 2017). 62% of the basin is located in Russia, 38% in Ukraine (*Rudenko* 2007).

4.1 Physical environment of the river basin

The river's catchment area is in a mostly lowland area with muddy flats and swampy valleys (*Marynich* et al. 1985) and the basin's climate is moderately continental (*Marynich* and *Shishchenko* 2005). The average annual air temperature ranges from 6.3°C in the upper basin to 7.0°C in the lower part. The mean annual precipitation is 650-700mm, with the majority falling during the warm season of the year. Generally, a persistent snow cover forms around the second half of January and remains for 90-100 days (*Lipinskyy* et al. 2003). From early December to early April, the river freezes over (*Canadian Institute of Ukrainian Studies* 2001). It "has quite a wide floodplain, which floods almost every year" (*Khrystyuk* et al. 2017: 64). The soils in the catchment are primarily podzolic and vegetation consists of coniferous and mixed forests (*Marynich* and *Shishchenko* 2005).

Based on measurements at the gauging station in Chernihiv, Ukraine, the hydrological regime of the Desna is generally characterized by spring floods. Circumstances that are highly likely to cause catastrophic and outstanding spring floods are a cold autumn-winter period, with a significant accumulation of snow in the river catchment and deeply frozen soils (*Khrystyuk* et al. 2017) in addition to a strong temperature increase during the main snowmelt period. Analysis of data from the gauging station Desna-Litky showed an average runoff of 12.1 km^3/year for the period 1980-1999 and a decrease to 10.6 km^3/year for 2000-2014 (*Gorbachova* and *Kolianchuk* 2012a).

The surface water of the Desna is characterized by high amounts of nutrients which lead to eutrophication. For example, the mean concentration of non-organic compounds of nitrogen reaches up to 0.68 mg N/l (*Osadchy* et al. 2008; *Luzovitska* et al. 2011). The water quality decreases over the course of the river: while the upper part shows processes of self-purification, the middle section suffers from intensive pollution – in particular in the form of ammonia nitrogen and phosphorous – and, lastly, the lower section shows a significant increase of nitrate pollution (*Luzovitska* et al. 2017).

4.2 Population, economy and political geography

Among the cities located on the banks of the Desna River are Oster, Chernihiv, and Novhorod-Siverskyi in Ukraine and Trubchevsk, Briansk, and Zhukovka in Russia (*Canadian Institute of Ukrainian Studies* 2001). Kyiv is located 16 km south of the river's confluence into the Dnieper. With roughly 1.53 million (61.6%) people living in the Russian part of the basin, and 0.96 million (38.4%) in Ukraine, the population distribution is in line with the respective countries' shares of the catchment (*Rudenko* 2007).

The gross domestic product in the Ukrainian part depends equally on agriculture and industry. Cereal is the highest priority agricultural product. Other focus areas include oil crops, potatoes, sugar beets, and cattle breeding. The industrial sector focuses on processing, e.g. food production and clothing (*Chernihiv Regional State Administration* 2015).

River regulation has an important influence on the water quality. In the Russian part of the basin, there is a cooling pond as well as off-stream water storages for two nuclear power plants. Downstream, in the Ukrainian sector, dozens of reservoirs have changed the river's hydrology and morphology (*Vishnevsky* et al. 2011).

In the Ukrainian sector of the river basin, the financial and management problems discussed above for the Western Bug catchment apply as well: administrative reforms have been improving the regional capacity to develop the water infrastructure. However, higher water use fees are needed to improve the financial situation and enable investments in infrastructure.

4.3 Resulting challenges for river basin management

The ecological state of the Desna at particular sections, especially in the downstream part of the river, is rather poor mainly due to problems concerning water quality. The main pollutants are organic substances and pesticides, which are not fully degraded and therefore accumulate in the basin. Sewage waters are a primary source of mineral forms of phosphorus. During the last 25 years, decreasing nutrient concentrations have been observed. This is likely to be associated with a phase of increased runoff and reduced emissions (due to a de-intensification of agriculture and decreasing population density). Nevertheless, bioassay-based toxicity assessments (using several indicator organisms) showed that pollution levels in the Desna and the Dnieper are serious (i.e. toxicologically relevant) under low-flow conditions (*Arkhipchuk* and *Malinovskaya* 2002).

After the end of the Soviet Union, data exchange between Russia and Ukraine came to a halt. Hydrochemical observations are limited to a low frequency of four measurements per year. Additionally, the substances being monitored are limited, omitting a number of priority substances (*Chalov* et al. 2017).

