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

Project acronym: ManTra-Rivers

WP 2 Comparison of data and methods needed to investigate the scientific basis of an IWRM

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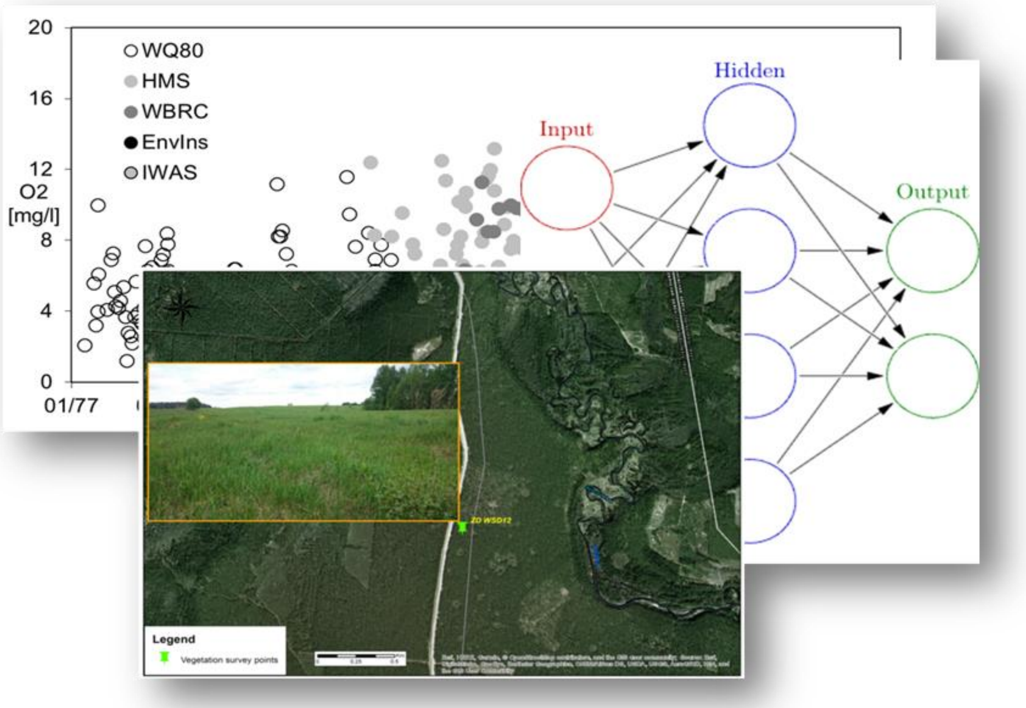

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Content

Introduction

Integrated Water Resources Management (IWRM) has been defined by the Technical Committee of the Global Water Partnership (GWP) as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

IWRM is based on the following three principles:

Social equity means ensuring equal access for all users (particularly marginalized and poorer user groups) to an adequate quantity and quality of water necessary to sustain human wellbeing. The right of all users to the benefits gained from the use of water also needs to be considered when making water allocations. Benefits may include enjoyment of resources through recreational use or the financial benefits generated from the use of water for economic purposes.

Economic Efficiency means bringing the greatest benefit to the greatest number of users possible with the available financial and water resources. This requires that the most economically efficient option is selected. The economic value is not only about price – it should consider current and future social and environmental costs and benefits.

Ecological Sustainability requires that aquatic ecosystems are acknowledged as users and that adequate allocation is made to sustain their natural functioning. Achieving this criterion also requires that land uses and developments that negatively impact these systems are avoided or limited.

Operationally, IWRM approaches involve applying knowledge from various disciplines as well as the insights from diverse stakeholders to devise and implement efficient, equitable and sustainable solutions to water and development problems. As such, IWRM is a comprehensive, participatory planning and implementation tool for managing and developing water resources in a way that balances social and economic needs, and that ensures the protection of ecosystems for future generations. Water has many different uses – for agriculture, for healthy ecosystems, for people and livelihoods – demands coordinated action. An IWRM approach is an open, flexible process, bringing together decision-makers across the various sectors that impact water resources, and bringing all stakeholders to the table to set policy and make sound, balanced decisions in response to specific water challenges faced (https://www.iwapublishing.com/news/integrated-water-resources-management-basic-concepts).

The goals of the work package B of this project are the following:

- comparison of available data and identification of differences in monitoring and data availability in Ukraine, Russia and the EU parts of the river basins;
- assessment of the consistency of data in transboundary regions;
- identification of data gaps and monitoring deficits;
- development of case studies for exemplary transboundary analysis of data;
- upgrading of water quality monitoring stations on Western Dvina river;

- comparison of methods commonly used for river basin analysis in the three countries;
- deficit analysis about the minimal additional data needs for the development of a science based IWRM concept.

Basically, the stages of IWRM implementation can be illustrated as it is shown on Figure 1.

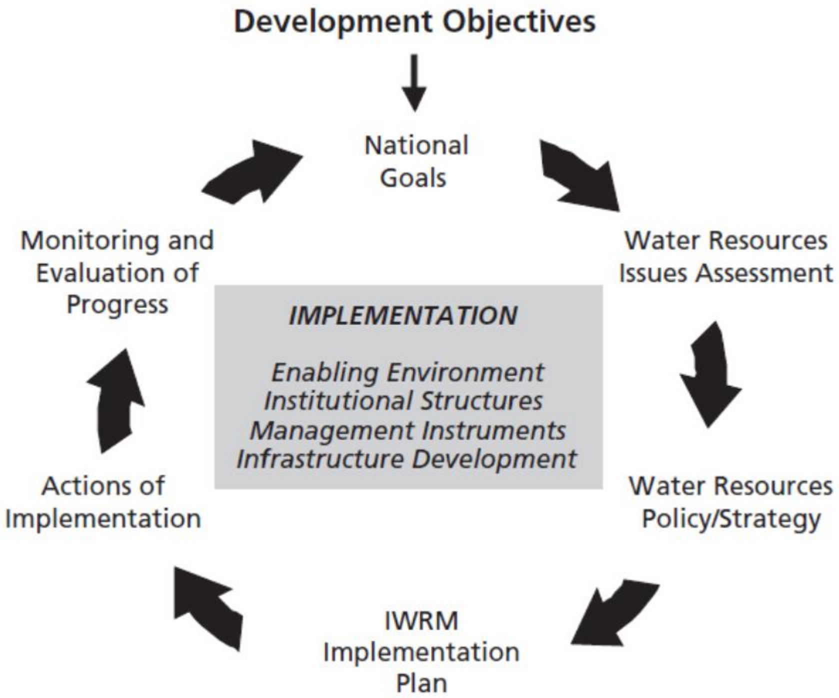

Figure 1: Stages of IWRM implementation (http://www.un.org/waterforlifedecade/iwrm.shtml)

Considering the concept of IWRM, this work is aimed at an improvement of water resources management in three studied transboundary river basins considering the best European practices and national legislations and experience.

Chapter I. European Directives, National and Transnational Legislation for an IWRM

1.1 European Directives

The European Water Framework Directive (WFD 2000**)** has the following key aims:

- Expanding the scope of water protection to all waters (surface waters and groundwater).
- Achieving "good status" for all water bodies and good potential of heavily modified water bodies (HMWB) by 2015 (may be extended to 2021 or 2027 at the latest).

The main principles of EU-WFD concerning assessment of the quality of natural water and water resources management could be summarized as following:

- Ecological, chemical and quantitative criteria (groundwater without ecol. criteria)
- Ecological means biological, hydromorphological and physico-chemical quality
- A water body fails in achieving the goal by missing only one of the criteria
- Exemptions are possible if justified.
- Water management based on river basins; for transboundary river basins: one international River Basin Management Plan (RBMP).
- A combined approach of emission limit values at the source and quality standards in the environment
- Pricing policy and economic instruments:
    - "recovery of costs for water services", including environmental and resources costs
    - polluter-pays principle
    - incentive pricing
    - cost effectiveness analysis for measures in Program of Measures (PoM)
- Public participation:
    - balancing the interests of various groups
    - increasing liability, enforceability, transparency
    - enabling, and allowing for, consultation and complaints procedures/courts
    - involving citizens, interested parties, NGOs
- Streamlining legislation and establishment of a common and coherent framework:
    - getting rid of old, now redundant or outdated legislation.

What are the key actions that Member States need to take? (EC 2003)

- To identify the individual river basins lying within their national territory and assign them to individual River Basin Districts (RBDs) and identify competent authorities by 2003 (Article 3, Article 24).
- To characterize river basin districts in terms of pressures, impacts and economics of water uses, including a register of protected areas lying within the river basin district, by 2004 (Article 5, Article 6, Annex II, Annex III).
- To carry out, jointly and together with the European Commission, the inter-calibration of the ecological status classification systems by 2006 (Article 2 (22), Annex V).
- To make the monitoring networks operational by 2006 (Article 8).
- Based on sound monitoring and the analysis of the characteristics of the river basin, to identify by 2009 a PoM for achieving the environmental objectives of the WFD cost-effectively (Article 11, Annex III).
- To produce and publish River Basin Management Plans (RBMPs) for each RBD including the designation of heavily modified water bodies, by 2009 (Article 13, Article 4.3).
- To implement water pricing policies that enhance the sustainability of water resources by 2010 (Article 9).
- To make the PoM operational by 2012 (Article 11).
- To implement the PoM and achieve the environmental objectives by 2015 (Article 4).

Other pieces of legislation must be coordinated in RBMPs where they form the basis of the programs of measures, this concerns:

- EU-Floods Directive (Directive 2007/60/EC). Flood Risk Management Plans (FRMP) shall consider the relevant environmental objectives of the WFD. The first cycle of FRMP ends by 2015.
- Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, Nitrates Directive.
- Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment.
- Drinking Water Directive (Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption) concerns the quality of water intended for human consumption. Its objective is to protect human health from adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean. (http://ec.europa.eu/environment/water/water-drink/legislation_en.html).
- Bathing water Directive (Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC) (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006L0007).

- The Baltic Marine Environment Protection Commission (HELCOM) is an intergovernmental organization governing the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention). HELCOM works on protection of the marine environment of the Baltic Sea. Contracting parties of HELCOM are, among others European Union, Latvia, Poland and Russia.
- The Commission on the Protection of the Black Sea Against Pollution (Black Sea Commission). The Black Sea Commission comprises one representative of each of the Contracting Parties (Bulgaria, Georgia, Romania, Russian Federation, Turkey and Ukraine) to the Convention on the Protection of the Black Sea Against Pollution. Concrete activities are based on the Convention on the Protection of the Black Sea Against Pollution, The Black Sea Strategic Action Plan, coordinated with national and regional projects/activities, International Financing Agencies, and national and regional policy measures and overall efforts of the countries to restore and preserve the environment of the Black Sea.

For a wide and common policy for the WFD enforcement a Common Implementation Strategy (CIS) was developed.

1.2 Poland

As a member of the EU, Poland falls under jurisdiction of European laws. The national regulations on the management of water resources are managed in the "Water Law". In the older version of 2001, Poland failed to transpose certain provisions of the EU-WFD (Tomasik 2016). The New Water Law (2017) has changes in:

1) Water Fees (for water intake):

- many exemptions abolished;
- increased fees;
- introduces fixed and variable fees for water services;
- calculation and collection done by Polish Waters (as opposed to calculation by the users themselves).

2) Fundamental restructuration of public institutions:

- National Water Holding "Polish Waters" (Państwowe Gospodarstwo Wodne Wody Polskie), instead of local governmental bodies;
- one unified organizational unit;
- focus on various water management issues, e.g. water-law permit issuance (Tomasik 2016), water law assessments, inspections, operation of the "Hydroportal" (formerly: Water Registry) (Robakowska and Wałkowski 2017).

3) New water-law assessment mechanisms (ocena wodnoprawna):

- more comprehensive environmental impact assessments (also for smaller investments that tended to be exempt) (Tomasik 2016);

- additionally, the State Treasury holds the "right of pre-emption in transactions involving land covered by inland standing waters" (Robakowska and Wałkowski 2017), enabling the respective starosta (i.e. county executives/local governments) to prevent certain real estate transactions with potentially negative outcomes for the environment.

4) New nitrate limits and reduction of obligations for all agricultural producers (Strzałkowska 2017).

Basic planning documents required by the WFD and the Water Law (2017) include the National Water and Environmental Program (NWEP) as well as RBMPs. NWEP defines basic and complementary activities aimed at improving or maintaining good water status in individual river basin districts, including actions aimed at promoting effective and sustainable use of water in order to prevent the threat of environmental goals and to optimize the principles of shaping water resources and conditions of their use, including actions to control water abstraction. NWEP is reviewed every 6 years and updated if necessary. The summary of the NWEP is a key element of the RBMPs.

The National Water Management Authority "Polish Waters" is responsible for the coordination, preparation and production of the NWEP and RBMPs. The first NWEP of the country was approved in 2010. The NWEP update was approved in 2016. Furthermore, Polish Waters provides advice on flood and drought control. Regional Water Management Boards are responsible for reporting, public information and consultation. The responsibility of implementation of WFD is split between a large number of national and regional authorities. The Regional Water Management Boards for Vistula is the RZGW Warsaw.

According to the Regulation of the Council of Ministers of January 12, 2018, all matters related to water man-agreement were transferred to the Ministry of Maritime Economy and Inland Navigation. In the past, at the Ministry of the Environment (Source: z Rozporządzeniem Rady Ministrów z 12 stycznia 2018 r. zmieniające rozporządzenie w sprawie utworzenia Ministerstwa Gospodarki Morskiej i Żeglugi Śródlądowej, poz. 105).

The first RBMPs for the planning cycle 2003-2009 were drafted in line with the WFD in 2009. Corresponding to WFD and Water Law, RBMPs have to be review and updated every 6 years. The RBMPs for the second planning cycle 2010-2015 aimed at reaching or maintaining at least good status of waters and ecosystems that depend on them, improving the status of water resources, improving the capability of using the waters, decreasing anthropogenic pressures and their impact on the status of waters and improving flood protection. Poland has drafted the second update of the RBMPs (2016-2021), however, publication in the Polish Official Journal is pending.

The Ministry of Environment created a special group for public participation at the national level, which is responsible for coordinating the public participation process and for preparing and publishing relevant information. A National Water Forum will be organized twice a year with the task of promoting a dialogue between public and private stakeholders with a strategic impact on water management issues. For further relevant Polish laws and regulations in the water sector see Annex 1.

To sum up, “The Polish water management system is consistent with the WFD in terms of basic principles and instruments. In addition, the systems of spatial planning and water management are well integrated (Hedin et al. 2007).

1.3 Belarus

Belarus is not a member of the EU, but EU directives progressively play a role in the field of water management. Water resource use and protection is regulated by three different types of legislative documents:

a) constitutional norms,
b) legislative acts adopted by the President and the Parliament and
c) regulatory acts issued by the executive authorities (Council of Ministers, the Ministry of Natural Resources and Environmental Protection, and the Ministry of Finance etc.).

Water legislation is based on the Constitution of the Republic of Belarus and on the law on Environmental protection. The main legislation concerning water management is the Water Code.

Law of the Republic of Belarus №1982-XII as of November 26, 1992 “On the Protection of the Environment” is an integral prerequisite of environmental safety and the sustainable social and economic development of society. It stipulates the bodies undertaking state administration in the sphere of environmental protection. Among them are:

- President of the Republic of Belarus;
- the Council of Ministers of the Republic of Belarus;
- the Ministry of Natural Resources and Environmental Protection and its territorial bodies;
- other specially empowered Republican bodies of state administration and their territorial bodies;
- local Councils of Deputies, executive and regulatory bodies within the scope of their competence.

The new Water Code of the Republic of Belarus (2014) replaces the 1998 Code. In force since May 2015, it is the principal legal act for pursuing state policy for sustainable development, and protection and rehabilitation of the country’s surface water and groundwater resources. It introduces the following main innovations:

- Advisory rivers basin councils apply a River Basin Management Approach. Before, responsibility for the rational use of water and its protection was administrated within the boundaries of administrative-territorial units of the Republic of Belarus and the catchment areas.

- RBMPs are developed for the integrated water resources management of the main river basins.
- Ecological state of surface waters is assessed using hydrobiological, hydrochemical and hydromorphological indicators as part of the National Environmental Monitoring System NEMS.
- Belarus puts particular effort into harmonizing its water-related legislation with EU legal acts, which is among the goals of the Water Strategy until 2020. There are a number of recently adopted technical regulatory legal acts that follow the relevant EU regulations but need to be made applicable for the conditions of Belarus through implementing various administrative, technical, capacity-building and other measures

National policy documents and state programs are:

- National Plan of Actions on rational use of natural resources and environment protection in the Republic of Belarus for 2006-2010 years.
- Water Strategy until 2020.
- National Sustainable Development Strategy for the period up to 2020.
- Main environmental policies of the Republic of Belarus for the period up to 2025.
- State Programme for water supply and sanitation “Clear water”.
- State Programme for Development National Monitoring System of Environment in the Republic of Belarus for 2011-2015 years.

The Ministry of Natural Resources and Environmental Protection (MNREP) is responsible in particular for:

- the development of a common state policy on environmental protection and the rational use of natural resources and also on hydro-meteorological activities;
- the coordination of the activities of other state authorities, local relevant executive and controlling authorities;
- the control of the activities in environmental protection, guaranteeing information on the state of the environment, and ensuring that protection and sanitation measures are taken (UN 2005).

MNREP develops draft environmental legislation considering that Belarus aims for an adaptation onto European Union’s body of environmental law.

UN (2005) assessed that much remains to be done to harmonize the national legal acts with the EU body of environmental law. Furthermore, “the environmental legislation remains too declarative and does not set forth concrete mechanisms to enable individual citizens to assert their right to obtain environmental information, to take part in decision-making and to be compensated for damage suffered as a result of violations of environmental legislation". The Law on Environmental Protection has no priority over other laws (like legislation on land, water, forestry, mineral resources, flora, and fauna). Therefore, it cannot play its role of framework law. This creates uncertainty and possible inconsistencies in the implementation of the legislation. "None of the laws is sufficiently precise about the number, the hierarchy and the approval procedure of secondary legal acts. The consequences are that the implementation of the legislation might be delayed and flawed."

1.4 Latvia

Latvia joined the EU in 2004. The National Water Management Law was adopted to comply with WFD in 2002. The primary national river basin authorities in Latvia are the Ministry of Environmental Protection and Regional Development (MEPRD) and the Latvian Environment, Geology and Meteorology Centre (LEGMC).

MEPRD is responsible for the transposition of the WFD into national legislation and ensuring the implementation of WFD. It develops the river basin management plans, coordinates the implementation of the PoM, and ensures the work of the RBD advisory councils - Daugava river basin district (EC 2012b). A schematic overview gives Figure 2. LEGMC is responsible for the implementation of the specific tasks set out in the Water Management Act and other legal acts such as:

- Environmental Protection Law (Latvia).
- Law on Water management (2002).
- Law on Water management Services: Exists the problem, that only part of water and wastewater services is regulated by the Public Utilities Commission (problems with tariffs, proper maintenance and investments). Since 2016, water consumption has to be metered in all households.
- Fishery Law.
- Forestry Law.
- Law on Environmental Impact Assessment (Latvia) (2005). These documents are harmonized with the respective EU Directives.
- Law on Environmental Protection (Latvia).
- Law on Pollution (2001): implementation of Council Directive 96/61/EC.
- Waste Management Law.
- Regulation No. 118 (2002): "Regulations regarding the Quality of Surface Waters and Groundwaters".
- Regulation No. 34 - "Regulations regarding Discharge of Polluting Substances into Water" (2002).
- Regulation No. 736 - "Regulations Regarding a Permit for the Use of Water Resources"; (2003).

- Regulation No. 857 - "Regulations regarding Procedures for Ascertaining of Groundwater Resources and Criteria of Quality" (2004).
- “Regulations on the Protection of Water and Soil against Pollution with Nitrates from Agricultural Sources”, Cabinet of Ministers Regulations No.531, (2001) → Ministry of Agriculture in cooperation with the Ministry of Environment developed the “Action Programme to protect water and soil against pollution caused by nitrates from agricultural sources”, 2004 (see Action-programm-Latvia-nitrate-reduction.doc). → Code of Good Agriculture Practice (GAP) (I part, II part) (for details see: http://www.varam.gov.lv/eng/darbibas_veidi/industrial_pollution/). GAP Code is a part of the harmonization of the Latvian legislation with both the EU legislation and HELCOM recommendations.
- “Regulations Regarding Utilisation, Monitoring and Control of Sewage Sludge and the Compost thereof”, Cabinet of Ministers Regulations No.362 (2006).

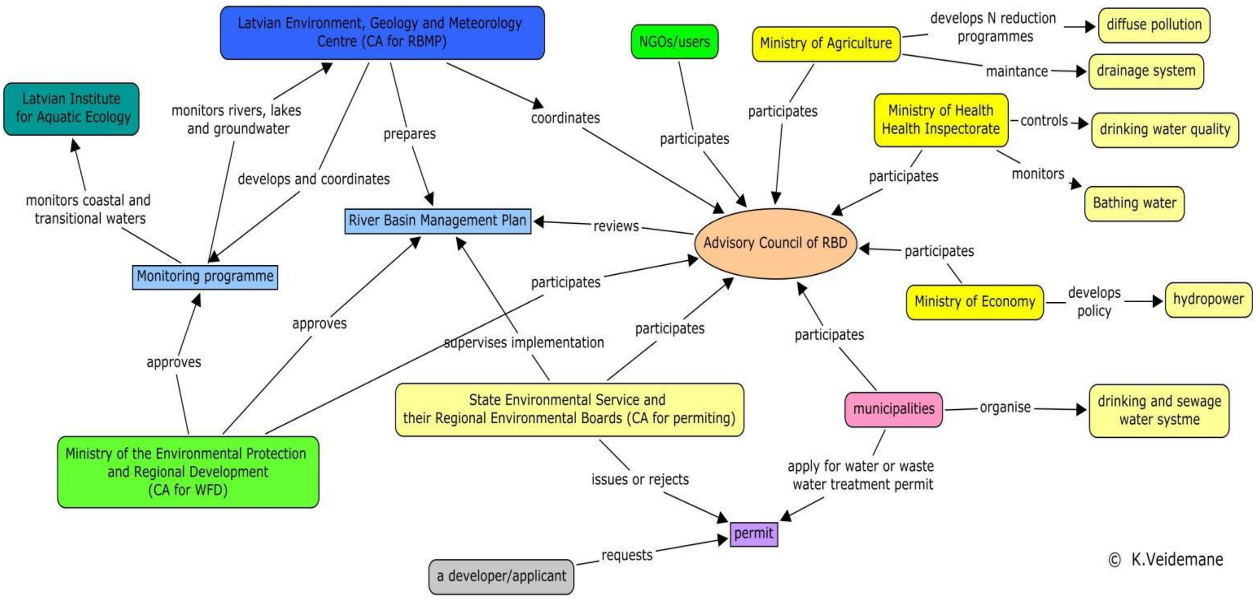

Figure 2. Responsibilities in the water sector

The RBMPs were approved by the Order of the Minister of Environment 2010. RBMPs and PoMs are planning documents which are approved by resolutions. They are legally binding, but cannot contradict existing laws. They are binding to all institutions subordinated to the Ministry of Environment and have to be considered when adopting internal legal acts. However, the plans are not binding to individuals. The RBMPs are linked with the other sectoral plans, of which the most important are: Environmental Policy Strategy 2009–2015, National Flood Risk Management Strategy 2008-2015, National Development Plan 2007-2013, Regional development plans (depending on a RBD), HELCOM, and EU directives.

Article 10 of the National Water Management Law specifies international cooperation in RBDs. It distinguishes between RBDs shared with EU member states respectively candidate countries, on the one hand, and countries outside the EU, on the other hand. In the former case, the MEPRD “should cooperate with the competent authorities of the relevant countries to establish and manage an international RBD" (Hedin et al. 2007). In the latter case, the MEPRD "should cooperate with the competent authorities of the relevant country with the aim of achieving the objectives of the law for the whole river basin" (ibid.).

There is a clear link between spatial planning and water management issues by setting up relevant requirements in the Governmental Regulations on Local Spatial Plans and District Spatial Plans adopted in 2004 and 2005, respectively.

1.5 Russian Federation

In Russian Federation, the water legislation consists of the Water Code, other federal laws and laws of the constituent territories of the Russian Federation adopted in accordance with the Code and applicable federal laws. 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.

Basin districts are the primary unit of management in the field of the use and protection of water bodies. They consist of river basins and associated groundwater sources and seas. There are 20 basin districts in the Russian Federation. Among them is Dnepr and Baltic basin districts, which cover territories of case study rivers - Desna and Western Dvina rivers respectively. On the water basins level, it is obligatory to formulate Basin Schemes of Integrated Use and Protection of Water Resources (SKIOVR in Russian). However, it is also possible to formulate "water management schemes" for the Russian regions. SKIOVR is done for the catchment and is obligatory. Some regions can do additionally water management schemes.

All data related to the water use agreements, decisions to grant water bodies for the use, assignments of rights and obligations under water use agreements and terminations of water use agreements is hold through the National Water Body Register which is a structured domain of documented information on water bodies owned by the federal government, constituent territories of the Russian Federation, municipalities, natural persons or legal entities, on their use, on river basins and basin districts.

According to Water Code (2006), the following main principles are applicable for the water legislation system in Russia:

- Significance of water bodies as the basis of human life and activities. Water relationships are governed based on the understanding of water bodies as an essential environmental component providing habitat for animals and plants, including aquatic biological resources, as a natural resource used by humans for their personal and domestic needs as well as for economic and other types of activity, and also as an object of property and other rights.
- Priority of the protection of water bodies over their use. The use of water bodies shall not have an adverse impact on the environment.
- Conservation of specially protected water bodies; the use of which is restricted or prohibited by federal laws.
- Intended use of water bodies. Water bodies can be used for one or more purposes.
- Priority of the use of water bodies for drinking and domestic purposes over any other purposes of their use. Water bodies can be allocated for other purposes only if water resources are sufficient.
- Participation of public and social groups in resolving issues related to the rights in water bodies as well as to their duty to protect water bodies. Citizens and social groups have the right to participate in decision-making process where the implementation of such decisions may have an impact on the use and protection of water bodies. Government authorities, local self-government, parties involved in economic and other types of activity shall ensure such participation in a manner and in accordance with the procedures established by the laws of the Russian Federation.
- Equal access for natural persons and legal entities to the right to use water bodies except as provided by the water legislation.
- Equal opportunities for natural persons and legal entities to acquire ownership of water bodies which can be owned by natural persons or legal entities under this Code.
- Regulation of water relations within the boundaries of basin districts (a basin-based approach).
- Regulation of water relations with account taken of water regimes in water bodies, their physiography, morphometry and other features.
- Regulation of water relations based on the interrelationships between water bodies and waterworks which form a water utility system.
- Transparency of water-use issues. Decisions regarding the grant of water bodies for the use as well as water use agreements shall be made available to any person except for such information, which is classified as restricted under the laws of the Russian Federation.
- Integrated use of water bodies. Water bodies can be used by one or multiple water users.
- Use of water bodies on a fee basis. Water bodies shall be used for a fee except as otherwise provided by the laws of the Russian Federation.

- Economic incentives to promote conservation of water bodies. A fee for the use of water bodies shall consider water users' expenses related to the protection of water bodies.
- Use of water bodies in areas of traditional residence of small indigenous peoples of the North, Siberia and Far East of the Russian Federation for their traditional water uses.

In case of transboundary rivers, additional legislation is developed using bilateral and multilateral agreements which regulate the water policy. In case of Western Dvina River, the following international environmental agreements are applicable:

- 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/.

The last IX meeting of joint Russian-Belorussian commission on transboundary water resources protection and management was held in May 2017 in Moscow (Russia).

1.6 Ukraine

In February 1997, the Parliament of Ukraine passed the "National Programme for Dnipro Basin Rehabilitation and Improvement of Drinking Water Quality" (Ukraine National Program), the first national environmental programme in Ukraine based on a water basin approach. A similar environmental program is being considered by Belarus.

Water relations in Ukraine are regulated by the Water Code, the Law of Ukraine "On Nature Environment Protection" and the other legislative acts. The Water Code of Ukraine 1995 is already adopting an integrated basin approach (Cf. Art.1) by considering "all waters" within Ukrainian territory, specifies the ownership of groundwater and surface waters and regulates the management, the conservation and use of the water resources. It also regulates the institutional competencies between governmental stakeholders in water sector. The last edition from 28/12/2014 together with the amendments passed on October 4, 2016 has completed the harmonization with the WFD.

The current legal framework for EU-Ukraine relations is provided by the Association Agreement (AA), which replaced the Partnership and Co-operation Agreement (PCA) in 2014. The signing of the political part of the agreement on March 21, 2014 made a step forward to the implementation of the results of 10 years work of Ukraine on harmonization/approximation of environmental legislation to the EU legislation, particularly the EU WFD. Under this AA, Ukraine has to transpose six water related directives:

- Water Framework Directive 2000/60/EC,

- EU Floods Directive 2007/60/EC,
- Marine Strategy Framework Directive 2008/56/EC,
- Urban Waste Water Directive 91/271/EEC,
- Drinking Water Directive 98/83/EC and
- Nitrates Directive 91/676/EEC.

There is an implementation plan for all of these directives. Most importantly, the Water Code was revised on 4/10/2016 to transpose WFD, Floods Directive and Nitrates Directive. In addition, there are working groups constituted for drafting of secondary legislation, with the support of EU-funded APENA project.

In 2009, the State Program on Water Sector Development up to 2020 was adopted. It addresses climate change adaptation issues, and the implementation of river basin management principles. The main directions of the National Water Program are:

- Development of water management and land-melioration by improving ecological status of drained and irrigated areas.
- Providing rural population with centralized water-supply.
- Protection rural settlements and agricultural land from negative water influence.
- Integrated flood control and protection areas within the Tisza, Dnister, Prut and Siret river basins.
- Ecological enhancement of the Dnipro river basin and drinking water quality improvement.
- Implementation of integrated river basin approach in water management.

As it has already mentioned, Ukrainian national legislation in water sector has to be harmonised with European one considering the AA and requirements of related EU directives. However, for the time being the following laws and normative acts are still in force:

A. Normative acts establishing rules and basic principles or characteristics of different hydrometeorological and Environmental monitoring activities or results of such activities.

- Law of Ukraine "On Hydrometeorolgical Activity" № 443-XIV, 18.02.1999 (in force, current version of 07.03.2018). The law establishes basic legal, economic, social, and organisational principles of hydrometeorological activity in Ukraine; among others, the legal status of the National Hydrometeorological Service and staff.
- Law of Ukraine "On Environmental protection" № 1264-XII, 25.06.1991 (in force, current version of 18.12.2017). The law establishes legal, economic, social, and organisational principles of environmental protection on favour of today and future generations.

- Order of the State Hydrometeorlogical Service “List of criteria of high and extremely high pollution of the Environment which are used in the system of Hydrometeorological Service” (№75, 31.05.1993.
- Decree of the Cabinet of Ministers of Ukraine “On approval of the Provisions of the state Environmental monitoring system” (№ 391, 30.03.1998).
- Decree of the Cabinet of Ministers of Ukraine “On approval of the Order of the State monitoring of water” (№ 815, 20.07.1996). This document currently is under revision.
- “Program of improvement of the quality of basic observations for Environmental pollution and monitoring”. Approved by the Order of the Ministry of Ecology and Natural Resources of Ukraine (№ 57, 08.02.2002). Program regulates functioning of the basic observations network of the Hydrometerological Service of the Ministry of Ecology and Natural Resources of Ukraine.
- Order of the State Emergency Service of Ukraine “On preparation and providing of operational and regime information concerning pollution of the Environment” (№ 777, 23.12.2013).
- Order of the State Emergency Service of Ukraine “On changes to the Algorithm of preparation, processing and submitting by hydrometeorological organisations, institutions of the State Emergency service of Ukraine the regime information concerning pollution of the Environment” (№451, 16.09.2016). Changes to the Order № 777.

B. Hydrology

- Water Code of Ukraine. Decree of the Supreme Council (Verkhovna Rada), №2013/95-ВР (current version 04.06.2017). Water Code promotes the forming of water-ecological order and providing of ecological safety of the people of Ukraine as well as more effective, scientifically proved use of water resources and prevention of water resources from pollution and exhaustion.
- Decree of the Cabinet of Ministers of Ukraine “On approval of the Order of the state water cadastre management” (№413, 08.04.1996). Current version of 07.06.2017.
- Order of the State Emergency Service of Ukraine “On approval of Methodological recommendations on the state water cadastre management concerning chapter “Surface water”” (№609, 03.12.2015).
- Order of the Ministry of Ecology and Natural Resources of Ukraine “On approval of the List of polluting substances for determination of chemical status of surface and ground water bodies and ecological potential of artificial or heavily modified surface water body” (№45, 06.02.2017).

C. Water quality

- Law of Ukraine “On assessment of Environmental impact” (№2059-VIII, 23.05.2017, in force). Law establishes legal and organizational principles of Environmental assessment aimed at prevention of harm to the Environment; providing ecological safety, Environmental protection, rational use and rehabilitation of natural resources. Law takes into account decision making process regarding industrial activity which can significantly influence Environment and considers state, public and private interests.

- "Methodology of ecological assessment of surface water quality by related criteria" (approved by the Order of the Ministry of Environmental Protection and Nuclear Safety of Ukraine №44, 1998).
- Normative document "Environmental protection and rational use of natural resources. Organization and performing of observations of surface water pollution" (KND 211.1.1.106-2003). This document sets up requirements for organization and performing of regime observations of surface water pollution on physical, chemical, hydrobiological, and toxicological indicators.
- "List of maximum allowable concentrations and roughly safe levels of impact of harmful substances for the fishery water objects". Approved by the Ministry of Fisheries of the USSR (№12-04-11, 09.08.1990). Legal status of this document is prolonged by the Order of the Ministry of Emergency Situations of Ukraine (№1128, 20.08.2011).

1.7 Transnational legislation and working groups

An agreement on collaboration in the sphere of water resources management on transboundary waters between the Government of Ukraine and Government of Republic of Poland has been signed on 10.10.1996 (in force in Ukraine since January 1999). According to Agreement Ukrainian-Polish collaboration covers the following main activities:

- Conducting of hydrological, hydrometeorological, and hydrogeological studies, observations and measurements and providing assessments of the results; data exchange.
- Joint studies aimed at identification of the quantity and quality of water resources taking into consideration of radioactive substances.
- Working out of water management balances taking into account of water resources quantity and quality; harmonization of joint assessments and water quality classifications.
- Agreement of water abstraction for population, industry and other water consumers.
- Water redistribution between transboundary water objects and other basins.
- Surface and ground water protection; providing of water quality control and prevention of water over-abstraction.
- Construction on transboundary water objects and development of hydro technical facilities with the aim of water resources utilization.
- Regulation and saving of water; protection of river channels and lands between the dikes.
- Flood and dangerous ice events protection.
- Prevention and mitigation of consequences of transboundary water pollution.
- Agreement of technical conditions for the construction of new and reconstruction and exploitation of existing bridges, flood protection and other hydrotechnical facilities, as

well as pumping stations, water abstraction units, sewage water discharge units, irrigation objects, pipelines, electricity and communication grids, etc.

- Materials excavation from rivers and reservoirs.
- Joint use of facilities and equipment located on transboundary water objects; their proper maintenance; agreement of technical conditions for their exploitation.
- Construction of hydrotechnical installations preventing fish passes to the water abstraction units.
- Conducting of the joint expertise of industrial and other activities, which can affect transboundary water objects.

The XVI Meeting of Ukrainian-Polish Commission on boundary waters affairs took place on 14.09.2017 in Hoczew, Poland. Protocol envisages further tight collaboration of the Parties to the agreement aimed at improving of transboundary water objects quality by the mean of resolving water management issues at the basis of good-neighbourliness and mutual understanding.

Exists an agreement between the Cabinet of Ministers of Ukraine and the Government of Republic of Belarus on joint use and protection of transboundary waters (signed 16.10.2001; approved by Decree of the Cabinet of Ministers of Ukraine №225, 28.02.2002; came in force for Ukraine 03.06.2002).

