“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

Report on WP A– Assessment of the status quo in the three investigated basins

Chalov S, Pluntke T, Nabyvanets Y, Kruhlov I, Helm B, Terskii P, Krengel F, Osadcha N, Habel M, Osadcha N, Osadchyi V, Reeh T, Karthe D and Bernhofer C

Funding agency
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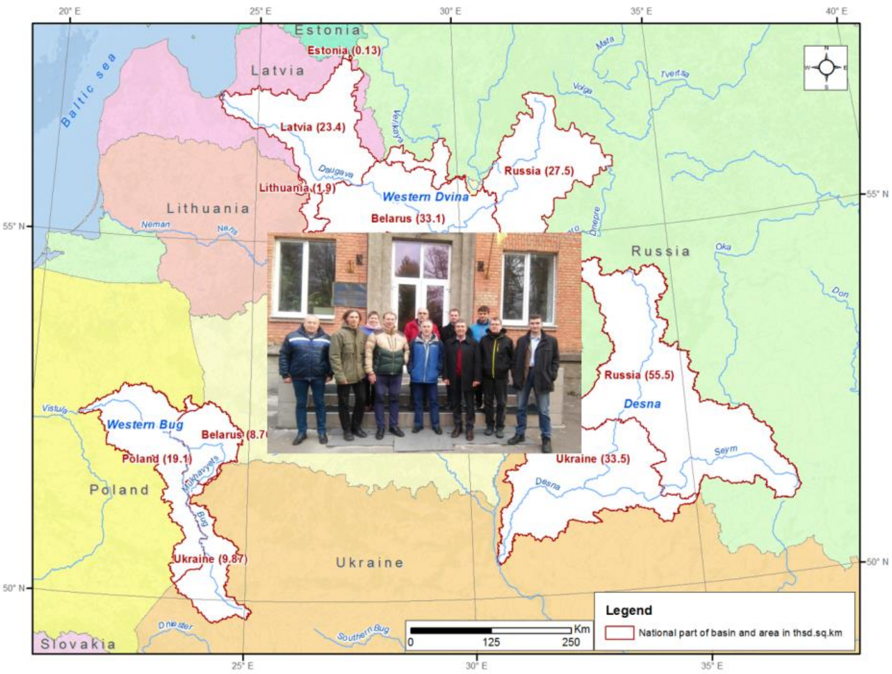
Project coordinator
Technische Universitat Dresden (TUD), Germany

Project partner
Helmholtz Center for Environmental Research (UFZ), Germany
Lomonosov Moscow State University (LMU), Russia
Ukrainian Hydrometeorological Institute (UHMI), Kiev, Ukraine



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Content

Abstract

This report is a part of trilateral project of the Volkswagen Stiftung, which aims at strengthening cross border cooperation, confidence, understanding and maintenance of the dialogue between scientific institutions and public authorities from Russia, Ukraine and countries of the EU. The project intends a transnational analysis of three river catchments: the Western Bug (shared by Ukraine, Belarus and the EU), the River Desna (shared by Russia and Ukraine) and the Western Dvina (shared by Russia, Belarus and the EU) (Figure 1). Water quality problems that need to be dealt with in a transboundary setting are the connective element of these basins.

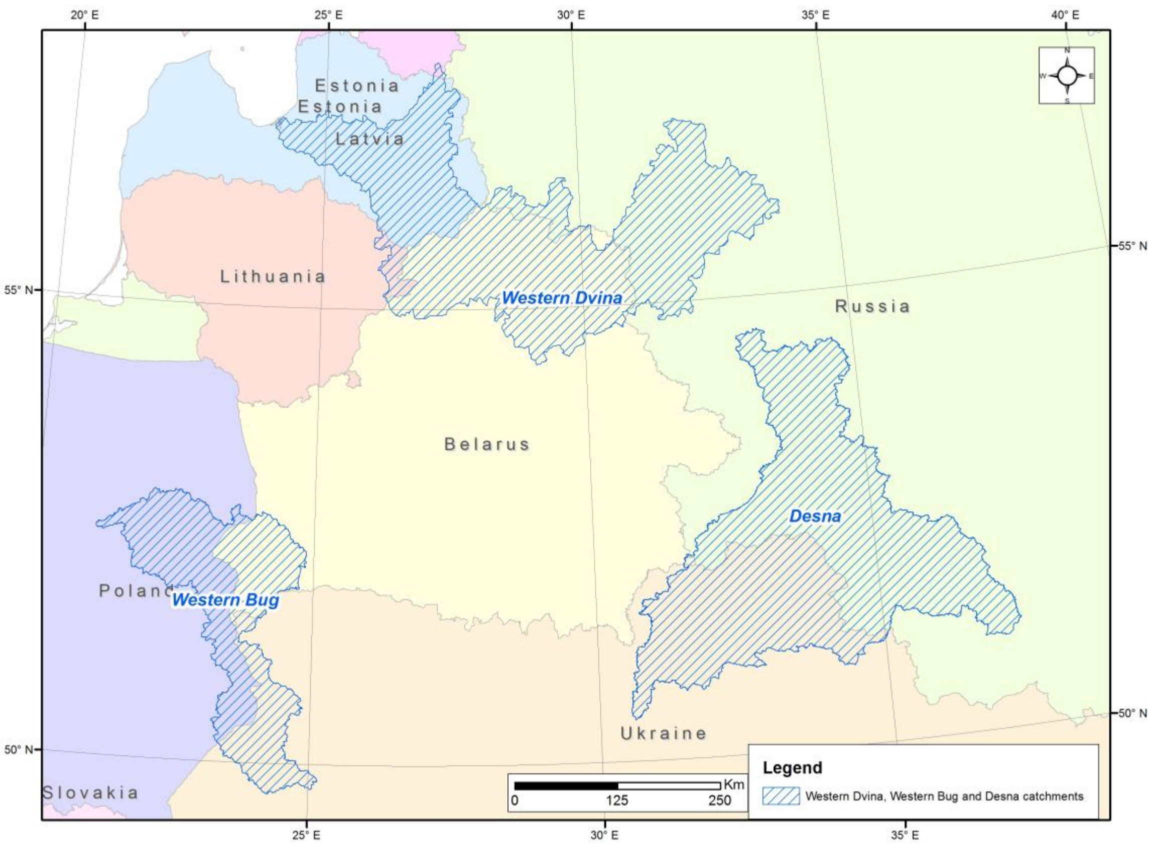


Figure 1. Overview of the transboundary river basins

This report aims at

I) a literature review on national and international publications,

II) expert talks on all relevant issues of an Integrated Water Resources Management (IWRM) and on political disputes in Ukraine, Russia and the EU,

III) an assessment of the hydrological, hydro-morphological, geochemical and ecological state of the rivers and their basins, including the consideration of ecosystem services and

IV) an identification of important stressors onto the water system, including point and diffuse pollutant sources and changing boundary conditions.

Chapter 1. General information about investigated basins

1.1 General features in the XXI century

The three transboundary catchments represent distinctive environmental and socio-economic patterns. The smallest catchment Western Bug has the largest population (Figure 2). The ratio of urban to rural population varies from 43.5 % in Polish part of Western Bug catchment to 95,6 % in Russian part of Desna River (Table 1), which is an evidence of drastic socio-economic changes in the traditionally rural area of Bryansk Oblast in Russia. Vegetation mosaic (forest, shrubland, grassland, cropland) and cropland-forest mosaic dominates in Western Bug and Desna rivers, whereas broadleaved forest is the main land use class in Western Dvina Basin. These distinctions have a significant impact on hydrology and water quality of the transboundary rivers and also lead to changes in the cooperation issues between riparian countries.

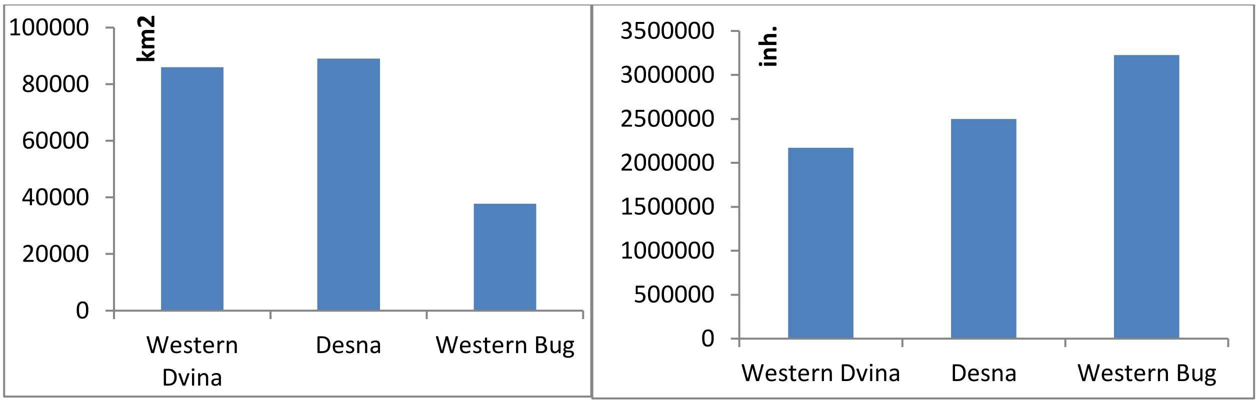


Figure 2. Catchments area (km2) and population (inhabitants) of the transboundary basins

Table 1. Administrative and demographic characteristics of the transboundary catchments

River	Western Dvina					Desna		Western Bug		
Countries	**Russia**	**Belarus**	**Latvia**	**Estonia**	**Lithuania**	**Russia**	**Ukraine**	**Ukraine**	**Belarus**	**Poland**
Area, km² (% from the total area)	27466 (32%)	33144 (38.6%)	23361 (27.2%)	131 (0.2%)	1862 (2.2%)	55494,0 (62 %)	33509,7 (38 %)	9877 (26.2)	8760 (23.2)	19120 (50.6)
Number of administrative areas (Province level)	3	2	3	1	2	6	3	2	1	3
Population, inhabitants	176469	842556	1109762	420	43810	1538677	960923	1441000	579000	1206000
population density, inh./km²	6.55	26.2	52.3	3.49	26.2	27,9	28,4	146	66	63
Urban/rural population, %*	60.9	86.3	84.9	84.1	85.6	95,6	89,4	79.0	77.0	43.5
Number of large cities (with population more than 100 000 people)	0	2	2	0	0	2	1	1	1	1

1.1.1 Western Dvina

Location

Western Dvina (RUS: Zapadnaya Dvina, LV: Daugava) river basin is a river rising in the Valdai Hills, Russia, flowing through Russia, Belarus, and Latvia into the Gulf of Riga of the Baltic Sea forming there a delta. Lithuania and Estonia have small shares of Western Dvina catchment (Table 1, Figure 3).

Topography and geology

The basin has mainly flat and wavy plain topography. River valley have been formed approximately 12-13 thousands years ago. Relatively high drainage density and mostly grey forest soils explain the low rates of infiltration losses.

Figure 3: Middle part of Western Dvina river near Velizh (Russian Federation)

Climate and hydrology

The climate of the Western Dvina river basin is temperate moderately continental. In Russian part, the average temperature in January ranges from −6 °C in southwestern part until −10 °C in the northeastern part. Temperatures in July range between +17 and +19 °C. Average annual precipitation is 650 mm. Climate in Latvia is characterized by wet and mild summers (18,2 °C, 85mm) (Second assessment…, 2011).

The total length of the river is 1020 km: 325 km in Russia, 338 km in Belarus and 317 km in Latvia. Western Dvina originates from the lake Ohvat, flows in South-West direction and downstream of the city Vitebsk in North-West direction. Information about total catchment area differs between sources: 87000 km^2 (International river basins…2006), 85600 km^2 (Resources…1975). According to our analyses based on SRTM v.4 Hydrosheds 30s, total catchment area was estimated to 85900 km^2.

Average annual water discharge into the sea is 20700 mln m^3 (656 m^3/s), annual nitrogen flux is 40600 tons and phosphorus flux 1400 tons (International river basins… 2006). Maximal discharges are observed in spring due to snow melting and spring rainfalls.

Soils

There are eight soil classes in the catchment according to Unified State Soil Registry (Harmonized World Soil Database) (Table 2).

Total population

Within Western Dvina river basin live 2.17 million people (University, 2016). The most populated is the Latvian part (51%) in comparison to Belorussian (39%), Russian (8%), Lithuanian (2%) and Estonian part (less than 1%). The largest city in Russian part is Zapadnaya 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.).

Economy and actual land cover / land use.

Land use varies significantly between adjacent countries. Mostly forestry and wood processing (Andreapol and Western Dvina cities) and agriculture (Western Dvina and Velizh cities) dominate in Russia. Agriculture and industry (engineering, wood processing, mechanical engineering and metal-working industry) (Vitebsk, Beshankovichy, Polotsk and Verkhnedvinskcities) are typical for Belorus, whereas Novopolosk is the largest regional oil refining industry center. There is a regional plan until 2020 to develop a cascade of 4 hydropower dams near the cities Vitebsk, Beshankovichy, Polotsk and Verkhnedvins.

In Latvia, a rather wide range of industrial facilities is located in the river catchment: food and chemical industry, electronics, clothing industry (Daugavpils and Ogre). The largest hydropower stations are Western Dvina, Plavino and Rizhskaya. There are few separate navigational waterways along river.

1.1.2. Desna

Location

The Desna is the longest and second-largest tributary of the Dnipro in terms of water runoff. The Desna rises in the Smolensk Highland of the Russian Federation from an area called the Blue Bog. Near Kyiv, Desna enters the Dnipro River, making the way from the source to the mouth through Smolenskaya, Bryanskaya, Kurskaya, Kaluzhskaya and Tulskaya Oblasts of Russia. After crossing the border of Ukraine it passes through Chernigivsyka, Sumsyka and Kyivsyka Oblasts (Figure 4).

The Desna basin within the territory of Ukraine locates inside two physico-geographical zones. The main part of the basin belongs to the zone of temperate forest, which is located within the Southern part of Polissya Lowland. South of the line Kyiv-Nizhyn-Baturyn-Krolevetsy-Glukhiv it gradually turns to the forest-steppe zone via broad terraces (Figure 4).

Figure 4: Desna river (Ukrainian part)

Topography and geology

Desna catchment belongs to Dniprovsyko-Donetsyka depression and Voronezh crystalline massive. Topography of the catchment determines the conditions of water exchange within its territory which, in result, influences the variability of the elements concentration in water flow. Relief in the Desna basin is a lowland; the hypsometric indicators vary between 100-227 m. Sandy and sandy-clay anthropogenic deposits dominate and led to the formation of predominantly erosion forms of relief.

The Desna is a typical plain river with a moderate gradient of 1 m/km, on average. The changes in geological structures (chalky deposits and Paleogene sandy-argillaceous rocks) are associated with terrain variability, which is characterized by abrupt changes of the gradients of rivers beds.

Climate and hydrology

The annual sum of the total and direct solar radiation in the Desna basin reach 3808 mJ/m^2 and 1720 mJ/m^2, respectively. Mean annual air temperature for the period of 1961-1980 for the upper part of the Desna basin is 6,3°C; for the middle part of the basin - 6,8°C; for the lower part of the basin (Kyiv) 7,0°C. For the period of 1991-2015 the above mentioned temperatures increased up to 7,3°C, 7,6°C and 8,0°C respectively.

The mean temperature of January is -4,0°C; mean temperature of July +18,8 °C. Duration of frost free period is 160 days. Mean annual amount of precipitation is 650-700 mm. The main portion of precipitation falls during the warm period of the year (425 mm); maximum is observed during June-July. Almost half of the days in the year have precipitation. On average, a stable snow cover is formed in the second half of January and lasts for 90-100 days. Snow cover high reaches 15-35 cm, and the depth of soil freezing is down to 40-45 cm.

Soils and vegetation

The sod podsolic soils of different mechanical composition are the most widely distributed in the Desna basin. Carbonate-free sandy and sandy-loamy glaciofluvial and moronic deposits are the soil-forming rock for these soils. To the South of the Seim river mouth they form loess. The part of the Desna basin occupied by these soils reaches 38,9 %. The relative distribution of this type of soils within the Russian Federation and Ukrainian territory is 39,6 % and 37,7 % respectively.

The typical forest-steppe landscapes are observed at the Ukrainian part of the basin within Voronezh crystalline massive and on elevated sites of the interfluves. The high degree of drainage resulted in forming of gray forest soils and black soils (14,2 % and 12,3 % respectively). Alluvial soils are distributed at floodplain sites occupying 12,1 % of Ukrainian territory of the basin.

Relatively high swampiness is observed in the Desna river basin. Many bogs were meliorated. The recent swampiness indicator (share of swamps of total area) is 8,3 %. The forest zone vegetation is represented by coniferous and mixed forests with impurities of broadleaf species: oak, birch, alder. The forest covers 33 % of the Russian catchment territory, while it covers 27 % of the Ukrainian catchment territory.

Economy and actual land cover / land use

There are two main classes of land cover - land use prevailing in Ukrainian part of the Desna basin: arable lands (52,4 %) and forest (34,8 %).

Gross Domestic Product of the Ukrainian part of the Desna basin is equally distributed between industrial and agricultural complex. Processing industry dominates in industrial production (food producing industry, textile industry, clothes production, etc.). In Agriculture, cereal production has the highest priority. Besides cereals, oil crops (sunflower, soya) and potato are cultivated in Polissya zone. Oil crops and sugar beet are dominant in forest-steppe zone. Privet households are the main producers of potato and vegetables.