Since 1917, there have been three catastrophic floods (1917, 1931, 1970) and one outstanding[4] flood (1942). As discussed above, the circumstances facilitating severe spring floods have been identified. Monitoring and transboundary exchange of information can mitigate the impact of future flood events (*Gorbachova* and *Kolianchuk* 2012a, 2012b). However, Ukrainian water monitoring systems are currently undergoing re-organization due to the implementation of European water resources management legislation. The goal is harmonization with the requirements of the European Water Framework Directive. New legislative acts concerning surface water monitoring and new lists of priority substances are currently being elaborated and adopted. Moreover, the frequency of sampling will be increased (*Yatsiuk* et al. 2017).

A comparison of temperature changes for the periods 2001-2016 versus 1980-2000 revealed that temperatures increased significantly both annually and for most seasons. For example, measurements in Kursk showed an increase of mean annual temperatures by 1.3°C, having the most pronounced change during winter (1.8°C). Precipitation trends differ between seasons and regions. The most striking features are that some stations show significant decreases in the summer months and one station an increased trend during winter (*Chalov* et al. 2017).

The main peculiarity of regional hydrological change is the seasonal redistribution of annual river discharge and subsequent changes in water quality. Especially the increased frequency of low flow events causes higher concentrations of water pollutants. Changing climatic conditions and human impacts cause an increased intensity of bank erosion (*Chalov* et al. 2017).

5. Case study: Western Dvina

The Western Dvina originates in Russia and flows through Belarus and Latvia into the Gulf of Riga of the Baltic Sea. 32% of the catchment belongs to Russia, 38.6% to Belarus and 29.4% to the EU – mostly in Latvia with very small shares in Lithuania and Estonia.

5.1 Physical environment of the river basin

Like the other case study basins, the catchment of the Western Dvina has a mainly flat, undulating topography. The climate is temperate, moderately continental with January temperatures ranging from −6°C to −10°C in contrast to +17°C to +19°C in July. The average annual precipitation is 650 mm. The total runoff of the Western Dvina River to the Baltic Sea is 20.7 km^3/year (656 m^3/sec) (*Nilsson* 2006) with snowmelt being the dominant source. As such, 50% of the discharge takes place in spring (*ICWS* 2001). The main soil classes are podzoluvisols, histosols, and podzols in the Russian and Belorussian parts, and luvisols, histosols, and podzols in the downstream EU part (*Nachtergaele* et al. 2009).

Comparable to the Desna River, an analysis of data from the gauging stations Velizh and Daugavpils revealed a negative runoff trend. Comparing the periods 1992-2015 and 1976-1991, the average runoff decreased in Velizh by 18% and in Daugavpils by 3%.

The surface waters of the Western Dvina are characterized by total dissolved solids (TDS) concentrations in the range of 110-280 mg/l. Total suspended solids (TSS) were lower than 100 mg/l during high water periods in the past, but nearly reached 500 mg/l during the dry season. A field sampling campaign in 2017 showed that the primary chemical composition of water from the Western Dvina River and most of its tributaries follows the pattern of Ca^{2+} > (Na^{+} and K^{+}) > Mg^{2+} and $HCO_3^{-} \gg SO_4^{2-} > Cl^{-}$.

Past monitoring efforts on the main stem of the Western Dvina showed that the water was relatively soft (hardness is less than 4 mg-eq/l with a pH between 6.5 and 7.5). The maximum sum of ammonium (NH_4^{+}) and nitrate (NO_3^{-}) observed in the water exceeds 2 mg/l, while total phosphorous concentrations are in the range of 50 to 100 µg/l or more.

The waters within Russian territory are mostly impacted by natural processes due to drainage from wetlands which lead to high concentrations of nutrients and organic matter. The annual average water content of ammonia and other nutrients are likely to exceed MAC values. The annual nutrient load is 40,600 tons/year for nitrogen and 1,400 tons/year for phosphorus (*Nilsson* 2006).

5.2 Population, economy and political geography

The total population within the Western Dvina basin is 2.17 million (*CIESIN* 2016). The Latvian part is the most populated (51%), followed by the Belorussian (39%), Russian (8%), Lithuanian (2%) and Estonian parts (less than 1%) (*CIESIN* 2016). The largest town or city in the Russian part is Western Dvina (8,347 inh.), in Belarus Vitebsk (376,226 inh.), Novopolotsk (102,394 inh.) and Polotsk (85,078 inh.), in Latvia Riga (641,007 inh.) and Daugavpils (95,467 inh.) (*AQUASTAT* n.d.).

Economic activity and land use in the catchment differ remarkably depending on the country. Forestry and wood processing dominate in the Russian cities Andreapol and Western Dvina and agriculture dominate in Western Dvina and Velizh. Agriculture and industry – especially wood processing, mechanical engineering, and metal-working industry – are typical for the Belorussian section of the catchment (in Vitebsk, Beshankovichy, Polotsk and Verkhnedvinsk). Novopolotsk is the largest regional oil refining industry center. According to regional development plans, a cascade of four hydropower dams near the cities Vitebsk, Beshankovichy, Polotsk and Verkhnedvinsk will be developed until 2020. In Latvia, the range of industrial facilities located in the river catchment area is rather wide: food and chemical industry, electronics, and clothing industry are located in the cities Daugavpils and Ogre. Among the largest hydroelectric power stations are the Western Dvina, Plavino and Rizhskaya stations. There are few split navigational waterways along the river (*United Nations Economic Commission for Europe* 2011).