In 1992, an agreement between Ukraine and Russian Federation on joint use and protection of boundary water objects was signed by the Government of Ukraine and Russian Federation (in force since 19.10.1992). Cooperation covers the basins of Dnipro, Desna, Siversykyy Donetsy and rivers of the Sea of Azov region.

According to the Agreement, the 19th Meeting of Commissioners of the Parties was held on June 12-14 2013 in Slovyansyk (Donetsyk Region, Ukraine). It was envisaged to organize the next 29th Meeting on III quarter of 2014 in Russian Federation.

The aims of Ukrainian-Belarusian and Ukrainian-Russian Agreements are basically the same as for Ukrainian-Polish Agreement.

Basin Councils

A) Western Bug Basin Council

Western Bug Basin Council was established on 17.03.2006. Three meetings of the Basin Council took place since:

- 1st Meeting: 17.03.2006 in Lutsyk;
- 2nd Meeting: 30.11.2006 in Lviv;
- 3rd Meeting: 12.06.2012 in Lutsyk.

International collaboration in Western Bug Basin is coordinated and implemented by Western Bug Basin Water Resources Authority of the State Agency of Water Resources of Ukraine (main office is in Rivne, Volyny Region).

The key aspects of international collaboration are the following:

- joint work in groups and commissions on collaboration on boundary water objects with Republic of Poland and Republic of Belarus in the sphere of water quality control and joint use of water resources;
- joint work with the Regional Authority of Water Management in Warsaw (Poland) and Brest Regional Committee of Water Resources and Environmental Protection (Belarus);
- participation to international basins organizations;
- participation to international projects and coordination of fund raising activities and investments aimed at improvement of the Basin ecological status.

B) Dnipro Basin Council

In 1995, the Ministers of Environment from the Republic of Belarus, Russian Federation, and Ukraine signed the Memorandum on Cooperation for the Dnipro Basin Rehabilitation expressing their intention to work together and pool their resources. On the basis of this document, financial support and technical assistance was sought from the Global Environment Facility (GEF) for the development of the international programme for environmental rehabilitation of the Dnipro Basin.

The self-standing GEF Program was approved by the GEF Council and launched in December 1999 in order to provide financial support and technical assistance to the Republic of Belarus, Russian Federation, and Ukraine. The main goal of the programme was to develop the Strategic Action Program for the Dnipro Basin and the mechanisms for its implementation. The Program consisted of two stages: i) the first stage 2000-2005; ii) PDF B Stage 2006-2008.

One of the output activities of the Program was formulated as: “The three countries will have a functioning International Dnipro Basin Council to include representatives of all Dnipro Oblasts, representatives of relevant ministries, the project implementation unit and various representatives from the civil society including scientific institutions, private sector and NGO representatives. The Council shall have specific functions assigned by the SAP and shall meet at least annually”.

Coordination Meeting to establish the Basin Council of Dnipro River took place on 09.12.2009 in Energodar (Zaporizyka Region, Ukraine). No further official information concerning activities of the Council is available. It was reported that the 4th Meeting of Dnipro Basin Council was held on 22.11.2012 in Cherkassy region (Ukraine).

It was planned to conclude a trilateral agreement between the governments of Latvia, Belarus and the Russian Federation concerning co-operation in the Western Dvina river Basin in 2003. The Latvian government approved a draft agreement, but it was not signed in 2003. After joining the EU on the 1st of May 2004, water quality became a topic of shared responsibility between the Member States and the EU. Co-operation agreements were on the list of topics to be discussed during high-level meetings of the EU and Russia; however, this has not led to renewal of the negotiations concerning river basin management agreement. Latvia has no framework agreement with Belarus and Russia on co-operation in river basin management and therefore it is not possible to plan joint activities or develop management plans with non-member countries.

Between Latvia and Belarus, the following agreements exist:

- Agreement between the Government of the Republic of Latvia and the Government of the Republic of Belarus on Cooperation in the field of environmental protection (1994).
- Agreement between the Government of the Republic of Latvia and the Government of the Republic of Belarus on basic principles for transboundary cooperation (1998).
- Agreement between the Ministry of the Environment of the Republic of Latvia and the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus on cooperation in protection and sustainable use of protected transboundary nature territories (2010).

Between Lithuania-Latvia, the following agreements exist:

- Agreement on Transfrontier Cooperation between the Government of Lithuania and the Government of Latvia (1999) (FAO 2016)
- Technical Protocol between Lithuania and Latvia on the implementation of river basin management of three international river basin districts (Venta, Lielupe, Daugava) (2003) → exists a commission.

Between Belarus-Russia, the following agreements exist:

- Agreement between the Government of Republic Belarus and the Government of the Russian Federation about cooperation in nature protection (signed in 05.07.1994).

1.8 Résumé

Resuming the information of chapter I, Table 1 was setup, partly based on the information in Hedin et al. (2007). The assessment is based on information that was published some years ago. Current activities, e.g. in Belarus and Ukraine, head in a direction that converge to the WFD.

Table 1 Principles of the WFD and the fulfilment in different countries).
(signs: - weakly applied; + - partly applied; + applied)

WFD principle	**Belarus**	**Latvia**	**Poland**	**Russia**	**Ukraine**
River basin as unit	-	+	+	+	+
International RBD/ cooperation	+ -	+	+	+ -	+ -
River basin authorities	-	+ -	+	+	+
Water quality objectives → good ecol. & chem. status	-	+	+	+ -	-
Economic analysis of water use	-	+	+	+ -	-
Combined approach for point and diffuse sources	-	+	+	+ -	-
Management plans for RBD	-	+	+	+ -	+ -
Public participation	-	+	+	-	+

Chapter II. Monitoring programs

The design of appropriate measures to achieve environmental objectives can only be done on the basis of adequate knowledge of the pressures, impacts and status affecting the water bodies. The WFD planning process is designed to deliver this knowledge base. Article 8 of the WFD defines the requirements for the monitoring of surface water status, groundwater status and protected areas. No environmental objectives are set for wetlands. However, wetlands that are dependent on groundwater bodies, form part of a surface water body, or are Protected Areas. The WFD requires the establishment of two primary monitoring programmes:

- the Surveillance Monitoring (SM) and
- the Operational Monitoring (OM) for surface waters and groundwater. In the case of groundwater monitoring, a separate quantitative monitoring programme is required.
- The role of Investigative Monitoring is also outlined as appropriate within each water category section. These programs had to be operational by 2006.

Surveillance Monitoring has to provide information for:

- supplementing and validating the impact assessment procedure,
- the efficient and effective design of future monitoring programs,
- the assessment of long term changes in natural conditions and
- the assessment of long term changes resulting from widespread anthropogenic activity.

At least for a period of a year, the parameters indicative of all biological, hydromorphological parameters and general physico-chemical quality elements have to be monitored.

The operational monitoring serves:

- to establish the status of those bodies identified as being at risk of failing to meet their environmental objectives, and
- to assess any changes in the status of such bodies resulting from the programmes of measures.
- It is highly focused on parameters indicative of the quality elements most sensitive to the pressures to which the water body or bodies are subject.

In specified cases, an investigative monitoring may be required:

- e.g. when the reason for any exceedances of Environmental Objectives are unknown,
- where surveillance monitoring indicates that environmental objectives for a body of water are not likely to be achieved and operational monitoring has not already been established

The WFD allows Member States to tailor their monitoring frequencies according to the conditions and variability within their own waters. These are likely to differ greatly from determinant to determinant, from water body type to water body type, from area to area and from country to country, recognizing that a frequency adequate in one country may not be so in another. However, the key is to ensure that a reliable assessment of the status of all water bodies can be achieved, and the reliability of that assessment in terms of confidence and precision must be provided. The latter has to be published in RBMPs. Table 2 provides a guideline for the frequency of sampling for various qualitative elements.

Table 2. Guidelines for sampling frequency according to WFD, Annex V

Quality Element	River	Lakes	Transitional/coastal
Phytoplankton	6 month	6 month	6 month
Other aquatic fauna, flora, macroinvertebrates, fish	3 years	3 years	3 years
Morphology	6 years	6 years	6 years
Hydrology	Continuous	1 month	
Physio-chemical (temp., oxygen, salinity, nutrients, acidification)	3 month	3 month	3 month
Priority substances	1 month	1 month	1 month

Laszlo et al. (2007) state that the minimum frequency of sampling suggested by WFD in space and time may not be adequate for a precise and accurate characterization of water quality. To estimate the pollutant load which is transferred across Member State boundaries, and which is transferred into the marine environment an enhanced sampling frequency is necessary. The legally binding requirements in WFD on transboundary river basins seem to be weak.

2.1 Latvia

The assessment for the first RBMPs was based on the Monitoring program 2006-2008. Exist complains about insufficient monitoring programs:

- EC (2015): Gaps in monitoring and assessment methods for surface water (e.g. biological quality elements). Good Ecological Potential (GEP) needs to be established. Improvements are needed in the pressures and impacts analysis and in particular for hydro-morphology.
- EC (2012b): There are significant shortcomings in the monitoring network, and monitoring data is not available for the assessment of all water bodies. There are also shortcomings on the classification of chemical status.

- Not all of the relevant quality elements required for the surveillance monitoring included in the design of the monitoring program are monitored, because of lack of the relevant national assessment methods and a lack of data to establish quality class boundaries.
- Monitoring of four priority substances (metals) and several other chemical pollutants – mainly metals and oil hydrocarbons. The selection of hazardous substances and priority substances monitored was planned in those water bodies only: 1) where significant amounts of such substances were discharged according to the permits issued by the regional environmental authorities; 2) which are strategically significant for Latvia, for instance, trans-boundary water bodies.
- In addition to that, selected water bodies were monitored in 2006 and 2007, to identify prospective concentrations of several organic pollutants, for instance, polyaromatic hydrocarbons PAH, monoaromatic hydrocarbons BTEX, and several organochlorine substances (solvents, pesticides etc.).
- There was no separate operational monitoring for groundwater in Latvia within the monitoring program for the period of 2006 – 2008. A quantitative groundwater-monitoring program has been established. There has been no groundwater chemical status monitoring to detect significant and sustained upward trends in pollutants.
- In the vicinity of Riga and Liepaja upward trends of chlorides, sodium, potassium and/or other ions indicative of saline intrusion or infiltration have been detected in the past. These processes started in the 1970s due to intensive water abstraction; today they are decreasing. Another area is identified where pollution of shallow groundwater is caused by numerous point sources; the monitoring network allows following up these processes as well.

In 2010, a new Monitoring program was approved by the Minister of Environment for 2009-2014. There are several monitoring systems coordinated by LEGMC, which include surface and groundwater as well as soil quality monitoring. These monitoring programs are determined by the National Environmental Monitoring Program (2002) and National Action Plan for Environmental Monitoring (2002).

Several large-scale screening projects have been implemented since 2009 in order to assess water pollution and to obtain sufficient information for the improvement of the monitoring programme. During these projects, the presence and concentrations of more than 200 substances/groups of substances (including sediments, wastewaters, sewage sludge and fish) have been examined. These studies significantly extended knowledge about surface water chemical quality in Latvia. The results of these studies also provide assurance that there are no reasons for concerns about surface water chemical quality.

Hydrological observations are carried out at 70 hydrological stations on Latvian rivers, lakes and reservoirs. LEGMC claims at its webpage that density of observation stations network is optimal to ensure a sufficient base for the analysis of lakes and rivers. Stations are fully equipped with automatic devices.

Operational monitoring in the parts of groundwater bodies considered as being at risk in the first RBMPs was included in the monitoring program for 2009 – 2014 and is operated by the State Geological Service.

Monitoring of marine waters is performed by the Hydro-Ecology Institute of the University of Latvia.

Agricultural runoff monitoring stations are established in three locations (Dobele, Saldus and Cēsis Districts, (not in Daugava district)).

2.2 Poland

Water quality monitoring is carried out under the State Environmental Monitoring (SEM). SEM is a system of measurements, assessments and forecasts of the state of the environment and the collection, processing and dissemination of information about the environment. The method of conducting research and assessment of water status is regulated by the Act of 18 July 2001 - Water Law in Chapter 6a.

The implementation of the WFD in the Polish legal system (since 2005) entailed many changes in existing monitoring. The most important of them are:

- monitoring planning and assessment of water status refers to uniform water body, not to a river or measuring and control point,
- introduction of new quality indicators (mainly biological),
- the condition of waters is defined as ecological state and chemical state, not as class quality,
- new types of monitoring (diagnostic, operational, research and protected areas) and
- monitoring planning in cycles consistent with the cycles of RBMPs.

The assessment of the first RBMPs by EC (2012a) revealed significant shortcomings in monitoring. For the second update of the RBMPs (2010-2015) monitoring of ichthyofauna and hydromorphological elements was implemented and the reference conditions for all types of rivers were supplemented, which allowed for a full assessment of the ecological status of waters.

Since 2011, a five-stage classification of the ecological status of surface water bodies has been in force, introduced by the ordinance of the Minister of the Environment of 9 November 2011 on the classification of ecological status, ecological potential and chemical status of surface water bodies. According to this classification, the ecological status of waters is divided into very good, good, moderate, weak and bad. According to EC (2015), there are still significant gaps in monitoring and assessment methods.

Monitoring of the Western Bug River is carried out under the SEM in the following network:

- Surveillance Monitoring at 13 control points (cp) (including monitoring of dangerous substances - 1 cp).
- Border monitoring - 9 cp.

- Eurowaternet networks - 2 cp.

Currently, surface water monitoring is designed with reference to uniform water bodies measurements. The Western Bug section is located in the province Lubelskie and includes 11 uniform water bodies and in the province Mazovia 5 uniform water bodies. Monitoring is carried out on the basis of regulations number 10 and 11 from Annex 1. According to these regulations, monitoring of Western Bug is carried out in the following 19 control points: Kryłów, Zosin, Horodło, Dorohusk, Kuzawka, Kuzawka/Kukuryki, Krzyczew, Gnojno, Zaburze, Mierzwice, Kózki, Drohiczyn, Nur, Brok, Brańszczyk, Wyszków, Barcice, Nowa Kania.

In relation to the whole Bug basin, the Provincial Environmental Protection Inspectorate (WIOŚ) established a Surveillance Monitoring in 17 cp. An operational monitoring was set up in 54 cp on uniform water bodies which: a) possibly fail to achieve the environmental objectives, b) belong to the monitoring of protected areas (Natura 2000 areas, which are sensitive to municipal eutrophication) and c) are exposed to contamination with nitrogen compounds from agricultural sources. The network is presented on Figure 3 and Figure 4.

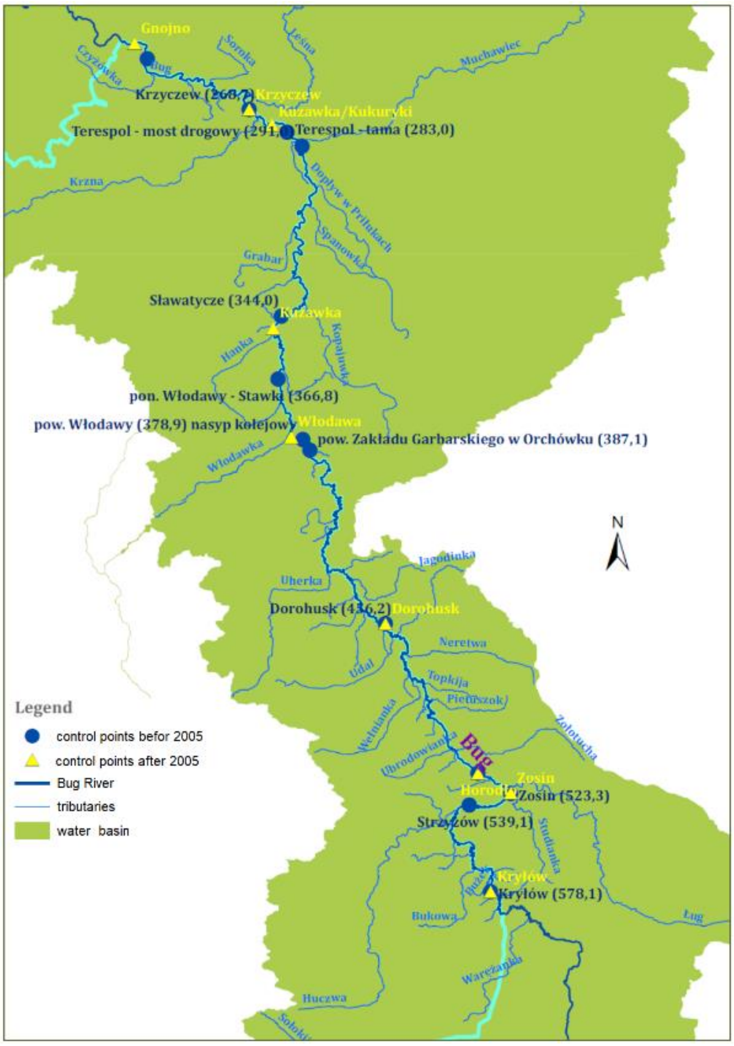

Figure 3. Location of control points in the Western Bug river basin in Lublin Province (source: WIOŚ in Lublin)

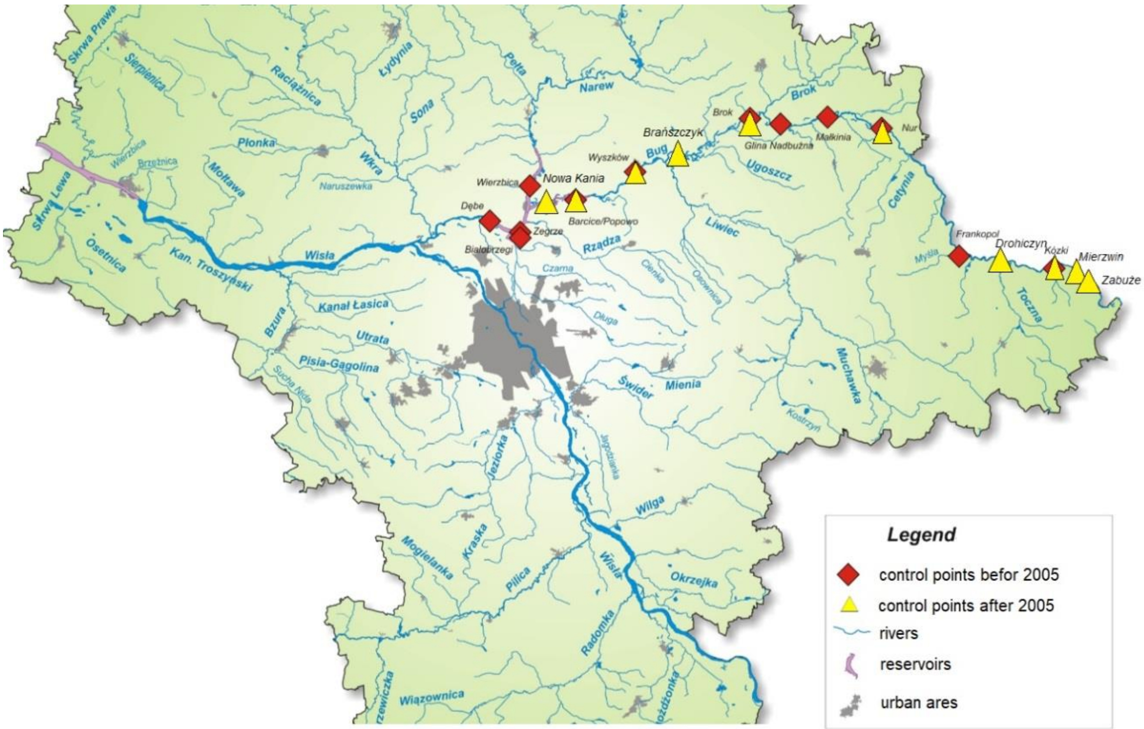

Figure 4. Location of control points in the Western Bug river basin in Mazovian Province (source: WIOŚ in Warsaw)

2.3 Russian Federation

Water monitoring is regulated by the Water Code (2006). Monitoring includes the sectors visualized on Figure 5. Surface waters monitoring; Hydromorphological monitoring (of banks and bottom) and water protection zones and near-shore protective belts monitoring; Ground water monitoring; Water use and water supply system monitoring.

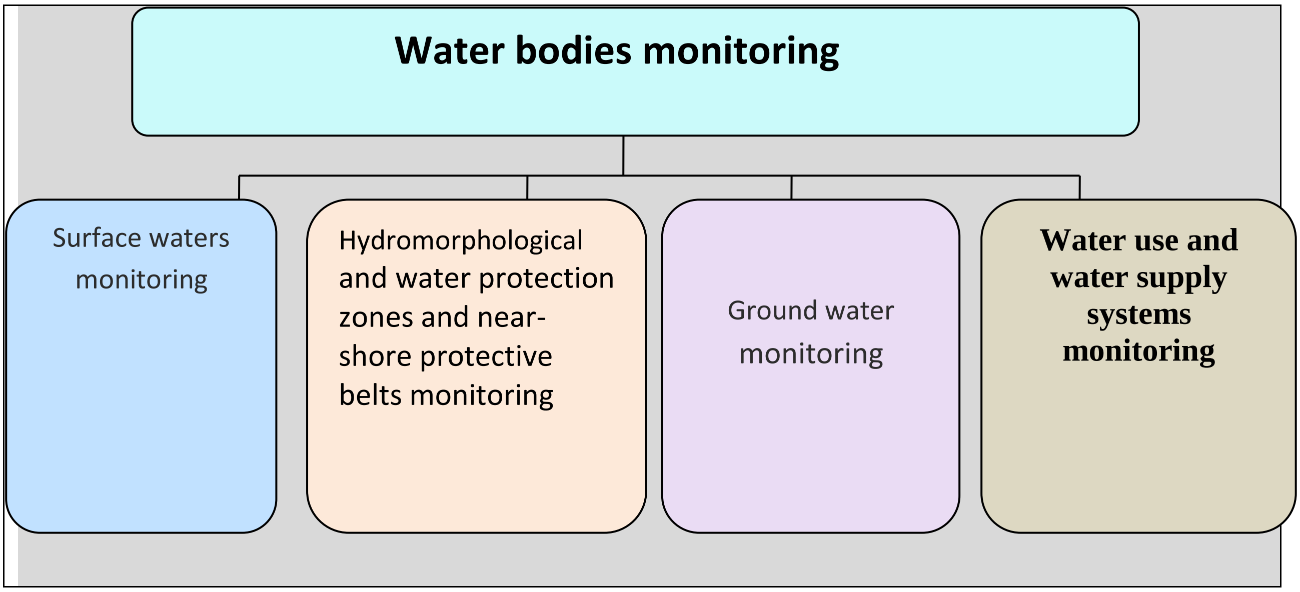

Figure 5. Structure of water resources monitoring in Russia

According to monitoring purposes, regular, emergency and special types of monitoring could be recognized.

Regular monitoring of surface waters includes monitoring of hydrological parameters (water level and discharge, sediment concentration, temperature, ice phenomena and water quality), hydromorphology, water supply and use and conditions of water protection zones. Regular monitoring at catchment level consists of hydrometeorlogical parameters (precipitation, snow, temperature, soil humidity). Emergency monitoring is done during extreme water level, water quality and ice events.

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 limb. During ice conditions, discharge measurements are done every 10-20 days, and during ice breakup – as often as possible. The frequency of water quality measurement is regulated by RosHydroMet protocol (Table 3) based on gauging station level.

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 (MPC) differ due to different economic activities are used: water pollution index (WPI) and specific combinative water quality index (WQI).

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

where: $\boldsymbol{C_i}$ – concentration of i pollutant, ***MACi*** - maximum allowable concentration of i pollutant.

WQI is being calculated iterative:

$$\boldsymbol{\beta_{mean} = \frac{\Sigma_1^{n_{ij}}\beta_{ij}}{n_{ij}}},$$

where: $\boldsymbol{\beta_{mean}}$ – mean value of multiples of MAC exceeding, n_{ij} – number of MAC exceeding, $\boldsymbol{\beta_{ij}}$ – MAC of if-components.

$$\boldsymbol{S_{\beta_i} = \beta_i \cdot 0.025 + 3},$$

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

$$\boldsymbol{S_i = S_{\alpha i} \cdot S_{\beta_i}},$$

where $\boldsymbol{S_i}$ - generalized assessment score for few water bodies.

$$\boldsymbol{S_A = \sum S_i}.$$

Table 3. Requirements for water quality monitoring at RosHydroMet stations

Monitoring station rank (category)	Frequency			
	Daily	Each ten days	Monthly	Each hydrological seasons
1	Temperature, DO, conductivity, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main (2-3) trace contaminants concentrations, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main ions, trace contaminants concentrations, visual observations, nitrogen (nitrites, nitrates, ammonia), phosphorus, silicium, petrochemicals, SSAS, phenols, pesticides, heavy metals
2	Visual observations	Temperature, DO, conductivity, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main ions, trace contaminants concentrations, visual observations, nitrogen (nitrites, nitrates, ammonia), phosphorus, silicium, petrochemicals, SSAS, phenols, pesticides, heavy metals
3	na	na	Na / available only during high water events	Extended program: temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main ions, trace contaminants concentrations, visual observations, nitrogen (nitrites, nitrates, ammonia), phosphorus, silicium, petrochemicals, SSAS, phenols, pesticides, heavy metals **Short program (allowed):** Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations
4	na	na	na	Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations

where S_A - combinative water quality index.

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

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

2.4 Belarus

Observations of the state of the environment are conducted under the National Environmental Monitoring System (NEMS). Monitoring is coordinated by the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus (Minprirody). An overview gives Figure 6.

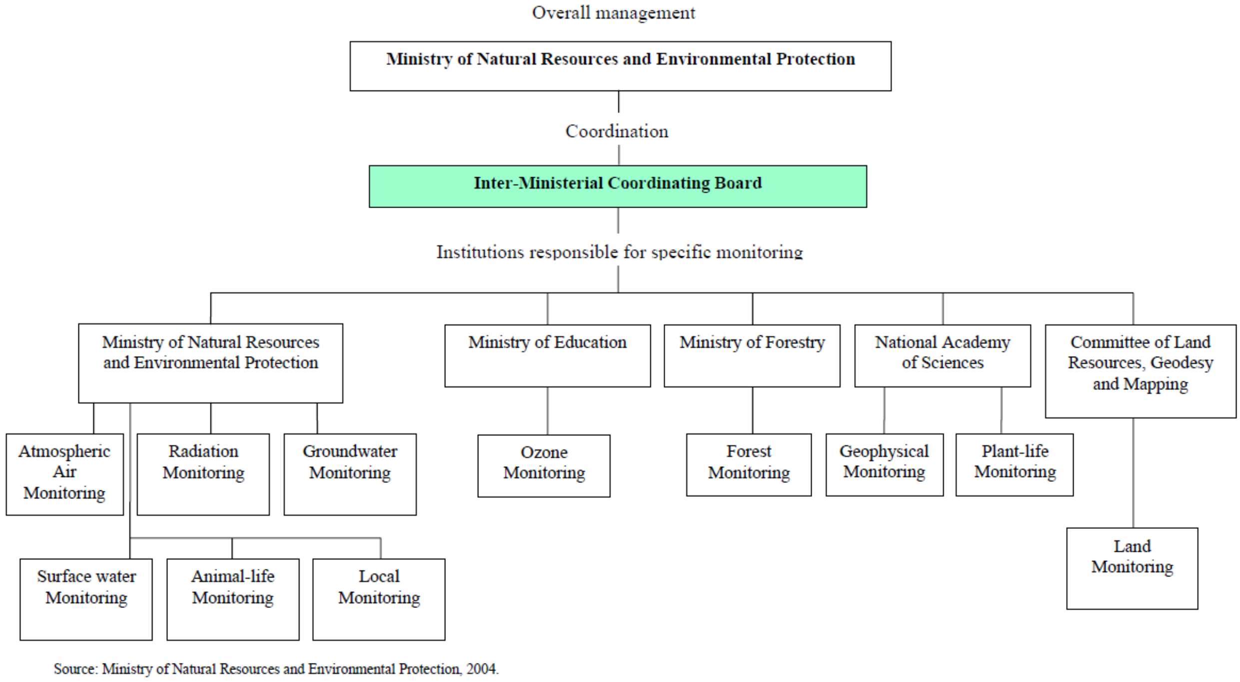

Figure 6. Responsibilities for Monitoring in Belarus

The main list of monitored parameters is provided in Annex 2. For each type of monitoring there is an Information and Analytical Centre. But also, the Main Information and Analytical Centre of the NEMS provides information. The NEMS program is heavily underfinanced but its network is being expanded and the quality of measurements improved (UN 2005).

Monitoring of surface waters

Hydrological, hydrochemical and hydrobiological parameters are regularly observed. Most observation points are near large urban areas and industries with a significant adverse impact on the water environment. Since 2003 water sampling and analysis has started at 11 transboundary gauges. Since 2004, water quality has been monitored at 35 observation points on transboundary rivers (Figure 7). There is no automatic monitoring station to ensure continuous water quality monitoring in Belarus.

Figure 7. Surface Water observation network (UN 2005)

Monitoring of the hydrological regime of the rivers and water bodies takes part at 8 am and 8 pm local time (water discharge according to water level, water temperature and ice phenomena, and suspended and bottom sediments at some points). The Republican Hydrometeorological Centre (http://hmc.by, http://www.pogoda.by/) implements hydrological monitoring. Data are part of the State Water Cadastre.

The State Institution Republican Centre of Analytical Control in the Sphere of Protection of the Environment (http://analitcentre.by/ru) monitors the state of surface waters using hydrochemical parameters. Surface water quality reports use a water pollution index for chemical quality and three indices for biological quality. For chemical quality, the index is based on six parameters – dissolved oxygen, BOD-5, ammonia, nitrite, oil products and zinc.

The State Institution Republican Centre of Radiation Control and Environmental Monitoring (http://rad.org.by/) monitors the state of surface waters using hydrobiological parameters (phytoplankton, phytoperiphyton, zooplankton and zoobentos, 3 times per year).

Monitoring of ground waters

Groundwater represents 93% of total drinking water supply in Belarus and its quality generally meets drinking-water standards. However, in some areas, groundwater quality is compromised due to leaching from landfills, pesticide disposal sites, manure storage sites and abandoned military bases. At present, nitrate concentration in water in 70% of groundwater wells exceeds the limit value. Monitoring of ground waters is organized and conducted by the Republican Unitary Enterprise The Belorussian Research Geological Exploration Institute (http://geology.org.by/) and Central Hydrogeology Party BGE RUE “Belgeology”. Figure 8 shows the locations of the monitoring stations.

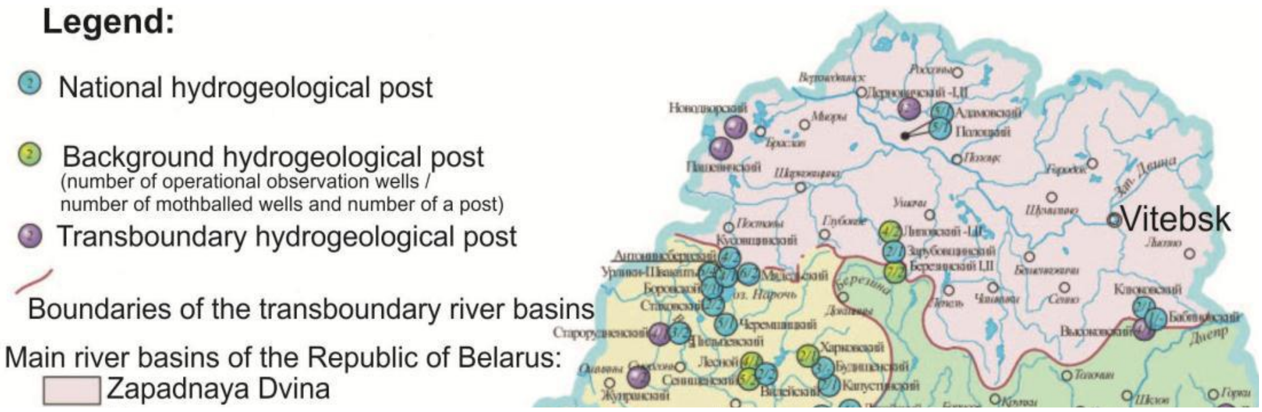

Figure 8. Geo-ecological stations

Sampling frequency of physical and chemical parameters is once a year, whereby ground water levels are measured 3 times a month (additionally: 101 automated gauges, four in Western Dvina). The Maximum Permissible Concentrations of Chemical Substances in Water Bodies for Domestic Use and Amenities are used to assess the state. In natural and lightly disturbed conditions, evaluation of ground waters quality is conducted according to Sanitary Norms and Rules (SanPiN 10-124 RB Drinking Water. Hygienic requirements for water quality in centralized systems of water supply. Quality control). As a result, 94.4% of the samples comply with sanitary and hygienic norms.

The Department for Hydrogeology and Monitoring of Ground Waters of the Republican Unitary Enterprise Belarusian Research Geological Exploration Institute (http://geology.org.by/otdel8.html) is the Information and Analytical Centre of Ground Water Monitoring.

Monitoring of land (soils)

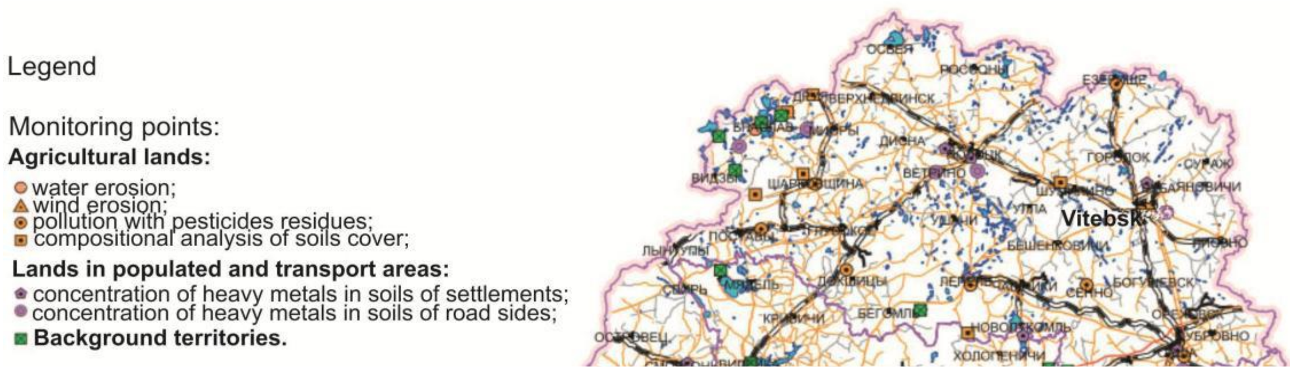

Figure 9. Monitoring points for agricultural lands, populated and transport areas and background territories

The Information-Analytical Centre of Land Monitoring of the NEMS operates on the basis of RUE “Information Centre of Land-Cadastral Data and Land Monitoring” (http://www.iczem.by/index.htm) of the State Committee of Property of the Republic of Belarus (Figure 9).

Local environmental monitoring

Exist 23 points where sewage discharge into surface water bodies in Western Dvina basin is measured (development of the network started in 2000). Over 90% of sewage waters are discharged into water bodies (of them 60% municipal, 16% industrial and 24% agricultural).
Ground waters and soils are monitored in areas, where identified or potential sources of pollution are situated (since 2005 and 2007, resp.).

Conclusions

The number of surface-water observation points on lakes and small rivers is very limited. Diffuse pollution of water bodies is not monitored. Belarus has improved its monitoring of transboundary rivers but decreased significantly the number of groundwater observation points (UN 2005). The existing monitoring system for surface waters in Belarus does not meet WFD criteria, in particular in the area of biological sampling and the assessment of the hydromorphological parameters of lakes.

There is no comprehensive observation network for land monitoring in Belarus.

The local monitoring provides information about the pollution load of major pollution sources and their compliance with environmental regulations. Furthermore, it helps in creating a national register of pollutant releases and transfers.