Cattle breeding is a strategic branch for the region, whereby dairy cattle's breeding is the main specialization. Region of the Desna basin occupies the fifth rank in cattle breeding complex of Ukraine.

Political divisions and population

Russian part of the catchment includes territories of six administrative provinces (Oblasts): Bryanskaya Oblast – 45.2%; Kurskaya Oblast – 35.7%; Kaluzhskaya Oblast – 9.3%; Orlovskaya Oblast – 4.1%; Smolenskaya Oblast – 4.1%; Belgorodskaya Oblast – 1.5%.

Ukrainian part of the Desna river basin is situated on the territory of 3 administrative districts (Oblasts): Chernigivsyka Oblast – 65%; Sumsyka Oblast – 33%; Kyivsyka Oblast – 2%.

Total population of the catchment area is 960 923 people. The urban population dominates (89,4%). There is only one city in Desna river basin territory where population exceeds 100000 – Chernigiv, the administrative center of the Chernigivsyka Oblast.

1.1.3. Western Bug

Location

The Western Bug river basin has a total area of 37,758 km^2 and spans three nations: Belarus, Ukraine, and Poland. Although its greatest part, including the outlet, is located in Poland, the headwaters of the main river are in Ukraine.

Figure 5. Western Bug near Busk

Topography and geology

The basin has mainly flat and wavy plain topography, although there are some hills at the upper reaches in the South. The mean elevation is 181 m, while the elevation span is 60-471 m abs (Table 2). From the morphotectonic perspective, the whole basin belongs to the Plain of the Central-Eastern-European Platform (Mesheryakov, 1965), and its surficial bedrock geology is formed by Late Cretaceous, Eocene, and Miocene sedimentary rocks (Gerasimov et al., 2004). The basin embraces several large geomorphic units: Western Podillia and Roztocha Uplands in the upper reaches (Kruhlov, 2015), Polissia Lowlands in the middle course, and Central-Polish and Podlaskie-Belarus Lowlands in the lower course (Kondracki, 1965). Continental deposits are predominantly represented by loess-like eluvial-colluvial loam on the uplands, while the lowlands are mainly formed of fluvioglacial and aeolian sand. Valley bottoms are filled with mineral alluvium and lacustrine deposits, including peat (Gerasimov et al., 2004).

Climate and hydrology

The climate of Western Bug basin is temperate moderately continental (Gerenchuk, 1972, 1975). The annual mean temperature is 7.0-7.6 °C, while the yearly mean precipitation sum is about 650-700 mm (Lipinskyy et al., 2003; Pavlik et al., 2014). Western winds prevail and most of the precipitation takes place during summer. According to simulated data for Wlodawa, a town located approximately in the center of the basin, the coldest month is January with temperature of -2 °C and the warmest month is July with temperature of 19 °C. July is also the wettest month with an average precipitation of 67 mm, while the driest months are February and October with an average precipitation of 32-33 mm (Figure 6 and Figure 7). The snow cower is unstable, on average it builds up in late November and melts down in mid-March.

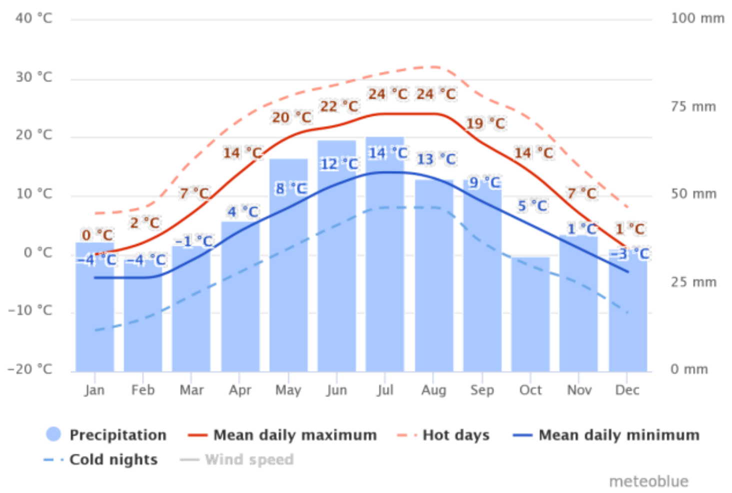


Figure 6. Simulated air temperature and precipitation values for Wlodawa (30 years of hourly simulations) (Weather Princeton website)

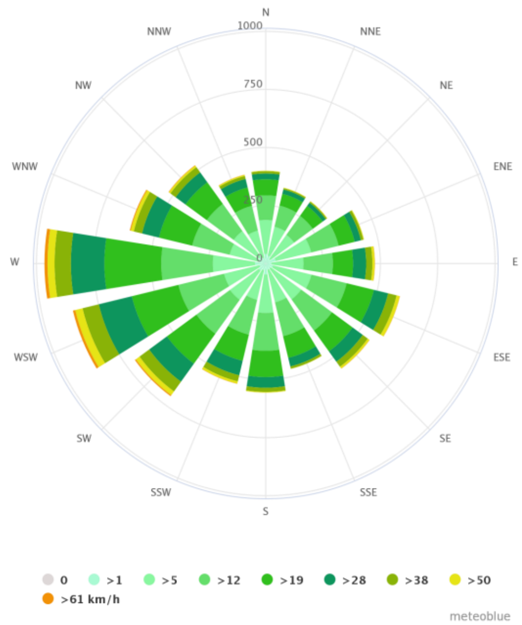


Figure 7. Simulated wind direction and speed values for Wlodawa (30 years of hourly simulations) (Weather Princeton website)

The Western Bug length is about 830 km, and it flows into the Narew, which belongs to the Vistula drainage system. The largest tributaries of the Bug are: within Ukrainian territory – the Poltva (drainage area of 1,490 km^2), the Rata (1,859 km^2), and the Luha (1,365 km^2), within Poland – the Huczwa (1,431 km^2) and the Liwiec (2,795 km^2), and within Belarus – the Mukhavets (5,557 km^2) and the Lesnaya (2,886 km^2). The high waters are observed in late February – early April and are caused by snow melt, while the low water is typical for winter and summer/early autumn. The low water periods are frequently disrupted by flash floods caused by rains. The alimentation is mainly from rain, to less extent from melting snow and from groundwater. There is a natural lake region located in the central part of the basin, called Shatsk Lake. The largest lake is Svitiaz, it has an area of 24 km^2 and the maximum depth of 24 m(Gerenchuk, 1972, 1975).

Soils and biota

The basin belongs to the Central-European mixed forests ecoregion and embraces a variety of soil classes (Table 2), among which sod-podzolic soils (Luvisols, Podzoluvisols and Podzols) prevail on fluvioglacial and aeolian deposits forming low interfluves. The potential natural vegetation for these soils is mesic and hygro-mesic oligo-mesotrophic oak-pine forests (*Querceto roboris – Pineta sylvestris*). The loess uplands, located in the upper reaches of the Western Bug, are predominantly occupied by grey forest soils (Phaeozems and Greyzems), which form habitats for mesic mesotrophic and eutrophic beech and oak forests. Alluvial mineral soils and lacustrine peat deposits (Fluvisols and Histosols, respectively) occur in river valley bottoms. They are favored by hydric and hygric formations of alder and willow (Kruhlov, 2015). The natural landscape provides habitat for many large animal species including brown bear, lynx, wolf, wisent, red and roe deer, beaver, otter, etc. (Gerenchuk 1972, 1975).

Political divisions and population

The Western Bug basin spans three nations and a number of Level 1 (province) administrative territories (Table 1). In Ukraine, the Basin partly embraces Lviv and Volyn oblasts, in Belarus – Brest oblast, and in Poland – Lubelskie, Mazowieckie, and Podlaskie voivodeships. The basin homes over 3 million of inhabitants, who are rather unevenly distributed across the area. The most densely populated is the Ukrainian sector: Lviv – a city of 0.8 million inhabitants – is located here at the sources of the Poltva River. Totally, there are 32 cities, towns and urban villages within the Ukrainian territory, but they are significantly smaller than Lviv. The second largest Ukrainian town is Chervonohrad with a population of 0.07 million. The second largest city of the whole basin is the Belarussian city Brest with 0.34 million of inhabitants. The Polish sector has the largest population, but the lowest population density (Table 1). There are 32 towns and cities here, and the largest urban developments are Siedlice (0.08 million of inhabitants), Chelm (0.06 million), and Biala Podlaska (0.06 million).

Economy and actual land cover / land use

The basin has been intensively developed since the medieval. The largest areas are now occupied by agricultural land (~67 %, Table 2). This is predominantly cropland and, to less extent, grassland. The fields are much larger, in comparison with the Polish territory, in the Ukrainian and Belarus sectors, where nationalization and consolidation of the agricultural land took place during the time of Soviet Union. Forests account for ~32 % of the basin area. Broadleaved forests of European beech and oak prevail on the uplands in the Western Bug headwaters, while mixed (pine-oak) and coniferous (pine) forests are typical for the rest of the Basin. There are coal mines in the Ukrainian sector within the area of Chervonohrad – Novovolynsk . The Dobrotvir power plant, which works on coal, and its cooling water reservoir are located on the Western Bug. The industries are concentrated in the cities of Lviv, Brest, Chervonohrad, Chelm, Sokal and other. Protected areas occupy 19 % of the basin (7159 km^2). The largest portion of it is located in the Polish sector (5739 km^2). In the Belarus and Ukrainian sectors of the basin, protected areas cover 9 % and 6 % of the area respectively. Among them are several national parks: Belovezhskaya Pushcha in Belarus, Poleski National Park in Poland, Shatskyi and Yavorivskyi National Parks in Ukraine (https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas). The infrastructure is best developed in the Polish sector, and least developed in the Ukrainian sector.

Population of the case study Transboundary Rivers catchments is shown in Figure 8.

Land use parameters (according to Globcover LU Type (Globcover LU code) of the case study Transboundary Rivers catchments are shown in Figure 9.

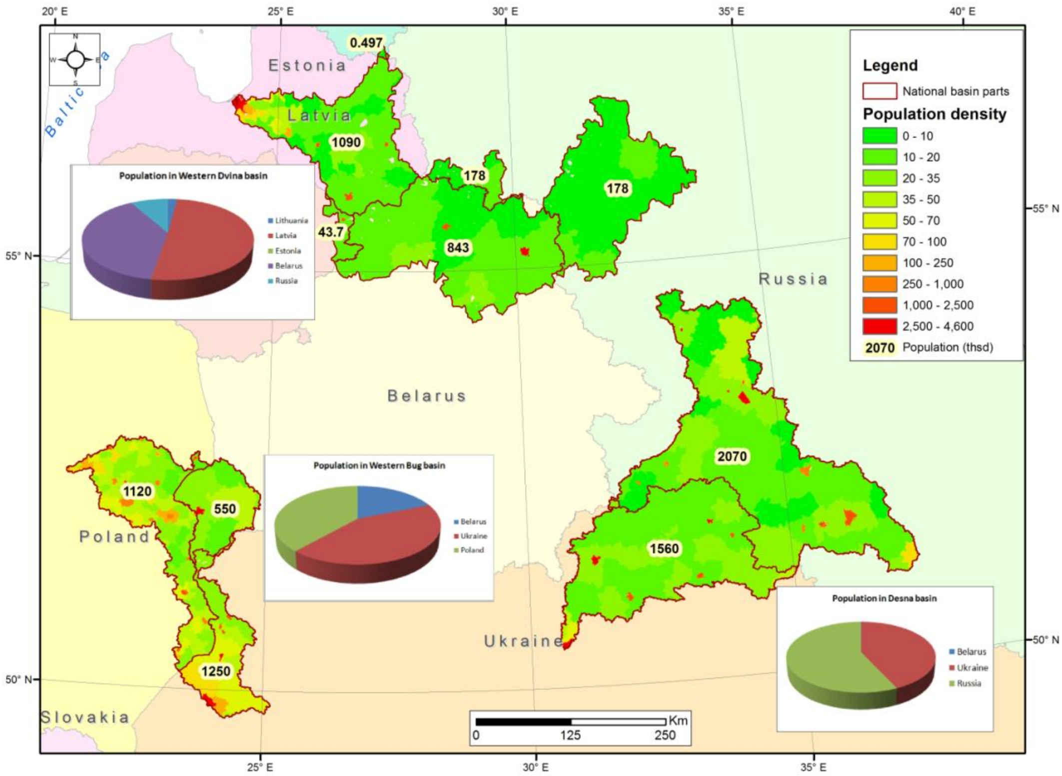


Figure 8. Population of the case study Transboundary Rivers catchments

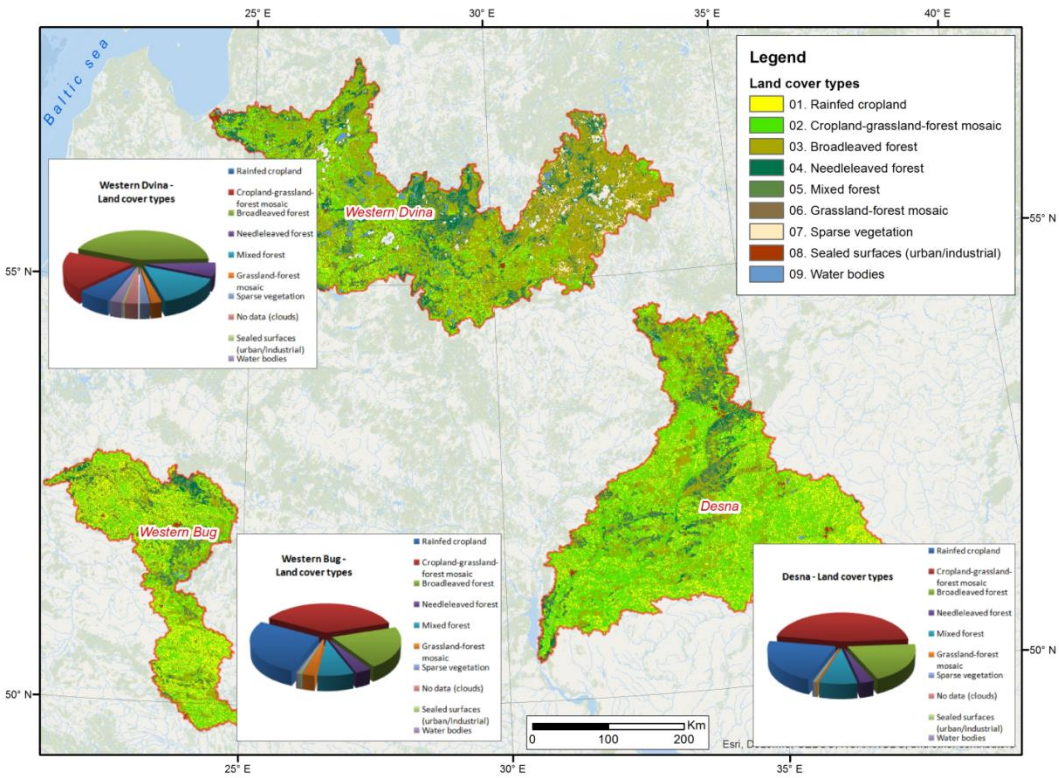


Figure 9. Land use parameters (accodring to Globcover LU Type (Globcover LU code) of the case study Transboundary Rivers catchments

Table 2. General eco-geographical characteristics of the case study catchments

River		Western Dvina					Desna		Western Bug		
Countries		**Russia**	**Belarus**	**Latvia**	**Estonia**	**Lithuania**	**Russia**	**Ukraine**	**Ukraine**	**Belarus**	**Poland**
Topography	Average elevation, m	197	157	121	189	159	192.13	140.96	218	162	169
	maximum elevation, m	321	290	292	216	274	282.00	231.00	471	~ 205	~380
SOILS (according to HWSD) km^2 (% from the total area)	Arenosols	-	10.9 (<0.1%)	262.9 (0.3%)	-	328 (0.4%)			0	0	568 (1.5%)
	Chernozems						4036 (7.3%)	4773.02 (14.2%)	53 (0.1%)	0	0
	Cambisols						2993.64 (5.4%)	1976.30 (5.9%)	0	0	754 (2.0%)
	Fluvisols	0 (0%)	8.7 (<0.1%)	28.2 (<0.1%)	-	23.9 (<0.1%)	4945.97 (8.9%)	4071.38 (12.1%)	1035 (2.7%)	855 (2.3%)	1573 (4.2%)
	Gleysols	334.5 (0.4%)	747.3 (0.9%)	1770.4 (2.1%)	-	-	667.32 (1.2%)	1766.09 (5.3%)	507 (1.3%)	1439 (3.8%)	411 (1.1%)
	Greyzems						12891 (23.2%)	4114.49 (12.3%)	1772 (4.7%)	0	0
	Histosols	1735.7 (2%)	1850.8 (2.2%)	1533.7 (1.8%)	17.4 (0%)	210.7 (0.2%)	791.72 (1.4%)	2775.86 (8.3%)	490 (1.3%)	1334 (3.5%)	2497 (6.6%)
	Leptosols						-	-	928 (2.5%)	0	625 (1.7%)
	Luvisols*	15.2 (<0.1%)	73.9 (0.1%)	14813.1 (17.2%)	39.1 (<0%)	149.9 (0.2%)	-	-	30 (0.1%)	0	2323 (6.2%)
	Podzoluvisols	23452.4 (27.3%)	29089.6 (33.8%)	91.2 (0.1%)	2.2 (<0%)	1116.6 (1.3%)	21966.1 (39.6%)	12637.79 (37.7%)	3434 (9.1%)	3729 (9.9%)	4517 (12.0%)
	Phaeozems						7202.00 (13.0%)	1394.8 (4.2%)	1409 (3.7%)	0	712 (1.9%)
	Planosols	-	-	-	-	4.3 (<0.1%)	-	-	0	0	0
	Podzols	1787.8 (2.1%)	1353.4 (1.6%)	4160 (4.8%)	71.7 (0.1%)	-	-	-	208 (0.6%)	1404 (3.7%)	5142 (13.6%)
	Disturbed and urban	-	-	421.4 (0.5%)	-	-	262.92 (0.47%)	128.06 (0.38%)	0	0	0
	Water	123.8 (0.1%)	10.9 (<0.1%)	282.4 (0.3%)	-	21.7 (<0.1%)	190.7 (0.3459	113.5 (0.34%)	0	0	0
Land use parameters (according to Globcover LU Type (Globcover LU code))	14. Rainfed Cropland	22.8 (0.4%)	229.2 (3.9%)	131.2 (2.2%)	19.5 (0.3%)	0.2 (<0.1%)	12841 (23.13%9	6624 (19.8%)	2835 (7.5%)	1637 (4.3%)	5790 (15.3%)
	20. Vegetation mosaic (forest, shrub. grassl., cropl.) Cropl.-forest mosaic	215 (1.4%)	1435 (9.2%)	1104 (7.1%)	95 (0.6%)	2.3 (<0.1%)	23635 (42.5%)	17427 (52.0%)	3726 (9.9%)	3060 (8.1%)	7178 (19.0%)