The total water consumption in the Western Dvina basin is about 347 million m^3 per year (0.56 in Russia, 197.5 in Belarus, 146 in Latvia and 3.35 in Lithuania). In the Russian part, surface water covers 5% of the total consumption, in the Latvian part 36% (*United Nations Economic Commission for Europe* 2011) and in the Belorussian part 44% for the whole country (*AQUASTAT* n.d.). Over 60% of the people within the Western Dvina basin are employed in services, 23-31% in industry and less than 10% in agriculture (*World Bank Group* n. d.).

5.3 Resulting challenges for river basin management

Water quality issues are mostly related to the opposite trends in land use in different countries. The Western Dvina basin is relatively weakly disturbed by human activities in the upper (Russian) part and heavily modified in the downstream part, i.e. in Belarus and the EU. Drainage from municipal waters originate for example from large cities in Belarus, i.e. Vitebsk and Polotsk. This increases the concentrations of chlorides, ammonia nitrogen, and phosphorous, among others. The main sources are oil and energy industry facilities (*Yushchenko* et al. 2015). High rates of chemical fluxes are seen in the Latvian stem of the river (*Kolmakova* and *Maslova* 2008). However, changes in the agricultural sector, such as abandonment of cultivated lands since 1980 in Russia, and improved water treatment plants help improving water quality in Latvia (*Tilis* and *Miris* 2001). The waters within Russian territory are mostly impacted by natural processes due to drainage from wetlands which lead to high concentrations of biogens and organic matter. The annual mean concentrations for ammonia nitrogen and other nutrients occasionally exceed the environmental standards (*Chalov* et al. 2017).

A screening of the monitoring revealed data gaps in both water quantity and quality. Setting up a model chain (meteorology, land use, hydrology, matter transport, erosion, hydrobiology) that simulates water and matter flows in the basin in relation to, for example, changes of natural and anthropogenic conditions or different management options can act as a substitute to fill such data gaps. Besides, experimental research can also provide information about impacts of changing hydrological and land use patterns on river flow conditions. For that, a pilot study in the Vilesa River, a left tributary of the Western Dvina was initiated in May 2017. A water quality monitoring station is operating to provide high-resolution data on sediment transport and nutrient loads. Furthermore, the study is devoted to understanding the mechanisms of runoff formation based on hydrochemical analyses of interaction of waters from various water sources of a river in the process of mixing within the river basin.

Since the river discharges into the Baltic Sea, the downstream parts of the Western Dvina fall under the jurisdiction of the EU-WFD (*Nilsson* 2006). However, since the end of the Soviet Union there are a number of different legal frameworks that affect the basin: in Russia, environmental protection of the river basin falls under the Ministry of Natural Resources. Belarus introduced their own Water Code in 1998, which was amended in 2010. Latvia, Estonia, and Lithuania have experienced deeper institutional changes by joining the EU in 2004. As such, EU regulations generally superseded national regulations if contradictions existed. However, implementation of the EU-WFD on all levels remains a main priority (*ICWS* 2001).

The hydroclimatic development in the wake of climate change in the areas is another important issue for transboundary dialogue. The reported decline in maximal discharge for different parts of the Western Dvina catchment area in the period 1966-2000 compared to 1877-1965 is challenging for water resources management and water legislation systems. These developments also need to be taken into account for plans of new dam construction in Belarus and Latvia (*Volchek* 2008).

6. Discussion and conclusions

Numerous river basins in Eastern Europe cross international boundaries between EU member states, the Russian Federation, and/or newly independent states which emerged after the end of the Soviet Union in 1991. The geopolitical reorganization of Eastern Europe in the last three decades has not only had a significant impact on the socioeconomic development of individual countries and regions, but has also created new challenges for transboundary water resources management (*Table 2*).

On the one hand, the entry of several Eastern European countries into the European Union has led to a harmonization in the field of transboundary water resources management between the new member states and their western neighbors (e.g. via the implementation of the EU-WFD). On the other hand, the disintegration of the Soviet Union has created the opposite development at the western border of the Russian Federation. Whereas some of the newly independent countries have joined the EU (such as the Baltic countries), those which did not join the EU have developed their own national water legislation, even though these laws are typically based on Soviet inheritance.