2.5 Ukraine

Surface water monitoring system in Ukraine is in process of reorganization according to Association Agreement and requirements of EU legislation. Formally, in the sphere of Environmental monitoring, the Decree of the Cabinet of Ministers of Ukraine (№391, 30.03.1998) is still in force, indicating 11 agencies responsible for the monitoring of different components of the Environment. Most of listed agencies and ministries do not exist anymore or were transformed/renamed. In fact, currently there are 2 main agencies providing monitoring of surface water: The State Agency of Water Resources of Ukraine (SWAU) and the State Emergency Service of Ukraine (SESU). SWAU, among others, has the following tasks related to the surface water monitoring:

- to provide water quality monitoring at control sites within main water abstraction facilities of complex functioning, water management systems of inter-sectoral and agricultural water supply;
- to ensure functioning of the state system of environmental monitoring, specifically by providing of radiological and hydrochemical observations at water objects of complex use, transboundary watercourses, water management systems of inter-sectoral and agricultural water supply, within the zones of nuclear power plants influence;

- to provide emergency monitoring of water objects;
- to provide water quality assessment and inform of the state executing bodies and municipal bodies;
- to develop of operational and long term prognosis of the change of ecological status of water objects and meliorated lands.

Functioning of the SWAU is directed and coordinated by the Cabinet of Ministries of Ukraine via the Minister of Ecology and Natural Resources.

The SWAU, with the main office in Kyiv, includes a number of regional water management organizations (basin water resources authorities, regional water management bodies, etc,). Organizations responsible for the Western Bug basin and Desna basin are Western Bug Basin Water Resources Authority (Lutsyk) and Desna Water Resources Authority (Chernigiv).

The SESU functioning is directed and coordinated by the Cabinet of Ministers of Ukraine via the Minister of Interior. Area of the SESU responsibilities is quite broad dealing mostly with emergency situations (preparedness, prevention, control), mitigation of the consequences of emergency situations, rescue operations, etc. However, as it is stated in the SESU legal provisions, activities in the sphere of hydrometeorology are also related to the SESU. Structural unit of the SESU which is responsible for hydrometeorological activities (including monitoring) is the Hydrometeorology Office.

The main task of Hydrometeorlogical Office regarding monitoring is formulated as “conducting of hydrometeorological, geliophysical observations, background radiation and basic observations on Environmental pollution**”.** Structural scheme of surface water monitoring is presented on Figure 10.

Figure 10. Surface water monitoring in Ukraine

Currently, both SWAU and SESU perform surface water monitoring based on their monitoring programs which are basically the same to those of the Soviet Union time. The SWAU does sampling quarterly analysing general physico-chemical parameters, heavy metals and radionuclides. There are 13 monitoring sites (7 of those are transboundary with Poland; 1 is transboundary with Belarus) in Western Bug basin, and 20 monitoring stations in Desna basin (6 of those are transboundary with Russian Federation).

Surface water monitoring programs of SESU for Western Bug and Desna basins are presented in Table 4.

Table 4. SESU surface water monitoring program

№	Station name	River	Station rank (category)	Frequency
Western Bug basin				
1	Bus'k	Western Bug	III	12 times a year
2	Kam'yanka-Buzka	Western Bug	III	12 times a year
3	vil Lytovezh	Western Bug	III	4 times a year
4	Volodymyr-Volynskyi	Luha	IV	4 times a year
5	Bus'k	Poltva	III	12 times a year
6	Lviv	Poltva	III	12 times a year
7	vil Mezhyrichchya	Rata	IV	4 times a year
8	Chervonohrad	Solokiya	IV	4 times a year
Desna basin				
1	Novgorod-Siversykyy	Desna	IV	4 times a year
2	Chernigiv	Desna	IV	12 times a year
3	Litky	Desna	III	12 times a year
4	Pokoshychy	Golovesnya	IV	4 times a year
5	Mutyn	Seym	IV	4 times a year
6	Schors (Nosivka)	Snov	IV	4 times a year
7	Kozelets	Oster	IV	4 times a year

Notes: Parameters are listed in the Annex (Metadatabase). Frequencies and list of parameters may vary depending on actual financial capacity of respective regional hydrometeorological organizations.

Assessment of surface water quality is made based on the values of Maximal Allowable Concentration (MAC) for certain hydrochemical parameters. Lists of the MAC values are presented in two documents:

- “Summarised list of maximal allowable concentrations and indicative safe levels (ISL) of harmful substances for water of fishery water objects”, Moscow, 1990 (Обобщенный перечень предельно допустимих концентраций (ПДК) и ориентировочно безопасных уровней (ОБУВ) вредных веществ для воды рыбохозяйственных водоемов. Москва, 1990 г.)

- "Sanitary rules and norms of surface water protection against pollution SanPiN №4630-88", Ministry of Health of USSR, Moscow, 1988 (Санитарные правила и нормы охраны поверхностных вод от загрязнения СанПиН № 4630–88. Министерство здравоохранения СССР, Москва, 1988 г.).

It should be noted that MAC for fishery water objects in general are more strict compare to MAC for water objects of other types of use. However, this approach to surface water assessment and classification is not in line with WFD requirements.

In order to harmonize Ukrainian national surface water monitoring system with WFD requirements and European practices the draft Decree of the Cabinet of Ministers of Ukraine "On approval of the Order of the state monitoring of waters" has been developed in 2017 with involvement of all stakeholders and respective agencies. This document sets up three types of monitoring (surveillance monitoring, operational monitoring, and investigative monitoring) and designates responsible agencies. They are: Ministry of Ecology and Natural Resources of Ukraine (coastal waters: biological parameters, general physico-chemical parameters, morphological parameters); the SWAU (rivers and lakes: specific pollutants, priority substances; monitoring of water bodies where water abstraction for drinking water supply is taking place); the SESU (rivers and lakes: biological parameters, general physico-chemical parameters, hydromorphological monitoring). Currently, the draft Decree is under consideration and approval by the Cabinet of Ministers of Ukraine.

2.6 Transnational monitoring/data exchange

2.6.1 Western Bug

The trans-boundary water management agreement has a long history. The agreement between Poland and Soviet Union, signed in 1964 (https://treaties.un.org/doc/Publication/UNTS/Volume%20552/volume-552-I-8054-English.pdf) regulates the system of monitoring the pre-border part of the Bug River.

Nowadays, the transboundary cooperation in Western Bug basin is performed by the Western Bug Basin Water Resources Authority. For instance, there was an international project entitled "Development of Polish-Belorussian-Ukrainian water policy in Bug basin" http://docplayer.pl/15064621-Projekt-wytycznych-do-opracowania-mapy-hydrograficznej-zlewni-bugu.html). The main results of the project are:

- preparation of the documents for establishing and functioning of trilateral Ukrainian-Polish-Belorussian Basin Commission;
- working out of methodology for the assessment of the basin water resources;
- development of the entire basin hydrographical map, database, information exchange.

2.6.2 Desna

Desna Water Resources Authority is responsible for transboundary cooperation and transboundary data exchange in Desna basin. However, because of current situation in relations between Ukraine and Russian Federation joint sampling and information exchange has been terminated since the 2nd half of 2014. Transboundary sampling sites were moved to the territory of Ukraine.

2.6.3 Western Dvina

Exchange of data and information is very limited in Western Dvina river basin, because there is no framework agreement between LV, BY and RU. Monitoring network on Western Dvina basin is presented on Figure 11.

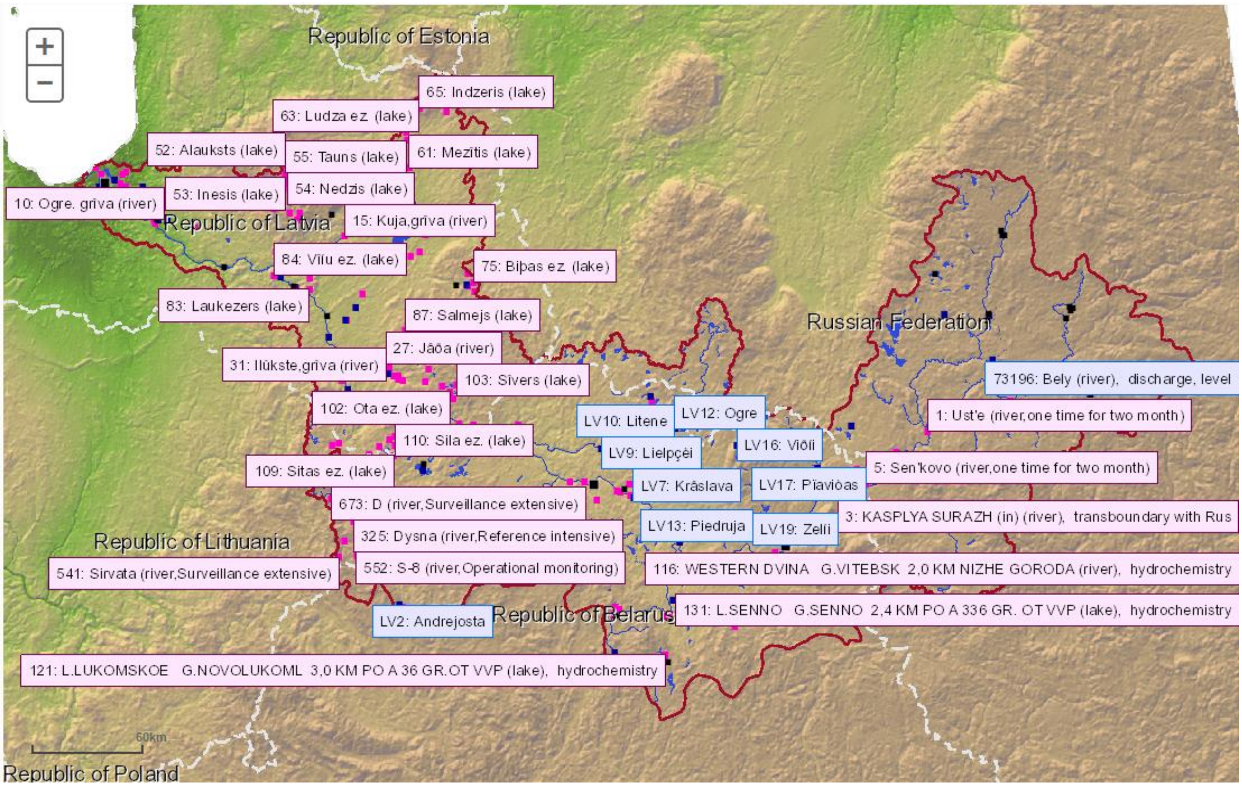

Figure 11. Surface water monitoring network in Western Dvina river basin

Nevertheless, Belarus has actively cooperated with its neighbours over the past few years to monitor transboundary rivers. Water-monitoring network were optimized on the Belarusian stretches of the rivers Dnepr, Neman, Pripyat, Western Bug and Western Dvina. The riparian States have agreed on monitoring parameters and sampling methods and analysis as well as on upgrading laboratory equipment and training monitoring experts (funds from EU/Tacis, the Global Environment Facility (GEF), the United Nations Development Program (UNDP) and the Governments of Canada and Sweden).

Chapter III. Transnational data consistency

3.1 Consistency check of runoff of Western Bug

Hydrological runoff data are essential for all hydrological, hydro-chemical and hydro-biological investigations as well as water management tasks. Mostly, the water level is measured at a hydrological station and - less frequently - the runoff. With the help of the water level - runoff- relationship, it is possible to determine runoff out of the water level observations. The water level - runoff relationship is not constant over time. Floods and low flows can alter the riverbed, which changes the water level - runoff relationship. Therefore, a frequent control of this relationship is essential. Maintenance of the stations and control measurements differ nationally, which can cause quality problems of the data. To investigate, if such problems occur at the Ukrainian Polish border, three runoff stations are investigated (Table 5).

Table 5. Runoff and precipitations stations

Station	Parameter	Country	Long	Lat	Code	km from mouth	Area (km²)
Lytovezh	Runoff	UA	24.1881	50.6514	---	602	6740
Wlodawa	Runoff	PL	23.5500	51.5500	151230040	378	14410
Wyszkow	Runoff	PL	21.4584	52.59278	PL01S0701_1220	34	39119
Lviv	Precipitation	UA	23.9650	49.8075	33393	319 m height	---
Kamianka- Buzka	Precipitation	UA	24.3400	50.1146	33288	212 m height	---
Siedlice	Precipitation	PL	22.25	52.25	WMO 123850	149 m height	---
Brest	Precipitation	BY	23.8965	52.1086	WMO 33008	146 m height	

3.1.1 Methods

An Artificial Neural Network (ANN) serves here as a model for runoff prediction of the station Wlodawa. Neighbouring runoff and precipitation stations are used as explaining variables. Large simulated deviations from observed runoff in Wlodawa can give hints to erroneous data.

The R-package "neuralnet (version 1.33)" was applied. Training of neural networks uses backpropagation, resilient backpropagation with (Riedmiller, 1994) or without weight backtracking (Riedmiller and Braun, 1993) or the modified globally convergent version by Anastasiadis et al. (2005).

Based on the Wikipedia entry "Artificial neural network", some basics are given: ANN is based on a collection of connected units called artificial neurons. Each connection between artificial neurons can transmit a signal from one to another. The artificial neuron that receives the signal can process it and then signal artificial neurons connected to it. In common ANN implementations, the signal at a connection between artificial neurons is a real number, and the output of each artificial neuron is calculated by a non-linear function of the sum of its inputs. Artificial neurons and connections typically have a weight that adjusts as learning proceeds. The weight increases or decreases the strength of the signal at a connection. Typically, artificial neurons are organized in layers. Different layers may perform different kinds of transformations on their inputs. Signals travel from the first (input), to the last (output) layer, possibly after traversing the layers multiple times.

Figure 12 shows a feedforward three-layer ANN: In our case constitute the neighbouring runoff and precipitation stations the Input layer. The Output layer is the runoff of Wlodawa (only one neuron). The number of hidden layers and the number of nodes in each hidden layer are usually determined by a trial-and-error procedure. A training process, also called learning, is employed to find optimal weight matrices. Back-propagation is applied for training the ANN. To minimize the network error function, a gradient descent technique is applied. Each input pattern of the training data set is passed through the network from the input layer to the output layer. The network output is compared with the desired target output, and an error is computed. This error is propagated backward through the network to each node, and correspondingly the connection weights are adjusted.

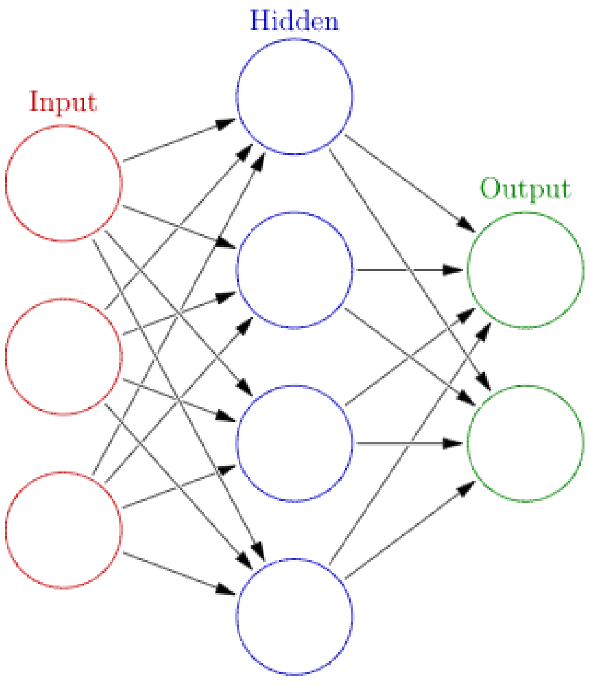

Figure 12. Feedforward three-layer ANN (By Glosser.ca - Own work, Derivative of File:Artificial neural network.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24913461)

3.1.2 Results

After a first visual inspection, the runoff station Lytovezh is suspected to have erroneous runoff values. Therefore, an ANN was set up to test, if the runoff of Wlodawa is determinable from the upstream station Lytovezh and the precipitation stations Lviv and Kamianka-Buzka. Coefficient of determination (R^2) between modelled (ANN) and observed runoff of Wlodawa is low (0.48), which means that uncertainty of predicting runoff in Wlodawa from the mentioned three variables is still high.

Therefore, further explaining variables were included in the ANN: the downstream runoff station Wyszkow and the precipitation stations Siedlice and Brest. The result of the ANN (two hidden layers with 5 and 3 neurons) shows very good results (R^2=0.84). Congruence between observed and modeled runoff is high until a runoff of 120 m³/s (Figure 13 and Figure 14). Simulation of higher runoffs is more uncertain, mostly simulated values are too low.

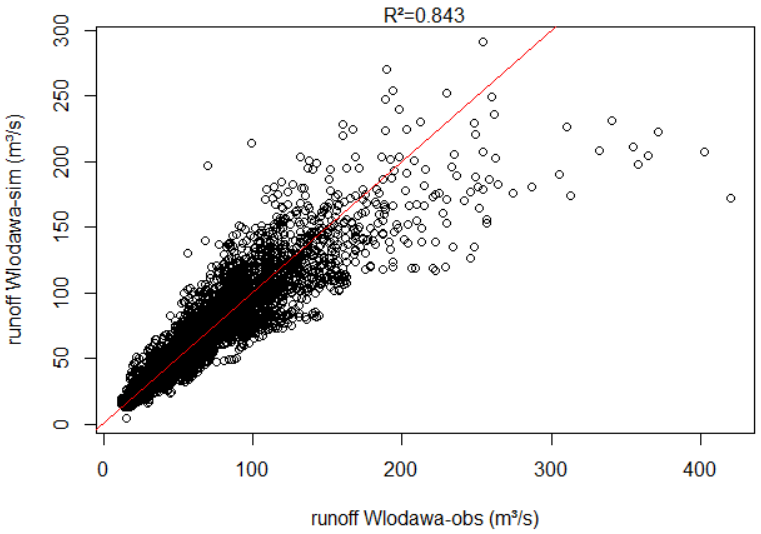

Figure 13. Scatterplot of simulated and observed runoff of Wlodawa

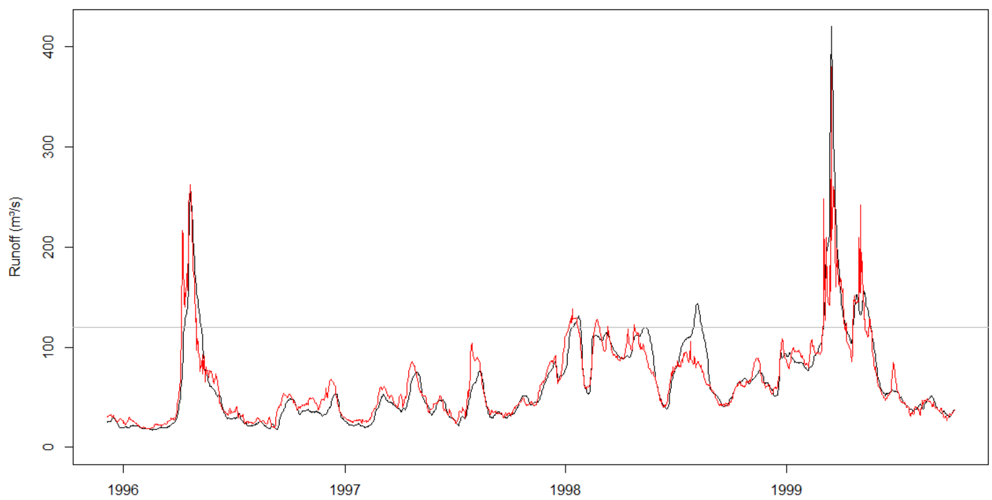

Figure 14. Hydrograph of simulated (red) and observed (black) runoff of Wlodawa

To check, if single runoff values are not plausible, all three observed and the simulated runoff time series were plotted. Over longer periods, measurements seem consistent (Figure 15). Upstream runoff (Lytovezh) is lower than Wlodawa and this - on his part - is lower than Wyszkow. Only in May 1991, runoff of Lytovezh seems too high. Simulated runoff matches quite well the observed runoff in Wlodawa. This indicates consistent runoff values of these three stations. Greatest uncertainties lay in the simulation of higher runoffs. Apparently, still not all influencing variables were captured in the model.

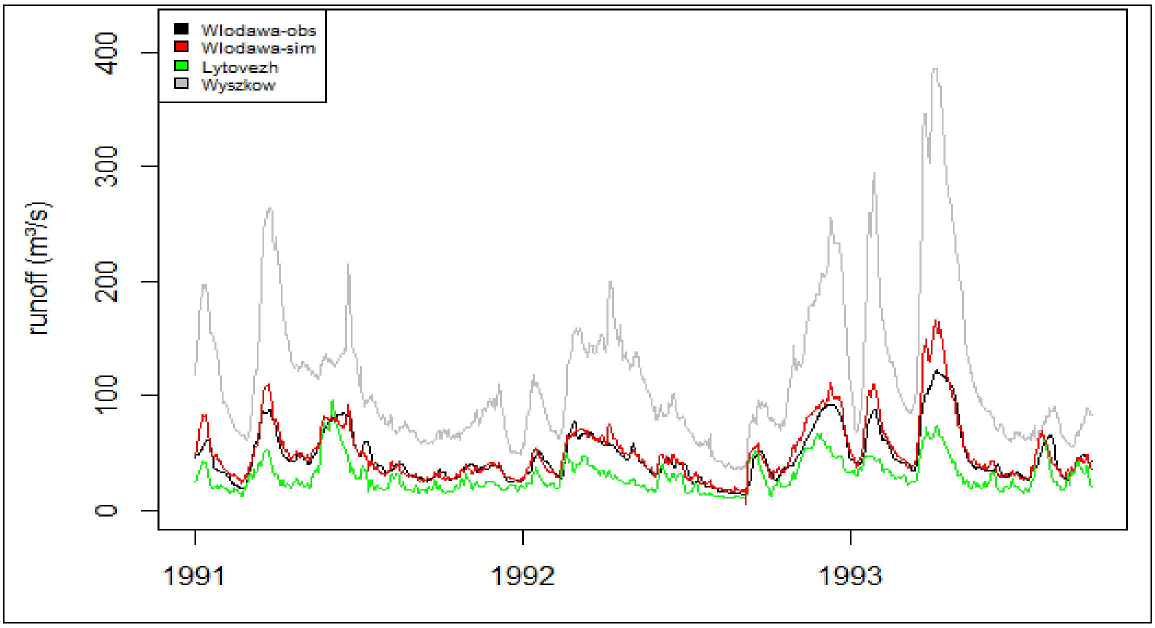

Figure 15. Hydrograph of simulated (red) and observed (black) runoff of Wlodawa and the upstream station Lytovezh (green) and downstream station Wyszkow (grey)

However, on Figure 16a and Figure 17a, several runoff values of Lytovezh (green line) are remarkably higher than the runoff of the downstream station Wlodawa, especially values above 120 m³/s (grey horizontal line). In these periods, congruence between modelled and observed runoff in Wlodawa is lower. The model (ANN) could not reproduce these situations well. There are different explanations for this:

- Upstream of Lytovezh there is the instream reservoir Dobrotvir, which serves as cooling pond for a thermal power station. Furthermore, the reservoir Skomorokhy (downstream of the reservoir Dobrotvir) is apparently only managed for flood control. The very similar shape of the flow peaks indicates that the reservoirs were opened for a short time to relieve them during high water flows.
- After Lytovezh, the river Western Bug becomes very natural, with lot of meanders, backwaters and forests (see for example Figure 18). Flood plains are wide, so that high flows are effectively retained and hydrograph flattens. Furthermore, no large tributaries enter Western Bug between Lytovezh and Wlodawa.

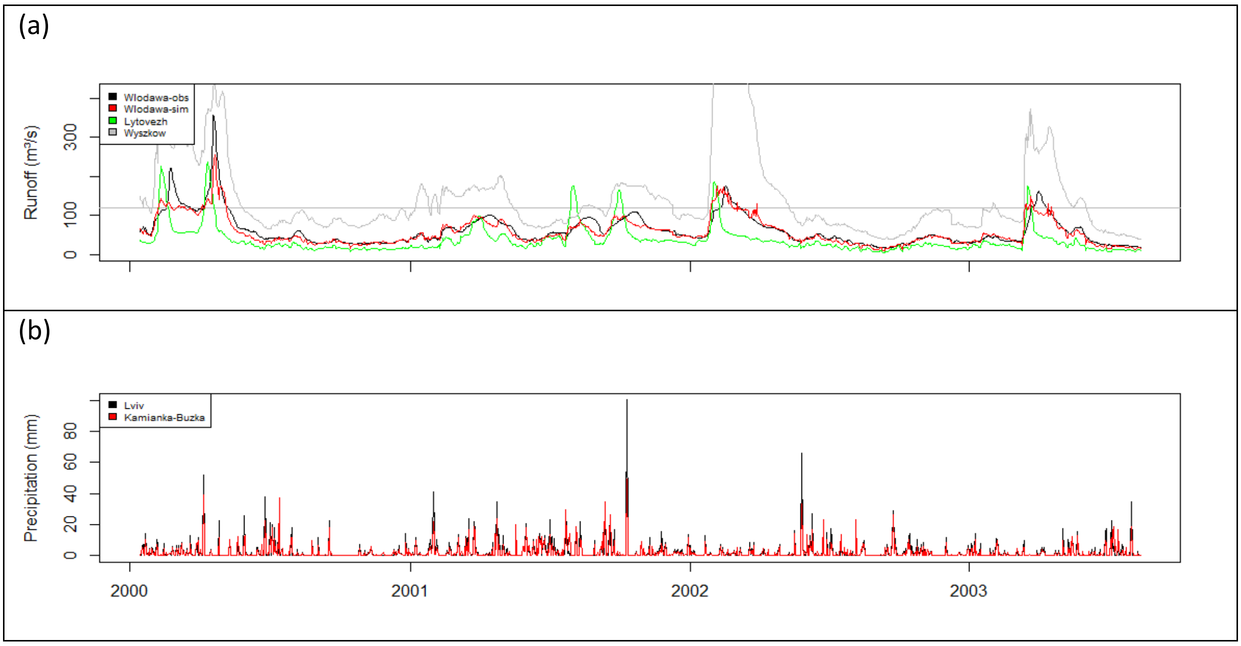

Figure 16. Hydrograph of simulated (red) and observed (black) runoff of Wlodawa and the upstream station Lytovezh (green) and downstream station Wyszkow (grey), Period 2000-2003

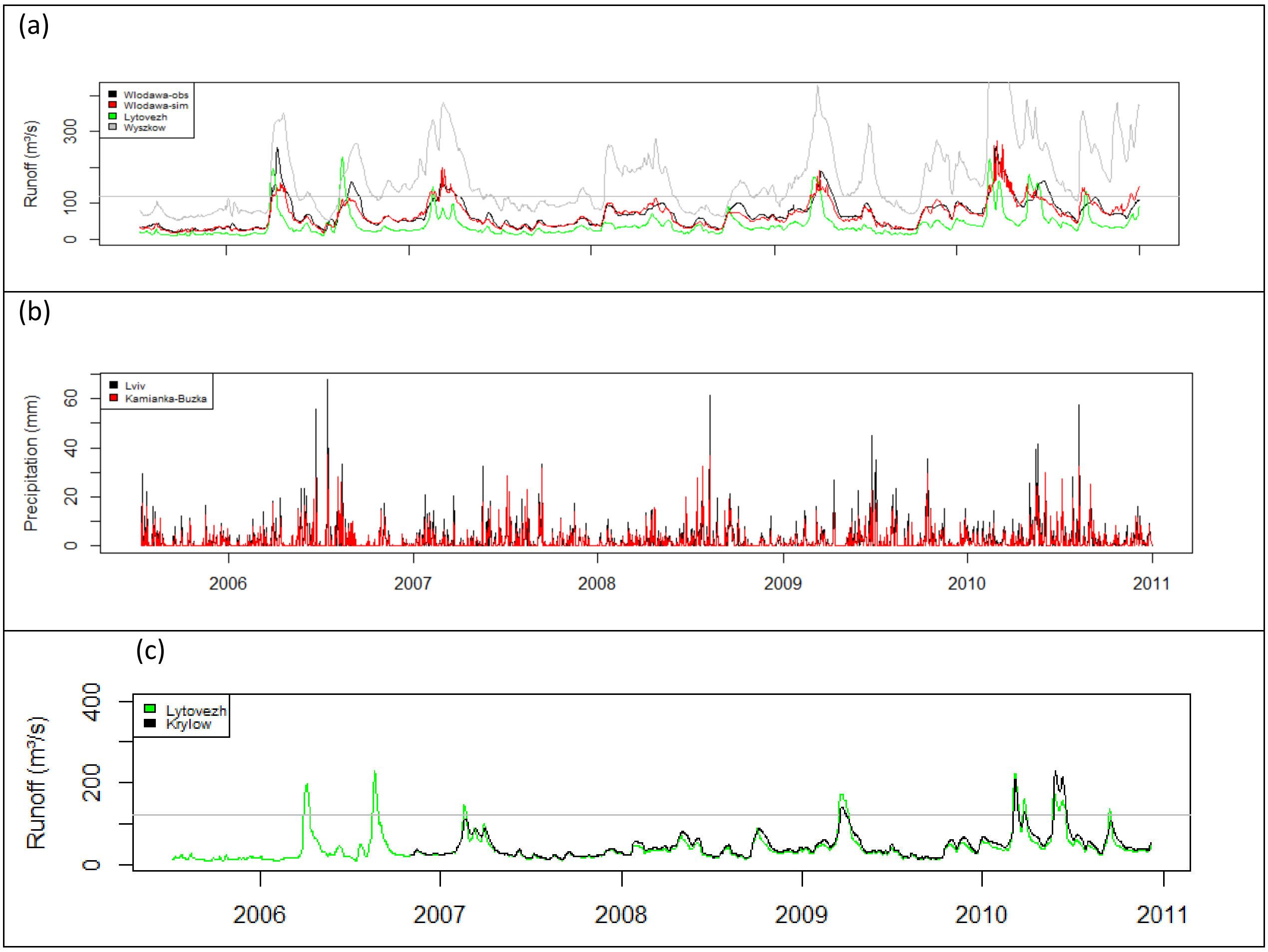

Figure 17. a) Hydrograph of simulated (red) and observed (black) runoff of Wlodawa and the upstream station Lytovezh (green) and downstream station Wyszkow (grey), Period 2005-2011, b) precipitation sums of two stations in the basin of Lytovezh, c) hydrograph of Lytovezh and Kryłow

- However, it is questionable if retention can be so effective. For example, in July/August 2001, runoff of Lytovezh exceeds (177 m³/s) significantly the values in Wlodawa and Wyszkow some days later (95 and 128 m³/s, resp.; see Figure 16). Misreadings or outdated water level-runoff relationships can cause such erroneous runoff values. Based on the available precipitation stations Lviv and Kamianka-Buzka (which are situated in the river basin), it is not possible to judge, whether observed runoff in Lytovezh is plausible. In many occasions, there are no hydrologic reactions onto high precipitation, and in other occasions, high runoffs occur without precipitation at these two stations. Probably, these two stations are not representative for the basin until Lytovezh. An indication of having erroneous data gives the comparison of the hydrographs of Lytovezh and Kryłow, a station with only 12 km linear distance from Lytovezh (Figure 17c).

Suspicious values of Lytovezh, like in 03.'07, 04'09, 04'10 and 10'10 (Figure 17a) show higher values than Kryłow, which should be the contrary.

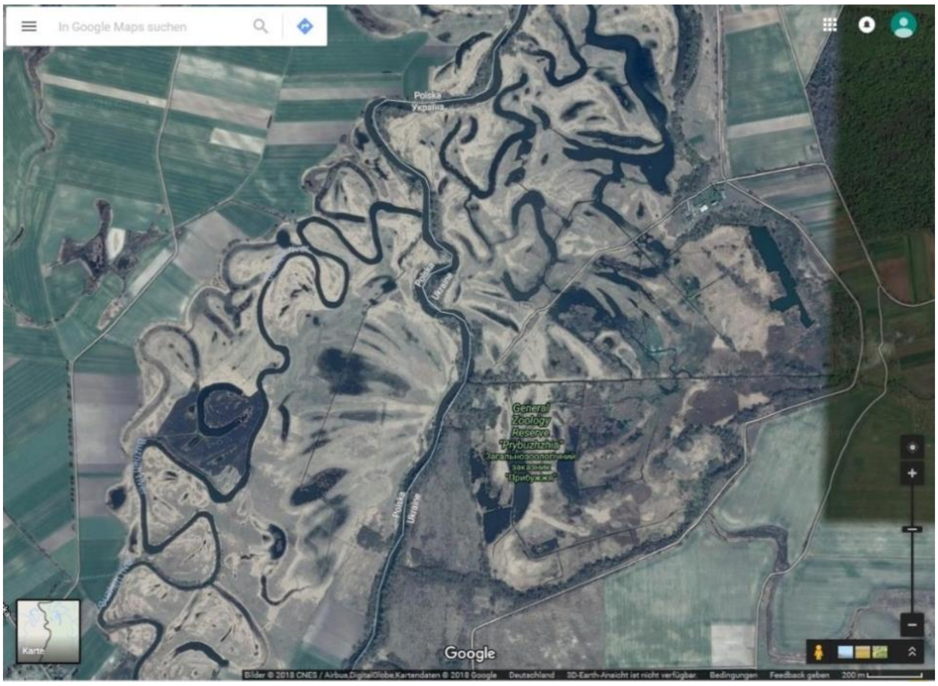

Figure 18. Google Maps picture of the Reserve "Prybuzhzhia", a floodplain at the Ukrainian/Polish border

Summarizing, the consistency analysis revealed that some of the higher runoff values of the station Lytovezh seem to be erroneous. Especially in periods with high runoff, the transboundary exchange of reliable data is vital to manage possibly problematic situations properly (control of water masses and pollutions).

To find out, if more values or other stations are effected, a more detailed analysis is necessary. Management data of the reservoirs and more precipitation stations are necessary.

Furthermore, an insight into the applied water level runoff relationships would help to discover wrong values.

3.2 Consistency of water quality data of Western Bug

Water quality occupies a key role for the ecological state and the resources management of rivers. The state of water quality comprises of multiple dimensions. Regular monitoring aims at the identification of pressures and control the success of implemented measures. Ukraine, Poland and Belarus, the three countries that share Western Bug's catchment, have set up independent water quality monitoring programs. As described in chapters 1 and 2, legislative requirements and resulting monitoring network differ among these countries.

Due to legislative and institutional changes as well as the intersecting responsibilities on regional and national level, several institutions conduct monitoring programmes in surface waters. For more than 300 km of its course, Western Bug is a boundary river between the adjacent countries. The central line of the rivers serves as dividing mark. Consequently, in these sections the river belongs to both countries and is monitored on both sides.

For our study, we want to assess the consistency of water quality datasets in space and time surveyed by the different institutions. We compile the data into a common database and compare the annual mean values and annual standard deviations.

3.2.1 Material and Methods

The Table 6 lists the data sources available for a consistency comparison in the part of Western Bug catchment located in Lviv Oblast. The Environmental Inspectorate (EnvIns), Hydrometeorological Service (HMS) and Western Bug River Council (WBRC) are institutions in charge of legally appointed monitoring tasks. Western Bug rehabilitation project (WQ80) was conducted to establish state infrastructure planning office in the late Soviet Union period. International Water Alliance Saxony IWAS was a research project from 2008 – 2013 implemented in five regions around the world, including one in the Ukrainian part of the Western Bug basin. Among the monitoring stations, four were covered in all data sets: Western Bug in Busk upstream and downstream of the confluence with Poltva River, Western Bug in Kamianka Buzka and Poltva upstream of the confluence with Western Bug. We selected Kamianka Buzka sampling site for the consistency check. For the years 1990, 1995, 2001, and 2011, means and standard deviations of the data from different institutions are compared. The t-test assesses equality of means, while the f-test is applied for equality of variance.

Table 6. Sources of water quality monitoring data in upper Western Bug catchment 1977 - 2015

Abbreviation	Long title	Number of monitoring stations	Number of parameters	Monitoring period [a]	Monitoring frequency [a^{-1}]
WQ80	Western Bug Rehabilitation Project	10	36	1977 – 1990	12
EnvInv	Lviv oblast Environmental Inspectorate emission control monitoring	48	39	2000 – 2008	0.25 – 6
HMS	Hydrometeorological Service	11	11	1990 – 2011	12
WBRC	Western Bug River Council	5	23	1993 – 2015	4
IWAS	International Water Alliance Saxony – Western Bug regional project	8	11	2009 – 2012	168*

in total four weekly measurement campaigns with hourly resolution throughout the project

It was chosen to assess the consistency of neighbouring water quality sampling sites. Data were available from four institutions. Table 7 gives a short summary of the sampling layout. The stations cover the entire length of Western Bug, from Busk, 24 km downstream of the source, to Barcice, 17 km upstream of the confluence with Narew River. Two Ukrainian and Polish institutions provided data respectively, while no data were available from Belorussian institutions. 2011 is the year with the widest spatial coverage of data. Therefore, it is used for the analysis.