Table 2. General eco-geographical characteristics of the case study catchments (continuation)

River		Western Dvina					Desna		Western Bug		
Countries		Russia	Belarus	Latvia	Estonia	Lithuania	Russia	Ukraine	Ukraine	Belarus	Poland
Land use parameters (accodring to Globcover LU Type (Globcover LU code))	50. Broadleaved forest	6667.7 (17.9%)	5332.4 (14.3%)	3882.2 (10.4%)	285.6 (0.8%)	17.3 (<0.1%)	11678.28 (21.0%)	5728.7 (17.09%)	2327 (6.2%)	1961 (5.2%)	3526 (9.3%)
	70. Needleleaved forest	38.5 (0.8%)	116.2 (2.5%)	86.3 (1.9%)	4.6 (0.1%)	2 (<0.1%)	1663.71 (3.0%)	1084.71 (3.24%)	118 (0.3%)	613 (1.6%)	567 (1.5%)
	100. Mixed forest	824 (6%)	845.7 (6.2%)	472.9 (3.5%)	27.1 (0.2%)	5.3 (<0.1%)	5112.82 (9.2%)	2314.49 (6.9%)	529 (1.4%)	1180 (3.1%)	1245 (3.3%)
	110 Vegetation mosaic	1.5 (0.4%)	0.1 (0%)	0 (0%)	0 (0%)	-					
	120. Grassland-forest mosaic	10.8 (0.8%)	8.3 (0.6%)	2.4 (0.2%)	0.1 (<0.1%)	-	12.84 (0.02%)	38.08 (0.1%)	180 (0.5%)	182 (0.5%)	643 (1.7%)
	140 Closed to open grassland	-	0.1 (0%)	0.6 (0.2%)	-	-					
	150. Sparse vegetation	40.3 (2.1%)	1.4 (0.1%)	0.2 (0%)	-	-	94.79 (0.17%)	55.34 (0.17%)	5 (0%)	8 (0%)	32 (0.1%)
	180 Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	37.2 (1.5%)	15.5 (0.6%)	19.4 (0.8%)	-	-	11.97 (0.02%)	0.19			
	190. Sealed land (urban, industrial)	-	0.3 (0.1%)	0.5 (0.2%)	-	-	262.92 (0.47%)	128.06 (0.38%)	57 (0.2%)	88 (0.2%)	89 (0.2%)
	210. Water bodies	14.2 (0.6%)	23.2 (1%)	16.8 (0.8%)	3 (0.1%)	0.1 (0%)	190.69 (0.34%)	113.48 (0.34%)	100 (0.3%)	32 (0.1%)	51 (0.1%)
European Ecological regions km2 (% from the total area)	Central European mixed forests								9877 (26.2%)	8761 (23.2%)	19120 (50.6%)
	Sarmatic mixed forests 46	24248.1 (29.3%)	31886.1 (38.5%)	21575.9 (26.1%)	125.5 (0.2%)	1785.6 (2.2%)					
	Scandinavian and Russian taiga 86	84.6 (2.6%)	0.7 (0%)	35.5 (1.1%)	-	.					

*Marked boxed are related to most dominant class in the national sector of the river catchment

1.2. Historical transformation of the environment and land use since the middle of the XX century

The regional evolution significantly influenced land use types and pressures on water resources in different national parts of the case study catchments in the Anthropocene and before. All areas were a traditional agricultural region till mid-20th century. It has been developed since the medieval. Urban settlements existed already in 10th century. In the XX century all catchments had been significantly destroyed by the war. World War II caused a considerable decrease of the population. Moreover, big migrations after the end of the war and rapid industrial development lowered the ratio of rural populations. These conditions fostered the change of agricultural lands into forests. The increase of forest area in central and eastern Europe from 1950 to 1970 can be explained by a high rate of afforestation after World War II (Ramankutty et al., 2009).

Population dynamics in the transboundary river basins most likely has followed national trends. In the Western Dvina river basin (Center for International Earth Science Information Network…2016; History Database of the Global Environment (HYDE)), there was 10 times increase in population from 1500 to the early XX century up to 1.7 million. In the beginning of 1940, there was about 2.1 million people. After the Second World War in 1950th the population was 1,97 million, and its maximum (2,5 million) was registered in 1990. The population density in the second part of the XXth century was rather stable except for the Russian part of the river basin territory where it is low (7 people per km2) and gradually declines (Table 3). During the period 1990-2010 the population of this territory decreased up to the pre-war level – 2,1 million of people due to the urbanization and decrease of the rural population

According to the data of The World Bank Group, the part of the population in agricultural sector is between 3,9 and 9,7 % with its maximum in Belarus (Table 4). It decreased by more than 6 times in Estonia from 1990th to 2015. The part of the population in the industrial sector was only 23,6–31,1 % during the period 1990–2015. More than 50 % of the population engaged in the service industry in all countries. A considerable increase was noted in Russia in the period 1990–2015 (Table 3).

Table 3. Modifications of the natural features and land use impacts in the Western Dvina transboundary rivers basin since the Middle of the XX century

River		Western Dvina				
Countries		**Russia**	**Belarus**	**Latvia**	**Estonia**	**Lithuania**
Total population /population density in the area	1950	339593/12	824546/24	760231/32	1732/13	46763/25
	1970	252410/9	951369/28	977598/41	1583/12	55550/29
	1990	240991/8	1086306/32	1101206/47	1764/13	63352/34
	2010	185867/7	884062/27	1006665/48	494/4	49529/30
Forest coverage (% from the total area)	1950 (ORNL DAAC)	1.01	21.2	11.1	-	2.02
	1970	-	-	-	-	-
	1990 (Corine LC, USSR forest map)	40.7	23.1	39.8	63.5	28.2
	2010 (Globcover)	30.76	29.18	19.19	1.26	0.17
% of the people working in the agriculture from total population	1950	-	-	-	-	-
	1970	-	-	-	-	-
	1990	13.9	24	-	21.0	-
	2010	7.9	10.6	8.6	4.2	8.8
List of water regulations relevant for the certain part of the catchments	1950	No comparable data about water policy				
	1970	Water Code RSFSR 1972				
	1990	Agreement 2002	Agreement 1992, Agreement 1995	Helsinki Convention 1992		Agreement 1999, Agreement 1995
	2010	Technical Protocol 2008				Technical Protocol 2008

In the Western Bug river basin there was a moderate/fast increase of population until ~1990 in all national sectors with a particular increase of urban inhabitants (owing to industrialization of the area). Then, stabilization of the population took place in the Polish part, and a moderate decline in Belarus and Ukrainian parts – e.g. population of Lviv oblast increased from 2.1 million in 1959 to 2.7 million in 1989 and then decreased to 2.5 million in 2014.

Forest distribution was highest (100 %) in the XV century and decreased down to 36% in the XX century due to active deforestation and agricultural sector growth (Table 4) (Goldewijk et al., 2011; Stone and Schlesinger, 2003). Huge amount of timber was urgently demanded in the late 1940s and in the 1950s as construction material, but the resources were very limited. It can be seen in the case of Poland that the forest area was badly plundered. There was an enormous area of forests that had been clear-cut during the war and were not regenerated. These conditions reminded people of the significance of wood resources and might also have convinced the authorities to pursue large-scale regeneration and afforestation programs during the 1940s until the 1960s. At this period, an extensive melioration program was implemented in Western Dvina catchment which lead to access to new forest massive in the area.

In the Western Bug river basin the existing forest cover has not changed much during 1989-2010 in the upper reaches (Burmeister and Schanze, 2016). It may be assumed that forest cover has been stable also in the other parts of the Basin – since these are primary old agricultural and recreational/protected areas with a limited development of forestry. So the current estimations of the forest cover (~32 % of total area – see Chapter 1.1) more or less reflect the maximum extent of deforestation. The agricultural land was nationalized and consolidated into large collective and state-owned farms in mid-20th century in the Ukrainian and Belarus sectors. Drainage systems were extensively constructed here to increase areas of cultivated land at the expense of wetlands. In the Polish sector, small private agricultural enterprises survived the Communist rule. The WBRB was intensively industrialized in 1950-80s. The main industrial development took place in Lviv, where a number of plants and factories were established in machine building, construction, light industry, and food production. Outside Lviv, coal extraction begun in Chervonograd – Novovolynsk region, the Dobrotvir Power plant was set to operation, and chemical industry started in Sokal. In the Belarus sector, manufacturing (primarily electrical) and light industry has been developed in Brest. In the Polish sector, Chelm is probably the most important industrial location with its concrete production. There was an economic decline, which started at the end of the Communist period. Many industries were closed, and agricultural land was abandoned (Baumann et al., 2011). However, there is a trend for the re-cultivation during the last decade (Smaliychuk et al., 2016).

Development of the areas was also related to the location within different countries. E.g., the Western Bug area quite frequently changed political dominance: it belonged to Russian, Poland, Habsburg and Russian empires, and the USSR. The Western Bug was an important trading rout, which connected the Baltic Sea with the Black Sea. And Lviv, located on the water divide between the two regions, was the main trading point of the region. Information about the land cover/land use in the upper reaches of the basin, which belonged to the Habsburg Empire, can be derived from Austrian metrics of late 18th and of 19th centuries (Josefinian and Fraciscanian surveys) as well as from military topographic maps (The Historical Map Portal). The intensive hydrological engineering started in the second half of the 19th century, when the railroads and heavy bridges were constructed, smaller rivers were channelized in urbanized areas and some of the wetlands were drained.

1.3. Water Legislation

1.3.1 Western Dvina

According to (AQUASTAT, 2016) Eastern Europe water management is based on a water code or on a specific water law or act. Belarus introduced a Water Code in 1998 that was amended in 2010. In Estonia, the water policy is based on the national Water Act (1994) which specifies the main legal obligations and regulation areas for the water protection and use. In Latvia, the Law on Water Management, approved in 2002, is the main regulation in water management and protection. In Lithuania, the Law on Water, approved in 1997 with amendments in 2000, regulates the ownership of the internal water bodies, the management, use and protection of water resources and the rights and obligations of users of internal bodies of water and their resources.

There are several bilateral and multilateral agreements which regulate the water policy. Furthermore, several international environmental agreements have been signed, e.g.:

- The Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 17.03.1992, Helsinkihttp://www.unece.org/env/water
- The Protocol on Water and Health to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 17.06.1999, Londonhttp://www.unece.org/env/water/text/text_protocol.html
- The Convention on the Protection of the Marine Environment of the Baltic Sea Area, 17.01.2000, Helsinki, http://www.helcom.fi/

1.3.2 Desna

The basic document in the water sector of Ukraine is the Water Code (with amendments and additions adopted in 2017).

At the basin level, transboundary cooperation is carried out by the Dnipro Basin Authority on Water Resources, which subordinates to the State Water Agency of Ukraine. Within the framework of an Interstate Agreement (signed in 1992) a joint Working Group was established by the Parties. A number of working documents was elaborated, namely:

- Order of work aimed at water resources management in the Desna Basin;
- Order of joint actions in a case of emergency situations on water objects;
- Program of joint analytical control of the quality status of water resources at transboundary monitoring sites.

According to the Agreement, meetings of a joint Ukrainian-Russian Working Group were carried out as well as the meetings of the Deputy of Authorized and Authorized of the Cabinet of Ministers of Ukraine and the Government of the Russian Federation. The last meeting took place in 2012 in Rostov-on-Don city (Russian Federation). The agenda comprised the following topics: floods, water quality management on transboundary rivers and among others reducing the impact of human activities (http://voda.mnr.gov.ru). There is no available information about later meetings.

1.3.3 Western Bug

The Polish sector of the WBRB is subjected to EU environmental legislation and regulations. Ukraine has to approximate its environmental legislation to the one of the EU until 2025 (Association..., 2014). This provides for the establishment of the informational and organizational framework of the IWRM according to EU standards, but does not bind for the implementation of physical measures (e.g. upgrade of water purification facilities). In the Ukraine the legislation is the same as in the Ukrainian part of Desna River basin.

Table 4. Historical transformation of the Western Dvina River basin

Period	What countries the territory belonged to	Total population /population density in the area	Forest coverage (% from the total area)	Gauging network (number of hydrological gauges in the catchment)	References
XV century	Lithuania, Republic of Novgorod, Grand Duchy Moscow, Knights	in 1500: 167854	-	-	Perry-Castaneda Library Map Collection. Historical Maps of Europe
XVI century	Grand Duchy Lithuania, Livonia, Grand Duchy Moscow	in 1600: 202448	-	-	Perry-Castaneda Library Map Collection. Historical Maps of Europe
XVII century	Russia, Lithuania, Belarus, Lifland, Courland	in 1700: 241589	Temperate mixed forest 100% (in 1700)	-	Perry-Castaneda Library Map Collection. Historical Maps of Europe
XVIII century	Poland, Russia, Livonia, Courland	In 1800: 659632	In 1800: Temperate mixed forest - 97.9%, Pasture/land used for grazing - 2%	-	Goldewijk, K.K., F.G. Hall, G.J. Collatz, B.W. Meeson, S.O. Los, E.BrownDeColstoun, andD.R. Landis. 2007. ISLSCP II Historical Land Cover and Land Use, 1700-1990. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/967 https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=967
XIX century (1900)	Russian Empire	In 1900: 1721866	In 1900: Temperate mixed forest - 82.5%, Pasture/land used for grazing - 15.46%, Cultivated land - 2%	-	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=967
Early XX century (before I World War)	Russian Empire	In 1900: 1721866	In 1900: Temperate mixed forest - 82.5%, Pasture/land used for grazing - 15.46%, Cultivated land - 2%	6 (4 Bel, 2 Lv)	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=967
First half of the XX century (before 2 World War)	Latvia, Lithuania, Soviet Union	In 1940: 2102903	In 1950: Temperate mixed forest - 36%, Pasture/land used for grazing - 55.7%, Cultivated land - 8.2%	18 (5 Rus, 6 Bel, 7 Lv)	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=967

Chapter 2. Status-quo in water resources assessment: monitoring and data

2.1. Hydrological and meteorological network

In Russia, the Ministry of Natural Resources and Environment (MNRE) is responsible for public policy-making and regulation in the field of the study, use and conservation of natural resources, including the subsoil, water bodies, forests, fauna, hydrometeorology, wastewater, environmental monitoring and pollution control. MNRE coordinates and supervises the Federal Water Resources Agency, the Federal Supervisory Natural Resources Management Service, the Federal Service on Hydrometeorology and Environmental Monitoring and the Federal Subsoil Resources Management Agency. The Russian Water Association (RWA), established in 2009, supports the water industry players' joint efforts to improve the performance of the Russian water enterprises through reform and modernization, to liaise with the international water community, and to represent the country's water-related interests abroad. The Federal Supervisory Natural Resources Management Service is responsible of nature management. Amongst other functions it controls and supervises the use and protection of water bodies. The Federal Service on Hydrometeorology and Environmental Monitoring carries out the functions of state property management and provision of public services in the field of hydrometeorology and monitoring of environmental pollution. Hydrological long-term data is published regularly in water books (Long-term… 1985). Recent data can be partly obtained for free (https://gmvo.skniivh.ru, http://cliware.meteo.ru/goskom_cat/list/index.jsp). Open access runoff data for the largest stations in Europe is situated on Global Runoff Data Center website (http://www.bafg.de/GRDC/EN/Home/homepage_node.htm).

Gauging stations in Russia and former USSR are working according to Instructions… (1972, 1978) and Guidance document… (1989); in Belarus according to Rules… (2008).

In the Republic of Belarus, Ministry of Natural Resources and Environmental Protection of the Republic of Belarus (hereinafter referred to as Minprirody) is responsible for data collection. The following departments provide information:

- the Department for Geology (http://depgeo.org.by/index.php) and
- the Department for Hydrometeorology (http://depgeo.org.by/index.php)
- The territorial bodies of Minprirody are the Oblasts Committees of Natural Resources and Environmental Protection and Minsk City Committee of Natural

Resources and Environmental Protection and City and Raion Inspections of Natural Resources and Environmental Protection.