Because the Eastern European countries have at the same time experienced socioeconomic changes (e.g. a decline of old industries but also partial re-industrialization, abandonment but also intensification of agricultural land use), this transition has had strong impacts on the region's water usage. While in some cases, pressures on aquatic ecosystems have been reduced, trends such as urbanization or a decay of wastewater treatment systems have locally increased water pollution. Moreover, some environmental legacies from the past continue to negatively affect the river systems of Eastern Europe.

Due to differences in the physical environment and anthropogenic impacts between and within the three case study catchments, the distribution of key challenges varies. Some challenges require attention in all basins, such as specific pollution sources like outdated waste water treatment plants, the impact of climate change, or harmonized water quality assessment methods. Also, a well-developed water governance structure and a strong civil society are essential for successful IWRM. Many countries lack sufficient capacities to initiate or maintain the complex processes required for IWRM. Therefore, capacity development measures are required on all levels (*Leidel* et al. 2012). Other challenges, however, are more urgent in specific basins, for example system modeling. While specific hydrological models were developed for a sub-basin of the Western Bug within the framework of an IWRM project (*Kalbacher* et al. 2012), comparable models for the Desna and Western Dvina catchments remain key research needs.

Despite some differences between the basins of the Western Bug, Desna and Western Dvina, in all cases problems regarding water pollution and aquatic ecology impairments can only be fully understood from a transboundary perspective. Therefore, interstate cooperation along Eastern Europe's borders constitutes an important prerequisite for the integrated management of the region's water resources. Key aspects for this include a harmonization of legislation regarding monitoring requirements and environmental standards, but also transboundary agreements on a more integrated management of international river basins. Ideally, such agreements should be arranged in a way that they are compatible with ongoing socioeconomic transition as well as geopolitical reorganization processes in Eastern Europe. In addition, they should base on a profound system understanding. For this

Table 2 Key challenges in the transboundary catchments of the case studies. Source: Own elaboration

	Western Bug	**Desna**	**Western Dvina**
Pollution: sources and mitigation	- Pollution from settlements, industrial areas, and agriculture - Maintenance and modernization of WWTPs - Optimization of the application of fertilizers and pesticides in agriculture		
	- Pollution from coalmines - Removal of illegal landfills/ pesticide storages		
Monitoring	- Systems are somewhat different and, e.g., not fully compliant with EU practices - Intensification of common transboundary monitoring programs - Harmonization of water quality assessment methods between countries and institutions, and upgrade and adjustment of analytical laboratories - Intensification of data exchange between different countries and between different national authorities - Deficits in monitoring of biological and hydro-morphological components, and of toxic substances as well as the toxicity and composition of discharged waste waters		
Governance	- Lack of consistent, transnational water management plans - Insufficient funding in water management sector, causing an investment backlog in infrastructure - Enforcement of national and transnational River Basin Councils as the central management instrument for IWRM		
Climate and hydrology	- Rising temperatures and altered precipitation throughout the year due to climate change, leading to changes in high and low flow with impacts on water quality		
	- Reduced water availability in summer	- Flood mitigation - Strong regulation of the river (water storages)	
Erosion		- Intensification of bank erosion	- Nearly no data available despite recognized problems
Capacity development (CD)	- Foster understanding of CD as an integral and inherent part of IWRM - CD needed on all levels (individual, organizational, etc.)		
System understanding and modeling	- Setup of a model chain that simulates water and matter flows and its ecologic impacts in the basin under changing boundary conditions in the past and future		

purpose, transnational model approaches are needed which comprise an appropriate understanding of the changing boundary conditions (climate, land use, resource management), and its hydrological and ecological impacts. The need for such integrated approaches is high, and further work should focus on this. Within the scope of the ManTra-Rivers project, we aim to develop comparative semi-distributed modeling approaches for water runoff and water quality for the case study areas.

Notes

[1] For the sake of consistency, we refer to cities, towns, and administrative regions according to the common transliteration of the respective country (e.g. Kyiv instead of Kiev). For transboundary rivers, however, we chose the common English spelling instead of deciding between different regional transliterations (e.g. Dnieper instead of Dnipro or Dnepr).

[2] ERA-Interim is a meteorological reanalysis from 1979 to present. The ECMWF (European Centre for Medium-Range Weather Forecasts) is responsible for the ERA (ECMWF re-analysis) project. NCEP-CSFR (NCEP Climate Forecast System Reanalysis) is a meteorological reanalysis ranging from 1989 to 2010 by the US-American National Centers for Environmental Prediction.

[3] Specifically, increased CO_2 concentrations stimulate growth and increase resource-use efficiency for radiation, water and nitrogen in plants that rely on C_3 and C_4 photosynthesis (*Fischer* et al. 2014).

[4] On the scale used by the authors, "catastrophic" floods are classified as the most severe, followed by "outstanding", "high", and "average high water" (*Gorbachova* and *Kolianchuk* 2012a: 9).

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