Table 7. Institutions in charge of water quality monitoring in Western Bug river 2011

Abbreviation	Long title	Number of sampling sites	Number of parameters	Monitoring frequency [a^{-1}]
HMS	HydrometeorologicaService	4	11	12
WBRC	Western Bug River council	5	23	4
WIOSL	WIOS Lublin	8	31	3 - 4
WIOSW	WIOS Warsaw	6	31	1*

**only annual means were available for these stations*

3.2.2 Results

Comparison between Ukrainian data sources

Figure 19 exemplarily concludes the numbers of water quality samples per year taken from different monitoring institutions upstream of Kamianka Buzka discharge gauge (Ukrainian part). The figure illustrates the varied history of water monitoring and management in the region. During Soviet times, data sampling was conducted in the context of a river rehabilitation project. Although the project perused a consistent program, in terms of parameters and sampling sites, the number of samples varies strongly throughout the years. From 1990 on, data from the HMS of the Ukraine could be obtained. The HMS conducts the most consistent sampling program in this study, with continuous sampling sites and parameters. The times of political change in 1992 and economic hardship in the late 1990s resulted in reduced sampling intensity. The WBRC provides sampling data since 1994, it is active with only one sampling site and quarterly samples in the region. For the period 2000 – 2008, data from the EnvInsp was included. The samples represent reference measurements for emission-based polluter control. The number of samples per year varies strongly.

Table 8 concludes the results of the consistency assessment of biochemical oxygen demand in five days concentrations BOD5 at Kamianka Buzka water quality sampling site. The means and variances of HMS and WQ80 in 1990 are compared with two-sided tests. For both aspects the hypothesis of same means and variances cannot be rejected, giving weak indication, that the descriptive properties of samples from both institutions are consistent. In the comparison for 1995, the hypothesis of equal means is rejected. For 2001, none of the institutions provides comparatively consistent samples in both distributional aspects.

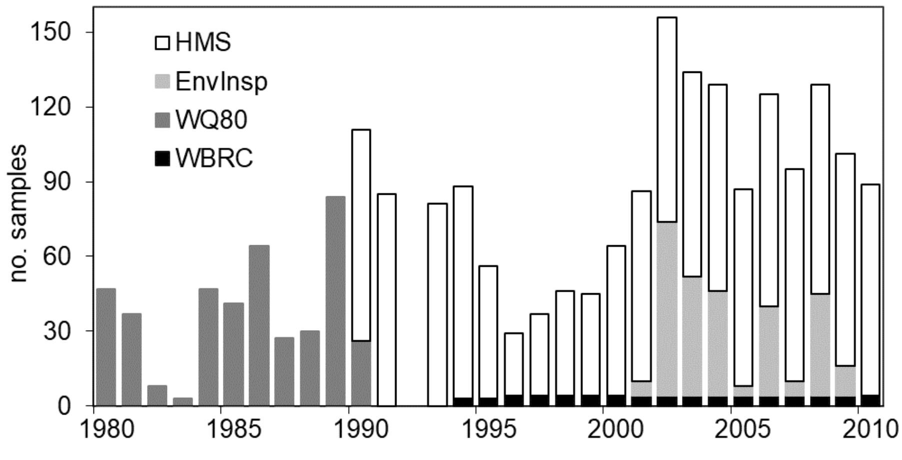

Figure 19. Numbers of water quality samples per year upstream of Kamianka Buzka gauging station in the Period 1980 – 2010.

Figure 20 provides a synoptical view on the BOD5 concentration time series of the different data sources. It confirms the results from the statistical consistency assessment. Some overall tendencies appear through all data sources: mean and variance of BOD5 concentrations are decreasing over time, especially in the period 1990 – 2005.

Table 8. Consistency assessment for mean and variance of annual biochemical oxygen demand in five days concentrations BOD5 at Kamianka Buzka water quality sampling site from different institutions. P-values in red indicate rejected hypothesis of same means or variances

Year	Institution	compare with	No. of observa-tions	Mean [mg/l]	St. deviation [mg/l]	Coeff. of vari. [-]	p(t-test)	p(F-test)
1990	HMS	WQ80	5	11.1	5.4	0.486	0.084	0.057
	WQ80		13	18.8	12.5	0.664		
1995	HMS	WBRC	9	3.8	1.1	0.289	0.004	0.933
	WBRC		3	7.7	0.8	0.103		
2001	HMS	WBRC	13	3.7	1.4	0.378	0.010	0.040
	WBRC	EnvIns	4	6.4	0.3	0.046	0.029	0.004
	EnvIns	HMS	4	12.9	2.9	0.224	0.009	0.031
2010	HMS	WBRC	13	3.7	1.1	0.297	0.219	0.501
	WBRC	IWAS	3	5.1	1.1	0.215	0.063	0.012
	IWAS	HMS	10	8.6	11.6	1.348	0.023	>0.001

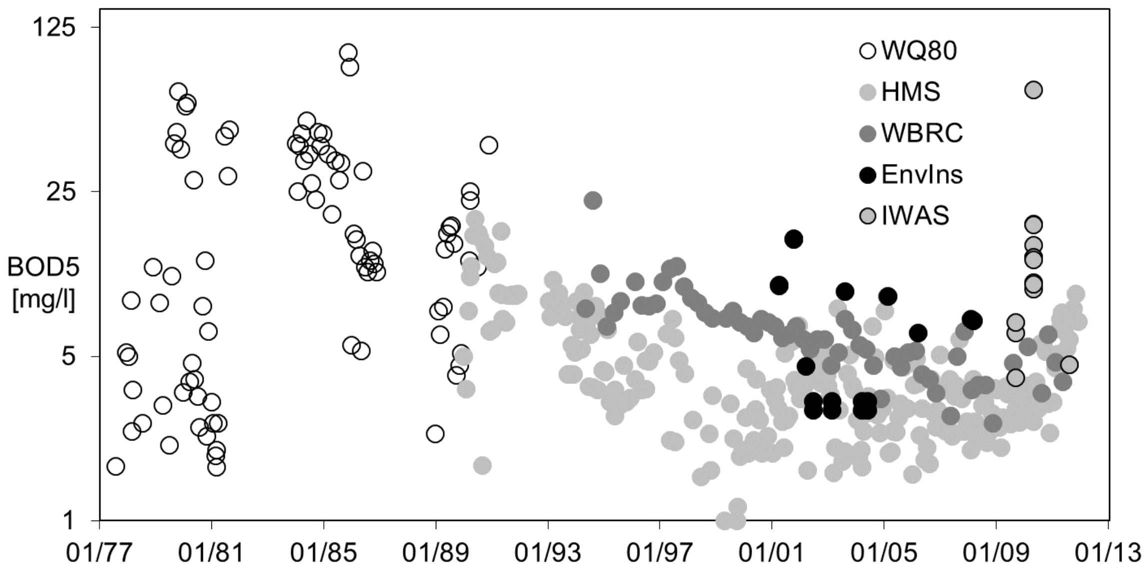

Figure 20. Biochemical oxygen demand in five days (BOD5) concentrations at Kamianka Buzka water quality sampling site in the period 1977 – 2013

Table 9. Consistency assessment for mean and variance of annual oxygen concentrations at Kamianka Buzka water quality sampling site from different institutions. P-values in red indicate rejected hypothesis of same means or variances

Year	Institution	compare with	No. of observa-tions	Mean [mg/l]	St. deviation [mg/l]	Coeff. of vari. [-]	p(t-test)	p(F-test)
1990	HMS	WQ80	5	5.6	1.6	0.286	0.108	0.0152
	WQ80		13	5.2	2.8	0.538		
1995	HMS	WBRC	9	10.0	2.5	0.250	0.309	0.155
	WBRC		3	8.9	0.6	0.067		
2001	HMS	WBRC	13	5.0	1.0	0.200	>0.01	0.140
	WBRC	EnvIns	4	8.4	0.3	0.036	>0.01	0.983
	EnvIns	HMS	4	6.3	0.3	0.048	0.02	0.135
2010	HMS	WBRC	13	6.8	1.8	0.265	0.829	0.263
	WBRC	IWAS	3	7.2	2.4	0.333	0.212	0.021
	IWAS	HMS	41	4.2	1.3	0.310	>0.01	0.076

Table 9 concludes the results of the consistency assessment of oxygen concentrations at Kamianka Buzka water quality sampling site. For both, mean value comparisons of 1990 and 1995, the hypothesis of equal means is not rejected. In contrast, 1990 variance comparison suggests a difference in variance. All comparisons for 2001 result in strong indication of differing means but similar variances. For 2011, comparison of the IWAS data with HMS results in differing means, while comparison of IWAS and WBRC indicates differing variances. The time series representation of O2 concentration on ***Figure 21*** visualizes similar means of data sources in the 1990s. In contrast, in the 2000s systematic differences prevail in the data sets.

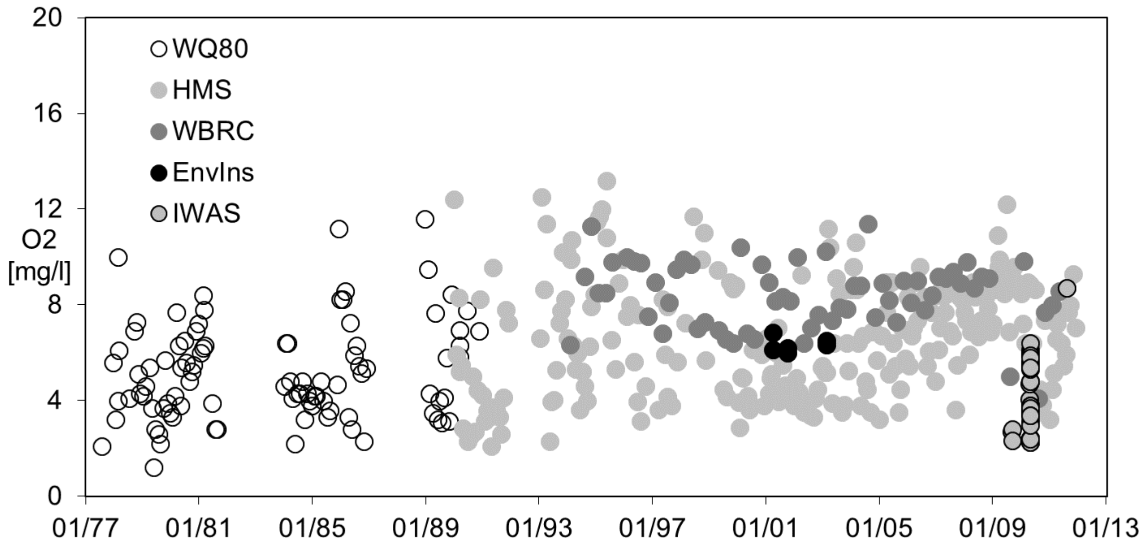

Figure 21. Dissolved oxygen (O2) concentrations at Kamianka Buzka water quality sampling site in the period 1977 – 2013

Table 10. Consistency assessment for mean and variance of annual ammonia nitrogen concentrations at Kamianka Buzka water quality sampling site from different institutions (1990). P-values in red indicate rejected hypothesis of same means or variances

Institution	compare	No. of observations	Mean	Standard deviation	Coeff. of vari. [-]	p(t-test)	p(F-test)
HMS	WQ80	4	5.9	2.6	0	0.108	0.869
WQ80		13	9.3	3.4	0		
HMS	WBRC	9	4.4	2.5	0	0.263	0.288
WBRC		3	3.1	0.9	0		
HMS	WBRC	13	1.2	1.8	1	0.500	0.012
WBRC	EnvIns	4	1.5	0.3	0	0.096	0.352
EnvIns	HMS	4	0.9	0.5	0	0.638	0.069
HMS	WBRC	13	0.9	0.5	0	0.048	0.093
WBRC	IWAS	3	1.7	0.3	0	0.337	0.031
IWAS	HMS	41	2.0	1.0	0	>0.00	0.017

Among the three water quality constituents assessed in detail, ammonia nitrogen, in ***Table 10*** shows the best agreement among the data sources. For the datasets from the 1990s, all equality hypothesis are not rejected and for 2001 only equality of variance among HMS and WBRC is rejected. For 2010, equal means for HMS and WBRC are rejected. The IWAS data set again shows the strongest dissimilarity of statistical properties, compared to the other data sets.

The station specific comparison of three wastewater related pollutants permits insight into the challenge of consistent water quality monitoring. The patterns of dissimilarity differ among the water quality parameters, years and institutions. A specific challenge of the data set seems to originate from the underrepresentation of variance in data sources with low sampling frequency. Mostly, the coefficient of variation is higher in the data sources with higher sampling frequency. The IWAS data set was not collected throughout the year but during intense sampling campaigns, this limitation is reflected by the fact that it is most dissimilar from the other data sets. But in particular the distributional properties confirm the value of high resolution monitoring.

With a retrospective perspective there seems little potential for a data processing that increases the consistency among the data sets. The patterns of dissimilarity are to variable. For future monitoring efforts, regular interlab-calibrations, common sampling and analytical procedures and common sampling exercises could improve the comparability of the different data sets.

Comparison between Ukrainian and Polish data sources

The second task of consistency analysis refers to data comparability along the course of the river. Due to location as a boundary river and divided monitoring responsibilities, different institutions take samples from Western Bug in close spatial distance. Tables 11 – 13 give the distance in kilometers flow path between the stations compared.

Highest oxygen concentrations (Figure 21 and Figure 22) are detected by WBRC at Kamianka Buzka upstream station. In general, Ukrainian institutions register lower oxygen levels than Polish institutions but the differences are not significant at a 5% significance level. For the only exception, the difference between Lytovezh and Krylow no major influential emission sources are known. Local boundary conditions e.g. aeration by weirs or morphologically induced turbulence could play a role. Standard errors from institutions with higher sampling frequency are generally lower than from those with lower frequency. This finding suggests, that low frequencies underrepresent the variability related the data.

Table 11. Consistency assessment for mean and variance of annual oxygen concentrations at neighbouring sampling points in Western Bug 2011 P-values in red indicate rejected hypothesis of same means or variances

Station	Institution	River km	compare with	Distance [km]	No. of observ.	Mean	St. dev. [mg/l	p(t-test)	p(F-test)
Kam. Buzka	WBRC	690	Kam. Buzka us	0	4	7.88	1.14	0.152	0.556
Kam. Buzka us	HMS	690	Kam. Buzka ds	2	13	6.71	1.69	0.713	0.894
Kam. Buzka ds	HMS	688	Kam. Buzka	2	13	6.46	1.63	0.090	0.605
Sokal	WBRC	617	Lytovezh	15	4	7.13	1.83	0.747	0.889
Lytovezh	WBRC	602	Krylow	24.9	4	6.71	1.68	0.045	0.275
Krylow	WIOS L	577	Sokal	39.9	4	8.88	2.65	0.325	0.562
Ustyluh	WBRC	525	Zosin	1.4	4	6.78	2.55	0.261	0.804
Zosin	WIOS L	523	Horodlo	8.6	4	9.22	2.98	0.993	0.977
Horodlo	WIOS L	514	Ustyluh	10	4	9.21	2.93	0.259	0.827
Krzyczew	WIOS L	269	Gnojno	46.7	4	8.47	2.26	0.747	0.932
Gnojno	WIOS L	222	Kozki	27	4	9.00	2.14	0.282	-
Kozki	WIOS W	195	Krzyczew	73.7	1*	10.4	-	0.187	-

** annual mean value provided*

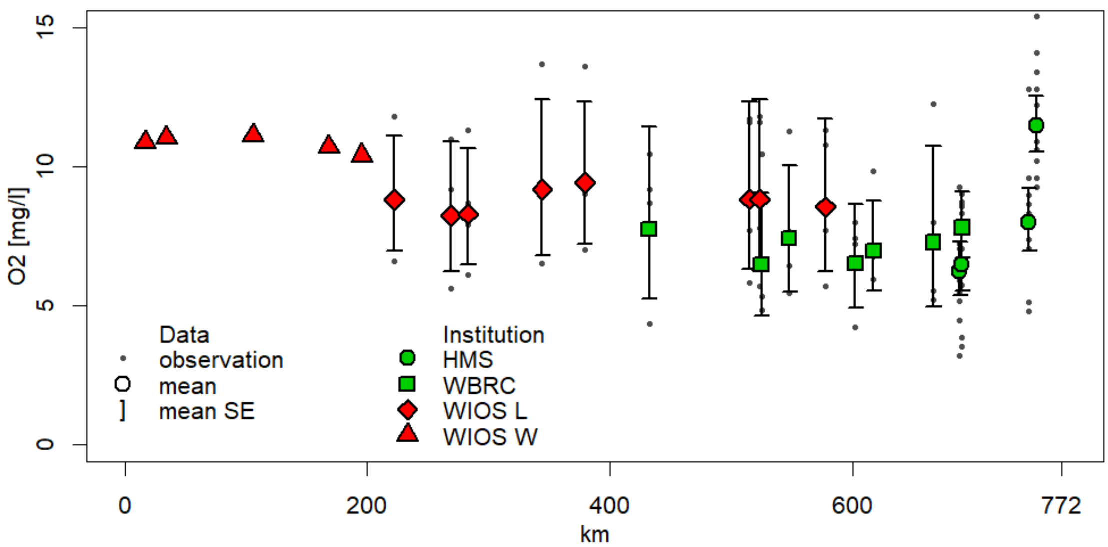

Figure 22. Longitudinal profile of mean annual dissolved oxygen (O2) concentrations and standard errors of means in Western Bug 2011.

The relations for BOD5 concentrations are less consistent.

Table 12 and Figure 23 conclude the analysis. Lowest concentrations are measured upstream of the inflow from Poltva tributary. Downstream of this point concentrations range from 2 to 10 mg/l for the whole flow path. With lower concentrations measured by the Polish institutions in the commonly monitored river sections. Equality of variance cannot be rejected for all neighbouring stations. In contrast, equality of means is rejected in some cases. Neighbouring stations Kamianka Buzka upstream and downstream of the dwelling show significantly different annual mean concentrations, with 2.8 versus 6.5 mg/l. As both stations are monitored by HMS, analytical and sampling related errors should play a subordinate role. The inflow of Kamianka creek, which carries the outlet of Kamianka Buzka wastewater treatment plant and industrial effluents, is located between both stations. With a mean annual discharge of 15.5 m³/s at Kamianka Buzka hydrological gauge, the concentration difference corresponds to a load increase of 57.4 g/s or 1800 t/a. This increase cannot be plausibly explained by the activities in the settlement. Possibly, the downstream sampling point is not representative for the mean concentration at this site. Other significant differences in means occur at the stations in Krylow (WIOS L) and Sokal (WBRC) at 40 km distance, Ustyluh (WBRC) and Zosin (WIOS L) at 1.4 km distance, and Gnojno (WIOS L) and Kozki (WIOS W) at 27 km distance. Notably, all significant differences, except the case of Kamianka Buzka, result from the comparison of samples from different institutions. Differences in the sampling and analytical approaches should be assessed and, if possible harmonized.

Table 12. Consistency assessment for mean and variance of annual biochemical oxygen demand in five days concentrations BOD5 at neighbouring sampling points in Western Bug 2011 P-values in red indicate rejected hypothesis of same means or variances

Station	Institution	River km	Compare with	Distance	No. of observ.	Mean	St. dev. [mg/l	p(t-test)	p(F-test)
Kam. Buzka	WBRC	690	Kam. Buzka us	0	4	3.94	1.04	0.117	0.873
Kam. Buzka us	HMS	690	Kam. Buzka ds	2	13	2.82	1.05	<0.001	0.143
Kam. Buzka ds	HMS	688	Kam. Buzka	2	13	6.46	1.63	0.006	0.496
Sokal	WBRC	617	Lytovezh	15	4	4.65	0.343	0.453	0.142
Lytovezh	WBRC	602	Krylow	24.9	4	4.24	0.914	0.092	0.961
Krylow	WIOS L	577	Sokal	39.9	4	2.92	0.943	0.029	0.131
Ustyluh	WBRC	525	Zosin	1.4	4	5.09	0.29	0.005	0.184
Zosin	WIOS L	523	Horodlo	8.6	4	2.95	0.695	1	1
Horodlo	WIOS L	514	Ustyluh	10	4	2.95	0.695	0.005	0.184
Krzyczew	WIOS L	269	Gnojno	46.7	4	2.7	0.616	0.9237	0.701
Gnojno	WIOS L	222	Kozki	27	4	2.65	0.785	0.008	-
Kozki	WIOS W	195	Krzyczew	73.7	1	5.05	-	0.005	-

** annual mean value provided*

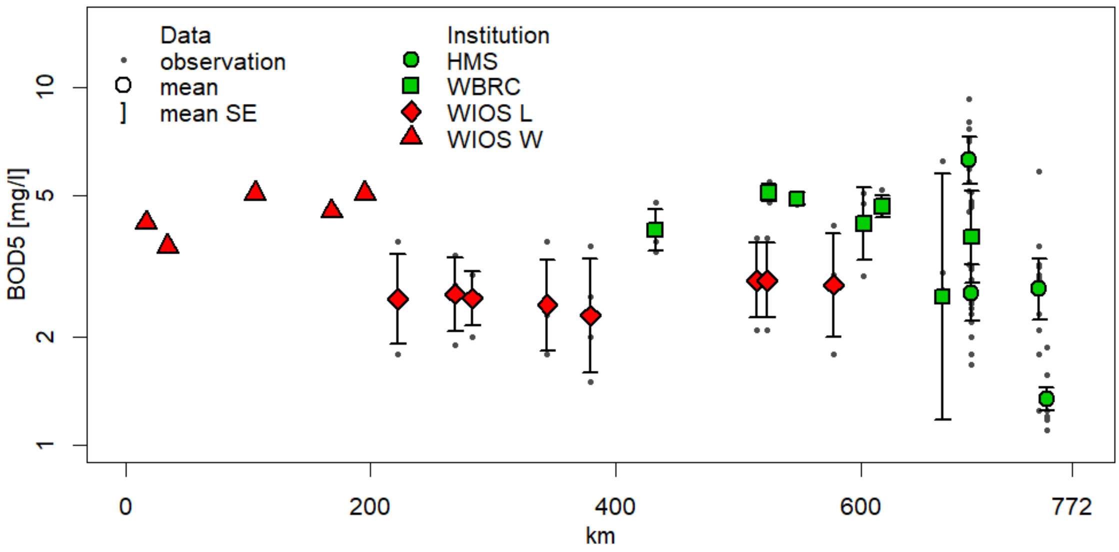

Figure 23. Longitudinal profile of mean annual biochemical oxygen demand in five days (BOD5) concentrations and standard errors of means in Western Bug

Table 13 and Figure 24 give the statistical and graphical consistency assessment of chemical oxygen demand concentrations in Western Bug. A general decrease of concentrations is observed in the 200 km flow path downstream of the inflow of Poltva river from around 40 mg/l to 7 mg/l. In the Polish inland sections of the stream, below river km 200, an increase to around 15 mg/l occurs. Despite of small-scale variability, non-systematic differences in mean concentrations are observed by the different institutions in the commonly monitored river sections. Inconsistency of means occur in the Kamianka-Buzka and Sokal to Krylow river sections especially among different institutions. The reasons are similar to the ones discussed for BOD5 above.

Table 13. Consistency assessment for mean and variance of annual chemical oxygen demand concentrations at neighbouring sampling points in Western Bug 2011 P-values in red indicate rejected hypothesis of same means or variances.

Station	Insti-tution	River km	Compare with	Distance [km]	No. of observ.	Mean [mg/l]	St. dev. [mg/l]	p(t-test)	p(F-test)
Kam. Buzka	WBRC	6	Kam. Buzka	0	4	14.9	1.73	0.066	0.066
Kam. Buzka	HMS	6	Kam. Buzka	2	13	32.9	5.97	0.324	0.324
Kam. Buzka	HMS	6	Kam. Buzka	2	13	32.9	8.00	0.028	0.028
Sokal	WBRC	6	Lytovezh	15	4	6.06	0.54	0.541	0.541
Lytovezh	WBRC	6	Krylow	24.9	4	15.0	0.796	<0.001	<0.001
Krylow	WIOS L	5	Sokal	39.9	4	24.7	34.5	<0.001	<0.001
Ustyluh	WBRC	5	Zosin	1.4	4	6.83	1.44	0.411	0.411
Zosin	WIOS L	5	Horodlo	8.6	4	7.34	2.44	0.598	0.598
Horodlo	WIOS L	5	Ustyluh	10	4	7.61	1.75	0.76	0.76

The longitudinal profiles of the nutrients ammonia nitrogen, nitrate nitrogen and phosphate phosphorous are illustrated in Figures 25 – 27. Due to their varying emission sources and spatial distribution, their prevalence in the river differs. Nitrate is a mostly dissolved compound with comparatively low reactivity. For nitrate, the values measured by the different institutions are in a similar range and means of neighbouring sampling points are mostly consistent. Ammonia is more reactive and more absorptive than nitrate. Neighbouring stations and different institutions deliver less consistent means. With Polish station showing lower means in the common monitoring sections. The same pattern occurs in phosphate but even more pronounced. For ammonia and phosphate, a joint monitoring approach would contribute to more consistent results.

The evaluation of 6 water quality variables emphasizes the challenges in developing consistent water quality data bases. Due to the variability in concentration patterns an individual evaluation of consistency and comparability are required. Future research could direct towards grouping or clustering of compound with similar inconsistency patterns in order to identify potential causes. Monitoring institutions should prioritize common sampling exercises, increase comparability in sampling and analytical approaches and coordinate monitoring points among each other.

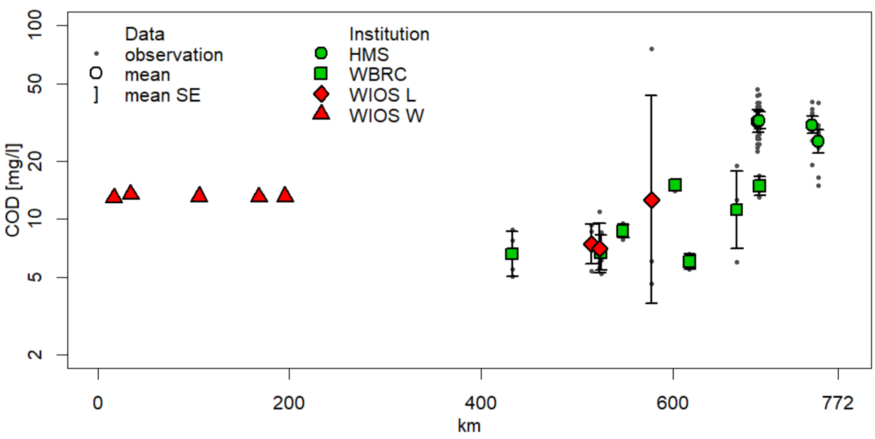

Figure 24. Longitudinal profile of mean annual chemical oxygen demand (COD) concentrations and standard errors of means in Western Bug 2011.

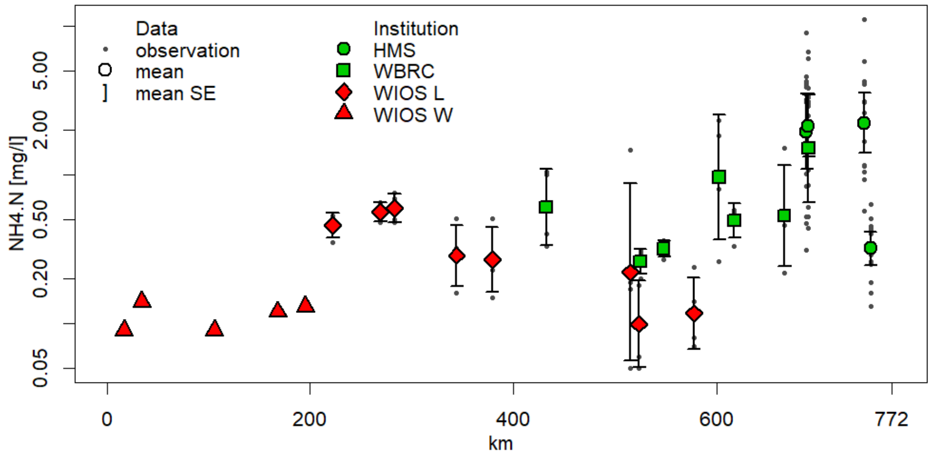

Figure 25. Longitudinal profile of mean annual ammonia nitrogen (NH4.N) concentrations and standard errors of means in Western Bug 2011.

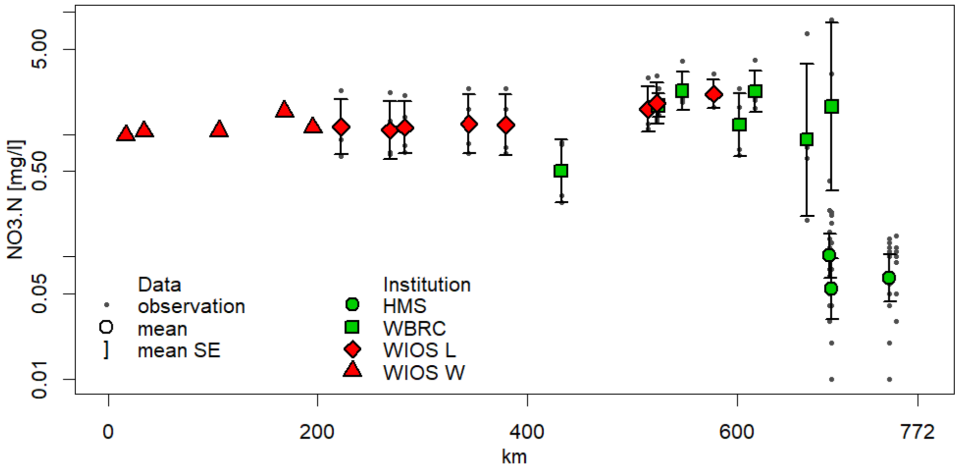

Figure 26. Longitudinal profile of mean annual nitrate nitrogen (NO3.N) concentrations and standard errors of means in Western Bug 2011.

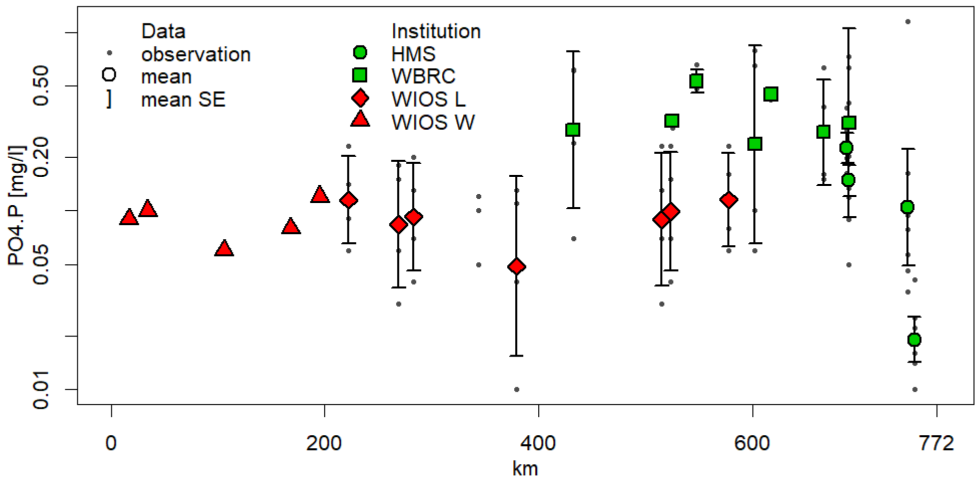

Figure 27. Longitudinal profile of mean annual phosphate phosphorous (PO4.P) concentrations and standard errors of means in Western Bug 2011.

3.3. Data consistency check for Western Dvina Basin

Hydrological gauging network in Western Dvina Basin is covered by Russian, Belorussian and Latvian stations. Water level, temperature, discharge, ice regime and river hydromorphology is monitored. There is evident discrepancy between gauging stations distribution between different countries (Figure 28).

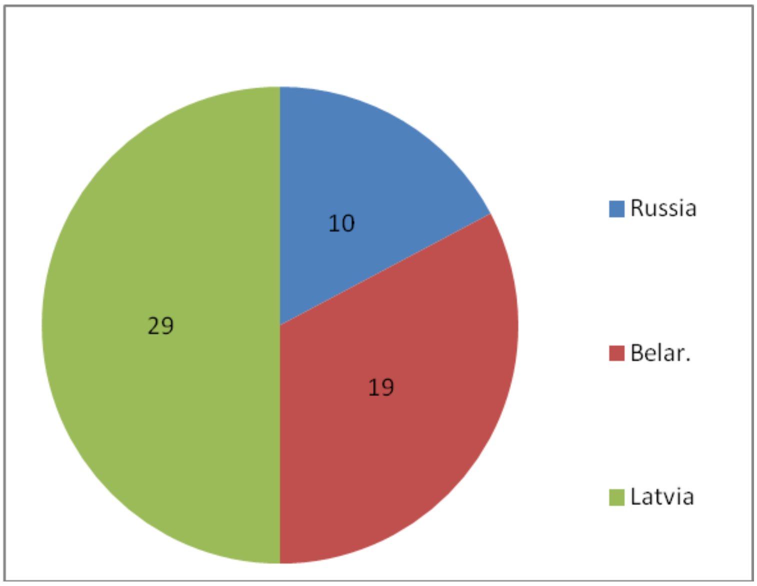

Figure 28. Total number and distribution of ongoing hydrological gauging stations in Western Dvina Basin

Hydrological measurements in Western Dvina Basin have started at the end of XIX century (in 1906 in Latvia), Table 14.

Table 14. Total number, parameters and period of station operation in Western Dvina Basin

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

H-water level, Q-discharge, T-temperature, I-ice thickness, S-snow depth

Discharge is measured on approximately half of stations in Russia and Belarus. Latvia has more stations and all are operating (Figure 29). Belarus also has 5 stations on lakes with Level, Temperature and Ice thickness measurements. Latvian gauges also provide the information about water object situation.

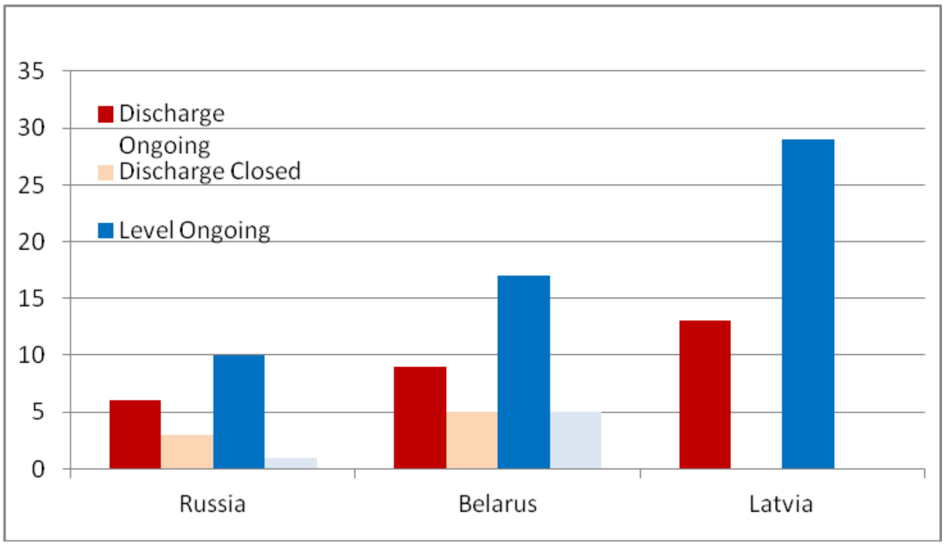

Figure 29. Number of ongoing and closed discharge stations

Water quality observations in Western Dvina Basin have been initiated in the middle of XX century. Most of these stations are located in Belarus (Figure 30). In Russia there are 4 gauging stations in progress, 2 of them are monitoring water quality at Russian outlet of WD and are situated upstream and downstream of Velizh town.