Gidromet (http://hmc.by/english/), the Center of Hydrometeorology, Radioactive Contamination Control and Environmental Monitoring of the Republic of Belarus is a non-profit organization established on 31st of December 2014. Ministry of natural resources and environmental protection of the Republic of Belarus acts as a founder and an agency of State administration. The activities of the Center are brought under regulation of the Statute dated 05.01.2015 and the law of the Republic of Belarus «About hydrometeorological works» dated 09.01.2006 No.93-3. Data were archived in the State Water Cadaster (2008, 2015) and the State Water Register (2015).

In Latvia, hydrological monitoring is operated by Latvian Environment, Geology and Meteorology Centre http://www.meteo.lv/, in Lithuania - Lithuanian Hydrometeorological Service under the Ministry of Environment. http://www.meteo.lt/lt/home

In Ukraine, hydrological and meteorological networks belong to the State Emergency Service of Ukraine. This Service is a central executive body which activity is coordinated by the Ministry of Interior of Ukraine.

In cases of emergency situations caused by floods and flash floods, hydrological measurements are also performed by regional organisations of the State Water Agency of Ukraine. This Agency is also a central executive body which activity is coordinated by the Ministry of Ecology and Natural Resources of Ukraine.

The gauging network varies significantly between the catchments and its national parts. In meteorology (Table 5) almost two-fold increase could be seen in terms of network density between Russia and Belarus and Poland and Latvia. To evaluate climate and hydrology at the borders of the catchment correctly it is advisable to include climate stations from the neighborhood. Therefore, station density in a 100 km buffer zone around catchment is mentioned as well.

Table 5. Meteorological monitoring in the transnational catchments

River	Western Dvina					Desna		Western Bug		
Countries	**Russia**	**Belar.**	**Latvia**	**Eston.**	**Lithua.**	**Russia**	**Ukra.**	**Ukra.**	**Belar.**	**Pol.**
Number of meteo stations in the catchment	6	8	16	0	1	9	21	19	2	10
Number of meteo stations in 100 km zone around catchment	22	12	15	3	6	16	12	15	3	19
The data when regular observations have been started	1881 (V. Luki)	1810 (Viteb.)	Beg. of XIX cent. (Riga)	-	-	1922	1922	1940		
Station density in the catchment (station/km^2)	$2,2*10^{-4}$	$2,4*10^{-4}$	$6,8*10^{-4}$	-	$5,4*10^{-4}$	$2,2*10^{-4}$	$5,4*10^{-4}$	$4,1*10^{-4}$	$2,3*10^{-4}$	$5,2*10^{-4}$
Station density in catchment plus 100 km buffer zone (station/km^2)	$2,1*10^{-4}$	$2,8*10^{-4}$	$14*10^{-4}$	$1*10^{-4}$	$2,6*10^{-4}$	-	-	$15*10^{-4}$	$5,7*10^{-4}$	$15*10^{-4}$

Hydrological monitoring programs differ significantly between the basins and countries (Table 6). There is only one automatic station that operates in Russian part of Western Dvina catchment, whereas most of the stations are equipped with automatic sensors in Latvia.

Data availability is since 1985 mostly subject to payment in Russia. In Belarus, unofficial data could be found at internet sources [http://www.twirpx.com/file/1857660/], whereas the averages and data of the last 30 days on water levels, temperatures and ice events are officially published http://www.pogoda.by/climat-directory/?page=231. In Latvia, historical data is mostly open source at the website of the Latvian Environment, Geology and Meteorology Centre http://www.meteo.lv/. Significant part of the datasets are available at Global Runoff Data Centre (Koblenz, Germany) for non-commercial use.

First hydrological observations started in most catchments at the times of Russian Empire – e.g. in Western Dvina catchment on the modern territory of Russian Federation (Velizh since 1878) and Republic of Belarus (Surazh since 1878). More than 75 % of the gauging network was operated since 1920-1966. The most recently established outlet station is Daugavriga (2009).

Discharge measurements at Russian gauging stations are done at large rivers during spring floods. Between four and five measurements are performed before peak flow and between 5-8 times after peak flow. Small rivers are monitored 1-2 times at flow rising limb and 2-3 times at the descending limp. During ice conditions, discharge measurements are done every 10-20 days, and during ice breakup – as often as possible.

Table 6. Hydrological monitoring in the transboundary catchments

River	Western Dvina				Desna		Western Bug		
Countries	**Russia**	**Belar.**	**Latvia**	**Lithua.**	**Russia**	**Ukra.**	**Ukra.**	**Belar.**	**Poland**
Number of gauges in the catchment on the rivers	10	19	23	0	13	10	15	3	14
Parameters measured at gauge	H, T, I, *3Q, 7S*	H, T, I, 10*Q, 2S*	H, T, I, 13*Q*	-		13	10		
Start of measurements	1878	1876	1906	-	1884	1887	1887		
Station density for discharge measurements (km^2/station)	3 $*10^{-4}$	3 $*10^{-4}$	$5*10^{-4}$	0	$3.15*10^{-4}$	$8.92*10^{-4}$	$1.52*10^{-4}$	$0.34*10^{-4}$	$0.73*10^{-4}$
Station density for water level measurements (km^2/station)	8 $*10^{-4}$	$4*10^{-4}$	$10*10^{-4}$	0	$2.42*10^{-4}$	$8.92*10^{-4}$	-	-	-

Q(10)-discharge is being measured on 10 stations, T-temperature, I-ice thickness, S-snow depth, C-chemical compound measurements

In Russia and Belarus, water quality monitoring programs are very similar. Surface water monitoring in the Western Dvina river basin is operated at 45 water bodies (10 water streams and 35 water reservoirs). Exist 79 gauging stations, among them 3 transboundary streams which cross the border between Russian Federation and Belarus (Western Dvina river and its influents – Kasplya and Usvyacha), and 1 transboundary river reach between Belarus and Latvia (Western Dvina river). Observations schedule on water streams depends on gauge station disposition (population and human activities on the surrounding territory) and varies from 4 (in different phases of water regime) to 12 (each month) or more times a year.

The list of hydro chemical measures is regulated by international standards. There are 34 obligatory parameters measured plus additional compounds: PAH, PCB, DDT, arsenic, hydrargyrum. The following criteria of chemical matters assessment are used: Water Pollution Index (WPI) and specific combinative Water Quality Index (WQI) (see Box 1).

Water Pollution Index (WPI):

$$WPI = \frac{1}{n}\sum_{1}^{n}\frac{C_i}{MAC_i},$$

C_i – concentration of i pollutant and

$MACi$ - maximum allowable concentration of i pollutant.

Specific combinative Water Quality Index (WQI) (calculated iteratively):

$$\beta_{mean} = \frac{\sum_{1}^{n_{ij}}\beta_{ij}}{n_{ij}},$$

β_{mean} – mean value of multiples of MAC exceeding,

n_{ij} – number of MAC exceeding,

β_{ij} – MAC of if-components.

$$S_{\beta_i} = \beta_i * 0.025 + 3,$$

$S_{\beta i}$ – local assessment factor of MAC exceeding multiples of i-component.

$$S_i = S_{\alpha_i} * S_{\beta_i},$$

S_i - generalized assessment score for few water bodies.

$$S_A = \sum S_i,$$

S_A - combinative water quality index.

$$WQI = \sum \frac{S_A}{n},$$

WQI - specific combinative water quality index for n - number of measured quality components.

Box 1: Details of the calculation of Water Pollution Index (WPI) and specific combinative Water Quality Index (WQI)

Hydrochemical monitoring program for Ukrainian surface water is also similar to what is presented for Russian Federation and Belarus. There are two main institutions responsible for measurements of physico-chemical and chemical parameters in surface water: the State Emergency Service of Ukraine (12 stations) and the Desna Basin Authority on Water Resources (5 stations). The list of parameters includes about 55 items, however it may vary from station to station of the State Emergency service of Ukraine and is a bit shorter for the stations belonging to the Desna Basin Authority on Water Resources (some organic pollutants are not measured). The assessment of water quality is provided based on maximum allowable concentrations (MAC).

The Instytut Meteorologii i Gospodarki Wodnej - Państwowy Instytut Badawczy (IMGW-PIB) is the Polish national hydro-meteorological service, which deals with the monitoring (http://monitor.pogodynka.pl).

2.2. Geodata availability

This chapter contains a comparative analyses of the geodata available for the case study areas with regards to specific local geodata. Global datasets are also mentioned in particular chapters.

2.2.1. Digital elevation Model (DEM)

One of the free of charge data that has appropriate horizontal and vertical resolution is SRTM HydroSHEDS (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales). It provides hydrographic information in a consistent and comprehensive format for regional and global-scale applications (SRTM v.4 Hydrosheds). HydroSHEDS offers a suite of geo-referenced data sets (vector and raster), including stream networks, watershed boundaries, drainage directions, and ancillary data layers such as flow accumulations, distances, and river topology information.

Within the Western Bug a DEM of Lviv produced from 1:10,000-1:25,000 topographic maps (personal archive) is available.

2.2.2. Weather grids (reanalysis)

There are several global datasets of reanalysis simulations available, which contain grids of numerous climatological elements. The most suitable datasets for the project are ERA-Interim and NCEP-CSFR.

ERA-Interim (Dee et al., 2011) is a global atmospheric reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) from 1979, continuously updated in real time. The data assimilation system used to produce ERA-Interim is based on a 2006 release of the IFS (Cy31r2). The system includes a 4-dimensional variational analysis (4D-Var) with a 12-hour analysis window. The spatial resolution of the data set is approximately 80 km (T255 spectral) on 60 vertical levels from the surface up to 0.1 hPa.

A second option is the NCEP-CSFR climate projection resource (Saha et al., 2014). The CFSR was executed as global, high resolution, coupled atmosphere-ocean-land surface-sea ice system. It includes coupling of atmosphere and ocean during the generation of the 6-hour guess field, an interactive sea-ice model and assimilation of satellite radiances by the Grid-point Statistical Interpolation scheme over the period 1979 to 2009.

2.2.3. Soil maps

The most well-known and widely used for hydrological purposes dataset is Harmonized World Soil Database (HWSD) (Nachtergaele et al., 2009). The HWSD is a 30 arc-second raster database with over 15.000 different soil mapping units that combines existing regional and national updates of soil information worldwide with the information contained within the 1:5.000.000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981).

Russian part of Western Dvina river basin is covered by Unified State Soil Registry (http://egrpr.esoil.ru/). It represents the soil map of the Russian Federation. The scale is 1:2.500.000. Attributes of the ESRI shape include soil type, physical and chemical conditions of different soil types and its layers.

Desna River catchment is covered by the electronic version of the soil map of Ukraine, presented in the "Atlas of soils of Ukrainian SSR" (1993). The soil map presented in Agroecological Atlas was vectorized for the Russian part of the basin.

For Western Bug basin, a soil map of Lviv Oblast 1:200.000 exists. Within the project IWAS, a new soil map for the upper Western Bug was created (Tavares et al., 2012). The older map from times of Soviet Union focused on soils of agricultural importance, whereas, forested, urban, industrial, and shallow soil territories were left underrepresented in the classification. With a combined application of fieldwork and modelling techniques (using digital terrain model, land use distribution, and expert knowledge) soil hydraulic properties were derived. Also a Soil and Natural Geo-Ecosystem Map of the Western Bug headwater in the scale 1:50.000 is available (Kruglov, 2015)

2.2.4. Land cover/land use

Available land use/land cover (LULC) sources which cover both Western Dvina, Western Bug and Desna rivers are:

Globcover Land Cover v2 data ("GlobCover Land Cover (v2.2)," n.d.) is a global land cover map at 10 arc second (300 meter) resolution. Its 22 global land cover classes are defined within the UN Land Cover Classification System (LCCS). GlobCover LC v2 was developed as part of the GlobCover project, a European Space Agency (ESA).

OpenStreetMap (OSM) is an editable map database built and maintained by volunteers and distributed under the Open Data Commons Open Database License("OpenStreetMap," n.d.). OSM data is used to add urban areas to LULC data.

CORINE Land Cover (CLC) is part of the EU-program Coordinate Information on the Environment (CORINE) and provides consistent and comparable data on land cover and land use on a scale of 1:100.000 based on remote sensing data (European Environment Agency, 2013). During the implementation period 1985-1990 an information system on the state of the European environment was established, nomenclatures and methodologies were developed and agreed at European level. 1990 is the reference-year for the first data acquisition (CLC1990). The CLC data inventory was first updated to the reference-year 2000 (CLC2000). A second update was finalized in 2010 to the reference-year 2006 (CLC2006). LULC dynamic for 1990-2006 years was assessed using CORINE.

Historical information of LULC, population, livestock and forest spatial distribution changes (and other historical geodata) is obtained from (Goldewijk et al., 2011;Stone and Schlesinger, 2004).

We have no information about specific datasets on Western Dvina.

For Desna River, a map of land use with 25 m resolution was developed based on the images of SRTM (STS-99, Shuttle Endeavour). Pixels of land use are precisely bound to the DEM grid of pixels.

For Western Bug exists a Landsat-based landcover change map (1988-2007) for the Lviv Oblast (Baumann et al., 2011). Furthermore, a Landsat-and Rapid Eye based landcover change (1989, 2000 and 2010) map for the Western Bug headwaters was created (Burmeister and Schanze, 2016). Each time step is represented by three inner annual satellite scenes gathered in the vegetation period. Classification of land cover is based on multi-sensoral remote sensing data using Landsat-5, which is pan-sharpened with SPOT-1/2/4/ 5-panchromatic channel for the year 1989 and 2010 and Landsat-7 (ETM) for the year 2000. The resolution is 15 by 15 m. As classification system, the CORINE Land Cover (CLC) system (European Environment Agency (EEA) 2006) is selected and adapted for the model region.

2.2.5. Drainage/irrigation maps

A drainage system map for the Lviv Oblast is available for the Western Bug in the scale 2:100.000 (result from IWAS project, Seegert et al. 2014).

2.2.6. Emission sources

Statistical reports on agriculture provide data on emission rates of fertilizers which are the main sources of nutrients. For the Russian part of basin this data is delivered by Federal Service of State Statistics http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/), which is provided by municipal areas since 2008. For Belorussian part, National Statistical Committee of Belarus Republic (http://www.belstat.gov.by/) is responsible for fertilization data. They are provided for the main provinces since 2005. Latvian fertilization data is provided for the whole country by Central Statistical Bureau (http://www.csb.gov.lv/en). Estonian and Lithuanian fertilization data is partly provided as tables, maps and graphs (http://ec.europa.eu/eurostat/).

Chapter 3. State of knowledge

Due to transboundary location, already a number of research projects dealt with various environmental tasks. Less attention has been paid to the upper parts of Western Dvina and Desna. The main concern in the projects was the impact on Baltic Sea or downstream areas (Table 7).

Table 7. List of water-related research projects in transboundary catchments

Name	Main objectives and further references
Western Dvina	
DATABASIN, Information management system and infrastructures for the transboundary Daugava/Western Dvina and Nemunas/Neman river basins (2006-2008)	-increase information access and exchange of data - propose an infrastructure and organization for transboundary information management and data exchange -Database of geographical information free access? -Interactive map service (Yemelin 2008)
WATERPRAXIS, From theory and plans to eco-efficient and sustainable practices to improve the status of the Baltic Sea (2004-2007)	-Assistance during implementation of river basin management plans into practice in the Baltic Sea region (Mednis et al. 2011)
ENPI-SEIS European neighborhood and partnership instrument, Towards environmental information system (2010-2020)	-collection, exchange and use of the data and information required for designing and implementing environmental policy (http://enpi-seis.pbe.eea.europa.eu/)
TACIS *1 -Management of Water resources in the Western Dvina river basins (-2002)	no information
TRABANT-Transnational River Basin Districts on the Eastern Side of the Baltic Sea Network (2005-2008)	-improve basis for the integration of significant ecological and management aspects in the Eastern Baltic Sea region, including links to spatial development.
Swedish EPA - Information management system and infrastructures for the transboundary Daugava/ Western Dvma and Nemunas/ Neman river basins (2007)	No information
Western Bug	
IWAS-Ukraine (2008-2013)	Multidisciplinary/interdisciplinary project studying soil-landcover-climate-hydrology/ hydromorphology/ hydrobiology interactions as well as socio-economic components to develop outlines for the IWRM. The project covered the Upper Western Bug Basin with an outlet at Dobrotvir reservoir (http://www.ufz.de/iwas-sachsen/index.php?en=18108)
IWAC-International Water Assessment Center (ongoing)	A Pan-European network of scientists and policy makers to support integrated water resources management: joint platform for scientists and policy makers to respond to new challenges in water policy and implementation at national, transboundary and international levels (http://www.iwacportal.org/?page=2)
TACIS *1 - development of transboundary co-operation on water quality monitoring and assessment in the Bug river between Belarus and Poland (-2002)	

*1 Technical Assistance to the Commonwealth of Independent States

To our knowledge, no international or national project was conducted in upper, Ukrainian part of the Desna basin. However, the project "Environmental Protection of International River Basins Project" can be mentioned (http://www.blacksea-riverbasins.net/en/project-synopsis). One of the outputs of this project was the elaboration of the management plan for the pilot river basin of Upper Dnipro. The studied area covered also the lower section of the Desna basin (see Figure 10).

Figure 10. Project «Environmental Protection of International River Basins» pilot area of Upper Dnipro (from http://www.blacksea-riverbasins.net/en/project-synopsis)

Some UN projects provide significant data for the transboundary rivers of the region. In 1999, UN Economic Commission for Europe, Committee on Environmental Policy delivered an Environmental Performance Reviews for Latvia and in 2005 for Belarus, which provided an overview over all aspect of water management. Furthermore, a report was produced from the Commission to the European parliament and the council on the Implementation of the Water Framework directive (2000/60/EC). Latvian river basin management plans included the classification of the ecological status, pressure impact analysis and setting of the ecological objectives for all water bodies. Both water quality parameters required by the WFD and available datasets have been collected. The project indicated the absence of specific pollutants, significant shortcomings in the monitoring network, and lack of data for the assessment of all water bodies.

There is a large list of publications on hydrological processes and water (Table 8). For the main parts of the catchment, abundant studies on statistical analysis of runoff observations, trends in runoff (1951-2009) and climate-related projections have been done. A number of regional studies were devoted to temperature and precipitation analyses (Avotniece et al., 2010; Loginov et al., 2003; Briede & Lizuma, 2007; Jaagus et al., 2010; Lizuma et al., 2010). These studies, anyway, have rather poor connections with management issues and transboundary water resources research. Roshydromet (2014) reports every year, e.g. "The Second assessment report of Roshydromet on climate change and their consequences on the territory of the Russian federation" provides an overview analyses on temperature, precipitation and discharges in rivers of Russia.

Transboundary issues are discussed in relation to water quality. Each of the catchment contains a number of publications dealing with transboundary fluxes of chemical components. Almost no studies have been devoted in the regional on eco-hydrology, hydro-morphology and sediment transport (Table 8).

Table 8. Review of the regional publications on hydrological topics relevant in the context of the ManTra-Rivers domain

River	Western Dvina	Desna	Western Bug
Water flow and climate change	Partasonek et al. 2014; Apsīte et al., 2009, 2013; Kļaviņš et al., 2008; Reihan et al. 2007; Wilson et al., 2010 Parfomuk, 2006; Volchek, Lusha, 2006; Volchek, Shelest, 2012. Loginov et al., 2015;Asadchaya, Kolmakova, 2014; Avotniece et al., 2010; Briede, Lizuma, 2007; Jaagus et al., 2010; Lizuma et al., 2010	Lepikh et asl.,2014; Gorbachova et al. 2011, 2013.	Fischer et al., 2014; Pavlik et al., 2014; Pluntke et al., 2014; Leidel et al., 2014 Tränckner et al., 2012
Water quality and river pollution	Vlasov, Grishenkova, 2011; Kolmakova, Maslova, 2008; Maslova, Kolmakova, Kozlov, 2009; Pakhomov, Kalinin, 2008; Savenok, Minaeva, Chepelov, 2012; Tilis Juhna and Miris KJavirs, 2001	Loboda et al., 2013; Luzovitsyka et al., 2011, 2014, 2017; Osadcha et al., 2014; Lozovitskyy, 2013; Myron, 2003. Prytula, 2010.	Ertel et al., 2011; Hagemann et al., 2014; F. Tavares Wahren et al., 2012
Terrestrial ecosystems and land use change		Tereschuk, Movenko, 2014; The Desna ecological corridor, 2010; Uvarova, 2012; Typology of the Desna elevations; Modern relief of the Desna basin; Lozovitsykyy, 2009	Baumann et al., 2011; Burmeister and Schanze, 2016; Schanze et al., 2011; Smaliychuk et al., 2016; Filipa Tavares Wahren et al., 2012; Kruhlov, 2015
Ecohydrology		Chornomoretsy, 2010	Ertel et al., 2011

Chapter 4. Hydrology and meteorology – long term and seasonal variability

In this chapter, an assessment of the climatological and hydrological state of the rivers and their basins has been performed for the case study transboundary rivers.

4.1. Precipitation and temperature

Environmental changes and human disturbances in the selected river basins have been associated also with hydro-climatic changes in East Europe.

We compared the periods 1961-90 and 1991-2016 (1961-90 used as reference period for climate change analysis); furthermore, the periods 1980-2000 with 2001-2016 and 1971-1992 with 1993-2016. The statistical values for the periods were calculated, independently of the count of years observed. A T-test was made to test, whether mean values of two periods differ significantly. Level of significance was set to 0.05, and the period length had to be at least eight years.

According to our data (Table 9 and Table 10), precipitation changes were mostly positive for the whole year and most pronounced in Western Dvina basin. Because of the high inter-annual variability of precipitation, the changes are often not significant. In addition, in some cases spatial variability is high: Trubachevsk and Brjansk are only 70 km apart but differ significantly from each other (Table 9).

Generally, variations in annual precipitation with a periodicity of 26–30 years were detected during 1922–2007 (Kriauciuniene et al., 2012) for the Baltic countries (including Latvia and Lithuania). The periodicity varied by season: spring (24–32 years), summer (21–33 years), autumn (26–29 years) but with no periodicity evident in winter. This increase originates from positive changes in spring, fall and winter. In summer, slight decreases in precipitation prevail.

Table 9. Observed precipitation changes for three comparison periods; significant changes (p=0.05) are marked in grey (t-test)

Basin	Station-Name	1980-2000	2001-2016	1980-00 vs 2001-16	1980-00 vs 2001-16	1980-00 vs 2001-16	1980-00 vs 2001-16	1980-00 vs 2001-16
		[mm/year]	[mm/year]	year	spring	summer	fall	winter
Desna	KURSK	658	614	-6.6%	-3.1%	-19.9%	-3.6%	6.5%
Desna	TRUBCEVSK	647	573	-11.4%	-9.9%	-23.8%	-3.1%	0.5%
Desna	BRJANSK	680	698	2.7%	-1.9%	0.1%	0.4%	20.0%
W. Bug	Siedlice	531	576	8.6%	13.1%	4.9%	-7.2%	38.4%
W. Bug	BREST	586	613	4.6%	12.4%	1.3%	-3.2%	13.4%
Z. Dvina	POLOCK	736	727	-1.3%	12.2%	-4.0%	2.3%	-4.3%
Z. Dvina	VITEBSK	711	772	8.5%	31.4%	1.5%	7.4%	12.7%
Z. Dvina	RIGA; UNIV.	661				-8.0%		
Z. Dvina	SMOLENSK	747	715	-4.3%	11.2%	-12.0%	-9.6%	3.1%
Basin	Station-Name	1961-1990	1991-2016	1961-90 vs 1991-16	1961-90 vs 1991-16	1961-90 vs 1991-16	1961-90 vs 1991-16	1961-90 vs 1991-16
		[mm/year]	[mm/year]	year	spring	summer	fall	winter
Desna	KURSK	607	626	3.2%	6.5%	-8.2%	18.4%	-3.7%
Desna	TRUBCEVSK	642	602	-6.2%	-0.3%	-13.7%	6.6%	-12.3%
Desna	BRJANSK	635	695	9.4%	9.0%	0.4%	16.2%	22.8%
W. Bug	Siedlice	540	565	4.8%	15.4%	4.6%	-6.9%	6.4%
W. Bug	BREST	601	604	0.5%	12.6%	-5.1%	1.1%	-5.4%
Z. Dvina	POLOCK	688	718	4.4%	21.1%	-5.2%	3.6%	14.7%
Z. Dvina	VITEBSK	667	747	11.9%	15.9%	3.5%	11.8%	29.6%
Z. Dvina	RIGA; UNIV.	629	715	13.7%	49.4%	-2.6%	35.9%	11.4%
Z. Dvina	SMOLENSK	693	730	5.3%	15.1%	-1.2%	6.5%	2.0%
Basin	Station-Name	1971-1992	1993-2016	1971-92 vs 1993-16	1971-92 vs 1993-16	1971-92 vs 1993-16	1971-92 vs 1993-16	1971-92 vs 1993-16
		[mm/year]	[mm/year]	year	spring	summer	fall	winter
Desna	KURSK	638	624	-2.3%	6.6%	-14.8%	-0.5%	2.9%
Desna	TRUBCEVSK	653	603	-7.6%	5.8%	-17.7%	-2.6%	-7.5%
Desna	BRJANSK	641	706	10.1%	14.7%	0.8%	8.3%	25.1%
W. Bug	Siedlice	528	571	8.1%	26.0%	1.9%	-7.6%	22.5%
W. Bug	BREST	593	613	3.3%	21.3%	-4.4%	-3.5%	3.0%
Z. Dvina	POLOCK	710	723	1.7%	20.4%	-4.5%	3.0%	4.7%
Z. Dvina	VITEBSK	671	755	12.5%	23.8%	9.0%	7.0%	19.3%
Z. Dvina	RIGA; UNIV.	653			64.1%	-6.0%		
Z. Dvina	SMOLENSK	704	733	4.1%	16.4%	0.3%	-1.0%	2.2%

Temperature increased significantly during all seasons at the stations of the Desna basin and at Smolensk (which is located at Dnipro River) (Table 10 and Figure 11). Changes in temperature extremes were also observed in Latvia using daily data from two stations for the period 1924–2008 and three stations for the period 1946–2008 (Avotniece et al., 2010). The Mann–Kendall test indicates statistically significant positive trends in the number of tropical nights (Tmin ≥ 20 °C) and of summer days (Tmax ≥ 25 °C) and negative trends in the number of frost days (Tmin ≤ 0 °C) and of ice days (Tmax ≤ 0 °C) (table 10). The most significant warming trends in the region is observed since 1987-1989 (Avotniece et al., 2010; Klavinš et al. 2007; Loginov et al., 2003; Podgornaya et al. 2015). According to the observation in Riga, annual temperatures increased up to 1,4°C since 1850 (Rutgersson et al., 2015). In Belarus the increase of temperature up to 1,2°C during 1989-2014 in comparison with 1961-1990 have been indicated by (Podgornaya et al., 2015) (fig. 4.1).

Table 10. Observed temperature changes for three comparison periods; significant changes (p=0.05) are marked in grey

Basin	Name	1980-2000 [°C]	2001-2016 [°C]	1980-00 vs 2001-16 [°C] – year	1980-00 vs 2001-16 [°C] - spring	1980-00 vs 2001-16 [°C] - summer	1980-00 vs 2001-16 [°C] – fall	1980-00 vs 2001-16 [°C] - winter
Desna	KURSK	6	7.4	1.4	1.4	1.7	1.8	0.7
Desna	TRUBCEVSK	6	7.1	1.1	1	1.3	1.4	0.7
Desna	BRJANSK	5.8	6.8	1	0.9	1.4	1.6	0.3
W.Bug	Siedlice	7.5						1.9
W.Dvina	RIGA; UNIV.	6.8			-0.3	2.1		2.6
W.Dvina	SMOLENSK	5.1	6	0.9	0.9	0.9	1.3	0.5
Desna	KURSK	5.7	7	1.3	1.2	1.4	0.8	1.8
Desna	TRUBCEVSK	5.6	6.7	1.1	1	1	0.5	2.1
Desna	BRJANSK	5.3	6.5	1.2	0.7	1.3	0.5	1.8
W.Bug	Siedlice	7.4	7.6	0.2	0.1	0.5	-0.6	0.9
W.Dvina	RIGA; UNIV.	6.3	7.2	1	0.1	1.2	-0.2	2.8
W.Dvina	SMOLENSK	4.6	5.7	1.2	1.2	1	0.6	2.1
Desna	KURSK	5.8	7	1.2	1.1	1.4	1.1	1.3
Desna	TRUBCEVSK	5.9	6.7	0.9	0.8	1	0.7	1.4
Desna	BRJANSK	5.6	6.5	0.9	0.4	1.3	0.5	1.1
W.Bug	Siedlice	7.4	7.5	0.1	0.2	0.3	-0.6	0.4
W.Dvina	RIGA; UNIV.	6.6	7	0.4	-0.2	1.2	-0.7	1.1
W.Dvina	SMOLENSK	4.9	5.8	0.9	0.9	0.9	0.7	1.2

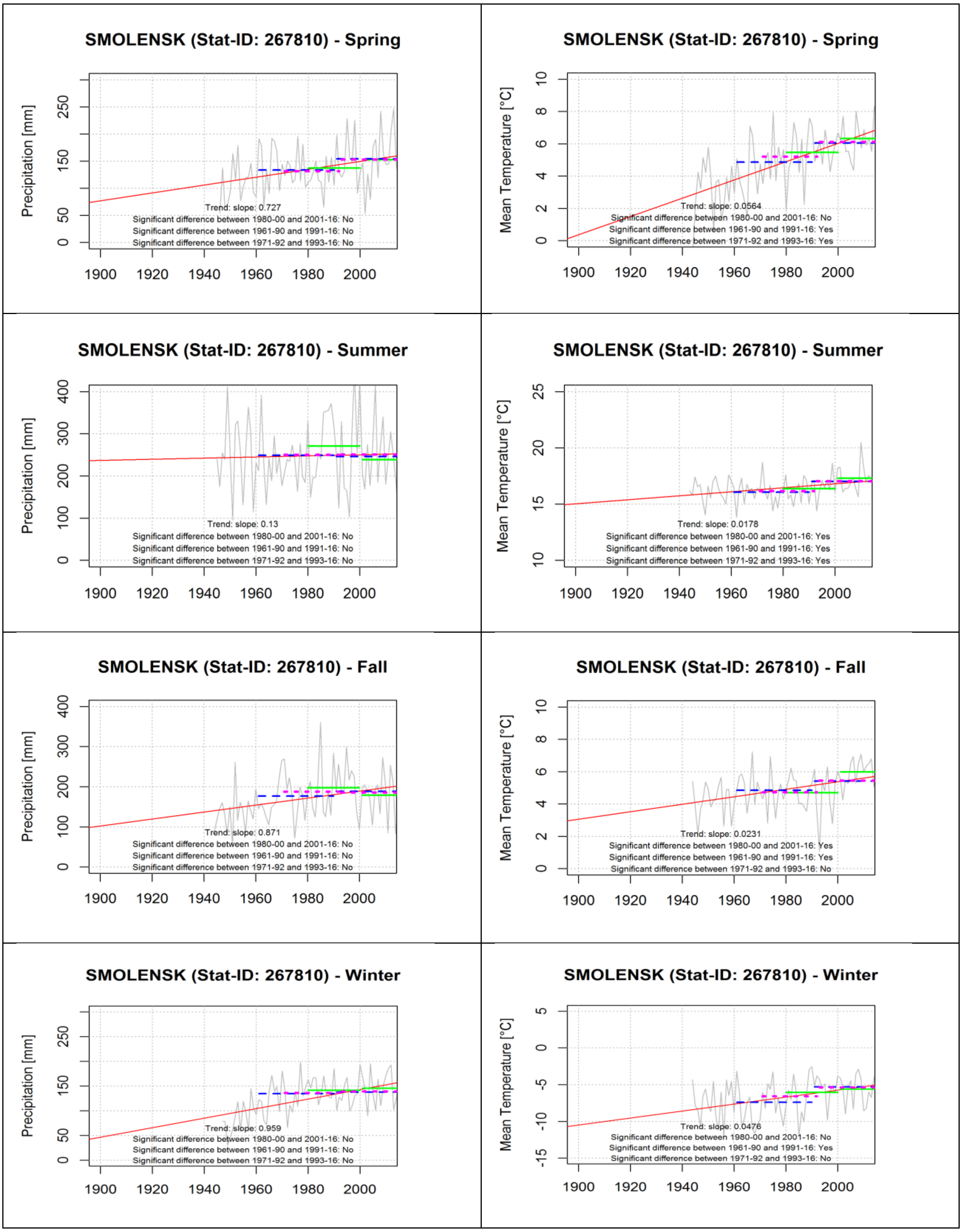


Figure 11. Observed trends in precipitation and temperature at Smolensk located in between of the studied catchments

4,324.2. Hydrological changes

In many rivers, precipitation pattern changes and hydropower dam constructions become the main drivers of hydrological change in the case study rivers (Table 11). Due to discrepancies in the mentioned processes, there are significant variations between different rivers, which are reviewed in the following texts. In the catchment, both negative (Western Dvina and Desna) and positive trends have been observed in the annual runoff between 1980-2000 and 2001-2016 periods (Table 11).

Table 11. Observed changes in water flow Q over representative stations of the case study catchments

River	Representative gauging station (in various national sectors of the rivers)	Period	Average Q, km^3/year	Observed change in Q (%)
Western Dvina	Velizh (1945-2014)	1976-1991	5.68	-18
		1992-2014	4.66	
	Daugavpils (1936-2015)	1976-1991	14.94	-3
		1992-2015	14.51	
Desna	Litki (88500 $km^{2)}$	1980-1999	12.1	-12
		2000-2014	10.6	
Western Bug	Lytovezh (6 740 $km^{2)}$	1980-1999	1.03	+12
		2000-2014	1.15	
	Wyszkow (39 119 $km^{2)}$	1983-2000	4.28	+18
		2001-2014	5.07	

Analyses of annual flow of Western Dvina river datasets indicate no trend in annual discharges (Parfomuk, 2006; Reihan et al., 2007; Käyhkö et al., 2015; Kļaviņš et al. 2009), which is in line to the results of our analyses (Figure 12). According to collected data in ManTra project, relative annual discharges Ki (ratio of annual discharge and long-term annual discharge), are synchronized until 2014. During the second half of XX century the declining trend have been observed (Figure 10).