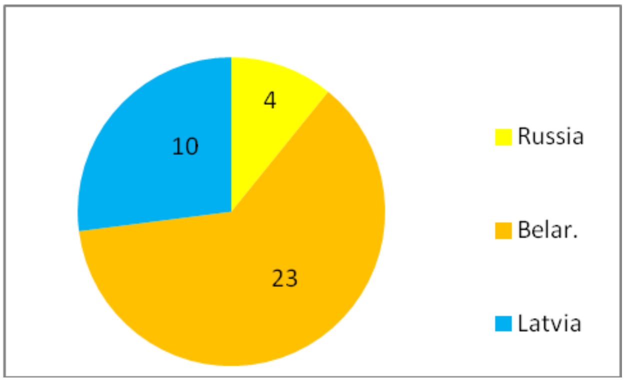

Figure 30. Number of water quality control stations in Western Dvina Basin

Datasets on daily discharge and water levels are available in Russia and Belarus only as subject of payment. In Latvia the situation is opposite and can be requested for free, but calculated continuous datasets are available with costs (Table 15).

Table 15. Datasets on daily discharge and water levels

Country	Level, Temperature, Ice thickness	Discharge measurement frequency	Temperature on surface and depth	Hydromorphological quality	Data access	Sediment concentration	Reservoir hydrologycal data	Water quality		Water quality data provider	Data access
RU	daily (2 times)	30-40 times a year	-	-	subject of payment		closed data	Set 1, Set 2 chemicals	4-8 times a year	Tver CGMS, Smolensk CGMS, Smolensk engineering-technical center "Ecology"	subject of payment with the exception of freely available average, maximum, minimum for the year.
BY	daily (2 times)	30-40 times a year	-	-	subject of payment		closed data	Set 1, Set 2 chemicals	12 times a year	Belhydromet	subject of payment
LV	several times a day	6-12 times a year	several times a day	daily	measured - free, daily - subject of payment		closed data	?	?	LEGMC	?

Water quality is measured with 2 sets of chemical parameters. Most part of chemical gauging stations operate with Set 1 and Set 2 chemicals (Table 16).

Table 16. Measured chemical elements (Set1 and Set2 chemicals)

Set 1	**Set 2**
Transparency	Phosphates
Temperature	Conductivity
Sulfates	Total phosphorus
Salinity	Iron total
Stiffness common	Copper
Hydrocarbonates	Zinc
Sodium	Nickel
Potassium	Chrome General
Calcium	Lead
Dichromate oxidation (COD)	Cadmium
BOD5	Manganese
Ammonium nitrogen	Phenols total
Nitrogen nitrite	Mineral oils
Nitrate nitrogen	Detergents (synthetic surfactants)

The important aspect of data consistency, besides discrepancies and mismatches in monitoring program, are related to methods applied for different elements analyses (Table 17). In some cases, due to long-lasting period of degradation of hydrometeorological monitoring service in post-soviet union countries, some of the still accepted methods are outdated and inconsistent with the novel approaches.

Table 17. Examples of discrepancies in hydrological parameters monitoring

Parameters	**Russia**	**Belarus**	**Latvia**
Discharge, Q	Current meter method, acoustic Doppler current profilers (rare)	Current meter method	Automatic gauging stations
Water object situation and ice conditions	Visual estimation of ice conditions classified by ice event types (about 10 classes), measurements of ice thickness and snow on ice.	Visual estimation of ice conditions classified by ice event types (about 10 classes), measurements of ice thickness and snow on ice.	Water situation description (9 types), ice development conditions (100 classes) ice width (5 classes), closeness, form of ice cover (15 classes), ice development stage (45 classes), measurements of ice thickness, snow on ice (9 classes) (https://www.meteo.lv)
Water quality	4 categories of stations with daily (only 3 general components) to several times a year observation and sampling with 35 chemical components analysis.	Near pollution sources – monthly, far from pollution sources – every 10 days (1 in 2 years) for chemicals to annual for biological characteristics. Analyzed components – main ions, gases, organic components, nutrients, metals, biological conditions. http://www.nsmos.by	Chemical quality elements (45 priority pollutants with European-wide consistent ecological quality standards) For priority pollutants in the water phase: 12 times p.a.; at least 1in 6 years (SM), at least 1in 3 years (OM); For priority pollutants in biota: 1–2 times p.a.; at least 1in 6 years (SM), at least 1in 3 years (OM) [Arle, Mohaupt, Kirst, 2016]
Sediment concentration	gravimetric analyses performed on water sediment samples collected manually (РД 52.08.104-2002)		physical principles of turbidimetry or nephelometry (see e.g. [Brils, 2008])

* in brackets – links to guide standard

The example of the outdated methods can be seen in methodology of sediment concentrations still applied at the outlet station in Russian part of Zapadnaya Dvina catchment (Velezh gauging station). In Russia according to (РД 52.08.104-2002), the gravimetric filtration is based on the old-style pumps and so-called “white paper” filters (approximately 10 μm size of pores). Vice versa, the EU monitoring service is based on continuous records of SSC which are obtained by monitoring the turbidity of the river water, provided there is a close relationship between fluctuations in sediment concentration and turbidity, and the physical principles of turbidimetry or nephelometry are respected when calibrating the equipment's sensor or probe ([Belozerova, Chalov, 2013]. The similar approach was used during monitoring experiment conducted at WD pilot study site (Velesa River station) using RGB-Solo instrument, which conduct NTU measurements during summer season 2017. The regional regression model mg/l=f(NTU) [Belozerova, Chalov, 2013] was used to recalculate obtained turbidity values (T, NTU) to sediment concentrations (SSC, mg/l).

Methodological drawback induces significant inconsistency in the results obtained at different hydrological stations. We analysed sediment concentration dataset obtained from Roshydromet (provided by Smolensk branch of Roshydromet), Western Dvina River, Velezh station (Figure 31). Observation period is 1992-2004, 2017, 11-12 per annum. We found that the Velezh station SSC observations are not consistent with other observations in the area in terms of the absolute values of monitored SSC (which are less than 10 mg/l). The long term averages of Velezh monitoring station for the period 1992-2017 was 3.13 mg/l (Table 18) , and maximal value – 10.3 mg/l. The observed values are contradictive to the regional estimates of sediment transport (e.g. [Dedkov, Gusarov, 2006]). The most recent estimate of average regional SSC lay in the range 10-25 mg/l [Bobrovitskaya, Kokorev, Lemeshko, 2003]. The reported average value for the period of Mantra station operation in 2017 (31 May-6 October) was around 7 mg/l, and the maximal value – 152 mg/l.

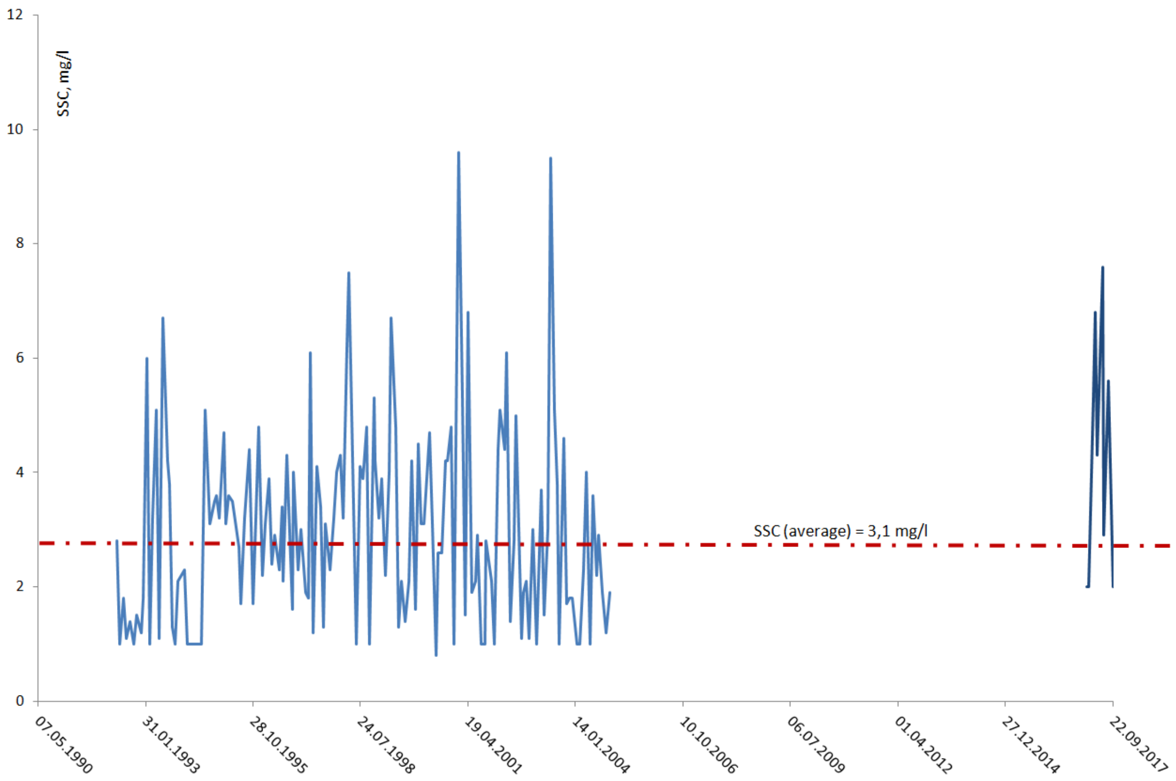

Figure 31. Sediment concentrations at Roshydromet Velezh station (provided by Smolensk branch of Roshydromet), Western Dvina River

Table 18. Annual averages of the sediment concentrations at WD gauging stations

Station	Results of raw data analyses [mg/l]							Published long-term average (calculated from data)	
								[Dedkov, Gusarov, 2006]**	[Milliman, 2010]
	2000	**2001**	**2002**	**2003**	**2004**	**2017**	Average (2000-2017)		
Russia									
Velesa River, Mantra station	-	-	-	-	-	7.95	-	-	-
Velesa River, Rudnya station	-	-	-	-	-	-	-	8.13	-
WESTERN DVINA, Velezh	3.2	3.4	3.2	3.2	2.1	3.10	3,13	18.06	-
WESTERN DVINA,Western Svina station	-	-	-	-	-	-	-	14,41	-
Belarus									
WESTERN DVINA, 0,5 km upper from Surazh*	6.00	8.14	6.40	5.10	3.40	na	4,52	-	-
WESTERN DVINA, 1,3 km below Vitebsk	7.30	10.12	8.40	5.40	4.70	na	5,72	-	-
WESTERN DVINA, 2 km below Vitebsk	6.40	7.22	7.70	6.20	6.20	na	5,85	-	-
WESTERN DVINA, 1,3 km upper from Polotsk	7.70	8.77	8.00	9.50	8.30	na	8,01	-	-
WESTERN DVINA, 1,5 km below Polotsk	9.70	8.30	7.90	9.90	9.20	na	8,31	-	-
WESTERN DVINA, 2 km below Polotsk	6.90	8.07	7.40	10.00	9.90	na	8,29	-	-
WESTERN DVINA, 15,5 km below NovoPolotsk	6.90	8.19	7.60	9.50	9.50	na	8,19	-	-
WESTERN DVINA, 2 km upper from Verhedvinsk	7.80	8.65	6.30	9.90	9.20	na	8,13	-	-
WESTERN DVINA, 5,5 km below Verhedvinsk	8.40	8.49	7.50	9.60	-	na	8,15	-	-
WESTERN DVINA, 0,5 km below Druya	-	-	-	10.60	5.30	na	4,87	-	-
Latvia									
WESTERN DVINA, Daugavpils	-	-	-	-	-	-		8,81	
WESTERN DVINA, Ekebpils	-	-	-	-	-	-		14,97	
WESTERN DVINA, Lipshi								18,26	20,4

* - the average values for station from Belarus were downloaded from http://old.cricuwr.by/gvk/default.aspx
** - period of observations (years) before 1984 indicated in brackets

Table 19. Maximal values of the sediment concentrations [mg/l] at WD gauging stations

Station	2000	2001	2002	2003	2004	2017
WD, Velezh	***4.8***	***9.6***	***6.1***	***9.5***	***4***	*10,3*
WD, 0,5 km upper from Surazh*	7.60	15.50	8.80	7.60	9.10	na
WD, 1,3 km below Vitebsk	12.50	17.40	15.00	6.80	8.50	na
WD, 2 km below Vitebsk	13.50	15.40	14.50	8.20	25.10	na
WD, 1,3 km upper from Polotsk	11.20	16.80	13.40	18.00	10.10	na
WD, 1,5 km below Polotsk	26.50	21.90	13.20	13.40	11.40	na
WD, 2 km below Polotsk	13.90	15.60	12.30	14.30	14.40	na
WD, 15,5 km below NovoPolotsk	12.60	14.70	11.40	12.80	14.60	na
WD, 2 km upper from Verhedvinsk	26.00	17.10	9.80	15.00	12.90	na
WD, 5,5 km below Verhedvinsk	28.10	15.70	14.00	14.10	-	na
WD, 0,5 km below Druya	-	-	-	14.30	12.70	na
Velesa River, Mantra station						152

* - the average values for station from Belarus were downloaded from http://old.cricuwr.by/gvk/default.aspx

Mean annual sediment concentrations (Table 19) indicate lower values at the reported period at WD Velezh gauging station (S_{WD}, mg/l) compared to other sediment concentration value S0 for the similar period (e.g. 2017 by MANTRA station at Velesa River) or other time laps (e.g. reported at [Dedkov, Gusarov, 2006]). The later was evaluated using simple difference-factor coefficient:

$$K_i = S_{0i} / S_{WDi}$$

where i – either mean annual (i=1) or maximal (i=2) observed sediment concentration (Table 20). The K_i values lay within the range of 2.5 to 5.8 for mean annual SSC, and from 2.9 for 14.8 for maximal values. Comparison with the downstream gauging stations should also assume, that since the 30's of the 20th century the construction of the cascade of dams on the Daugava river has essentially reduced the amount of river sediments reaching the most downstream of the river. All dams are located below Russian part of the catchment (below Velezh station), and the sediment load decline should be more evident there then in the relatively stable upper part of the catchment. Vise versa, the results indicate drastic decline of the sediment load at the downstream station – this also support the idea that the observed values at Velezh gauging station (after 1992) are reduced due to methodological drawbacks.

Table 20. Difference-factor of ongoing state monitoring data (Western Dvina River, Velezh station) compared to other sediment concentrations datasets in the Western Dvina Basin

	Velesa River, Mantra station	Velesa River, Rudnya station [Dedkov, Gusarov, 2006]	WESTERN DVINA, Western Dvina station	WESTERN DVINA, 10 stations located in Republic of Belarus (See Tables 1,2)
Period	31 May-16 October 2017	6 years (before 1984)	6 years (before 1984)	2000-2015
Observational methods / reference	Nephelometry, RGB solo turbidity meter	Gravymetric analyses	Gravymetric analyses	Gravymetric analyses
Compared to observational period at Velezh station	2017	1992-2004, 2017	1992-2004, 2017	2000-2004
Mean annual SSC	2,5	5.8	4.6	2,60
Maximal yearly SSC	14.8	na	na	2,93

The most significant differences are related to the maximal values of SSC, which are much smaller in the datasets from Velezh station compared to other datasets (see Figure 31). This induce significant discrepancies in the frequency curve (Figure 32), which is in case of the Velezh station is shifted to low values of SSC (< 10 mg/l) with only 1 value in the range > 10 mg/l, whereas the observed dataset at Mantra Velesa station in 2017 identified over 25 % of the values > 10 mg/l. It is also important to note that observed interannual variability is contradictive to the fact that over 50 % of the sediments in the rivers of forest zone of European plain are transported during spring flood (e.g. [Bobrovitskaya, Kokorev, Lemeshko, 2003]. Also this variability do not indicate any relationship to water discharges (Figure 33), which is also might be considered as an evidence of mistakes associated with SSC assessment at Velezh station.

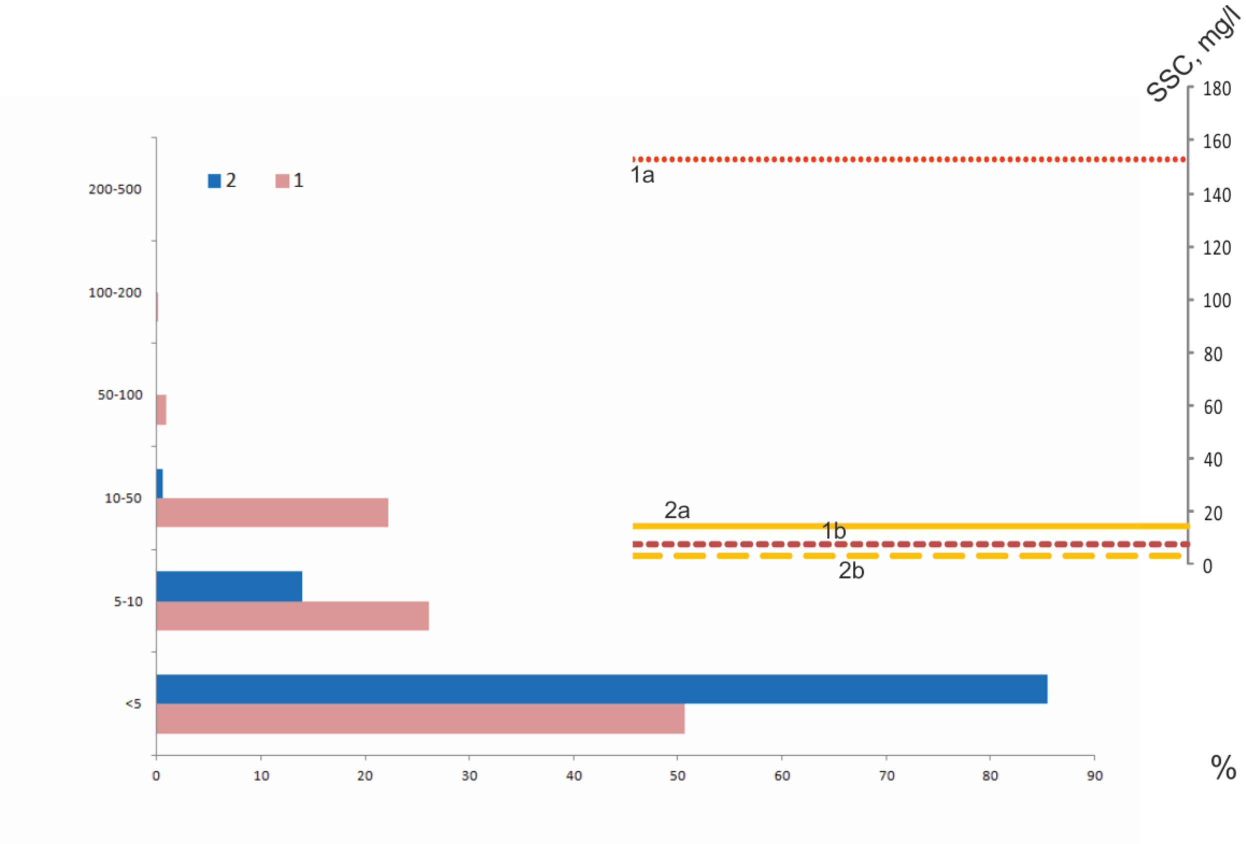

Figure 32. Frequency curve and average values (a – annual maximal, b- annual mean) for SSC (1- Mantra pilot study station, Velesa River, 2017; 2 –Western Dvina River, Velezh station, 1992-2004,2017;)

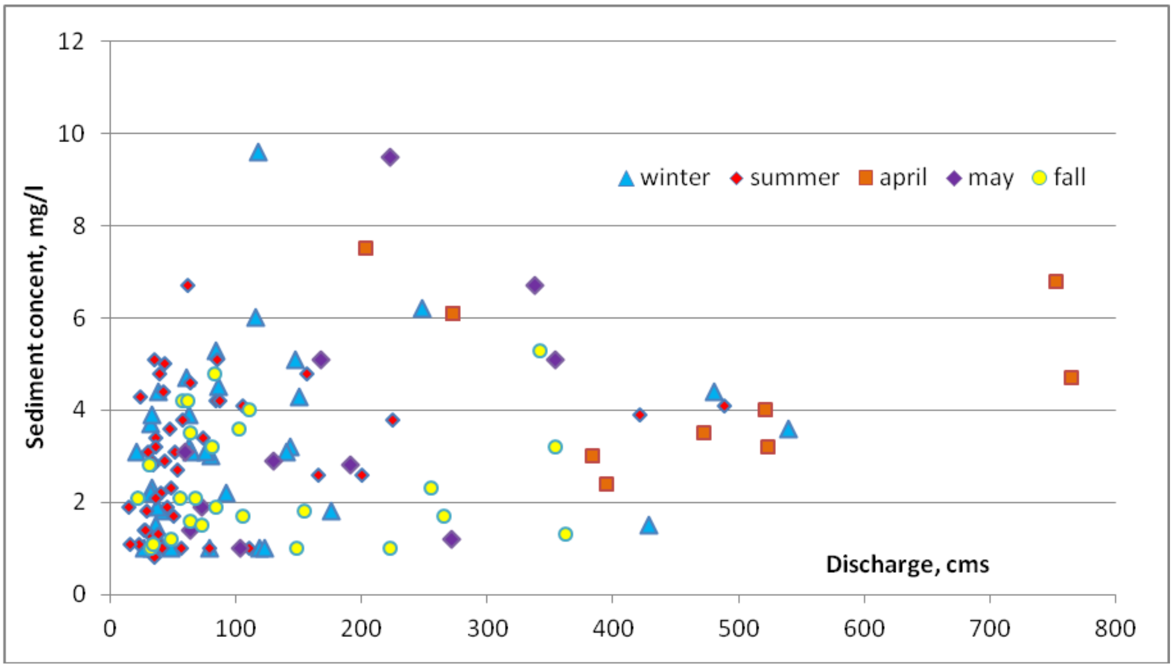

Figure 33. Relation plot between measured sediment concentration and daily discharge for Velezh station

The observed trends between the annual values are in general similar with observations in Belarus for 10 gauging stations where SSC measurements, but also characterized by lowest consistency. We proceeded with correlation analyses between mean and maximal annual values of S_{WD} (mg/l) and similar values S_0 for each of the Belarus where SSC measurement are performed (Tables 18, 19) using Pearson's correlation coefficient r_{xy} which compares two ratio variables:

$$r_{xy}= C(x,y)/\sigma_x\sigma_y \ ;$$

where σ_X and σ_Y are standard deviations of each of the pair of SSC annual variables (mean or maximal respectively) X and Y for each of I stations used in the analyses (i=10), C(x,y) – covariance, which is defined as

$$C(x,y)=M(x-mx)(y-my);$$

where M is the expected value operator, μ_X and μ_Y are expected values of both SSC annual values variables. The revealed matrixes (Table 21 and Table 22) revealed very few significant correlations between pair of SSC datasets for each of the analyzed stations. At the same time, in the whole group there is no SSC mean annual variable which has significant correlations ($r_{xy} > 0.95$ at $p < 0,05$) with Russian Western Dvina Velezh station.

Table 21. Correlation matrix of the SSC annual mean values between WD station in Russia (Velezh) and Belarus (2000-2004)

[redacted]	Means	Std.Dev.	WD, 0,5 km upper from Surazh*	WD, 1,3 km below Vitebsk	WD, 2 km below Vitebsk	WD, 1,3 km upper from Polotsk	WD, 1,5 km below Polo	WD, 2 km below Polo	WD, 15,5 km below NovoPolotsk	WD, 2 km upper from Verhedvinsk	WD, 5,5 km below Verhedvinsk	WD, Velezh
WD, 0,5 km upper from Surazh*	6,410000	1,275042	1,000000	0,971696	0,620524	-0,164807	-0,698135	-0,392797	-0,280093	-0,218833	-0,427679	0,904545
WD, 1,3 km below Vitebsk	7,805000	1,979251	0,971696	1,000000	0,755765	-0,348439	-0,808557	-0,551396	-0,435345	-0,442833	-0,629051	0,779756
WD, 2 km below Vitebsk	6,880000	0,702567	0,620524	0,755765	1,000000	-0,360278	-0,992308	-0,453921	-0,325055	-0,743453	-0,840199	0,322627
WD, 1,3 km upper from Polotsk	8,492500	0,808842	-0,164807	-0,348439	-0,360278	1,000000	0,288754	0,970894	0,984031	0,842411	0,803495	0,228722
WD, 1,5 km below Polotsk	8,950000	0,998332	-0,698135	-0,808557	-0,992308	0,288754	1,000000	0,407718	0,271483	0,666421	0,786552	-0,434057
WD, 2 km below Polotsk	8,092500	1,359004	-0,392797	-0,551396	-0,453921	0,970894	0,407718	1,000000	0,988983	0,815312	0,829777	-0,011037
WD, 15,5 km below NovoPolotsk	8,047500	1,102584	-0,280093	-0,435345	-0,325055	0,984031	0,271483	0,988983	1,000000	0,768409	0,758597	0,086161
WD, 2 km upper from Verhedvinsk	8,162500	1,511828	-0,218833	-0,442833	-0,743453	0,842411	0,666421	0,815312	0,768409	1,000000	0,975264	0,214971
WD, 5,5 km below Verhedvinsk	8,497500	0,860247	-0,427679	-0,629051	-0,840199	0,803495	0,786552	0,829777	0,758597	0,975264	1,000000	-0,005812
WD, Velezh	3,250000	0,100000	0,904545	0,779756	0,322627	0,228722	-0,434057	-0,011037	0,086161	0,214971	-0,005812	1,000000

Marked correlations are significant at $p < 0,050$
N=5 (Casewise deletion of missing data)

Table 22. Correlation matrix of the SSC annual maximal values between WD station in Russia (Velezh) and Belarus (2000-2004)

[redacted]	Means	Std.Dev.	WD, 0,5 km upper from Surazh*	WD, 1,3 km below Vitebsk	WD, 2 km below Vitebsk	WD, 1,3 km upper from Polotsk	WD, 1,5 km below Polo	WD, 2 km below Polo	WD, 15,5 km below NovoPolotsk	WD, 2 km upper from Verhedvinsk	WD, 5,5 km below Verhedvinsk	WD, Velezh
WD, 0,5 km upper from Surazh*	9,72000	3,30257	1,000000	0,697117	0,174179	0,366029	0,262515	0,645278	0,620978	-0,062967	-0,149447	0,493463
WD, 1,3 km below Vitebsk	12,04000	4,40715	0,697117	1,000000	-0,001369	0,079100	0,501462	0,024321	-0,017041	0,077389	-0,441977	0,168438
WD, 2 km below Vitebsk	15,34000	6,13050	0,174179	-0,001369	1,000000	-0,721783	-0,266588	0,118959	0,555506	-0,241240	0,892285	-0,656338
WD, 1,3 km upper from Polotsk	13,90000	3,43511	0,366029	0,079100	-0,721783	1,000000	-0,033456	0,334663	-0,004641	-0,154788	-0,703379	0,988291
WD, 1,5 km below Polotsk	17,28000	6,56940	0,262515	0,501462	-0,266588	-0,033456	1,000000	0,316397	0,055598	0,898740	-0,378689	0,048511
WD, 2 km below Polotsk	14,10000	1,18954	0,645278	0,024321	0,118959	0,334663	0,316397	1,000000	0,886001	0,332071	0,144515	0,445981
WD, 15,5 km below NovoPolotsk	13,22000	1,41138	0,620978	-0,017041	0,555506	-0,004641	0,055598	0,886001	1,000000	0,082517	0,536163	0,112223
WD, 2 km upper from Verhedvinsk	16,16000	6,12642	-0,062967	0,077389	-0,241240	-0,154788	0,898740	0,332071	0,082517	1,000000	-0,155652	-0,102791
WD, 5,5 km below Verhedvinsk	34,58000	37,59331	-0,149447	-0,441977	0,892285	-0,703379	-0,378689	0,144515	0,536163	-0,155652	1,000000	-0,677090
WD, Velezh	6,80000	2,62011	0,493463	0,168438	-0,656338	0,988291	0,048511	0,445981	0,112223	-0,102791	-0,677090	1,000000

Marked correlations are significant at $p <0 ,050$
N=5 (Casewise deletion of missing data)

To compare consistency SSC observations obtained from Velezh station (Russia) and 10 station at Western Dvina River in Belarus average AVG(r_{xy}) for each of the i station (Table 23). The results also confirmed that mean annual values of the observed SSC are better fitted to the other datasets, whereas maximal mean values are not in line with observation at downstream station.

Table 23. Average correlations ratios between average and maximal SSC values for 2000-2004 in the list of gauging station in Russia and Belarus where SSC measurements are performed

WD, 0,5 km upper from Surazh*	*WD*, 1,3 km below Vitebsk	*WD*, 2,0 km below Vitebsk	*WD*, 1,3 km upper from Polotsk	*WD*, 1,5 km below Polotsk	*WD*, 2 km below Polotsk	*WD*, 15,5 km below NovoPolotsk	*WD*, 2 km upper from Verhedvinsk	*WD*, 5,5 km below Verhedvinsk	*WD*, *Velezh*
0,65	0,69	0,65	0,42	0,52	0,70	0,66	0,64	0,56	0,58
0,46	0,30	0,26	0,09	0,39	0,48	0,52	0,26	0,12	0,19

The possible explanation of the reported error in Velezh station SSC data can be related to both sampling location and procedure and analytical method (Table 18). Regarding sampling, the significant drifts in the measured quantities may arise due to the absence of integrating sampling technique, which do not allow to take a representative water within cross-sections of the rivers (Horowitz, 1997). The detailed study of the associated error is provided within Mantra pilot study at Velesa River, but as recently discussed by (Chalov et al., 2018), associated uncertainties may reach 50 %. Another important methodological aspect is the type of filter used for sediment partitioning from dissolved load. According to Russian standard РД 52.24.468, filter with pore size 5 µm is used. Comparison with grain size distribution measured at Western Dvina tributary Velesa River indicate, that up to 12 % of the sediment load is associated with <5 µm fractions which can be lost during pumping through filters (Figure 34).

Harmonization of the transboundary water resources monitoring is focus of research efforts. It aims at improving comparability of the assessment of the ecological status of waters, and thus also to more coherently activate action programs of measures (e.g. [Arle, Mohaupt, Kirst, 2016]. Both with differences in monitoring approaches applied in different countries, monitoring inconsistency originates from methodological uncertainty of river monitoring. In the present study, we focused on suspended sediment monitoring problems, which is usually associated with considerable higher sampling uncertainties than soluble concentrations [Rode, Suhr, 2007]. Uncertainty components associated with the automatic pumping procedure, discharge measurement and turbidity fluctuation at the short time scale are reported to be characterized by the greatest uncertainties [Navratil et al. 2011]. A literature review was carried out both with detailed statistical analyses of suspended sediment monitoring consistency between international gauging stations located in transboundary Western Dvina River in Russia and Belarus. The study further continued with additional experimental data of the Western Dvina tributary – Velesa River, to provide uncertainty analysis of estimate accuracy and precision of water quality components accounting types of river material (suspended particulate matter, nutrients, heavy metals), the sampling strategies and the reporting period (Thomas and Lewis, 1993; Littlewood, 1995; Robertson and Roerish, 1999), iii) and seasonal variability (the role of transport regime).

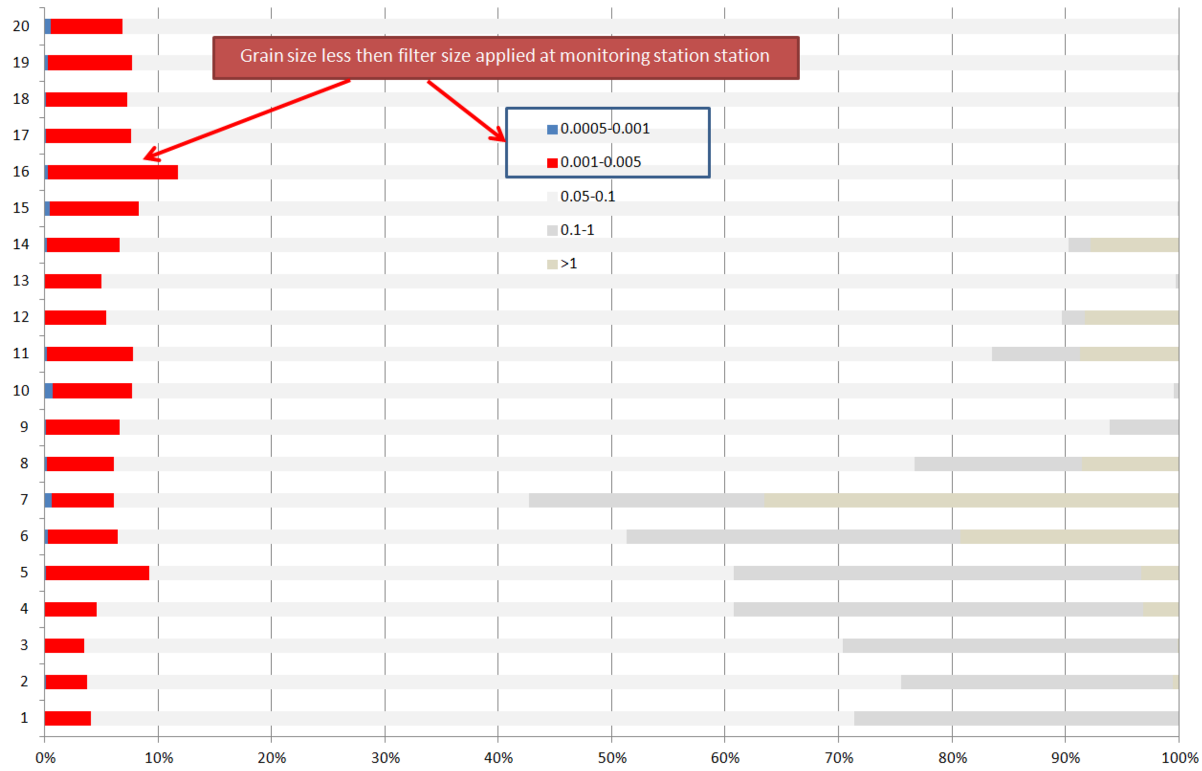

Figure 34. Possible "lost" of the suspended load due to insufficient filter pore used for water samples pumping at Western Dvina Velezh station (number indicate samples collected at pilot study reach)

Analyses of water monitoring consistency in transboundary river reveals important methodological problem, related to outdated methods applied at various gauging stations. In particular, the study was focused on the suspended concentrations data from most downstream gauging station located in Russian part of Western Dvina Basin (Velezh station) on the period from 1992 to 2004 and 2017. The various statistical approaches revealed that recent obtained datasets are not consistent both with current observations in the downstream part of Western Dvina Basin (in Belarus and Latvia), as well as with historical datasets. The possible explanation of the error indicate that the largest uncertainty can be related to the applied method, type of filters (<5 µm) and pumping procedure, as well as (possibly) insufficient sampling frequency. As far as Velezh station since 90th is the only one station in Russian part of Western Dvina Basin where sediment load monitoring is proceeded, the data demonstrate the basin-wide gap in the transboundary river monitoring. It also highlights the importance of existed methods and techniques check, which should be the part of monitoring harmonization.

Chapter IV. River Basin Analysis and management in the three case study basins (current practices)

The WFD establishes a framework for sustainable water management through the development of RBMPs and PoMs, with the objective of preventing deterioration of the aquatic environment and of achieving good status of all water bodies by 2015. The RBMPs and PoMs have to be updated every 6 years.

River basin planning – as set out in the WFD – should ensure that water management is based on a better understanding of the main risks and pressures in a river basin. As a result, interventions should be cost effective and ensure the long-term sustainable supply of water for people, business and nature. The different steps of the planning process have to be linked: Information on pressures and risks should feed into the development of monitoring programmes, information from the monitoring programs and the economic analysis should lead to the identification of cost-effective programs of measures and justifications for exemptions. Transparency on this whole process within a clear governance structure will encourage public participation in both the development and delivery of necessary measures to deliver sustainable water management.