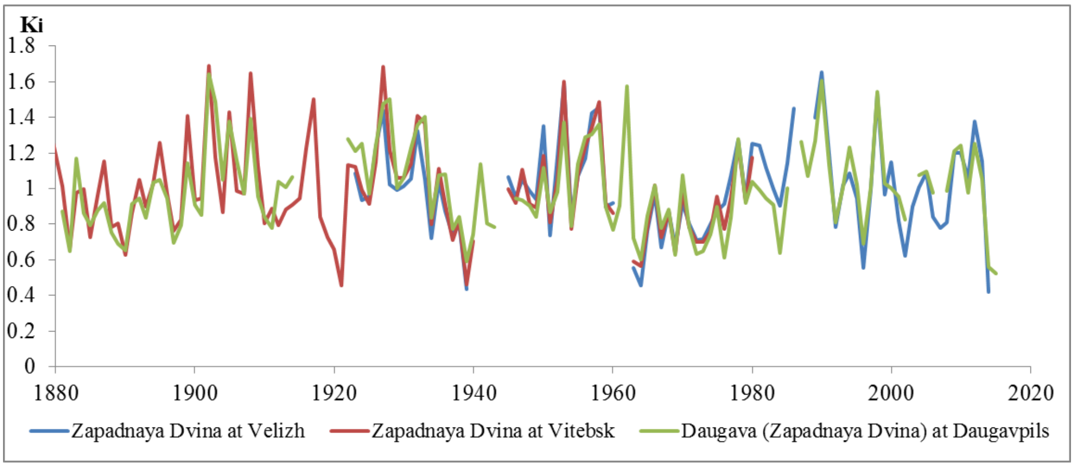


Figure 12. Long-term changes of relative annual discharges (Ki) of Western Dvina

The revealed water runoff fluctuations (Kļaviņš and Rodinov, 2008) are related to dry and wet periods between 1881 and 2004 with a duration from 6 to 27 years (Daugavpils, Latvia). Statistical analyses identified short-term (2-5 year) and long-term (10-15 years) fluctuations in Vitebsk, which are also connected with fluctuations in precipitation, mostly in 4 and 11 years cycles (Volchek, Lusha, 2006). Decline in maximal discharge have been reported for different parts of the catchment (Volchek, 2008) in the period 1966-2000 compared to 1877-1965, and between 1986-2000 and 1877-1985 for Vitebsk (Belarus) and Velizh (Russia). Most of the Western Dvina tributaries in Latvia as well as Western Dvina (Daugavpils) is characterized by negative maximal water discharge trends from 1951 to 2009 (Apsīte et al. 2013; Reihan et al., 2007). During the last 3 decades maximal discharges were higher than long-term averages in 1994, 1999, 2004, 2010 and 2013 (Figure 13).

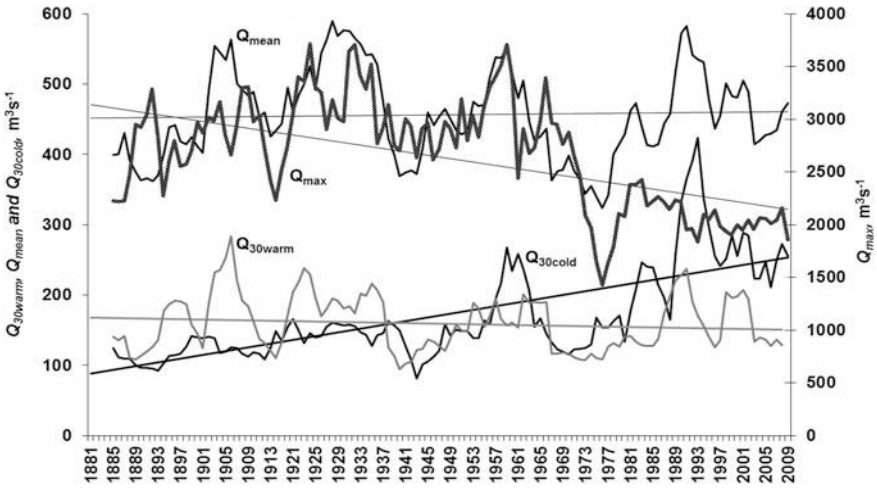
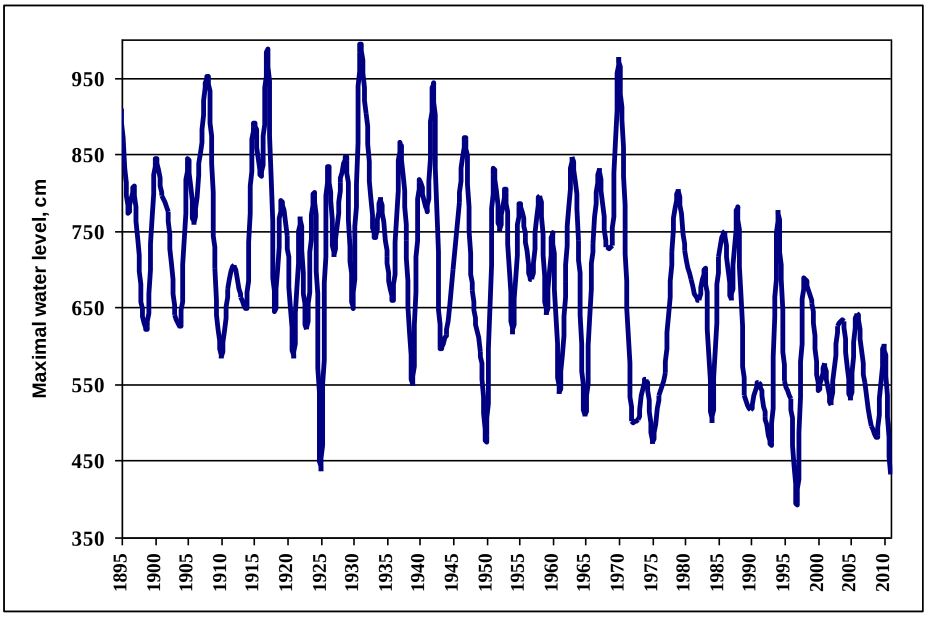


Figure 13. Trends in annual mean discharge (Qmean), maximum of the year discharge (Qmax), 30-day minimum discharge in low flow of cold (Q30 cold) and warm (Q30warm) periods at the hydrological station Daugava–Daugavpils for the period 1881–2009. Discharge curves are smoothed with a 5-year moving average (Apsīte et al. 2013)

Hydrological regime of the Desna River is monitored on 13 gauging stations. Data for the period of 1895-2012 show some changes in water level and water discharge (Figure 14). It is quite clearly seen that maximal water level and maximal water discharge values of the Desna River are characterized with steep decrease (Tereschuk and Movenko, 2014).



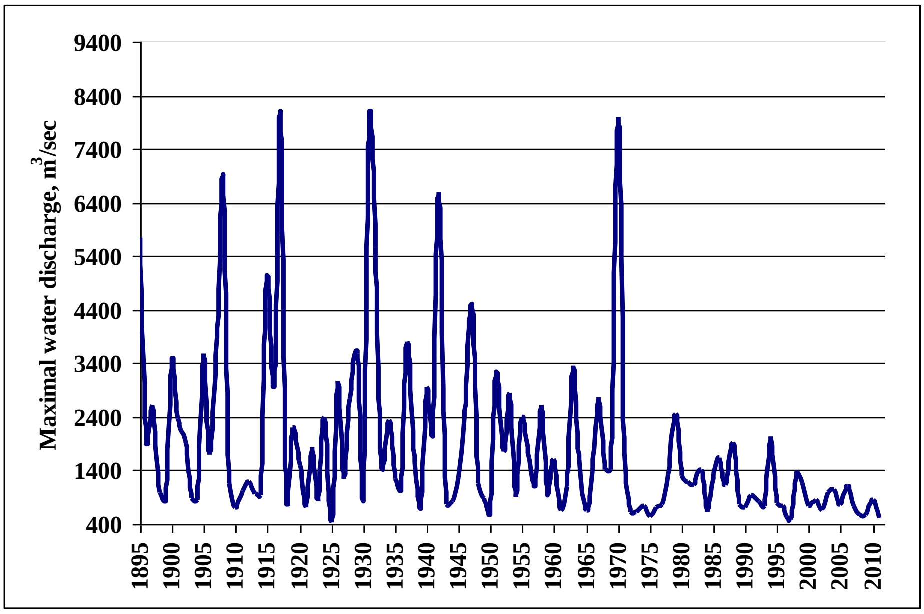


Figure 14. Water level and discharge dynamics of the Desna River (maximal values).

For the river Western Bug, an analysis of the gauging station Wyszkow for the period 1983-2014 is exemplarily shown in Figure 15. This gauge is situated only some kilometer upstream of the confluence with Narew river and represents nearly the whole basin. A significant increasing trend of the discharge is observed. Other gauging stations like Wlodawa (PL) or Lytovezh (UA) are in agreement with this trend. Some large flooding events in the years after 2009 are responsible for this trend.

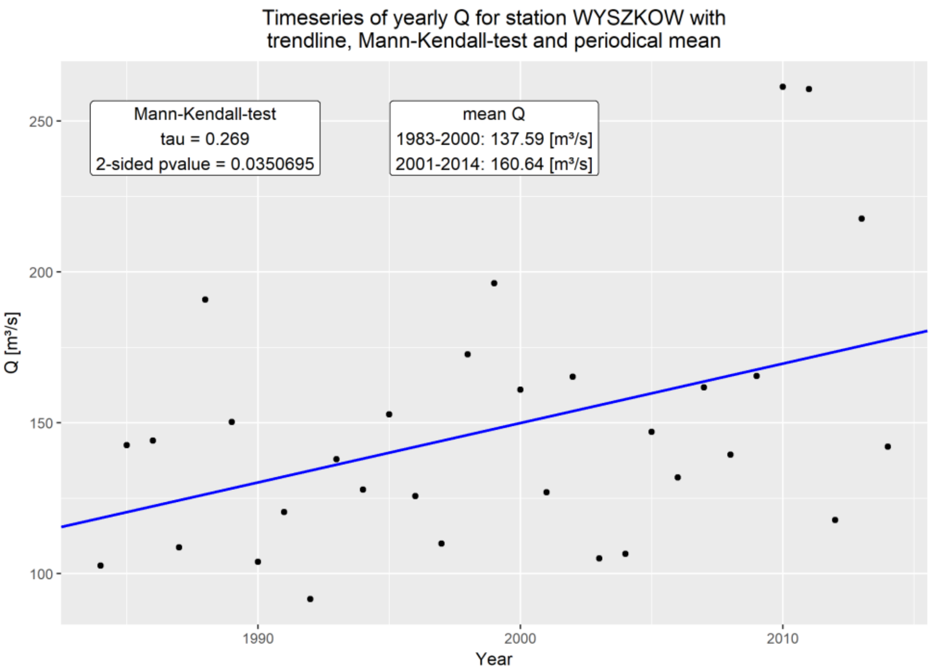


Figure 15. Yearly mean water runoff (m³/s) of Western Bug River at Wyszkow gauge

There are very few datasets on sediment transport (Table 12) with only few gauging stations, which operate sediment concentration and suspended load measurements. In Western Dvina basin, the recent decline of water flow causes a significant decrease (up to 50 %) of annual sediment yield on most of the rivers (Table 12). This could be also due to abandonment of cultivated lands and negative population trends. In Western Bug river catchment, transport of suspended sediment is relatively small in general, because washout of eroded material is regulated by reservoirs and ponds and the erosive potential is low in lower parts of the river (Kovalchuk, unpublished). Only in the headwaters, higher concentrations of suspended sediment occur. Highest concentrations occur in spring and occasionally during summer high water periods (Kamyanka-Buz'ka 40-50 g/m^3). In summer and fall, concentrations are low (5-20 g/m^3).

Table 12. Observed changes in suspended sediment transport (annual sediment yield, R) over representative stations of the case study catchments

River	Representative gauging station (in various national sectors of the rivers)	Period	Parameter		
			Average R, t/year	Specific sediment yield, W_R t/year/km^2	Observed change in R (%) *
Desna	Desna-Chernigiv F=81400 km^2	1980-1999	380741	4.68	-42.4
		2000-2014	219430	2.70	
Bug	Bug-Kamianka-Buzka F=2350 km^2	1980-1999	25326	10.8	-50.7
		2000-2014	12476	5.31	

Chapter 5. Water quality and pollution

This chapter concludes the current state of information on water quality in the three river basins. The comparative approach will focus primarily on physico-chemical parameters (total suspended solids concentration (TSS), electric conductivity (EC), pH value, oxygen concentration (O2)), organic constituents (chemical oxygen demand (COD), bio-chemical oxygen demand (BOD), organic carbons (OC)) and nutrients (nitrate (NO3), nitrite (NO2), ammonia (NH4), total nitrogen (TN), orthophosphate (oPO4), total phosphorous (TP)). Specific locally prevalent pollutants may be additionally discussed for each river distinctively.

As described above, catchment characteristics and water management status vary significantly between national sectors of the three transboundary rivers. Therefore, constituent concentrations and pollution prevalence show distinctive patterns along each of the water courses as well as comparatively between the river basins. Annual average content of organic matter (BOD5) in water of rivers, usually does not exceed the maximum permitted concentration MPC, with the exception of the Western Bug. With the annual average water content of ammonia nitrogen more MPC exceedances occur, for some sections of the river the Western Dvina and its tributaries average annual concentrations of nitrates in the water of the rivers also do not exceed the MPC. However, in some of rivers marked the annual average phosphorus content of phosphate, which is greater than MPC.

5.1 Western Dvina

Surface waters of the Western Dvina are characterized by total dissolved concentrations, which have historically ranged from about 110-280 mg/L and total suspended solids (TSS), which have ranged from about (< 100 mg/l) during high water period to (<500 mg/l) during dry season. The primary chemical composition of Western Dvina river and most of its tributaries follows the pattern of Ca2+ > (Na+ + K+) > Mg and HCO3- >> SO42- > Cl-.

Past monitoring efforts on the main stem of the Western Dvina reported that the water was relatively soft (hardness is less then mg-eq/L with a pH between 6.5 and 7.5. Waters are enriched by ammonium ion (NH^{4+}) and nitrate (NO^{3-}) which are more than 2 mg/L, and total phosphorous is more than 50-100 mg/L.

The waters within Russian territory are mostly influenced by natural processes, mostly due to drainage from wetlands, which lead to high concentrations of biogens and organic matter. The annual average water content of ammonia nitrogen and other biogens could be more than MPC noted. Elevated concentrations of the petrochemicals were measured at a local spot (Figure 16).

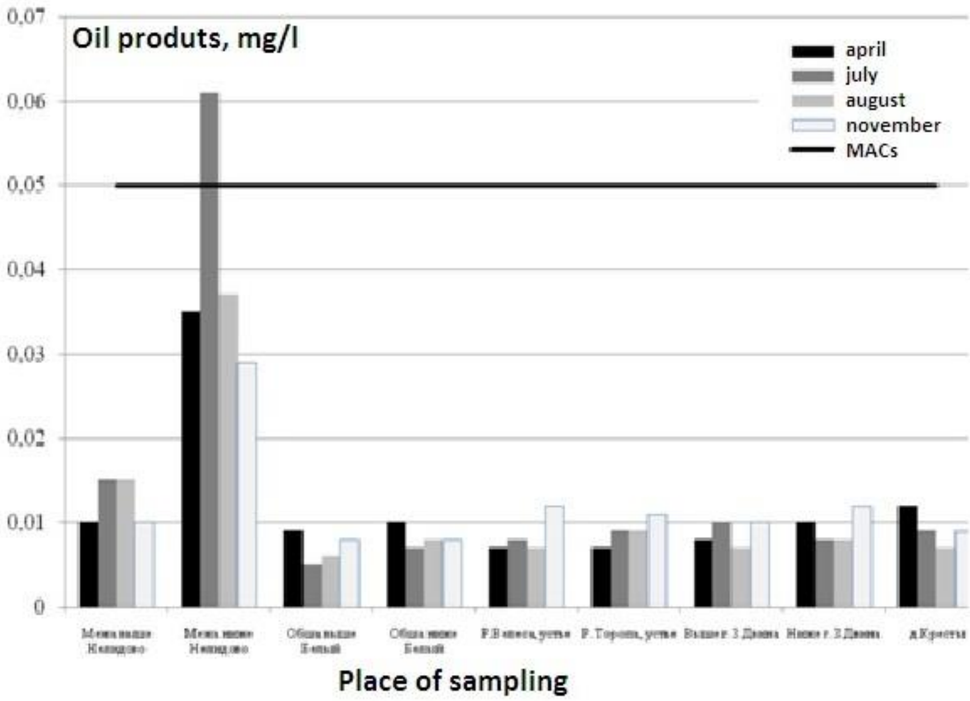


Figure 16. Spatial variability of petrochemicals in sampling points of Western Dvina River within Russia (data from Yushenko et al., 2015) (horizontal line indicates MPC level)

Large cities are located within Belorussia (Vitebsk, Polotsk) which lead to increases of chlorides, ammonia nitrogen, phosphorus etc., mostly from drainage municipal waters (over 30 % of the total fluxes in the catchment). The main sources are oil and energy industry facilities (Yushenko et al., 2015). Most of the chemical components are characterized by high rates of transboundary fluxes from Belorussia to Latvia (Kolmakova, Maslova, 2008). In Latvia due to recent changes in agricultural sector and municipal treatment plants water quality has been improved (Rusaya et. al.)

The catchment of Western Dvina is relatively low disturbed by human activities in the upper (Russian) part and heavily modified in the downstream part. Among the main efforts needed for implementation water resources management, regional studies (e.g. Project DATABASIN) identified the following national priorities for the water management and water use:

- Industrial and agricultural water use as well as water distribution, water supply to urban and rural population,
- Insurance of recreational facilities, hydropower, fishing
- Rational use of natural resources
- Reducing of number of sources of water pollution
- Preservation and protection of water ecosystems

- Development of early warning and notification systems in case of emergency situations
- Monitoring and evaluation of water quality (development of a common program for transboundary monitoring of water resources at the river basins for evaluation of the transboundary movement of pollutants, international research…)
- Exchange of transboundary information

For Latvia and Lithuania, the main priority for water quality improvement is related to implementation of WFD.

5.2 Western Bug

Previous studies (TACIS, 2001; HELCOM, 2005; UNECE, 2007) come to contradictive conclusions about the contribution of different emission sources to the pollution of Western Bug River. At an early stage of the research conducted within the project IWAS, Lviv urban system was identified as main cause of the desolate ecological condition of rivers Poltva and Upper Western Bug (Ertel et al. 2013). Western Bug is a pollution hotspot within the Vistula basin (Kowalkowski, 2009) with agriculture and point sources as main emitters of nutrients. In this river the most significant problems of water quality are the following (Ertel et al., 2011; Hagemann et al., 2014; Tavares et al., 2012):

- high concentrations of nutrients → eutrophication
- high concentrations of organic pollution,
- poor sanitary state of the waters,
- increasing groundwater pollution,
- regulation of the tributaries, damming and draining,
- toxic pollution (especially heavy metals),
- high variability of the flows, at low levels causing deterioration of water quality and at high levels increasing erosive processes and flood hazards.

High concentration of pollutants are caused by inadequate methods of sewage collection and treatment in cities and towns. Reasons are:

- lack of processes for removing nutrients,
- lack of facilities for rainwater purification in urban areas,
- lack of sewage collection systems and sewage treatment plants in rural areas,

- poor operational state of wastewater treatment plants,
- excessive use of fertilizers in agriculture causing diffuse pollution,
- droughts and floods, which might destroy the biocenosis and cause excessive pollution of the waters etc.

Accidental pollution might occur, caused by accidental spills of oil, emergency discharges of industrial and municipal sewage, and accidents during the transport of hazardous substances, inflow of pollutants from uncontrolled municipal and industrial solid waste disposal sites as well as storage sites for toxic substances.

5.3 Desna

Mean mineralization of the Desna water at closing cross-section is 384 mg/l with a variability of 229-582 mg/l. Waters are characterized by hydrocarbonate-calcium which is due to the distribution of carbonate rocks on the watershed. Anions ratio varies on the following order: HCO3->SO42->Cl-; the general order of cations varies as: Ca2+>Na+>Mg2+>K+. Mean water hardness is 4,4 mmol/l.

Water of the Desnas largest tributary river Oster is much more mineralized with a mean value of 570 mg/l varying in the range of 449-778 mg/l. This could be explained by relatively close deposition of the cretaceous rocks to the surface within the river Oster catchment and even by appearing of them on the ground. The hardness of Oster water is 6,5 mmol/l, and during the low water period it reaches 9,4 mmol/l.

Long-term decrease of SO_4^{2-} and Cl^- concentrations in water can be partly explained by decreasing atmospheric emission of SO_2, which is observed since the beginning of 1990s (Figure 17). Intra-annual variability of main ion concentrations is due to the characteristics of the river water generation. Minimal concentrations are observed during the spring flood period when the value of water discharge is more than 50% of the total annual.

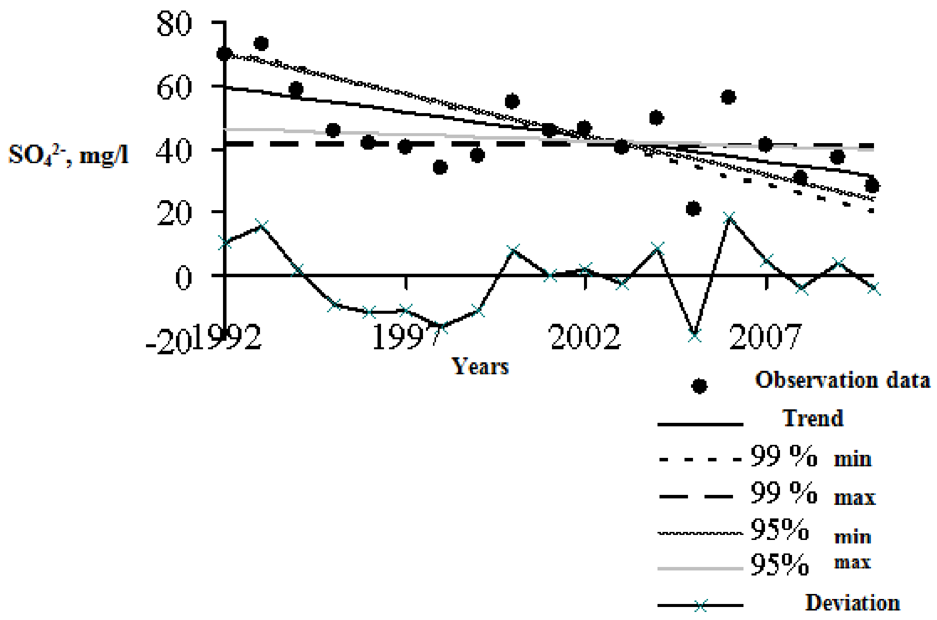


Figure 17. Trends of sulphate ions in the water of Desna River

Water of the Desna is characterized by high amounts of nutrients which cause water eutrophication. Critical concentrations of nitrogen and phosphorous for the beginning of eutrophication are supposed to be around 0.1 mg N/l and 0.02 mg P/l. Mean concentration of non-organic compounds of nitrogen in the Desna reaches 0.68 mg N/l. The ammonia form is dominant and serves as a marker for the influence of point sources. Mean concentration of ammonia form exceeds the value of the maximum permissible concentration (MPC) – 0.39 mg N/l. High concentrations of the mineral forms of phosphorous are delivered primarily by sewage waters (0.38-0.60 mg P/l). In general, nutrient contents in the river water gradually increased during the last 20 years. All trends were significantly positive (Mann-Kendall test).

An assessment of the spatial distribution of nutrient pollution of the Desna water was performed applying the method of discharge balance between upper and lower cross-sections for each specific compound. Results show that the processes of self-purification are dominant in the upper part of the river. Quite intensive pollution of nutrients (primarily ammonia nitrogen and phosphorous) is characteristic for the middle section of the Desna at the monitoring site of Chernihiv. Pollution of nitrate forms significantly increase in the lower section of the river due to the influence of diffuse sources.

Content of organic compounds in the lower section of the Desna is minor, which reflects the optimum conditions in forming of ecological state of the water. There is rather small percentage of bogs in the basin (about 5 %) that generally induces increased concentrations of the organic substances of humus origin. However, in a case of high water of the tributaries, which have a high percentage of bog soils, the water color increases. This is associated with increasing contents of organic compounds, iron, and nutrients. In such cases oxygen is consumed for the oxidation of organic compounds which leads to the hypoxia. Last case of hypoxia has been identified in 2016 in the basin of Oster.

An important impact on the water quality is river regulation. There are a number of reservoirs constructed at the river: cooling pond of Smolenskaya Nuclear Power Plant; offstream water storage for the Kurskaya Nuclear Power Plant (both at the territory of Russian Federation). Dozens of reservoirs are located on the Ukrainian part of the Desna. Small Sednivsyka Water Power Plant is functioning on the river Snov, the right tributary of the Desna.

Chapter 6. Identification of research needs and collaboration efforts

The main part of the report is devoted to a comparative analyses of the natural and anthropogenic conditions and the monitoring within the three chosen catchments. It revealed a variety of natural features and anthropogenic impacts which are historically formed over selected areas. Due to national socio-economic peculiarities, the national parts of the catchments differ remarkably in population density, land use, economic situation and its current trends. This led to diverse trends of the water pollution and the transboundary fluxes. Furthermore, the importance of water management issues, the willingness to cooperate in the riparian countries differs a lot. Main research needs are listed in the following:

Monitoring concepts and deficits:

- Set-up of a metadatabase to allow a deficit analysis
- Methods of water quality assessment differ in each country → develop and agree a common assessment method and a common transboundary monitoring program (stations, parameters, frequency, instruments, methods)
- Lack of associated hydrometrical measurements during hydrochemical sampling
- Deficits in the monitoring of biological and hydro-morphological components, and of toxic substances as well as the toxicity and composition of discharged waste waters

Improvement of monitoring

- upgrade and adjustment of analytical laboratories
- capacity development for personnel
- Pilot study in Vilesa River basin (left tributary of Western Dvina, Figure 18) since May 2017. A water quality monitoring station is operating, which provides high-resolution data on sediment transport. Furthermore, monitoring is devoted to understand 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.

Figure 18: Velesa river – tributary of Western Dvina river (Russian Federation), pilot study

Data handling and analysis

- Improvement of data exchange between different countries and between different national authorities
- Preparation of data needed for modelling, e.g. harmonization of data, reduction of data gaps
- Hydro-climatic development of the last decades

Modelling

- Setup of a model chain (meteorology, land use, hydrology, matter transport, erosion, hydrobiology) that simulates water and matter flows in the basin in dependency on changes in natural and anthropogenic conditions, management options etc.
    - Future projections of climate and land use

Water governance structures

- Comparison of regional approaches to improve water quality (e.g. with the Water Framework Directive)
- Comparison of water governance structures

Capacity development measures

  - Capacity development as an integral and inherent part of IWRM
  - Capacity assessment needed to plan measures
  - Capacity development at all levels (individual, organizational,)

Chapter 6. References

Apsīte, E., Bakute, A., Rudlapa, I. (2009), Changes of total annual runoff distribution, high and low discharges in Latvian rivers. P Latvian Acad Sci B 63: 279-286.

Apsīte, E., Rudlapa, I., Pallo, I., Elferts, D. (2013), Changes in Latvian discharge regime at the turn of century. Hydrol Res 44:554-569.

Asadchaya, M., Kolmakova, Y. (2014), Tendencies of changes of Belarusian rivers water flow in years of minimum and maximum water availability in climate warming conditions // Bulletin of the Belarusian State University. Ser. 2. No. 1. P. 84-88.

Association agreement between the European Union and its Member States, of the one part, and Ukraine, of the other part (2014).

Agroecological atlas of Russia and neighboring countries: economically significant plants, their pests, diseases and weeds (2008).

Automated information system of state monitoring of water bodies of the Federal Agency for Water Resources (2012). URL: https://gmvo.skniivh.ru/

Automated system of accounting for Roshydromet's monitoring units (2012). URL: http://cliware.meteo.ru/goskom_cat/list/index.jsp.

AQUASTAT website (2016). Food and Agriculture Organization of the United Nations (FAO), http://www.fao.org/nr/water/aquastat/main/index.stm (Accessed 28 June 2017)

Avotniece, Z., Rodinov, V., Lizuma, L., Briede, A., Kļaviņš, M. (2010), Trends in the frequency of extreme climate events in Latvia // BALTICA Volume 23 Number 2 December. P. 135-148

Briede, A., Lizuma, L. (2007), Long-term variability of precipitation in the territory of Latvia. In: Kļaviņš M. (ed.). Climate change in Latvia. University of Latvia, Rīga. P. 35–45.

Baltic Sea Region Program BSR Interreg III B. Access Mode: https://www.interreg-baltic.eu/home.html (Accessed 20 Apr. 2017)

Baumann, M., Kuemmerle, T., Elbakidze, M., Ozdogan, M., Radeloff, V.C., Keuler, N.S., Prishchepov, A.V., Kruhlov, I., Hostert, P. (2011), Patterns and drivers of post-socialist farmland abandonment in Western Ukraine. // Land Use Policy 28. P. 552–562. doi:10.1016/j.landusepol.2010.11.003

Burmeister, C., Schanze, J. (2016), Retrospective analysis of systematic land-cover change in the Upper Western Bug River Catchment, Ukraine. ACC Journal 22, 7–18. doi:10.15240/tul/004/2016-1-001

Chornomoretsy Yu.A., Grebiny V.V. (2010), Inter annual dynamics of the Desna feeding regime. Hydrology, Hydrochemistry and Hydroecology. Volume 3, issue 20, pp. 59-66.

Convention on the protection and use of transboundary streamflow and international lakes of the United Nations Economic Commission for Europe (1992). Helsinki.

Central Statistical Bureau of Latvia http://www.csb.gov.lv/en

Collins, A., Zhang, Y., McChesney, D., Walling, D., Haley, S., Smith, P. (2012), Sediment source tracing in a lowland agricultural catchment in southern England using a modified procedure combining statistical analysis and numerical modeling // Sci. Total Environ. 414. P. 301–317.

Dee, D., Uppala, S., Simmons, A., Berrisford, P., Poli, P., Kobayashi, S., Vitart, F. (2011). The ERA-Interim reanalysis: configuration and performance of the data assimilation system // Quarterly Journal of the Royal Meteorological Society, 137(656). 553–597. https://doi.org/10.1002/qj.828

Development of geography in the Latvian SSR 1941-1975 (1976). Republican interdepartmental collection of scientific papers. Riga. 167 p.

Ertel, A., Lupo, A., Scheifhacken, N., Bodnarchuk, T., Manturova, O., Berendonk, T., Petzoldt, T. (2011), Heavy load and high potential: anthropogenic pressures and their impacts on the water quality along a lowland river (Western Bug, Ukraine) // Environ Earth Sci 65. P. 1459–1473. doi:10.1007/s12665-011-1289-0.

European Environment Agency (2013), Corine Land Cover 2006 seamless vector data (Version 17), Kopenhagen, Denmark.

Eurostat http://ec.europa.eu/eurostat/

Edelstein, K., Smahtina, O. (1991), Genetic structure of river flow and the chemical-statistical method for isolating its elements // Water resources. № 5. 5-20.

Economic Commission for Europe. Convention on the Protection and Use of Transboundary Watercourses and International Lakes. The second assessment of transboundary rivers, lakes and groundwaters. Access mode: http://cs5930.userapi.com/u38563579/docs/05e40aa64f9a/ECE_Second_Assessment_Ru.pdf (Accessed 20 Apr. 2017).

Federal Service of State Statistics (Russian Federation) http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/

Fischer, S., Pluntke, T., Pavlik, D., Bernhofer, C. (2014), Hydrologic effects of climate change in a sub-basin of the Western Bug River, Western Ukraine // Environ Earth Sci 72, 4727–4744. doi:10.1007/s12665-014-3256-z

Gorbachova, L., Koshkina, O. (2013), Time characteristics of the dates of beginning of the spring flood main characteristics in the Desna basin // Hydrology, Hydrochemistry and Hydroecology. Volume 2, issue 29. 30-37.

Gorbachova, L., Kolyanchuk, O. (2011), The catalogue of the spring floods in the Desna basin // Proceedings of UHMI. 2011. Issue 261. 179-192.

Gerasimov, L., Chaly, S., Plotnikov, A., Gerasimova, I., Polkunova, G., Kostik, I., Yevtushko, I. (2004), State geological map of Ukraine, m-1: 200000. Volyn-Podilsky series M-34-XVIII (Rava-Ruska), M-35-XIII (Chervonograd), M-35-XIX (Lviv). Manuscript. Kiev.

Gerenchuk, K.(1972), Nature of Lviv Oblast. Publisher of Lviv University. Lviv.

Gerenchuk, K.(1985), Nature of the Volyn region. Higher school. Lviv.

GlobCover Land Cover (v2.2). (n.d.). https://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=idn_ceos&KeywordPath=%5BParameters%3A+Topic%3D%27LAND+SURFACE%27%2C+Term%3D%27LAND+USE%2FLAND+COVER%27%2C+Variable_Level_1%3D%27LAND+USE+CLASSES%27%5D&OrigMetadataNode=GCMD&EntryId=geodata_2059&M (Accessed 1 July 2017)

Goldewijk, K., Beusen, A., Van Drecht, G., & De Vos, M. (2011). The HYDE 3.1 spatially explicit database of human-induced global land-use change over the past 12,000 years // Global Ecology and Biogeography, 20(1), 73–86. https://doi.org/10.1111/j.1466-8238.2010.00587.x

Hydrographical characteristics of Belarusian rivers. Access mode: http://www.pogoda.by/315/gid.html (Accessed 20 Apr. 2017)

Instructions for hydrometeorological stations. Issue 6. Part II. Hydrological observations and work on large and medium rivers. Leningrad. Gidrometeoizdat. 1978. 384 p.

Instructions for hydrometeorological stations (1972). Issue 6. Part II. Hydrological observations and work on small rivers. Leningrad. Gidrometeoizdat. 266 p.

Guidance document. Addition to the instructions for Hydrometeorological Stations (1989). Issue 6, Part I. (RD 52.08.163-88). Leningrad. Gidrometeoizdat. 108 p.

Hagemann, N., Blumensaat, F., Tavares Wahren, F., Trümper, J., Burmeister, C., Moynihan, R., Scheifhacken, N. (2014), The long road to improving the water quality of the Western Bug River (Ukraine) – A multi-scale analysis // Journal of Hydrology, Water governance across competing scales: Coupling land and water managementIncorporating water resources in integrated urban and regional planning 519, Part C, 2436–2447. doi:10.1016/j.jhydrol.2014.01.013

Hooper, R. (2003), Diagnostic tools for mixing models of stream water chemistry // Wat. Res. Res. V. 39, № 3. 1055 p.

Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales product website https://hydrosheds.cr.usgs.gov/

Jaagus, J., Briede, A., Rimkus, E., Remm, K. (2010), Precipitation pattern in the Baltic countries under the influence of large-scale atmospheric circulation and local landscape factors // Int J Climatol 30, 705-720

Kalinin, M., Pakhomov, V. (2008), Assessment of the state of water resources in the Western Dvina and Neman river basins in the Republic of Belarus // Republican Unitary Enterprise "Central Scientific Research Institute for the Integrated Use of Water Resources". Minsk, Belsens, 60 p.