RMBPs consist of 8 chapters, which contain information required by the national legal acts and the Water Framework Directive 2000/60/EC:

1. a characterization of a river basin district;
2. information regarding the most important anthropogenic loads and impact of human activity on the status of surface water and groundwater;
3. information regarding protected areas;
4. information regarding the monitoring network and results of the implemented monitoring programs;
5. a summary of the economic analysis;
6. the quality objectives determined for water bodies and protected areas;
7. information regarding the planned measures in order to prevent or reduce emission of pollutants, as well as to achieve the environmental quality objectives (Program of measures);
8. information regarding other programs related to the management of the river basin district;
9. a survey regarding public information and consultations performed when developing and updating the plan.

Further important directives from the EU which are closely linked with the WFD are:

- The EU-Floods Directive EU-FD (EU, 2007) takes place also in the river basins (flood risk and river basin management plans). Physical flood protection infrastructure can determine the ecological status of water with regards to hydro-morphological quality elements; many measures for flood risk reduction which has multiple benefits for water quality, nature, biodiversity etc. The EU-FD is highly relevant in the context of adaptation to climate change impacts (EEA 2009).

- The EU-Nitrate Directive (EU 1991) aims at a reduction of water pollution from nitrates used for agricultural purposes and to prevent any further pollution. It is closely linked to other EU policies which address air and water quality, climate change and agriculture. EU members must establish action programs for vulnerable zones and monitor the success of the programs. Furthermore, they must draw up a code of good agricultural practice which farmers apply on a voluntary basis.

As a planning tool for management tasks, models are frequently used. Options in management and changing boundary conditions (climate change, demography, economy) can be considered and impacts onto the system (e.g. quantity and quality of water in a river basin) estimated.

For the three basins, the status of management plans and exemplary modelling approaches are presented.

4.1 Western Bug

A lot of transboundary collaboration and coordination took part in projects, some of them are mentioned:

- Development of transboundary co-operation on water quality monitoring and assessment in the Bug river between Belarus and Poland (TACIS 2002).
- Water Management in the Bug and Latorits/Uh river basins (2004, accomplished in the Ukrainian part of the basin within TACIS CBC).
- Creation of the Polish-Belarusian-Ukrainian Water Policy in the Bug basin – the Neighbourhood program Poland-Belarus-Ukraine INTERREG III – TACIS CBC (2009).
- Sustainable Use and Protection of Groundwater Resources – Transboundary Water Management- Belarus, Poland, Ukraine (NATO 2009).

4.1.1 Poland

Water management

The European Commission assessed the first RBMPs (EC 2012) and found:

- Inconsistency of the planning process (no integrated approach on water management and no evidence of an integrated policy approach between water management and other related policy areas such as navigation, energy production, flood protection, agriculture, etc.).

- Monitoring programs do not include all the required quality elements. The ecological status assessment methods are not fully developed for all required biological quality elements.
- Some of biological methods need to be intercalibrated.
- Methods for the classification of ecological status were not fully compliant with the requirements of the WFD.
- No evidence that the PoM has been coordinated with other countries, although a Polish-Ukrainian commission on the management of trans-boundary/international water exists.
- Limited number of measures in relation to chemical pollution and no monitoring of the effectiveness of the measures.
- Climate change issues were only superficially mentioned.
- No complete monitoring of surface water (e.g. priority substances were not being extensively monitored, therefore 92% of water bodies were reported with an unknown chemical status).
- Not possible to assess how the designation of Heavily Modified Water Bodies HMWB has been done.

A current assessment of the implementation of the WFD, performed by EC (2017a), found:

- Improved implementation of the WFD required in the areas of governance and strategic planning of projects in navigation, hydropower, flood defense and any other economic activities likely to have significant negative effects on the water environment.
- Further preparation and implementation of investments in urban waste water treatment infrastructure required (as per the Urban Waste Water Treatment Directive).
- Poland is recommended to apply new approaches such as green infrastructure to manage flood risk. This could be measures like restoration of floodplains and wetlands.
- Poland contributes significantly to the overall nitrogen load in the Baltic Sea, whereby a large part of it comes from agriculture. Poland is not complying with the Nitrates Directive (http://curia.europa.eu/juris/liste.jsf?language=en&jur=C,T,F&num=C-356/13&td=ALL). The designation of nitrates vulnerable zones is not appropriate and does not consider the criteria set of the WFD. Furthermore, established action programs are insufficient.

2nd RBMPs (2016-2021) were adopted by the Government on 18 October 2016. Publication in the Polish Official Journal is pending.

Floods

A flood management plan according to all aspects of the EU-FD for the Western Bug River is not available. The EU-FD is already in line with the existing Polish water policy and therefore it is expected that no substantial changes regarding the Polish policy are necessary (FLOOD-WISE, 2012).

Modelling

Using models as a tool for water management task is widely used in Poland. Some examples are given:

- Climate modelling is performed to analyse possible future projections of the climate. Downscaling from global conditions to regional (Polish coastal zone) was performed under the KLIMAT project (Mietus et al. 2009)
- For water balance modelling the widely used model SWAT is applied (Ostojski et al. 2014)
- Nitrogen and phosphorous loads to the Baltic Sea originate mainly from agricultural diffuse sources (HELCOM 2011), hence European leaders have shifted their focus to agriculture with a number of research programs executed recently (e.g., Baltic Deal, Baltic Compass, Baltic Manure, BERAS Implementation, etc.).
- The hydrological model SWAT was applied to simulate nitrogen and phosphorous flows under a changing climate (Piniewski et al. 2014).
- SWAT was applied for the dimensioning of buffer zones around surface water bodies (Brzozowski et al. 2011).
- Geochemical modelling of groundwater was performed with PHREEQM (Postma et al. 1991)

4.1.2 Belarus

Water Management

RBMPs are developed for the integrated water resources management of the main river basins, based on data of the State Water Cadastre, of the State Cadastre of Mineral Resources, of the surface and ground water monitoring and of the Basin Councils recommendations.
About how do they comply with the WFD, no information was found so far.

Floods

A management plan according to all aspects of the EU-FD for the Bug River is not available. Pilot implementation of the WFD and EU-FD has begun only. The new wording of Water Code of the Republic of Belarus will consider EU directives and experience in the field of transboundary river basins management. The EU-FD is already in line with the existing Belarus water policy but not in line with existing Belarus legislation. Therefore, it is expected that some substantial changes regarding the Belarus legislation are necessary.

Exist flood risk plans from the “Republican Program of Engineering Protection Measures from floods for population and agriculture for 2005-2010”. The focus of this Program lies on technical measures, on safety against floods for the main towns, villages, rural, industrial and agriculture lands in Polesye Region in Belarus (Pripyat River Basin), and partially for the Bug River Basin.

4.1.3 Ukraine

Water Management

Water management issue in Western Bug basin is under responsibility of the SWAU. Activities of the water management are regulated by the National target program of water management development and ecological rehabilitation of the Dnipro River for the period up to 2021 (approved by the Law of Ukraine №4836-VI, 24.05.2012). This Program envisages implementation of IWRM based on the basin principle; development and realization of river basin management plans; implementation of economic model of target-oriented financial support for the measures undertaking in river basins; establishment of basin councils, etc.

According to Decree of the Cabinet of Ministers of Ukraine "On approval of the Order of river basin management plan development" (№336, 18.05.2017) delineation of water bodies for Ukrainian part of Western Bug basin has been finalized. Currently, the process of Western Bug basin management plan development is ongoing.

Floods

A management plan according to all aspects of the EU-FD for the Bug River is not available. The EU Flood Directive is already in line with the existing Ukrainian water policy. Approximation of Ukrainian national legislation in water sector to European one is being performed with technical and expert support of EU project APENA (http://env-approx.org/index.php/en/).

The Cabinet of Ministers of Ukraine has approved the Order of development of Flood risk management plan (Decree №247, 04.04.2018). It is stated that SESU is responsible for development of Flood risk management plans (in cooperation with the Ministry of Ecology and Natural Resources of Ukraine, SWAU, other respective central executive authorities) for the certain territories within the River Basin Districts where the high risk of floods exists.

Specialists of Ukrainian Hydrometeorological Institute of the State Emergency Service of Ukraine and National Academy of Sciences of Ukraine in cooperation with specialists of SESU and APENA experts have worked out the Methodology of preliminary flood risk assessment (approved by the Order of the Ministry of Interior №30, 17.01.2018). According to this Methodology and time plan of EU-FD preliminary flood risk assessment for all River Basin Districts of Ukraine has to be finalized by the end of 2018.

Modelling

A comprehensive system analysis, using a complex and coupled modelling approach, was done within the project International Water Science Alliance Saxony IWAS (http://www.ufz.de/iwas-sachsen/index.php?en=18108). The complexity of the IWRM process was successfully analysed by a model cascade which encompassed models of climate, land use, hydrology, hydrobiology, hydrochemistry (surface and groundwater) as well as Urban sewage models (Figure 35). Moreover, this trans-disciplinary approach was set into a context with the analysis of governance and capacity development aspects to integrate political and institutional issues. Fischer et al. (2014) and Pavlik et al. (2014) investigated climate effects on hydrology at different scales and presented projections of decreasing water availability especially in summer. How to overcome data scarcity problems was shown by Pluntke et al. (2014) for surface water modelling, by Blumensaat et al. (2012) for urban water infrastructure, Tavarez-Wahren et al. (2012) for nitrate modelling and Körner et al. (2014) for groundwater recharge modelling.

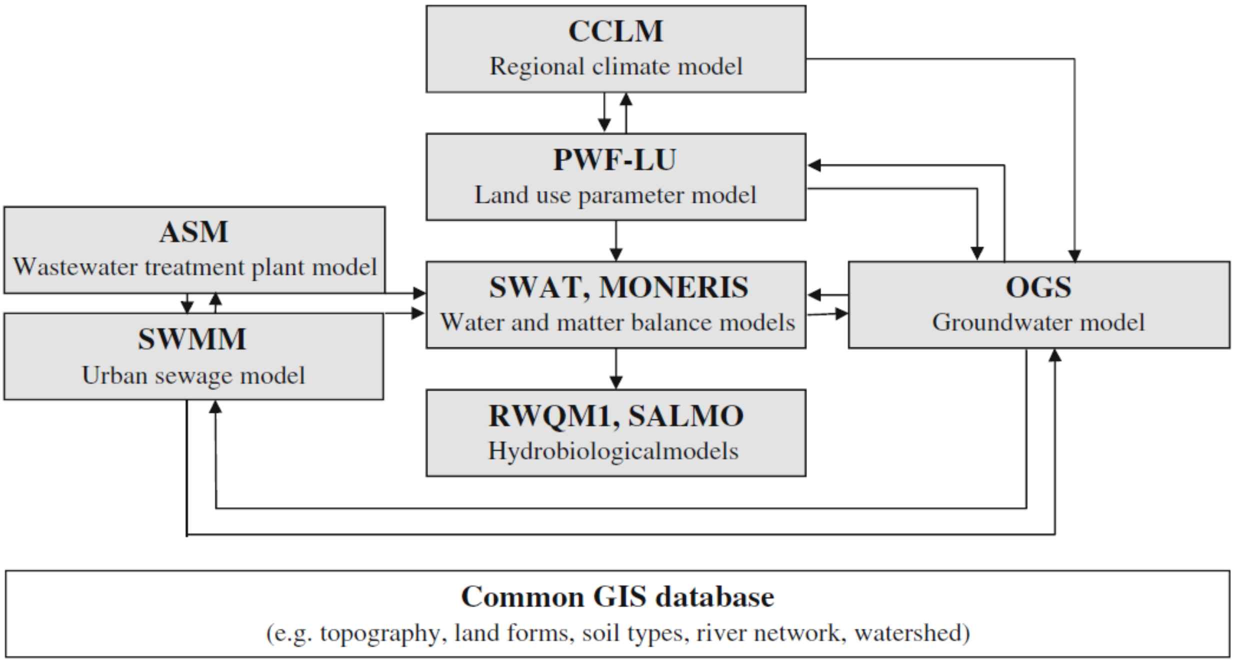

Figure 35. Model cascade in Western Bug basin (Schanze et al. 2012)

4.1.4 Transnational approaches

Cross-border hazard and risk maps with compliance to EU FD were generated within FLOOD-WISE project (FLOOD-WISE 2012). An example is presented on Figure 36.

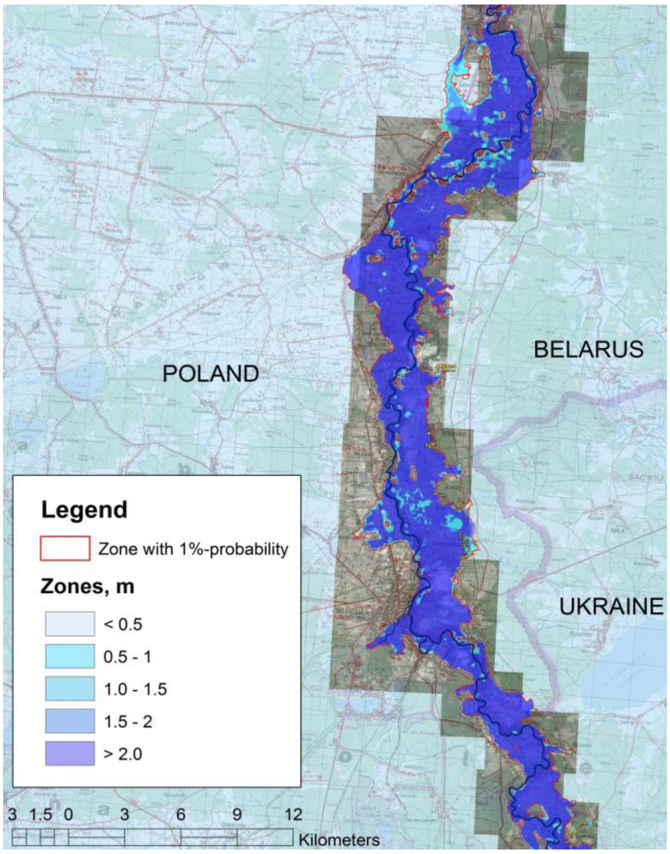

Figure 36. Example of flood hazard map for the Western Bug pilot district

4.2 Western Dvina/Daugava

Some of the projects that dealt with water management in the region are:

- Management of water resources in the Western Dvina river basin (TACIS 2002).
- Information management system and infrastructures for the transboundary Daugava/ Zapadnaya Dvina and Nemunas/Neman river basins (Swedish EPA 2007).
- Transnational River Basin Districts on the Eastern Side of the Baltic Sea Network (TRABANT).
- European neighborhood and partnership instrument, Towards environmental information system (ENPI-SEIS).
- From theory and plans to eco-efficient and sustainable practices to improve the status of the Baltic Sea (WATERPRAXIS).
- Information management system and infrastructures for the transboundary Daugava/Western Dvina and Nemunas/Neman river basins (DATABASIN).
- SKIOVO and NDV (document like Integrated water resource management and protection – IWRM).

4.2.1 Russian Federation

Water management problems and plans for Russian part of WD basin are described in SKIOVO and NDV. This document is prepared by Moscow-Oka basin Department of Federal Water Resources Agency. It points to main problems in water management and collects solutions. Main goals of SKIOVO and NDV are:

- ensuring sustainable operation of the system in the Western Dvina river basins,
- conservation of biological diversity;
- prevention of negative impact as a result of economic and other activities;
- preservation and improvement of the state of the system within water bodies or their sites;
- conservation and improvement of the state of the ecological system within water bodies or their sites;
- minimizing the impact of anthropogenic impacts creating a risk of irreversible negative changes in the ecological system;
- ensuring sustainable and safe water use in the process of social and economic development of the territory;
- identification of water resources needs in the future;
- ensuring the protection of water bodies;
- definition of the main directions of activities to prevent negative impacts of water.

According to SKIOVO main problems of WD river basin are:

- Water resources management, usage and protection (pollution of rivers and catchments by sphere social and agriculture).
- Negative effects of water (floods, ground water level rise, and erosion).
- Water supply problems (high water consumption by economics and transportation losses).

Water management

SKIOVO contains several points on water management strategy for Western Dvina catchment:

- achieving the long-term targets, corresponding to natural concentrations at reference water bodies;
- ensuring the safe operation of hydraulic structures;
- achieving the state of water, characterized as “slightly contaminated”;
- close to 100% provision of the population with drinking water.

Floods

According to SKIOVO and Russian Federal Legislation (Decision No. 360 of the Government of the Russian Federation dated 18 April 2014) in every settled area flood zones should be delineated until 2019. The benchmark figures of negative flood consequences are zones of flooding by high water levels with different probability (1%, 3%, 5%, 10%, 25% and 50%). These flood zones are prepared for the State Cadastre of Estate and should be used for new construction, waste location management and monitoring of water bodies.

4.2.2 Belarus

The project "Environmental Protection of International River Basins (EPIRB)" (http://www.blacksea-riverbasins.net/en/pilot-basins/upper-dnieper-river-basin) aimed at an improvement of the water quality of transboundary rivers in the Black Sea region. The principles of IWRM in accordance with the EU WFD was promoted.

Water management

Draft RBMP was developed within the project EPIRB for the Upper Dnieper River Basin according to the approaches and methodologies of the WFD and the national water legislation of Ukraine and Belarus. WFD-compliant monitoring programs were prepared.

Floods

A management plan according to all aspects of the EU-FD for Western Dvina is not available. Exemplarily for the city Dobrush, a flood risk assessment and mapping was performed within the project EPIRB.

Modelling

Flood risk modelling was exercised with 1-D hydraulic calculations and mapping with GIS.

4.2.3 Latvia

Water management

River basin analysis and practices base on EU directives and national laws and regulations. The river basin and groundwater management approach has been introduced to surface and groundwater management in Latvia. It has been approved by the Cabinet of Ministers and it is binding to everyone who is using those resources.

The first national RBMPs were developed and approved in 2010. The transboundary pressure was evaluated based on the total load of N and P coming from the neighbouring country. No water bodies were identified which are considered as significantly affected from the transboundary pollution pressure.

Stakeholder groups were involved (farmers, foresters, local municipalities, Regional development agency, Ministry of Environment, NGOs and community representatives).

The RBMP is linked with the other sectoral plans, of which the most important are: Environmental Policy Strategy 2009–2015, National Flood Risk Management Strategy 2008-2015, National Development Plan 2007-2013, Regional development plans (depending on a RBD), HELCOM, and EU directives.

Consultative RBD boards exist, which are an effective panel for the discussion of the RBMP issues.

An assessment of the first RBMPs was performed by the European Commission (EC 2012).

Later on, EC (2017b) compiled an Environmental Implementation Review. The main points are:

- The RBMPs define clear goals and propose measures towards good water quality.
- Generally, Latvia exhibits a good level of environmental protection and a good water quality.
- As regards drinking water, Latvia reaches very high compliance rates.
- There are certain deficiencies in RBMPs. In particular the methods to assess the status of water bodies, the pressure impact analysis, and the setting of ecological objectives are not fully developed.
- Measures to reduce the hydromorphological pressure in river basins should be reviewed and improved.
- Many exemptions were applied, without proper reasoning.
- Some significant shortcomings exist in the monitoring (e.g. river basin specific pollutants, monitoring of designated HMWBs, and biological quality elements).
- Definition of the ecological potential of each HMWB type needed.
- Although nitrate levels from agricultural sources have been slightly decreasing in the period 2008-2011, eutrophication of the Baltic Sea remains an issue for Latvia. More appropriate measures for nitrate reduction in agriculture should be applied.
- With regard to the implementation of the Urban Waste Water Treatment Directive, Latvia reaches overall high compliance rates. Still it is necessary to improve the situation of the physical connections to the wastewater collection systems.
- Waste management should be improved particularly increasing recycling.
- Resource efficiency, particularly in waste management and in water resources management, should be more encouraged.
- For the first planning period (2009 – 2015), transboundary issues have not been coordinated, and international RBMPs have not been developed.
- Climate change is mentioned as a possible pressure to water bodies. As there is no methodology developed within the framework of RBMP, results of the KALME project (http://kalme.daba.lv/en/) were used. No water bodies were identified which are significantly affected from climate change. Therefore, it has not been considered in the PoM.

The second update of RBMPs (2016-2021) was adopted on December 22, 2015 (http://ec.europa.eu/environment/water/participation/map_mc/countries/latvia_en.htm), but no assessment of the EC was done until now.

Floods

National flood hazard maps were produced in the scale 1:200.000 in 2005.

Modelling

Applying models for a system analysis and for planning and management issues is a widely used concept in Latvia. Some examples are mentioned:

- Hydrological modelling.
    - For rivers: with the conceptual rainfall-runoff METQ model, version METQ2007BDOPT.
    - For groundwater simulations: Model METUL (Lauva et al. 2012).
- Water quality models (Ruskule 2011).
- Hydrogeological Model of Latvia (https://ortus.rtu.lv/science/lv/publications/15353/fulltext): In general, the groundwater resources in Latvia are in good condition. However, shallow groundwater is poorly protected from surface sources of pollution (waste dumps, territories of former military bases, oil product storage, agricultural activities, etc.). Incorrect and excessive use of groundwater has resulted in worsening of its quality (in Liepaja sea water intrusion took place; in Jelgava the quality of artesian groundwater is worsening, the well field Baltezers is endangered by economic activities in its vicinity, etc.).
- Riga Technical University (RTU), upon the assignment of the former State Geological Survey established the HM LAMO for the whole territory of Latvia. It was used for management of potable groundwater resources and for evaluating their recovery measures.

4.3 Desna

Water Management

Water management issue in Desna basin is under responsibility of the SWAU. Legal background of Desna basin management is the same as in Western Bug (refer to sub-section 4.1.3). However, no delineation of water bodies for Desna has been done yet. It is planned within the development of the Dnipro Basin Management Plan (Desna basin is a sub-basin to the Dnipro basin) will be done during implementation of EUWI+ project (http://www.euwipluseast.eu/en/about/project-description). The main objective of the project is to improve the management of water resources, in particular trans-boundary rivers, developing tools to improve the quality of water in the long term, and its availability for all. One of the specific thematic areas of the project is development and implementation of River Basin

Management Plans, including: organization of joint field surveys in trans-boundary rivers; development and strengthening of national databases on water related issues; support to river basin management institutions in the implementation of management plans; establishing a system for regular monitoring of the implementation of management plans.

Floods

A management plan according to all aspects of the EU-FD for Desna River is not available. The process of EU-FD implementation is described in sub-section 4.1.3.

Modelling

The SWAT model (Soil & Water Assessment Tool, https://swat.tamu.edu/) is used for Desna basin by the specialists of Ukrainian Hydrometeorological Institute. The SWAT model was tested to simulate the water flow of a large plain river with a predominant snow supply. River discharges (12 gauges), snow cover depth (13 stations), and the soft data, including graphically defined surface runoff and MODIS evapotranspiration, were used to calibrate the model. The calibration flowchart, along with a detailed source data description, is proposed to aid with streamflow simulation for the snowmelt-driven watersheds and fill the existing gap of distributed hydrological modelling in the region.

Chapter V. Pilot study in Western Dvina Basin

5.1. Introduction

Riverine fluxes, which represent the amount of chemicals transported along the river, is an important subject in transboundary rivers, being responsible for pollutants delivery from the upstream to the downstream country. At the same time, the measurement and calculation of riverine material fluxes are subject to significant statistical errors which should be evaluated and made clearly visible to the users of flux data, such as water-quality managers and users of riverine waters (Moatar et al., 2012). As concentration samples are usually infrequent (from weekly to monthly), only a minor part of the daily river flux population is known, representing the first source of flux uncertainties (Rode et al., 2007). Significant drifts in the measured quantities may arise due to the location of the sampling in the river section, because suspended sediment concentration varies within the river cross-sections, thus necessitating a series of depth- and width-integrated measurements (Horowitz, 1997). Accuracy and precision of flux estimates depend on: i) the type of river material (suspended particulate matter, nutrients), ii) the sampling strategies and the reporting period (Littlewood 1995; Robertson and Roerish 1999), iii) catchment characteristics such as basin size, and iv) the role of transport regime (F. Birgand et al. 2011; Moatar et al. 2013).

Estimates of water, sediment and tracers fluxes, which are crucial for the transboundary rivers management, are widely known to have large uncertainty due to discrete (infrequent and irregular) concentration data (Moatar et al. 2013), location of the sampling in the river system and section (Horowitz 1997), drawbacks in methodology (both sampling and calculation) (Rode and Suhr 2007). The transboundary rivers also face problems related to spatial inconsistency of stations location due to discrepancies in monitoring program in different countries. Also, in many places of the world, particular parts of transboundary river are rather poorly studied. The latter is being the main cause of significant uncertainties and gaps in knowledge on water quality of Western Dvina (WD) Basin, which is the case study of this project.

Russian part of WD Basin is approximately 17 000 km^2, annual runoff is about 1% of total inflow to Baltic Sea. Gauging network is sparse and has a lot of gaps in data, especially related to water and sediment quality (Chalov et al. 2017). Within the MANTRA project a multidisciplinary ecohydrological study has been established in the Russian part of WD basin which represents a poorly gauged segment of the transboundary river basin. The study is based on a novel field-based campaign documenting the origin and fluxes of water and chemicals in the WD catchment. This approach is treated as guidance for assessing potentials and uncertainties of the existing monitoring strategy of water and sediment quality and the river fluxes.

According to the general objectives of the MANTRA project, the main goals of the pilot study were set:

1. To introduce a measuring and modelling concept for investigating water and sediment transport and quality in transboundary river basins.

2. To quantify water and sediment rates and quality along the Russian part of WD through intensive monitoring (snapshot and regular) and modelling of water runoff and quality during period of project implementation.
3. To estimate accuracy and precision of water quality components accounting for the types of river material (suspended particulate matter, nutrients, heavy metals), the sampling strategies, the reporting period and seasonal variability (the role of transport regime).

The study aims at general improving of knowledge on river fluxes in the upper part of the MANTRA case study WD River, in particular water and pollutants, as well as providing an insight into the transboundary river monitoring strategy.

In this report, we aim to present the concept of the pilot study. The chapter 'Data and methods' contains methodological aspects of particular parts of the approach. In 'Preliminary results', the main outputs achieved until now are presented.

5.2. Data and methods

5.2.1. Measuring and modelling concept

An integrated conceptual approach of water and sediment transport and quality is applied for WD catchment. The approach is based on integrating independent field and numerical tools (hereafter Work packages, WP) to develop a comprehensive conceptual model of the sources and transport of water, sediment and tracers. Two principal research scales are concerned: sources (A) and hydrological pathways (B) (Table 24).

The development of the process-based water, sediment and tracers dynamic integrated approach for pilot study in Western Dvina Basin involved several field-based (I) or numerical and remote sensing (II) working packages. The field-based studies consisted of Field reconnaissance, water and sediment sources sampling, experimental study on stream flow-river bed mass exchange (all related to AI, Table 1) and water flux assessment from regular discharge datasets, spatio-temporal assessment of water quality in the WD catchment, sediment and tracers (total dissolved load) flux assessment from regular discharge datasets obtained (all related to BI).

The numerical working packages (II) included field-based and remote sensing monitoring program to determine the principal factors of water, sediment and tracers dynamics, adoption of an existing distributed hydrological model (SWAT) based on climatic reanalysis and field-based GIS catchment inventory, development of soil erosion, sediment transport and deposition modules for channel and hillslope areas separately using statistical model LOADEST and integration of these modules with SWAT consistently (Table 24). The model calibration additionally uses results of field-based catchment land cover and soils description and classification. Each of the work packages was numbered in 3-digit format (A, B – research scope (sources or pathways); I, II – type (I – field-based; II – numerical and remote sensing); 1,2,3,4,5 – exact tool). Altogether, the integrated approach is aimed to provide a full quantitative description of river fluxes and sediment and water quality in poorly gauged catchments.

Table 24. Integrated approach for pilot study in Western Dvina Basin: model chain

Research scope	Work package		
	Type *	Water	Sediments and tracers
A. Sources	I	1. Field reconnaissance and land cover classification 2. Water and sediment sources sampling 3. Experimental study on stream flow-river bed mass exchange	
	II	1. Discriminating runoff sources using end-member mixing analysis (EMMA)	2. Discriminating sediment sources using fingerprinting technique sediment concentration – water discharge hysteresis rating curves analyses
B. Hydrological pathways	I	1. Water flux assessment from regular discharge datasets	2. Spatio-temporal assessment of water quality in the WD catchment 3. Sediment and tracers flux and associated uncertainty assessment from regular measurements datasets
	II	1. Long term data for flow discharge (Q) from available gauges (daily and monthly) 2. Large scale semi-distributed hydrological and erosion model (SWAT): 2a. meteorological ERA-Interim reanalysis 2b. catchment delineation 2c. land cover and soil classification 3. Small scale detailed semi-distributed hydrological model (SWAT)	3. Long term data for sediment discharge (S) from downstream station (Velezh) (event based) using statistical sediment load model (LOADEST) 4. Semi-distributed erosional model using hydrological SWAT model

Work package type: I – field-based; II – numerical and remote sensing

The following chapters represent methodology used for each Working package in Pilot study.

5.2.2. Description of modules

AI-1. Field reconnaissance and land cover classification

Development of pilot study work packages was based on the field reconnaissance, which includes routes in the WD basin to identify possible pilot study plots. Based on the preliminary overview of the catchment, the representative case study area was chosen in the Velesa River – one of the left tributaries of the WD within the Russian part of its basin. This is typical river for the WD River catchment which flows through plain marshy areas of the Tver region. The total catchment area of the river is 1420 km². The gauging station water regime is monitored at the Rudnya gauging station (catchment area is 890 km^2). The main strategy for water and sediment sources inventory, as well as key pilot study channel plot for water quality monitoring uncertainties study was developed during reconnaissance surveys.

Reconnaissance included field investigation of catchment land cover description which consisted of geobotanical descriptions of main significant land classes of the catchment. Geobotanical descriptions consist of textual vegetation type description, precise coordinates and photo pictures of the surrounding for the following types of vegetation: mixed forest, deciduous forest, wetlands, bare ground, pine and spruce forests, sand quarries, abandoned and cultivated lands. Obtained data were used for an automated image interpretation as landscape standards classified on the image.

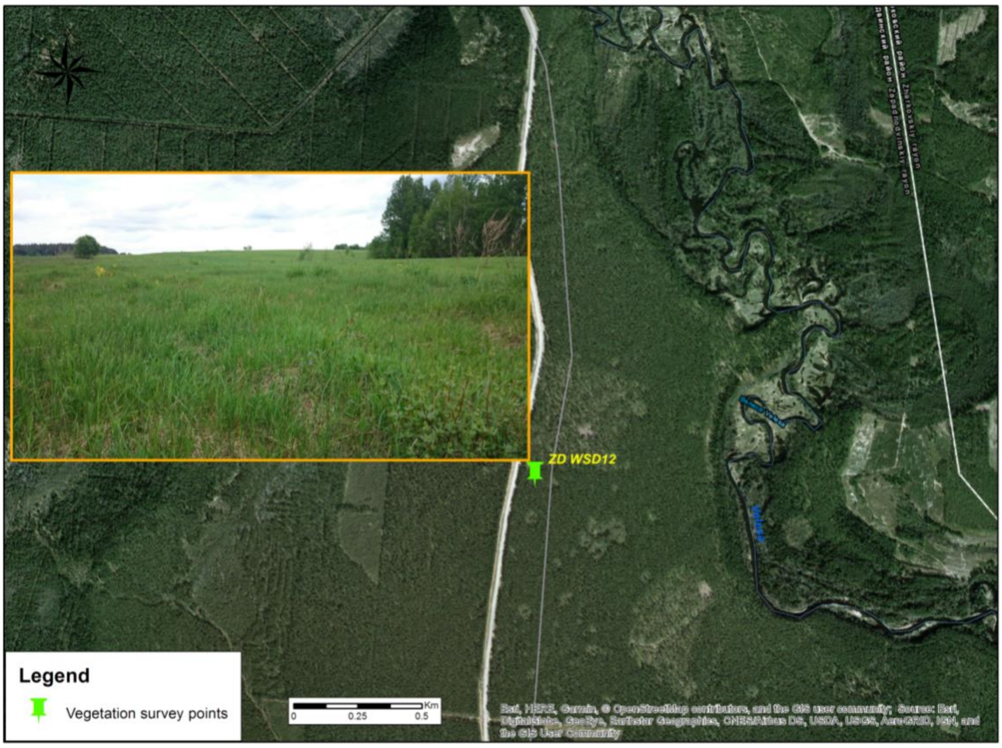

Figure 37. Example of vegetation survey point location and landscape

Collected standards (training datasets) and pictures during fieldwork in May 2017 were used to define standards for main land cover classes inside the catchment area (Figure 37). Homogeneous land cover type sites were chosen with at least 90x90 meters to use with Landsat

Imagery. Geobotanical descriptions for vegetation survey sites and pictures were collected for the centres of these sites to help the supervised image classification. Descriptions include general landscape information, species composition for tree, shrub layers and understory vegetation, vegetation density, site coordinates and comments for pictures (Figure 38).

Figure 38. Examples of wooded wetland, abandoned pasture and coniferous forest

The best open-source image covering the most part of the catchment is Landsat 8 OLI obtained on 17 September 2014. Others contemporary images are highly clouded and not appropriate for land cover classification. The best result of automatic image classification was obtained using the Isodata method based on 20 user defined classes and standard based Maximum Likelihood Methods. These classes were generalized and reclassified into NLCD92 land use/land cover classification.

Three Landsat images were used (Landsat 4 TM of July 26, 1992, Landsat 5 TM of July 27, 1992 and Landsat 8 OLI of 17 September 2014) in order to estimate the past conditions of the WD watershed land cover/land use.

All images were classified separately using Maximum Likelihood supervised classification and then merged into mosaic. The training datasets were derived from Landsat images. We chose them on the base of field data points with vegetation descriptions. Initially 45 classes were produced that were further grouped manually into 12 classes according to NLCD 92 classification.

Several NLCD92 classes (21, 23, 32 and 61) were produced from OSM vector layers (as of July 2017) and incorporated to the initial Landsat classification. This allowed increasing the quality of the classification as these classes are usually mixed and are difficult to distinguish from Landsat images.

The final classes were assigned with standard NLCD92 colours.

For present-day classification of the WD watershed land cover/land use we used the same algorithm but Landsat 8 OLI images of 17 and 26 September 2014.

AI-2. Water and sediment sources sampling

Water and sediment samples were collected between May and October 2017 and February and June 2018. A total of 90 water samples were collected, covering all the major terrestrial sources of water to river and the water in the river (Figure 39). Various hydrological seasons (from wet to dry season, both with upper and lower limbs of the hydrographs, as well as ice- and ice-free conditions) were surveyed (Figure 39).