Kolbasov, O. (1972), The theoretical basis of the right to use water in the USSR. Moscow.

Kolmakova, E., Maslova, O. (2008), Dynamics of transboundary pollutants transport in the Western Dvina catchment // Vestnik BSU. Ser. 2. № 2. 97-100.

Kruhlov I. (2015), Natural geoecosystems of the Upper Western Bug catchment // Science. App. Ternopol pedagogic university. Ser. Geography, 39. 165-173.

Kļaviņš, M., Briede, A., Rodinov, V. (2009), Long term changes in ice and discharge regime of rivers in the Baltic region in relation to climatic variability // Climatic Change 95, 485-498.

Kļaviņš, M., Rodinov, V., Timukhin, A., Kokorīte, I. (2008), Patterns of river discharge: long-term changes in Latvia and the Baltic region // Baltica 21, 41-49.

Kalbacher, T., Delfs, J., Shao, H., Wang, W., Walther, M., Samaniego, L., Schneider, C., Kumar, R., Musolff, A., Centler, F., Sun, F., Hildebrandt, A., Liedl, R., Borchardt, D., Krebs, P., Kolditz, O. (2011), The IWAS-ToolBox: Software coupling for an integrated water resources management // Environ Earth Sci 65, 1367–1380. doi:10.1007/s12665-011-1270-y

Kondracki, J. (1965), Geografia fizyczna Polski. Panstwowe Wydawnictwo Naukowe, Warszawa.

Kowalkowski, T. (2009). Classification of nutrient emission sources in the Vistula River system. Environmental pollution, 157(6), 1867-1872.

Körner, P., Pluntke, T., Sachse, A., Böttcher, N., Naumov, D., Kolditz, O., Bernhofer, C. (2014), Inverse determination of groundwater inflow using water balance simulations // Environ Earth Sci 72, 4757–4769. doi:10.1007/s12665-014-3327-1

Kriauciuniene, J., Meilutyte-Barauskiene, D., Reihan, A., Koltsova, T., Lizuma, L., Sarauskiene D. (2012), Variability in temperature, precipitation and river discharge in the Baltic States // Boreal Environ Res 17, 150-162.

Kruglov, I. (2015), Soil and natural geoecosystems map of the Western Bug // Sciences Bull of Ternopol Univ., Geography, 39, 165-173.

Leidel, M., Hagemann, N., Seegert, J., Weigelt, C., Zakorchevna, N., Blumensaat, F., (2014), Supporting decisions in water management by exploring information and capacity gaps: experiences from an IWRM study in the Western Bug River Basin, Ukraine // Environ Earth Sci 72, 4771–4786. doi:10.1007/s12665-014-3863-8

Loginov, V., Volchek, A., Shelest, T. (2015), Analysis and modeling of hydrographs of rain floods on Belarusian rivers // Water resources, T. 42, № 3, 268.

Long-term data on the regime and resources of surface waters of the land (1985), volume 3.

Lizuma, L, Briede, A, Klavinš, M. (2010), Long-term changes of precipitation in Latvia // Hydrol Res 41, 241-252.

Lepikh, Ya., Prystupa, A., Bunyakova, Yu. et al. (2014), Analysis of the water regime of the Desna basin rivers of near border areas // Proceedings of Kharkov National University. № 1104, Series "Ecology", issue 10, 94-98.

Loboda, N., Daus, M., Dycherenko, Yu. (2013), Assessment of the water of Desna river by the complex of hydrochemical indicators // Proceedings of Odessa State Ecological University, Issue 16, 124-133.

Luzovitsyka, Yu., Osadcha, N., Osadchyy, V. (2011), Outflow of nutrients from the Desna basin // Proceedings of UHMI. 2011. Issue 261, 117-138.

Luzovitsyka, Yu., Osadcha, N. (2014), Characteristics of diffuse input of the nutrients to the water ecosystems // Scientific Journal "Geopolicy and Ecogeodynamics of Regions". Volume 10, issue 1. Simpheropoly, 157-161.

Luzovitsyka, Yu., Koshkina, O., Osadcha, N. (2014), Influence of water flow on the nutrients discharge forming in the Desna basin // Hydrology, Hydrochemistry and Hydroecology, Volume 2, issue 33, 37-45.

Luzovitsyka, Yu., Osadcha, N., Artemenko, V. (2017), Analysis of factors of nutrients composition of the Desna water using summing and integral curves // Hydrology, Hydrochemistry and Hydroecology, Volume 1, issue 44, 85-94.

Lozovitsykyy, P., Luzovitsyka, Yu. (2009), Pre-cartographic studies of the Desna. Cartography and Highest School // Proceedings of the Kyiv State University of T.G. Shevchenko, Geography Department, , issue 14, 73-83.

Lozovitsykyy, P. (2013), Quality of the Desna water at the border with Russia and transboundary matter flux with water flow // Journal of Cartography, Issue 9, 62-83

Maslova, O., Kolmakova, E., Kozlov, E. (2009), Geographical and hydrochemical types of streamflows of the Western Dvina basin // Bulletin of the Belarusian State University. СЕР. 2, № 2, 76-80ю

Meshcheryakovб Yu. (1965), Structural geomorphology of the plains. Science, Moscow.

Modern relief of the Desna basin. Electronic source: http://www.zaecomir.ru/r-bryansk-geo.htm.(Accessed 20 Apr. 2017)

Mednis, M., Matisovs, I., Teirumnieka, E., Martinovs, A., Vaļģis, G. (2011), Overview of the river basin management plans in the Baltic region under the WATERPRAXIS project // Proceedings of the 8th International Scientific and Practical Conference. Volume 1.

Myron, I. (2003), Utilization and quality of the Desna water within Chernigivsyka Oblasty // Proceedings of UHMI, issue 251, 150-155.

Nachtergaele, F., Van Velthuizen, H., Verelst, L., Batjes, C., Dijkshoorn, K., Van Engelen, V., Shi, X. (2009), Harmonized World Soil Database - Version 1.1. Retrieved from http://www.fao.org/docrep/018/aq361e/aq361e.pdf (Accessed 10 March 2017)

Nałęcz, T. (Ed.) (2012), Transboundary Aquifers in the Eastern Borders of The European Union, NATO Science for Peace and Security Series C: Environmental Security, 45-59.

National Statistical Committee of Belarus Republic http://www.belstat.gov.by/

Osadcha, N., Osadchyy, V., Lutkovsky, V., Luzovitska Y., Artemenko V. (2014), Experimental research and mathematical modeling of nutrients release in a small watershed // Die Bodenkultur journal for Land Management, Food and Environment. special issue: environment water. 65 band Heft 3 – 4/2014, 7–13.

Osadcha, N., Osadchyy, V., Lutkovsky, V., Luzovitska, Yu., Artemenko, V. (2014), Experimental research and mathematical modeling of nutrients release in a small watershed // Advances in Hydrologic Research on Pristine, Rural and Urban Small Basins. 15th Biennial Conference of the Euromediterranean Network of Experimental and Representative Basins, Book of Abstracts of the 15th Biennial Conference of the ERB 2014, 9-13 September 2014, Coimbra, Portugal, 22.

OpenStreetMap. (n.d.). Retrieved July 1, 2017, from http://www.openstreetmap.org/copyright

Pavlik, D., Söhl, D., Pluntke, T., Bernhofer, C. (2014), Climate change in the Western Bug river basin and the impact on future hydro-climatic conditions // Environ Earth Sci 72, 4787–4799. doi:10.1007/s12665-014-3068-1

Pavlik, D., Söhl, D., Pluntke, T., Mykhnovych, A., Bernhofer, C. (2011), Dynamic downscaling of global climate projections for Eastern Europe with a horizontal resolution of 7 km // Environ Earth Sci 65, 1475–1482. doi:10.1007/s12665-011-1081-1

Pluntke, T., Pavlik, D., Bernhofer, C. (2014), Reducing uncertainty in hydrological modelling in a data sparse region // Environ Earth Sci 72, 4801–4816. doi:10.1007/s12665-014-3252-3

Parfomuk, S. (2006), Analysis of perennial fluctuations in the annual water flow of the Western Dvina River // Bulletin of the Polotsk State University. Ser. B, Applied Sciences, N3, 2006, pp. 178-182.

Parfomuk, S. (2006), Analysis of long-term fluctuations in the annual flow of the water of the Western Dvina river // Bulletin of the Polotsk State University, Series B, No.3, 178-182.

Pakhomov, A., Kalinin, M. (2008), Assessment of the state of water resources of the Western Dvina and Neman river basins in the Republic of Belarus.

Prytula, L. (2010), Characteristic of the mean annual ion discharge of the Desna. Hydrology, Hydrochemistry and Hydroecology. Volume 11, issue 19, 147-154.

Podgornaya, E., Melnik, V., Komarovskaya, E. (2015), Features of climate change in the territory of the Republic of Belarus over the past decade // Proceedings of the Hydrometeorological Center of Russia. 2015. No. 358, 111-120.

Program of the Swedish Environmental Protection Agency for Transboundary Waters, 1997-2002. http://www.naturvardsverket.se/ Documents/publikationer/620-5278-0.pdf (Accessed 20 May 2017)

Ramankutty, N., Foley J. (1999), Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992. Global Biogeochemical Cycles 13(4), 997–1027.

Reihan, A., Koltsova, T., Kriauciuniene, J., Lizuma, L., Meilutyte-Barauskiene, D. (2007), Change in water discharge of the Baltic State rivers in the 20th century and its relation to climate change // Hydrology Research, 38 (4-5) 401-412, DOI: 10.2166/nh.2007.020

Rules for the conduct of hydrological observations and works (2008), Part 1. - Minsk: Ministry of Natural Resources, TKP 17.10-08 / 1-2008 (02120).

Rusaya, I., Tishchikov, G., Selitskaya, V., Tishchikova, E. Modern Approaches to the Assessment of Surface Water Quality in the Republic of Belarus – Presentation.

Savenok, V., Minaeva, O., Chepelov, S. (2015), Evaluation of watershed areas as potential pollutants of the Western Dvina river // Vestnik VDU. 2012. № 5 (71), 40-44

Second assessment of transboundary rivers, lakes and groundwaters (2011) / Economic Commission for Europe. Geneva : United Nations, XIII, 428 p.

SocioEconomic Data The World Bank Group IBRD IDA http://www.worldbank.org/. (Accessed 20 Apr. 2017)

Schanze, J., Trümper, J., Burmeister, C., Pavlik, D., Kruhlov, I. (2011), A methodology for dealing with regional change in integrated water resources management // Environ Earth Sci 65, 1405–1414. doi:10.1007/s12665-011-1311-6

Seegert, J., Berendonk, T.U., Bernhofer, C., Blumensaat, F., Dombrowsky, I., Fuehner, C., Grundmann, J., Hagemann, N., Kalbacher, T., Kopinke, F.-D., Liedl, R., Leidel, M., Lorz, C., Makeschin, F., Markova, D., Niemann, S., Röstel, G., Schanze, J., Scheifhacken, N., Schuetze, N., Siebert, C., Stefan, C., Strehlitz, B., Teutsch, G., Weigelt, C., Weiß, H., Kolditz, O., Borchardt, D., Krebs, P. (2014), Integrated water resources management under different hydrological, climatic and socio-economic conditions: results and lessons learned from a transdisciplinary IWRM project IWAS // Environ Earth Sci 72, 4677–4687. doi:10.1007/s12665-014-3877-2

Smaliychuk, A., Müller, D., Prishchepov, A.V., Levers, C., Kruhlov, I., Kuemmerle, T. (2016), Recultivation of abandoned agricultural lands in Ukraine: Patterns and drivers // Global Environmental Change 38, 70–81. doi:10.1016/j.gloenvcha.2016.02.009

Saha, S., Moorthi, S., Wu, X., Wang, J., Nadiga, S., Tripp, P., Becker, E. (2014), The NCEP Climate Forecast System Version 2 // Journal of Climate, 27(6), 2185–2208. https://doi.org/10.1175/JCLI-D-12-00823.1

SRTM v.4 Hydrosheds 30shttps://hydrosheds.cr.usgs.gov/ (Accessed 20 Apr. 2017)

State water cadastre. Section 1. Surface waters. Series 3. Perennial data (2008), Long-term data on the regime and resources of surface waters. Part 1. Rivers and canals / Minsk: 2008. 221 p. URL: http://www.twirpx.com/file/1857660/(Accessed 15 May 2017)

State water cadastre. Section 1. Surface waters. Series 3. Perennial data. Long-term data on the regime and resources of surface waters (2009), Part 1. Rivers and canals. Table 1.3. Average and typical water consumption, Minsk.

State Water Register (2015), water bodies and water resources. Reference edition. - Moscow: Rosvodresursy, SevKavNIIVH. Novocherkassk, Lick, 553 p.

Stone, T., Schlesinger, P. (2004). RLC Forest Cover of the Former Soviet Union. https://doi.org/10.3334/ORNLDAAC/692

Tavares Wahren, F., Helm, B., Schumacher, F., Pluntke, T., Feger, K.-H., Schwärzel, K. (2012), A modeling framework to assess water and nitrate balances in the Western Bug river basin // Ukraine. Adv. Geosci. 32, 85–92. doi:10.5194/adgeo-32-85-2012

Tavares Wahren, F., Tarasiuk, M., Mykhnovych, A., Kit, M., Feger, K.-H., Schwärzel, K., (2012), Estimation of spatially distributed soil information: dealing with data shortages in the Western Bug Basin, Ukraine // Environmental Earth Sciences 65, 1501–1510. doi:10.1007/s12665-011-1197-3

The Historical Map Portal http://mapire.eu/en/ (Accessed 1 May 2017)

The concept of energy security of the Republic of Belarus. Resolution of the Council of Ministers of the Republic of Belarus on 23.12.2015 No. 1084.

The Unified State Register of Soil Resources of Russia (2014) [http://egrpr.esoil.ru/] (Accessed 20 Apr. 2017)

The Desna ecological corridor (2010), Under edition of V. Kostytushin, E. Prekrasna. National Ecological Center of Ukraine, Kyiv, 186 p.

The Global Runoff Data Centre, 56068 Koblenz, Germany URL: http://www.bafg.de/GRDC/EN/Home/homepage_node.html.

Tilis, J., Miris, K. (2001), Water-QualitCyh anges in Latvia and Riga 1980-2000: Possibilities and Problems // Ambio Vol. 30 No. 4-5, 306-314.

Tränckner, J., Helm, B., Blumensaat, F., Terekhanova, T. (2012), Integrated water resources management: Approach to improve river water quality in the Western Bug River Basin // Nałęcz, T. (Ed.), Transboundary Aquifers in the Eastern Borders of The European Union, NATO Science for Peace and Security Series C: Environmental Security, Springer Netherlands, 61–78.

Typology of the Desna elevations. Electronic source:: http://only-maps.ru/karty-rek-i-vodoxranilishh/reka-esna.html(Accessed 20 Apr. 2017)

Wilson, D., Hisdal, H., Lawrence, D. (2010), Has streamflow changed in the Nordic countries? Recent trends and comparisons to hydrological projections // J Hydrol 394, 334-346.

Tereschuk, O., Movenko, V. (2014), Hydrological regime and ecological state of the river Desna within Chernigivsyka Oblasty // Proceedings of international conference "The modern achievements of geodesy, geoinformatics, and land rendering – European experience". Issue 10, Chernigiv, 62-71.

Vlasov, B., Grischenkova, N.(2011), The content of heavy metals in aquatic plants of water bodies and watercourses of Belarus according to the monitoring data // Vestnik BSU. Ser. 2., № 3, 117-121

Volchek, A. (2008), Fluctuations in the maximum flow of spring flood water in the rivers of Belarus // Izvestiya RAS. Ser. Geogr. № 2, 93-104.

Volchek, A., Luksha, V. (2006), Cyclicity of the annual flow of the Western Dvina // Bulletin of the Polotsk State University, Series V, №3, 172-177.

Volchek, A., Shelest, T. (2012), Winter floods forming on Belarusian rivers // Uchenye zapiski Rossiyskogo gosudarstvennogo gidrometeorologicheskogo universiteta, № 25, S-Peterburg, 5-19.

Voronkov, P. (1970), Hydrochemistry of local runoff in the European territory of the USSR. Leningrad, Gidrometeoizdat, 188 p.

Uvarova, G. (2012), Recreational use of the Desna // Geography and tourism, Issue 22, 140-147.

University, C. for I. E. S. I. N.-C.-C. (2016). Gridded Population of the World, Version 4 (GPWv4): Population Count. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). Retrieved from http://dx.doi.org/10.7927/H4X63JVC

Weather Princeton website https://www.meteoblue.com (Accessed 23 Apr. 2017)

World Database on Protected Areas https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas (Accessed 15 May 2017)

Water Code of Ukraine http://zakon2.rada.gov.ua/laws/show/213/95-%D0%B2%D1%80 (Accessed 1 August 2017)

Water Framework Directive of the European Union. 2000/60 / EC.

World economic indicators https://tradingeconomics.com/(Accessed 1 June 2017)

Yemelin, V. (2008), DATABASIN, Information management system and infrastructures for the transboundary Daugava/Western Dvina and Nemunas/Neman river basins, Final report, pp 25. (http://maps.grida.no/databasin/daugava/)(Accessed 20 Apr. 2017).

Yushchenko, V., Galuzo, A., Kupriyanchik, T. (2015), Analysis of the operation of facilities for removal of phosphorus compounds from wastewater at the treatment plant of Vitebsk // Bulletin of the Polotsk State University. Series B Industry. Applied Science. No. 3, 115-119.