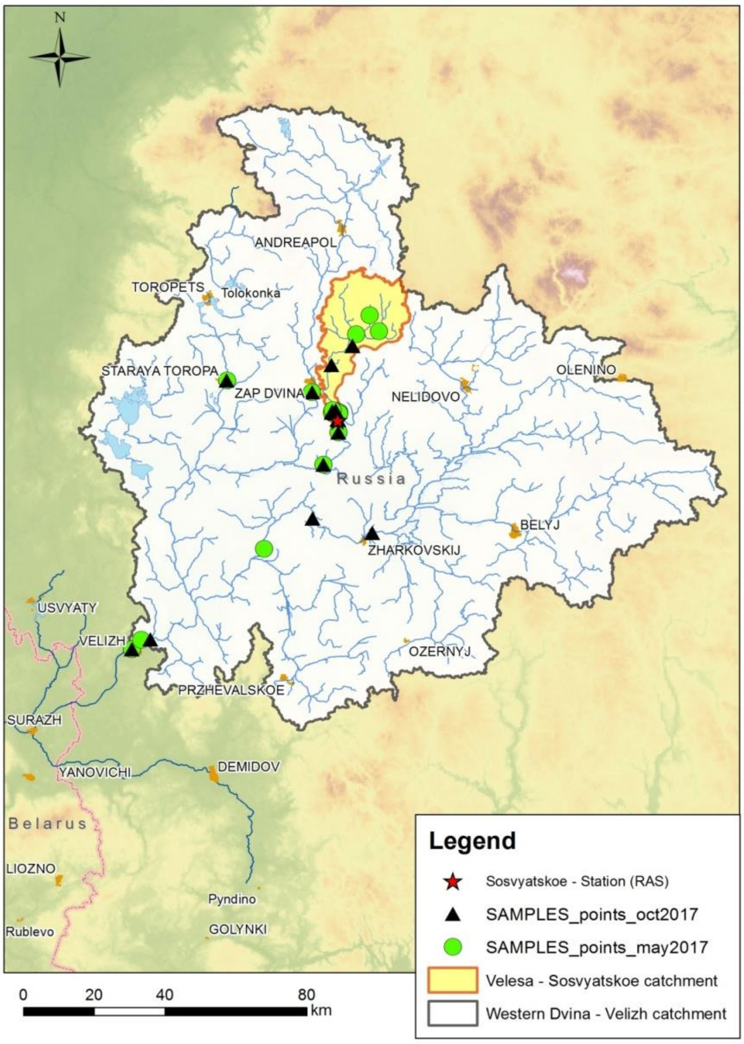

Figure 39. Sampling location for discriminating runoff sources in the Velesa river catchment (WD tributary)

Sediment sampling involved two main stages – mainly following recession of the spring snowmelt floods in May 2017 and 2018 with limited additional sampling between those. In total, 29 source samples and 42 time-integrated suspended sediment samples (TISSS) (21 from main channel bars and 21 from fresh post-flood over bank deposits) were taken in May 2017. At the same time, 4 time-integrated suspended sediment samplers were installed to collect integral samples over the summer low-water period since May 2017 to October 2017. The May 2018 sampling campaign involved sampling of freshly deposited spring flood sediments including 7 samples from main channel bars and 15 samples from overbank deposits. Except for the 4 time-integrated samplers, at each sampling location 3 subsamples were taken that were packed and labelled separately in order to assess possible local variability. In the laboratory, samples were oven-dried (105°C), sieved to separate >2 mm fraction. Representative subsamples were taken for determination of: 1) mobile forms of selected elements by atomic-absorption spectrometry; 2) total concentration of selected elements by X-ray fluorescence; 3) selected radionuclide activity by gamma-ray spectrometry; 4) particle size by laser diffraction.

The following potential sediment sources have been considered: 1) channel bank erosion (undercut floodplain and terrace banks); 2) tributary channel bed incision; 3) small temporary tributary streams located in gullies; 4) cultivated areas; 5) active timber harvesting territories; 6) unpaved road erosion. Each of them was investigated during the sampling campaign (Figure 40).

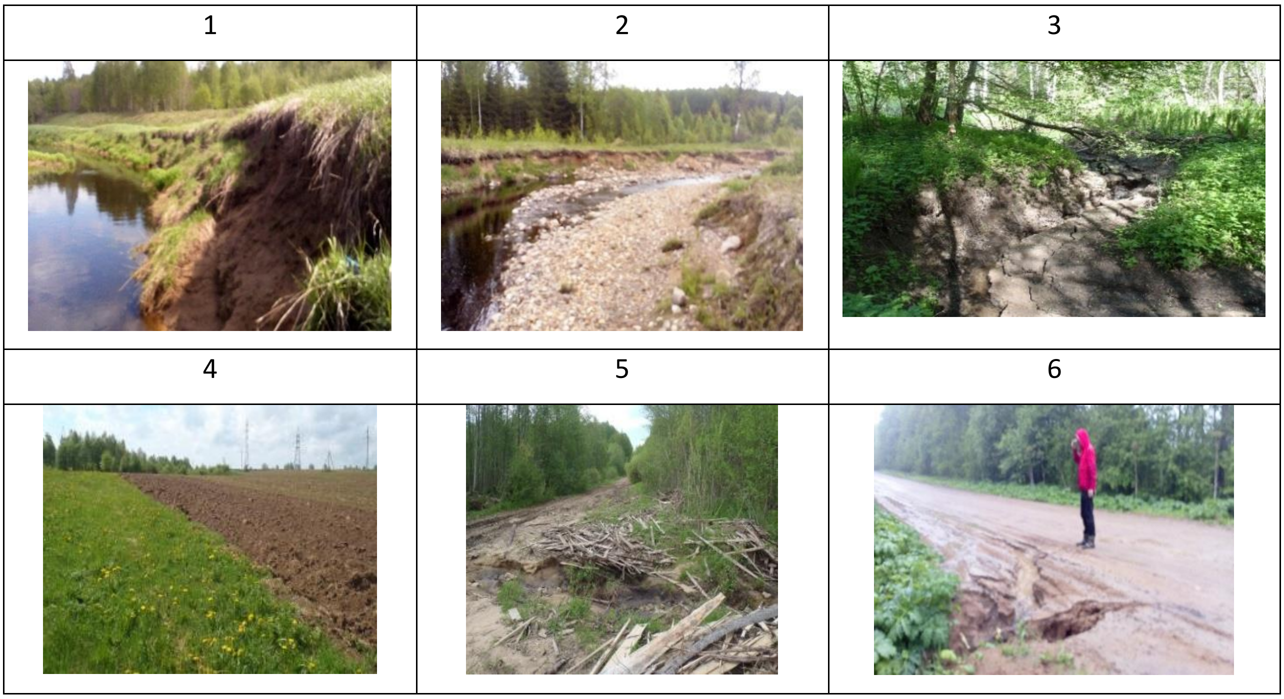

Figure 40. Main considered sediment sources (see in the text explanations)

AI-3. Experimental study on stream flow-river bed mass exchange

Experimental field-based study was initiated at the Velesa case study reach to define the number of organic compounds (C) and biogens (P, Fe, Mn) which is released or stored in the river water due to mass exchange of hypogeic zone. At the border between "water and sediments" there is a constant exchange of suspended and dissolved material. Sediments can absorb different substances, and there are many chemical and biological processes there. In water objects, such as lakes and some reservoirs, bottom sediments have a significant effect on the hypolimnion zone. In rivers with higher stream velocities, influence of bottom sediments in usually neglected in the mass exchange. Due to this, field studies documenting chemicals exchange in sand rivers are rare. In this project, an experimental technique was used to assess longitudinal variability of chemicals due to exchange in near-bottom water-channel interface. The experiments conducted on the Velesa river channel with pool-riffle morphology are used to document in-channel sources of organic compounds (C) and biogens (P, Fe, Mn) in the river.

The experimental set up is based on the balance equation for the selected particulate forms to define the ratio between bottom-water exchange ΔC and longitudinal changes in sediment transport W2-W1 based on the Kuznetsov-Romanenko tube method (Romanenko 1985)

$$\Delta C / (W2-W1) \qquad (1)$$

where W2 – the flux of the element in the downstream section (pool) and W1 – the flux of the element in the upper section (riffle). Assessment of the ΔC is based on an evaluation of the chemicals in the water column. For this bottom sediments were sampled in glass tubes (Figure 41). Further exposition of the glass tube with bottom sediments and “empty” tubes was done to define matter flux from bottom area during time of installation (mg/m^2 per day):

$$F\ (mg/m^2 * d^{-1}) = 240*(C_{tube}-C_{idle})*L/t, \qquad (2)$$

where F is the flow of the substance to be determined from the bottom sediments from m2; C_{tube} and C_{idle} – concentration of substance in a tube with a ground and a blank (control) tube, mg/l; L – height of the water column above the ground in the tube, cm; t – the exposure time, hour.

Samples of bottom sediments were taken at two locations of the study reach of Velesa river, both representing sandy material. Further experiment of oxygen consumption by bottom grounds rate (by the consumption of oxygen in tube in exposal time) was made. The total destruction of OM in muds was determined by the amount of HCO_3^- exited from the column of sediments during the exposure time. The transition from the amount of oxygen consumption to aerobic degradation of OM through the carbon concentration was carried out based on the respiratory coefficient (Sakharova, 1974). Anaerobic destruction was calculated as the difference between total and aerobic destruction of OM. Flows of phosphorus, ferrum and manganese from bottom sediments and the content of organic matter (OM) in the upper layer of the bottom sediments (loss on ignition) and hygroscopic soil moisture as a difference in the air-dry and absolutely dry weight of the soil were also determined. The destruction of OM in the bottom layer of water by the bottle method (according to the method of Vinberg) was also evaluated.

Figure 41. Experimental setup to study bottom sediment – water exchange

AII-1 Discriminating runoff sources using end-member mixing analysis (EMMA)

Study of runoff generation is based on hydrochemical assessment of interaction of waters from various water sources of a river in the process of mixing within the river basin based on the samples collected in Working package AI-2. Various origins and properties of water bodies associated with the main physical processes involved into runoff generation – water of deep underground horizons, slope (or soil) water, and atmospheric water coming into rivers, preferentially by surface flow – are considered (Voronkov, 1970; Edelshtein, 1992). The water sources can be estimated on the basis of the three-component mixing model with 2 tracers that were developed on mass balance equations for water and tracers. The model equations are:

$$\begin{cases} Q_1 + Q_2 + Q_3 = Q_t \\ C_1^1 Q_1 + C_2^1 Q_2 + C_3^1 Q_3 = C_t^1 Q_t \\ C_1^2 Q_1 + C_2^2 Q_2 + C_3^2 Q_3 = C_t^2 Q_t \end{cases}, \quad (3)$$

where Q is water discharge; C is the concentration of tracers; t is the current time step; the superscript is the tracer; the subscript is the component (water source). The equation system in general form is represented as follows:

$$Q_1 = \frac{(C_t^1 - C_3^1)(C_2^2 - C_3^2) - (C_2^1 - C_3^1)(C_t^2 - C_3^2)}{(C_1^1 - C_3^1)(C_2^2 - C_3^2) - (C_2^1 - C_3^1)(C_1^2 - C_3^2)} Q_t$$

$$Q_2 = \frac{C_t^1 - C_3^1}{C_2^1 - C_3^1} Q_t - \frac{C_1^1 - C_3^1}{C_2^1 - C_3^1} Q_1 \quad (4)$$

$$Q_3 = Q_t - Q_1 - Q_2$$

The equations (3) can evidently be rewritten using the ratio of discharges of components to the total discharge using the equation $f_i = Q_i / Q_t$. In this case: $f_1 + f_2 + f_3 = 1$. In the selected case study area, the identification of the representative sources of water is based on selected tracers by "end-member mixing analysis" (EMMA) (Hooper et al., 1990). The method involves the graphical plotting of the concentrations of one environmental tracer against that of another, with the constraint that all stream water samples fall within a triangular space bounded by three end-members (water sources). The principal design of the study in Western Dvina basin (Velesa river catchment) includes inventory of ground, rain and surface water combined with river flux. Chemical parameters are measured *in situ*: temperature, pH, specific conductivity (SPC), total dissolved solids (TDS), and content of hydrocarbonate ion (HCO_3^-). Concentration of the sulphate ion (SO_4^{2-}), chloride ion (Cl^-), nitrate ion (NO_3^-), calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), potassium ion (K^+), sodium ion (Na^+); and silicon (Si), phosphorus (P), organic characteristics (colour, chemical oxygen demand) were additionally determined in the laboratory.

AII-2 Discriminating sediment sources using fingerprinting technique

Similar to the water sources study, a combination of geochemical, radionuclide and physical sediment fingerprinting approach (Collins et al., 1997) was conducted to evaluate the sources of suspended sediments. The modelling procedure involves the use of the Kruskal-Wallis test, to identify those fingerprint properties capable of discriminating between the potential sources. A stepwise multiple discriminant analysis was performed to determine the optimum set of properties for the composite fingerprint. For each element, the Goodness of Fit (GOF) was estimated as a statistical model describes how well it fits into a set of observations to summarize the discrepancy between the concentration in sediments values and the values in a source. The composite fingerprint was used in a mixing model, which was optimized by minimizing the objective function *R* (5), based on the sum of squares of the deviations from the measured concentrations of the concentrations estimated for individual tracer properties, for given relative contributions *P* from the *m* individual sources *s*,

$$R_{es} = \sum_{i=1}^{n} \left(\frac{C_{ssi} - \left(\sum_{s=1}^{m} C_{si} P_s \right)}{C_{ssi}} \right)^2 \quad (5)$$

where: *Csi* is the concentration of tracer property *i* in the suspended sediment sample, *Cssi* is the mean concentration of tracer property *i* in source group *s* and *P* is the relative proportion from source group *s*.

B I-1. Water flux assessment from regular discharge datasets

During summer-autumn season 2017, a gauging station was operating on the Velesa river at the case study reach (56.161412N, longitude 32.188517E). Two data loggers (***Figure 42***) were installed at 50 cm under the water surface (low water). The "RBR solo" is a turbidity sensor for NTU (Nephelometric Turbidity Unit) measurements and the "Solinst Levelogger Junior Edge" serves for water level and temperature measurements. The logging interval was set to 10 minutes. For the analyses, precipitation and air temperature data were collected from the nearest meteorological station (Toropec).

Figure 42. RBR solo and Solinst Levelogger sensors (data loggers) used to monitor sediment concentrations and water levels, respectively

Additionally, for purposes of water level records calibration, during field work several series of discharge measurements in Russian WD catchment were performed:

1. Winter 2017 (February 1-6)
2. Spring 2017 (May 1-5)
3. Fall 2017 (October 22-23)
4. Spring 2018 (May 4-7)

Measurements were made using the current meter (ISP-1M) and the SONTEK Acoustic Doppler Profiler (ADP) in May 2018 (***Figure 43***, ***Figure 44***, ***Figure 45*** and ***Figure 46***).

Figure 43. Velocity measurements with propeller current meter

Examples of a discharge profile made with the ADP are presented in Figure 44, Figure 45 and Figure 46.

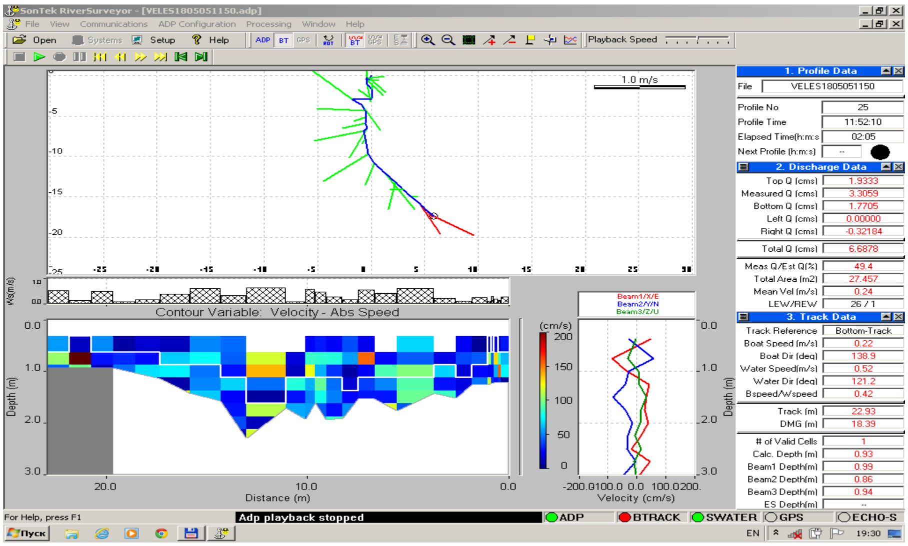

Figure 44. Velesa river – Mukhino central cross section, 5 May 2018, Qmean=6.6 cms.

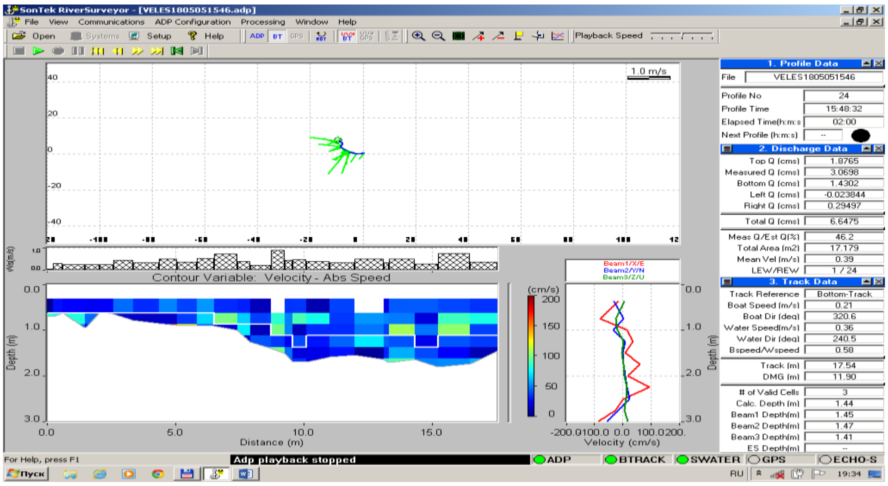

Figure 45. Velesa river – Mukhino downstream cross section, 5 May 2018, Qmean=6.3 cms.

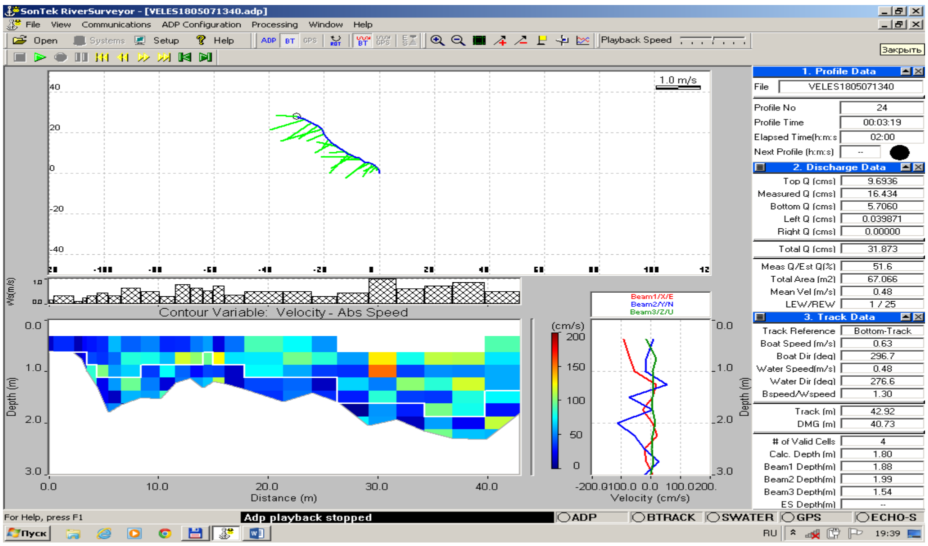

Figure 46. Western Dvina river – WD (bridge), 6 May 2018, Qmean=33.4 cms.

B-I-2. Spatio-temporal assessment of water quality in the WD catchment

For the first time in the region, extensive field-based study was done to assess the variability of the water quality parameters in the WD catchment. The location and frequency of the snapshot sampling campaigns focused on a characterization of most diverse conditions. The following methods were used for analytical procedures to process with sampled water:

- P_{min} - determined by the method of the Morphy-Riley (GOST 18309-2014)
- P tot -determination of total phosphorus was carried out according to the method of Morphy-Riley scheme Sugawara
- Si – Photometric method in the form of yellow H4[Si(Mo3O10)4]. (PNDF 14.1:2:4.215-06)
- Alk - The method of volumetric titration (GOST 31957 — 2012)
- Salt composition, NO3 - method of capillary electrophoresis (Practice guidelines for the use of capillary electrophoresis systems “Kapel”, 2006)
- Organic matter (GOST 31868-20120).

B I-3 Sediment and tracer fluxes and associated uncertainty assessment from datasets of regular measurements

Together with water level recording, turbidity and conductivity of the Velesa river was monitored. The main aim of this study is to discuss uncertainties in sediment and water quality transport monitoring related to temporal resolution of the sampling strategy, e.g. impact of big events etc. (Thomas and Lewis, 1993; Littlewood, 1995; Robertson and Roerish, 1999). To understand role of particular hydrological conditions on sediment monitoring program, river hydrographs were divided into separate hydrological events within which further analysis was introduced. The separation was carried out based on the identification of the base runoff using the local minimum method (Sloto and Crouse, 1996), which is a mathematical interpretation of the graphical method of B.V. Polyakov (1946). The local minimum method verifies each value to determine whether it is the lowest level per one half of the interval minus 1-time unit before and after the considered one. If so, then it is a local minimum. A hydrological event will be the change in water runoff over a period of time between adjacent local minima.

For each hydrological event, the contribution of optical turbidity fluctuations within one hour was evaluated using the following method. Each hour, the difference between the maximum and minimum turbidity for a given period of time (ΔT_i) was calculated and referred to the difference in turbidity for the hydrological event (ΔT_{HE}):

$$\Delta T_i = T_{max} - T_{min}, \qquad (6)$$

where T_{max}, T_{min} are the maximum and minimum turbidity value for *i* period of time, NTU. The authors suggested indicating the ratio of the range of variations of ΔT_i to ΔT_{HE} as *TI* (turbidity index – the optical turbidity index):

$$TI_{HE} = \frac{\Delta T_i}{\Delta T_{HE}} \qquad (7)$$

Thus, the calculation of the coefficient characterizing the mean contribution of urgent turbidity fluctuations for the entire series of observations was carried out using the following formula:

$$TI_{av} = \frac{\sum_{i=1}^{n} TI_{HE}}{n}, \qquad (8)$$

where TI_{HE} is the index of optical turbidity fluctuations for a hydrological event, no measure; TI_{av} is the index of fluctuations of optical turbidity for the whole series of observations, no measure; *n* is the number of hydrological events.

Here, uncertainties associated with estimating water quality parameters attributing data pilot monitoring program at WD with an emphasis on different spatial and temporal scales are assessed. We consider sampling uncertainties associated with representative samples at a sampling location and given river cross section and sample frequency. Sampling location was therefore was characterized by x coordinate (x, m) and represent length between various sampling sites (Figure 47). Variability's within the cross section of a given river reach was characterized by y (width y, m) and z (depth z, m) coordinates. At the end, regular sampling and samples in duplicates was used to estimate uncertainties associated with time (t, sec). The seasonal variations of nutrients and metal concentrations in particulate and dissolved mode based on the data obtained for the same point during different hydrological seasons. Uncertainties related to basin-wide variability of water quality parameters will be studied based on data from the same hydrological season obtained from different locations within WD catchment. Uncertainties due to sampling conditions will be examined based on the cross-sectional (the same depth within one cross-section at the certain sampling time) and depth-wide (through the water column at different depths) variability. For all datasets using standard procedures in Microsoft Excel 2010 average (M), variance (D, dispersion of the data around the mean), standard deviation $\sigma = \sqrt{D}$ and coefficient of variation $CV = \sigma / M$ was estimated (Figure 47).

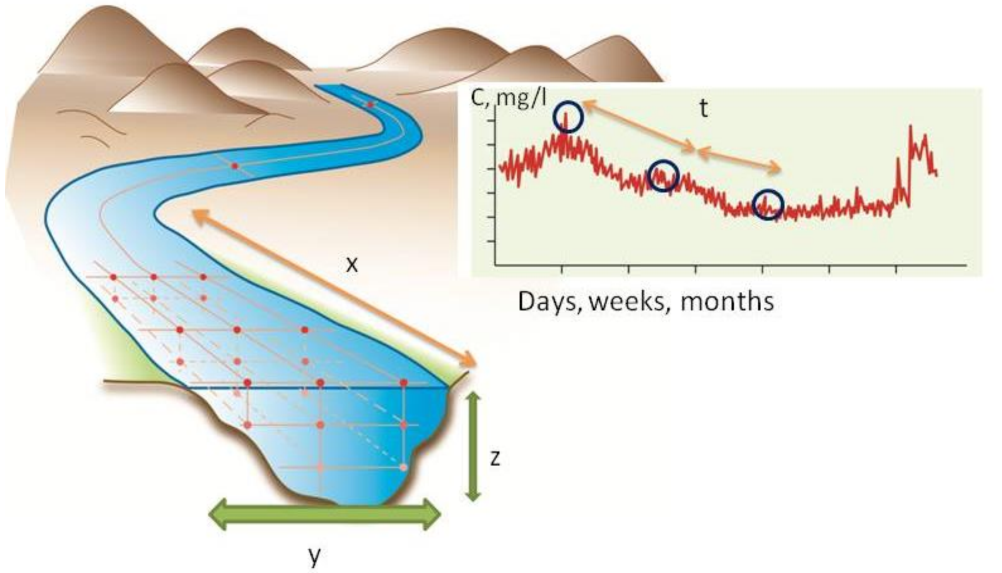

Figure 47. Scales of uncertainties studies at MANTRA pilot study plot

B II-1 Water flow (Q) assessment from available gauges (daily and monthly)

The pilot study also includes statistical analyses of long-term series of water flow changes. Discharge data for the Velesa river is based on water level and discharge observations for the Roshydromet gauging station – Rudnya (1250 sq.km). This gauging station is located 30 km downstream to Sosvyatskoe pilot study outlet. Daily discharges are available since set up of until 2004. Daily water levels are available from 1965 until 2014. For Russian outlet of Western Dvina catchment – Velezh (17250 sq.km), daily runoff and water levels were obtained until 2014. Daily discharge data were aggregated into monthly and annual runoff (Table 25). Daily discharges were used for SWAT model calibration, and annual runoff – for long term runoff analysis and to choose a representative period for runoff modelling.

Table 25. Available water discharge datasets for WD river catchment (Russian part)

Gauging station code	River	Gauging station name	Available daily discharges datasets
73108	Western Dvina	Zapadnaya Dvina	Before 1993
73110	Western Dvina	Velizh	Before 2004, 2007-2014
73182	Velesa	Rudnya	Before 2004
73186	Toropa	Staraya Toropa	before 2004, 2009-2014
73190	Mezha	Ordynok	Before 1996, 2009-2014
73196	Obsha	Beliy	Before 1996

B-II-2. Semi-distributed hydrological and erosion model (SWAT)

For the development of a hydrological model for WD catchment experiences with other models in the region were used. For a Russian sub catchment (Velizh outlet) the hydrological model HYDROGRAPH was applied, which simulated mean and extreme flow. The most well-known similar approach was done for Western Dvina by SHMI (Sweden) using HYPE model (Arheimer et al. 2012), but it is calibrated for whole catchment and does not focus on water runoff in the upper part of WD basin.

In this study a hydrological model based on Soil-Water Assessment Tool SWAT (Gassman et al. 2007) software was prepared (Terskii, Kuleshov, 2018). Two time-step models were developed separately (Figure 48). The general approach of modelling includes collecting and processing of input data, preparing the catchment model (preparing land surface datasets – topography, land use, soil). Initial runoff calculation is divided into test of model performance due to catchment components and inner features of model setup. Then finding the sensitive parameters, developing of calibration approach and then – using the model. Model is based on open source spatial data (details see below). A meteorological database was prepared for monthly time step, based on global datasets.

The calibration of parameters is based on hydrological observations. Continuous series of hydrological measurements were available for the gauging stations Velesa River – Rudnya, Toropa River – Staraya Toropa and WD River – Velezh for the period 1992-2004. It was decided to the following periods for the daily and monthly discharge model: 1989-1992 – warm-up period, 1992-1998 – calibration period, 1999-2004 – validation period.

A SWAT-intern intersection of land use map, soil map, and slope classes resulted in creation of 172 Hydrologic Response Units (HRUs).

The list of the most sensitive modelling parameters depends on the genesis of river flow, the size of the catchment and temporal resolution of the model (daily, monthly or annually), and on the modelling approach – lumped or distributed (for the distributed parameters).

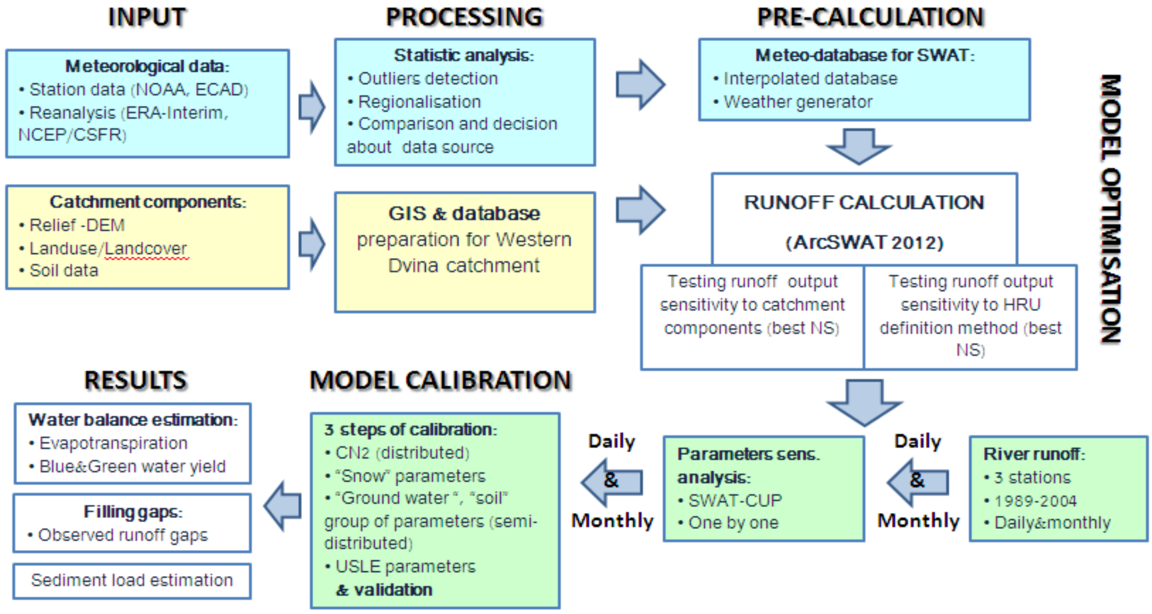

Figure 48. The conceptual framework of the study: water balance model flow of Western Dvina catchment

B II-2a. Meteorological input data

Free available station data from NOAA (https://www.noaa.gov) and from the European Climate Assessment & Dataset project (https://www.ecad.eu/) were used as well as gridded re-analysis data from the ERA-Interim. Precipitation, temperature and relative humidity were obtained from weather stations. Because no station data were available for wind speed and solar radiation ERA-Interim were used for the period 1979–2016 (https://www.ecmwf.int). Two weather stations near the Velesa catchment with continuous and public open observations (Toropec and Beliy) were used (Figure 49).

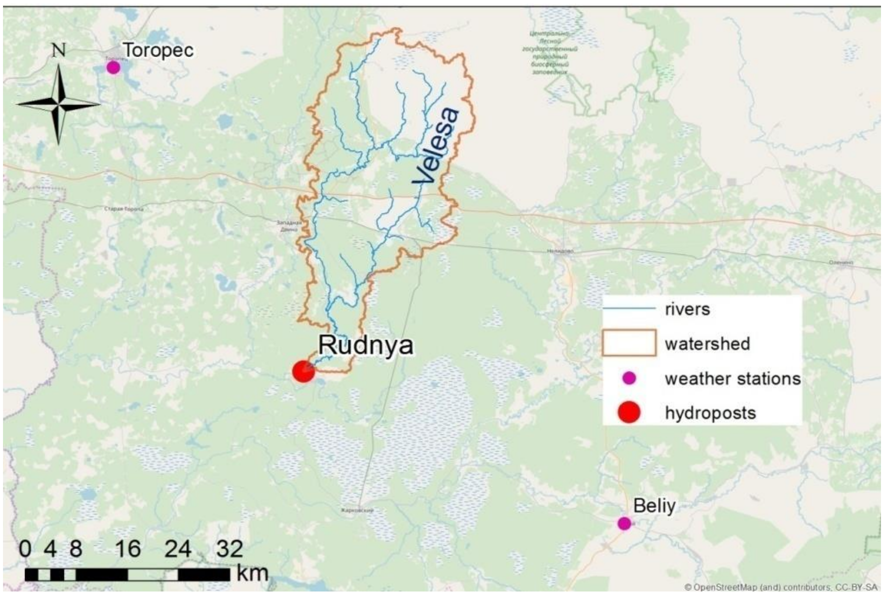

Figure 49. Scheme of the Velesa river catchment

B II-2b. DEM and catchment delineation

To construct the model of the Velesa river catchment, watershed data of low resolution was used both with non-bulky reliable spatial data. Monthly time-step model is based on medium-resolution DEM - ALOS PALSAR (Digital Elevation Model (DEM), resolution 12 m) https://www.asf.alaska.edu/. Terrain model was realized using the ArcSWAT software package. This DEM has been used for automatic catchment delineation and its division into 47 sub-catchments.

B-II-2c. Land cover and soil classification

For further characterisation of the investigation area, the global dataset GlobeLand30 (LandCover/LandUse layer (https://landcover.usgs.gov/classes.php), resolution 30 m. Land cover classes include the following types (based on NLCD92 classification): cultivated lands, forest, pasture shrublands, water bodies and artificial landscape http://globallandcover.com/GLC30Download/index.aspx) was used.

To characterize the soil conditions the HWSD-FAO soil map (resolution ≈ 1km, http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en) was used. Soil cover of the Velesa catchment contains two classes – Eutric Podzoluvisols (PDe) and Gleyic Podzoluvisols (PDg) based on Food Agricultural Organization global classification.

B II-4. Long term data for suspended sediment discharge (R) from downstream station (Velezh) (event based) using statistical sediment load model (LOADEST)

Runoff (Q) and suspended sediment concentration (SSC) observations at the outlet station Velezh were used to study sediment transport in the WD river basin. We were looking on extrapolating scarce sediment concentrations data from 1992-2004 and 2017 (11-12 measurements per annum) using calibration regressions constructed with daily discharge data (Figure 50). The obtained regression will be used to extrapolate fluxes over the entire whole period of discharge observations. For SSC=f(Q) analyses, the statistical regression model LOADEST (Runkel et al. 2004) was used to construct a calibration regression, which is then applied to a continuous daily discharge record to obtain daily sediment loads (mass per day). The LOADEST calibration equation is chosen from a suite of predetermined multiple regression models using Akaike’s information criterion. The LOADEST models we considered included discharge and seasonality as independent variables, with discharge and time centred to avoid multicollinearity. We excluded all models containing long-term time functions because our short data series did not lend itself to detecting such trends. We used the adjusted maximum likelihood estimator to fit the calibration equation.

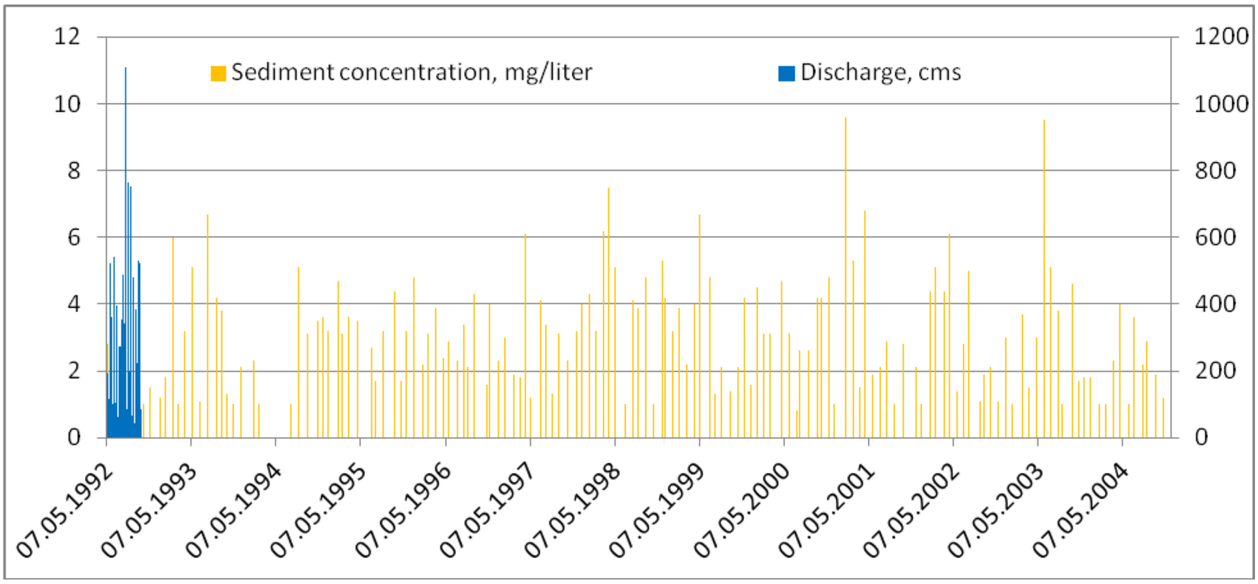

Figure 50. SSC-Q dataset for calibration model of sediment load for Western Dvina Velezh gauging station

B II-4. Semi-distributed erosional model using hydrological SWAT model

The chosen model for WD catchment is intended to be freely used and has the mathematic framework with sediment and nutrient load calculation, and with high sensitivity to the catchment condition (topography, soil and land use data). We chose the hydrologic model SWAT v.2012 (Gassman et al. 2007). The advantages of the SWAT model are the availability of reliable and helpful documentation, absence of limitations on catchment area, compatibility with GIS software (ArcGIS, QGIS, MapWindow), the open-source module of auto calibration SWAT-CUP (Atkinson et al. 2010), and also the open-access library of publications and scientific community.

The assessment of erosion and sediment yield was performed based on the HRUs and on the results of the calibrated hydrological model. Water flow is routed through the channel network using the variable storage routing method or the Muskingum river routing method. The peak runoff is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method. Based on that, sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by Williams & Berndt (Williams and Berndt 1972) (modification of standard USLE (Universal Soil Loss Equation; (Wischmeier and Smith 1960)):

$$Y = 11.8 \cdot (Q_T \cdot Q_{max})^{0.56} \cdot K \cdot LS \cdot C \cdot P \, , \quad (9)$$

where Y is soil losses in tons per a studied period; Q_T is the total volume of discharge in the studied period (m^3); Q_{max} is the maximum water discharge during the studied period (m^3/s); K is a soil erodibility factor (h·MJ^{-1}·mm^{-1}); *LS* is a dimensionless slope length and gradient factor; *C* is a dimensionless land management factor; and *P* is a dimensionless erosion control practice factor (in our case this parameter is equal to 1). The MUSLE approach and its modified versions have been widely applied in different river basins (Williams and Berndt 1977; Erskine et al. 2002; Chalov et al. 2016).

5.3. Preliminary results

The integrated approach is used to assess water flows, water and sediment quality and associated uncertainties that exist in river monitoring for the WD River basin. The following results were achieved until now through the implementation of various working packages.

5.3.1. Land use/land cover classification

Land use/land cover maps were produced reflecting the land cover conditions for 2014 (Figure 51) and 1992 (Figure 52) approximately in a 1:50 000 scale built on field verification data. These datasets will be used for SWAT model of the Western Dvina catchment to prepare more detailed land cover input. Most territory of the WD watershed is covered by mixed forest (NLCD class 23), however wetlands (NLCD class 92), occupy a significant part, and due to the intensive development of the territory there are a lot of agricultural lands (NLCD classes 61 - Orchards/Vineyards/Other; 71 - Grasslands/Herbaceous, 82 - Row Crops).

The areas of the land cover/land use classes defined during the Landsat classifications of 1992 and 2014 are compared in the Table 26.

Table 26. Changes in area of the WD watershed NLCD land cover/land use classes

NLCD land cover/land use class number	NLCD land cover/land use class name	Area in 1992, km^2	Area in 1992, % of the water-shed	Area in 2014, km^2	Area in 2014, % of the watershed
11	Open Water	265.8879	1.51	254.7531	1.45
21	Low Intensity Residential	329.5845	1.87	329.5845	1.87
23	Commercial/Industrial/Transportation	188.2341	1.07	188.2341	1.07
32	Quarries/Strip mines/Gravel pits	0.2925	0.00	0.2925	0.00
41	Deciduous Forest	1538.6085	8.74	1939.4406	**11.02**
42	Evergreen Forest	943.1703	5.36	1230.4836	6.99
43	Mixed Forest	5716.9341	32.47	9796.7583	**55.64**
51	Shrubland	5409.9198	**30.727**	1670.7051	9.49
61	Orchards/Vineyards/Other	3.6423	0.02	3.6423	0.02
71	Grasslands/Herbaceous	1489.6161	**8.46**	133.8021	0.76
82	Row Crops	684.585	3.89	650.637	3.70
92	Emergent Herbaceous Wetlands	1037.62	5.89	1409.7636	**8.01**

The Table reflects not only some remarkable trends in land cover/land use dynamics but errors and weaknesses of the classification results as well. Thus, grasslands/herbaceous were hugely overestimated in the 1992 classification due to the big spot of haze in the northern part of the 1992 image and several plums of wildfires in the central part. These results are preliminary and not considered in the model yet. Runoff changes caused by the land cover changes should be tested using calibrated model but it seems to be insignificant in comparison to model uncertainties.

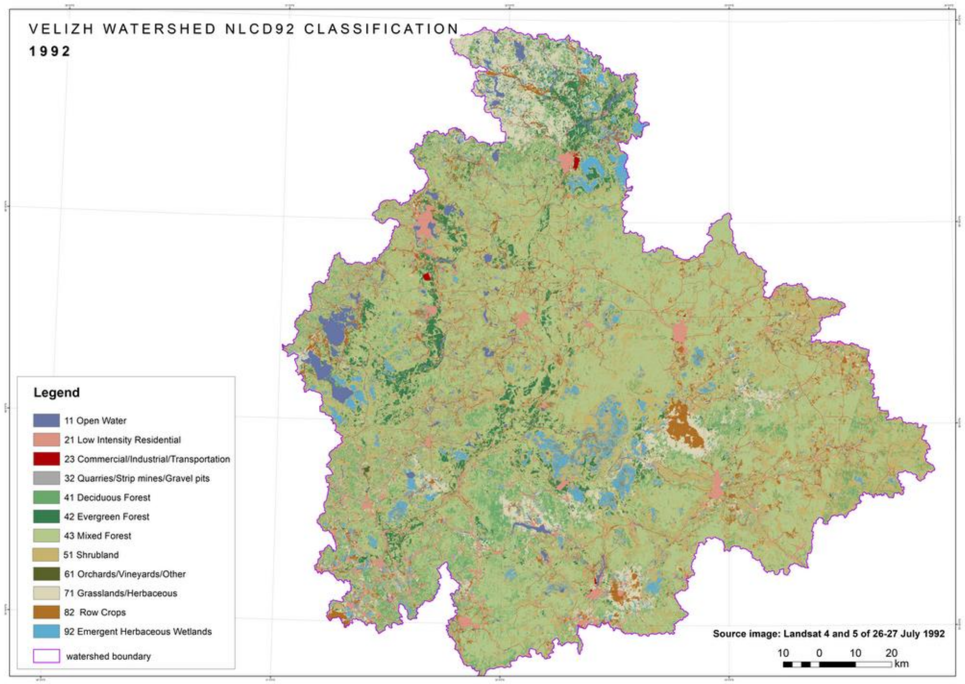

Figure 51. Landsat based land use/land cover map (NLCD92) for 1992

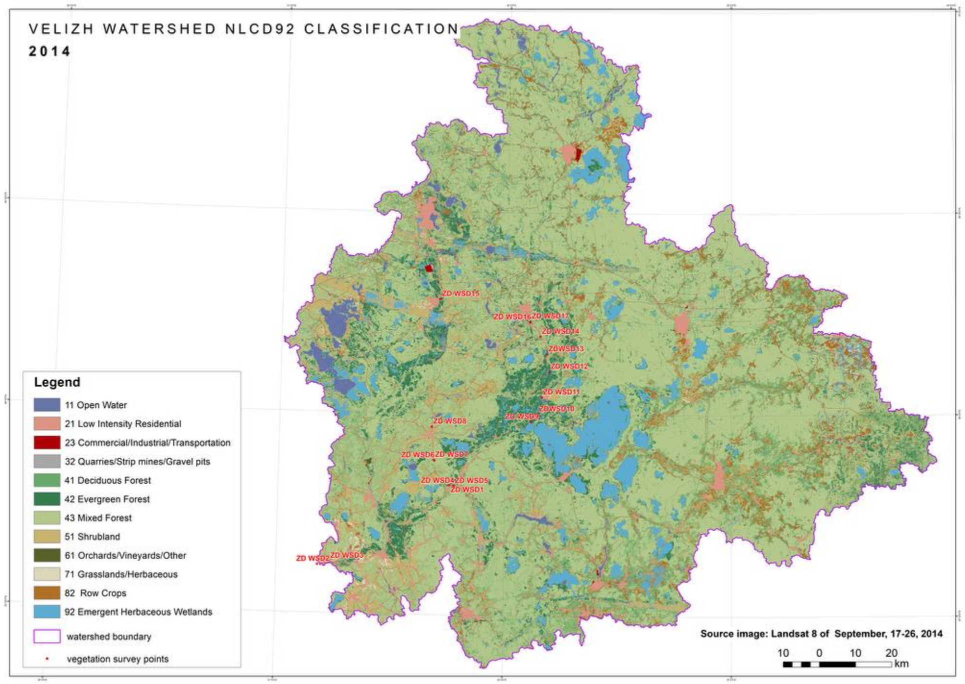

Figure 52. Landsat based land use/land cover map (NLCD92) for modern conditions 2014 and vegetation survey points location

5.3.2. Water and sediment flux and quality assessment

Flow and sediment transport series were collected at the Velesa River during period of monitoring station implementation in 2017 (Figure 53 and Figure 54), combined with meteorological observations at Toropec gauge (Figure 55).

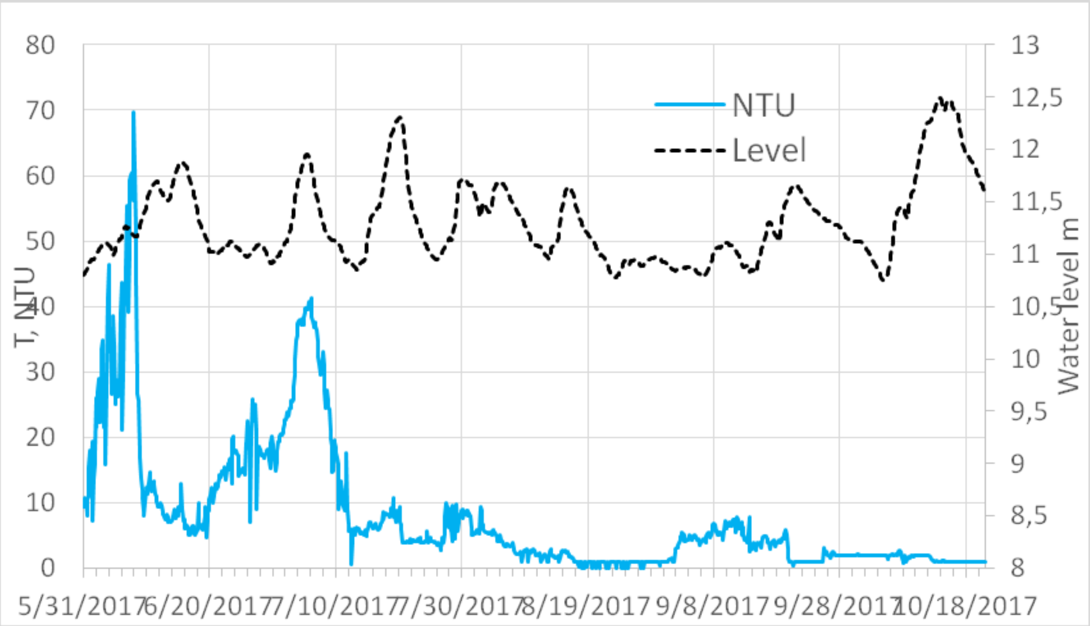

Figure 53. Water level and turbidity (NTU) records during the 2017 summer season

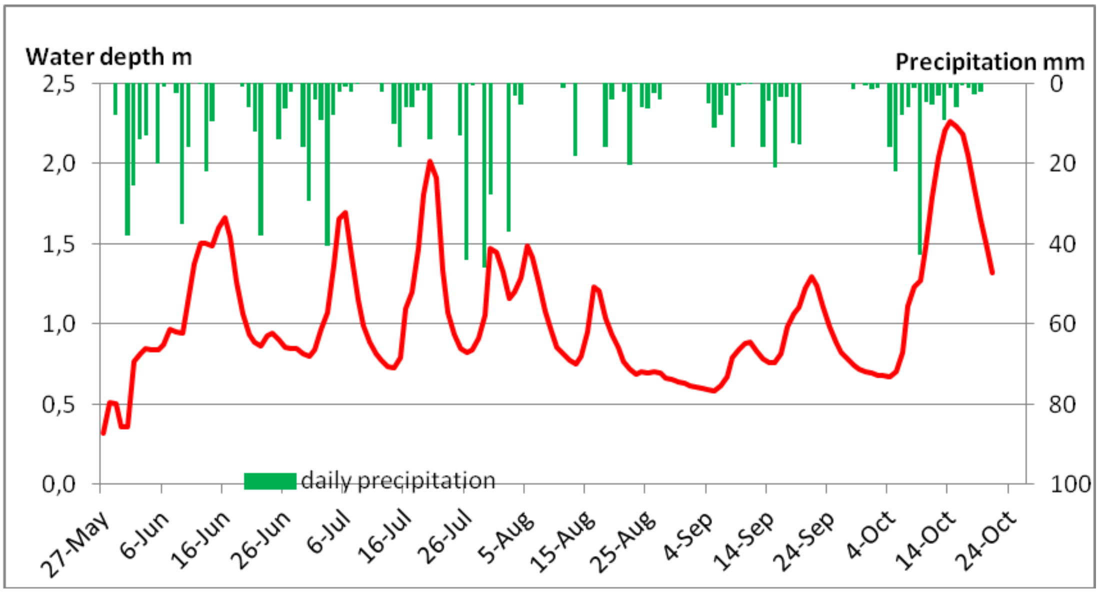

Figure 54. Daily water level in Velesa River (Sosvyatskoe gauging station) and precipitation in the meteorological gauge Toropec

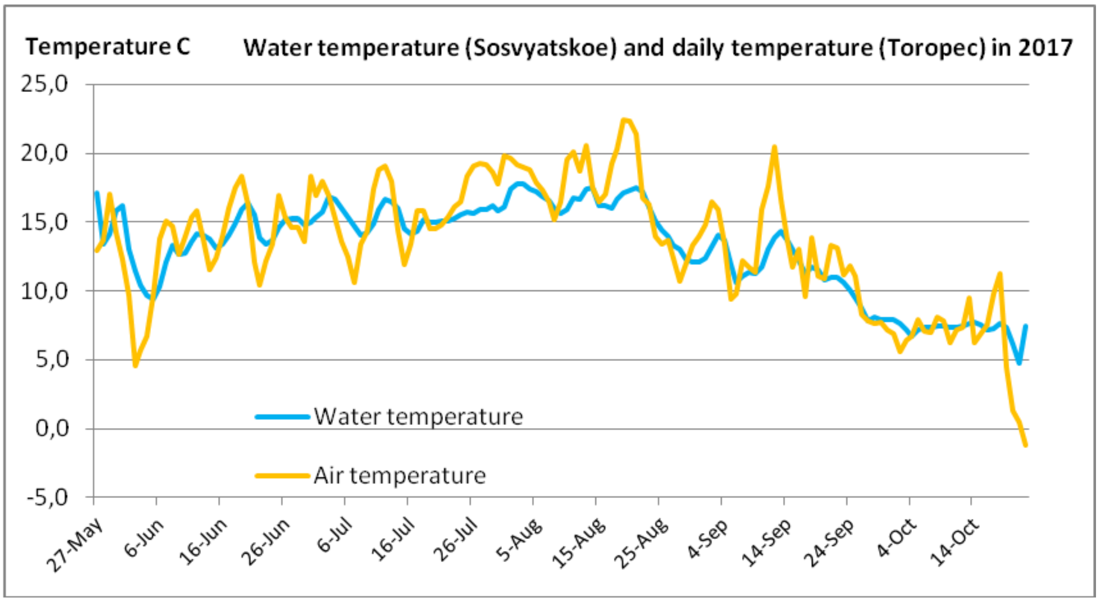

Figure 55. Daily water temperature and mean daily air temperature at Toropec meteorological station

The basin-wide water and sediment flux were assessed based on the established MANTRA monitoring station. Observed water quality results distinguished two groups of river waters by chemical composition. The first group of samples is river water (Velesa river near Mukhino) samples and samples of main tributaries (str. Bolotnyi, str. Dorozhnyi). The second group consists of samples collected from the upper reaches of the river Velesa (Velesa River near farm Kalekino and village Semenovskaya) and samples from WD mainstream. Other three groups of samples are admittedly potential end-members. The spring Lagernyi is specific water mass in Velesa catchment characterized by a high content of dissolved solids (509 mg/l), which can be explained by water from deep aquifers delivery during spring. Two group of soil waters are presented by samples collected from hillslope streams. They represent water of surface slope enriched with organic matter.

Table 27. Averages of field-based inventory of water quality in WD catchment

Studied period	Mineralization, salt composition and pH	Colour of water, permanganate oxidation, DOC)	The content of nutrients (Pmin, Ptot, Si, NO3)
Winter low-water period (Feb 2017)	43	-	43
The decline of spring snow-melting flood (May 2017)	42	42	42
Autumn rainy floods (Autumn 2017)	19	19	19
Winter low-water period (Feb 2018)	In progress	In progress	In progress
Spring snow-melting flood (April 2018)	In progress	In progress	In progress
The decline of spring snow-melting flood (May 2018)	In progress	In progress	In progress

Six snapshot measuring campaigns were done to assess water quality parameters over the catchment (Table 27). At the Zapadnaya Dvina gauging station (Western Dvina river) and Velesa river gauging stations, the water quality sampling campaigns were accompanied with discharge measurements (Table 28).

Table 28. Results of discharge measurements in the WD River basin

River	Location	Lat	Lon	Date	Area m²	Mean Vel m/s	Total Discharge m³/s
Velesa	Mukhino central crossection	56.18394	32.18111	27.05.2017	5.52	0.35	1.94
Velesa	Mukhino downstream crossection (pool)	56.18388	32.18079	27.05.2017	8.55	0.23	1.99
Velesa	Mukhino central crossection	56.16141	32.18852	07.10.2017	13.0	0.39	5.18
Velesa	Rudnya	56.04751	32.10603	07.10.2017	12.0	0.45	5.38
Velesa	Rudnya	56.04751	32.10603	06.05.2018	15.7	0.49	7.67
Velesa	Mukhino upstream crossection (riffle)	56.04751	32.10603	05.05.2018	13.1	0.43	5.57
Velesa	Mukhino central crossection	56.18394	32.18111	05.05.2018	26.84	0.25	6.65
Velesa	Mukhino central crossection	56.18394	32.18111	05.05.2018	30.312	0.19	5.90
Velesa	Mukhino central crossection	56.18394	32.18111	05.05.2018	25.087	0.22	5.63
Velesa	Mukhino downstream crossection (pool)	56.18388	32.18079	05.05.2018	22.342	0.25	5.61
Velesa	Mukhino downstream crossection (pool)	56.18388	32.18079	05.05.2018	23.542	0.26	6.05
Velesa	Mukhino downstream crossection (pool)	56.18388	32.18079	05.05.2018	21.436	0.34	7.18
W.Dvina	Zap Dvina bridge	56.23373	32.07954	07.05.2018	69.574	0.51	35.1
W.Dvina	Zap Dvina bridge	56.23373	32.07954	07.05.2018	70.715	0.47	33.1
W.Dvina	Zap Dvina bridge	56.23373	32.07954	07.05.2018	68.478	0.47	32.1

5.3.3. Statistical basin-wide analyses of water runoff

Long-term river flow changes show statistically significant, positive trends for the small Velesa river and the Russian part of the Western Dvina (Figure 56 and Figure 57).

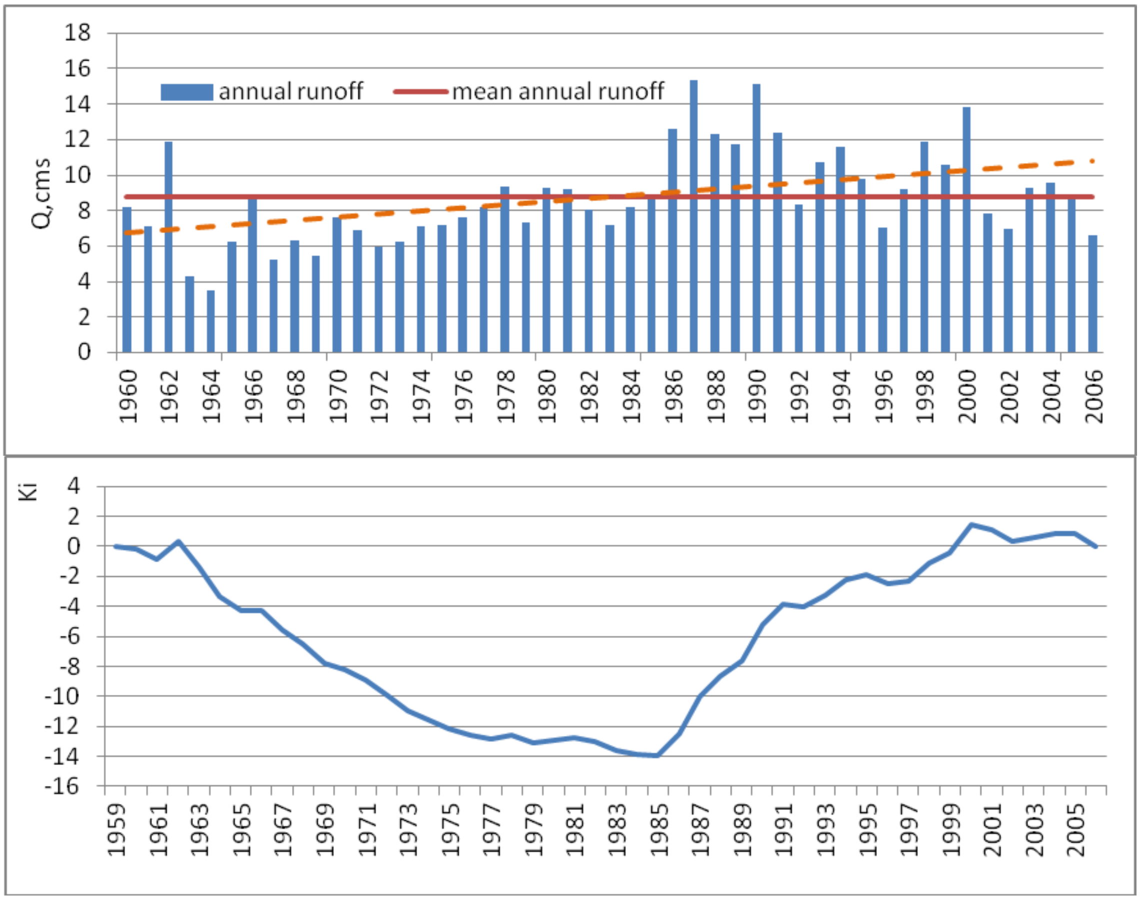

Figure 56. Annual runoff plot and integrated curve for the Velesa river – Rudnya station

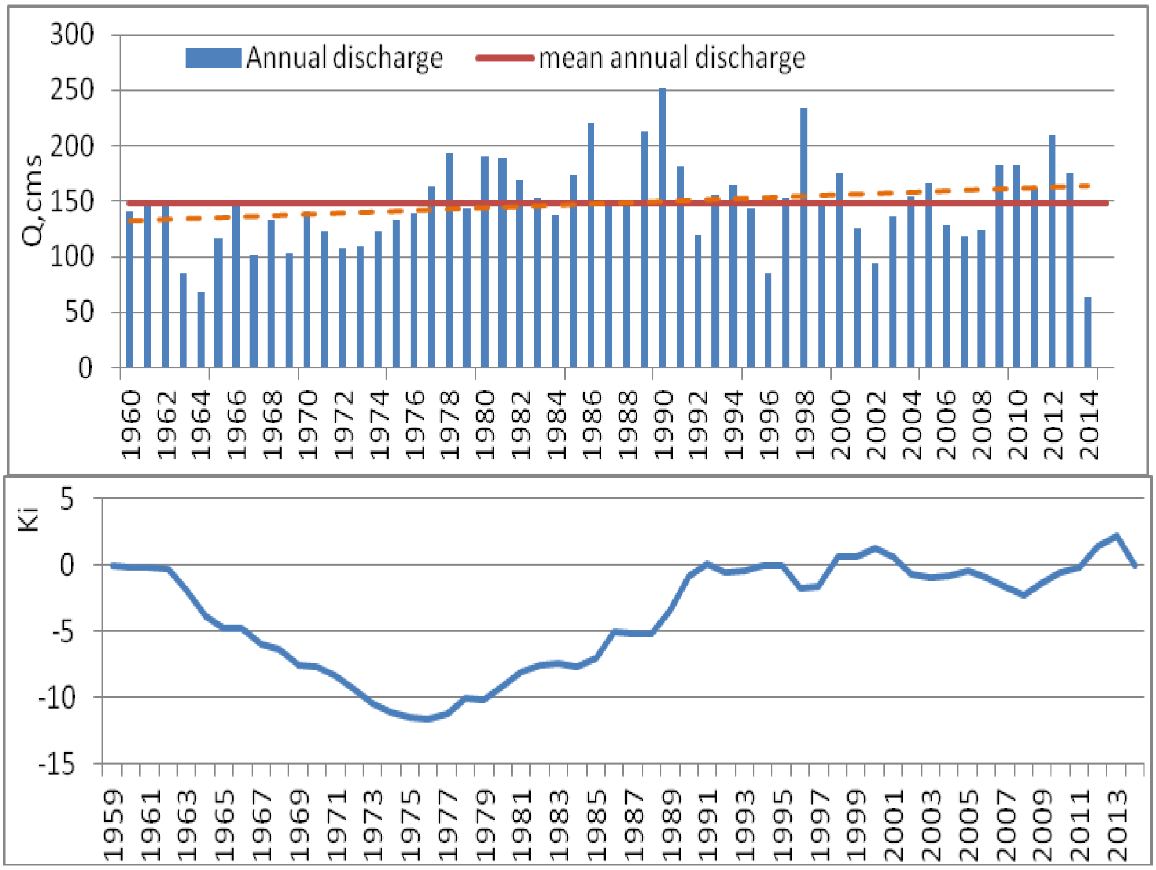

Figure 57. Annual runoff plot and integrated curve for the Western Dvina river – Velezh

5.3.4. Results of hydrological modelling

Hydrological model (see working package B II-2) aimed to assess water balance components and process wide climatic data and on-site measurements with further calculations of inter-annual actual evapotranspiration, snowmelt water yield, and river runoff and it's spatial distribution was build. Initial runoff calculation is divided into a test of model performance due to catchment components and inner features of model setup. Then finding the sensitive parameters, developing of calibration approach and then – using the model.

The initial model shows quite adequate performance – annual characteristics correspond well to measured evapotranspiration (ET) (MODIS) and river runoff (observed). For parameter calibration, we have used separate calibration for genetically different parameters, especially – for snowmelt parameters and runoff curve number.

The most sensitive parameter is the rainfall-runoff curve number, which is also sensitive to land cover distribution. It is calibrated separately for forested and non-forested lands. Other sensitive group includes lumped parameters responsible for snow cover generating and melting (snowfall and snowmelt temperature, amount of snow decreasing dependent to air temperature, a snow temperature lag factor dependent to air temperature, maximum snow water content before melting). Soil water losses calibrated mostly with soil bulk density and available water capacity, groundwater losses – with groundwater flow delay, groundwater minimum depth, recharge to deep aquifers. Water flux transformation caused by canopy is calibrated mainly with plant evaporation compensation factor.

The results for calibration fall into good to very good (and very good to satisfactory depending on objective function) (Table 29). We can recognize, that extreme hydrological events are performed not very well. For example – enormous high spring flood and also enormous low spring flood following heavy rainfalls. This kind of uncertainty most likely appears because of too rough soil database.

In the WD catchment, the annual distribution of the river flow is genetically non-homogeneous. The standard approach of the model auto-calibration was not successful. In this study 19 to 21 sensitive parameters (for monthly and daily runoff respectively) were chosen manually one by one. The parameters affecting the snowmelt runoff were grouped together and calibrated separately from the others.

Rainfall distribution plays a significant role for this middle-size catchment and should be prepared very carefully. We recommend using interpolated data against reanalysis. Using detailed DEM (12.5 m) and land use/land cover (30 m) improves the results for daily time step, but almost does not have effect for monthly discharge calculations.

Table 29. Results of daily and monthly runoff modelling

Objective function	Definition	Monthly model	Daily model
R2	Square correlation	0.83/0.78*	0.77/0.78*
NS	Nash-Sutcliff coefficient	0.77/0.76*	0.72/0.76*
PBIAS %	percent BIAS	-11.5/-15.5*	-11.7/-16.5*
KGE	Kling Gupta coefficient	0.8/0.78*	0.8/0.75*
Model quality		good	good

* - Calibration (1992-1998)/ Validation (1999-2004)

Calculated water balance components illustrate the inter-annual variability of river runoff, ET and snowmelt water yield. Maximum snow water yield absolutely corresponds and exceeds river runoff, because of storing inside the catchment (Figure 58).

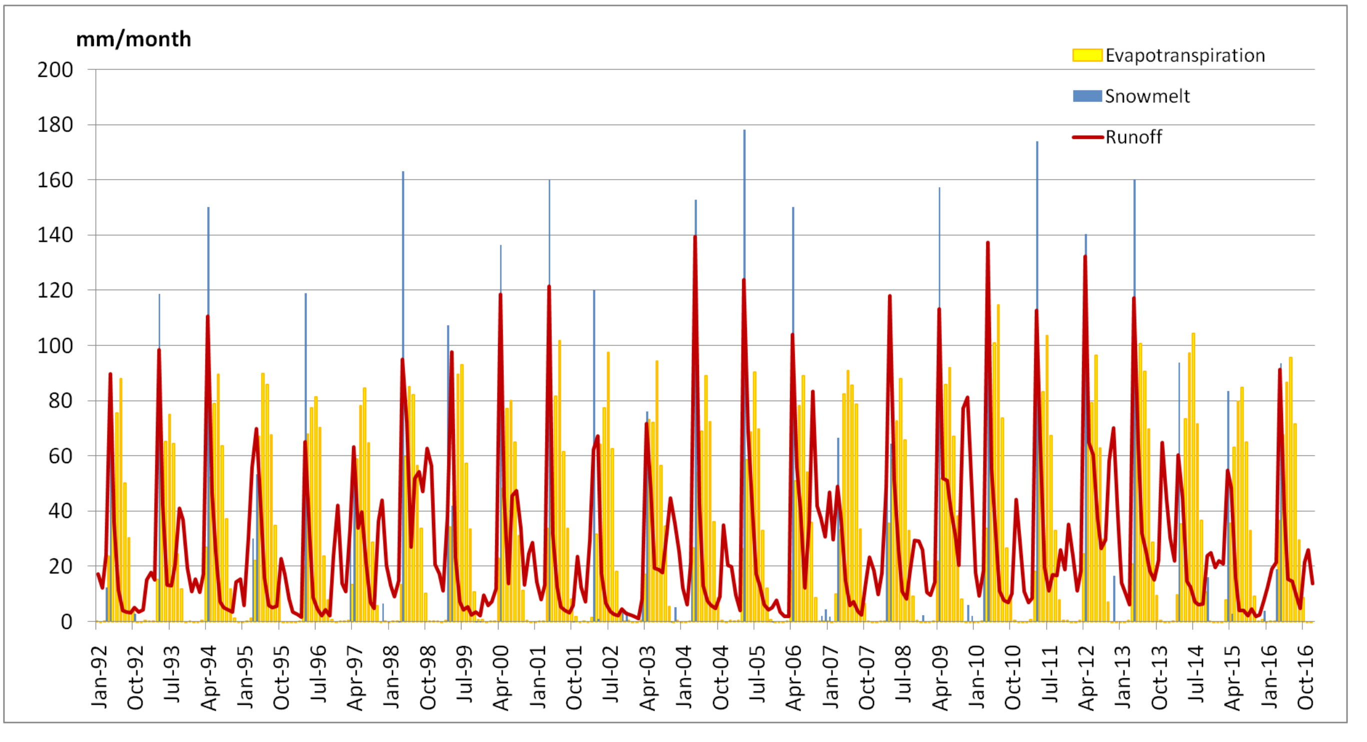

Figure 58. Simulated monthly water balance components for the Western Dvina Russian sub-catchment (at Velezh) – Evapotranspiration, snowmelt water yield, and river runoff

Modelling results gave valuable information about optimal input parameters of the river catchment and the method of defining elementary catchments. The results also include the estimation of the model parameters sensitivity and their calibration for river runoff calculation with daily and monthly temporal resolution. Based on the study results, we recommend to use interpolated observed weather data against reanalysis (except downward solar radiation). Using detailed DEM (12.5 m) and land use/land cover (30 m) significantly improve results for a daily time step, but almost does not have effect for monthly. The most sensitive are snow and groundwater parameters, and also distributed rainfall-runoff curve number parameter. Calibration of snow parameters should be done separately from others because of different genesis of snowmelt processes against infiltration and evapotranspiration. That's why all together calibration causes inadequate values of many parameters and unstable result. Separate calibration is being made by only 5 snow parameters setting to naturally adequate range and then implementing the autocalibration procedure using SWAT CUP software. Evaporation is simulated well, but snow water equivalent is slightly overestimated (in comparison to observed). Soil database should be more detailed for daily time step calculations.

5.3.5 Sediment sources appointment using fingerprinting techniques

The preliminary results of suspended sediment sources appointment using fingerprinting techniques (working package A II-2) within the Velesa River basin provides valuable information on spatial and temporal variability of the contribution of different sediment sources to the total suspended load. Accordingly, a sediment source fingerprinting technique was used to assess the spatial sources of fine-grained (<10 μm) sediments. Total content of selected elements and ^{137}Cs radioactive isotope was used for discriminating sources (Table 30) to compare it with time-integrated suspended sediment samples (TISSS). The results suggest that the main contributors of fine-grained sediment are the intensively eroded river banks. The results of the sediment source appointment are in accordance with earlier findings for the rivers of similar size from the forest zone (e.g. Theuring et al., 2015). According to the obtained results, river bank erosion generates over 70 % of the total fine-grained sediment load (Theuring et al., 2013).

The use of a combination of independent statistical tests helps to take account of potential uncertainties in source estimates, associated with the use of a single composite signature. We found that the application of mobile forms of elements for fingerprinting purposes is questionable because these may not meet the criteria of conservativeness. Active gullies and river channel erosion (undercut bank) sections should be determined (based on topographic maps and remote sensing data with field validation).

Table 30. Summary of deviations estimates for sediment sources-TISSS relationships in the Velesa River catchment

Mobile forms of elements						
id	**GOF**	**BE**	**GE**	**RE**	**BankE**	**TE**
27	0,558536	0,095274	0,028797	0,216011	0,644274	0,015643
28	0,430266	0,003993	0,004816	0,023474	0,962683	0,005033
29	0,485871	0,017945	0,034456	0,00835	0,340425	0,598824
30	0,531338	0,002806	0,031588	0,714138	0,248757	0,00271
Total elements						
27	0,722252	0,000844	0,002112	0,025388	0,958452	0,013203
28	0,511125	0,008679	0,004427	0,040808	0,93245	0,013636
29	0,744127	0,026575	0,006028	0,003915	0,961025	0,002458
30	0,668173	0,003619	0,011489	0,056273	0,92798	0,000639

Sources of sediments: BE – bed erosion; GE – gully erosion; RE – road erosion; BankE – bank erosion; TE –Erosion on timber cultivated lands; GOF – goodness of fit.

5.3.6 Experimental study on stream flow-river bed mass exchange

The experimental study was conducted to determine rates of mass exchange at the water-bottom sediments interface in the river channel (working package A I-3).

The concentration of microorganisms normally correlates well with sediment parameters such as the content of organic matter OM, granulometric composition and hygroscopic moisture of sediments. The rate of aerobic degradation of OM was very low in the sandy bottom sediments (43 and 37 mg C/m2 s, in the first and second locations, respectively). Moreover, the water temperature was low (14.4 ° C). The small values of the turbidity of the bottom water (8.1 mg / l) and the low content of OM in the upper sediments layer (0.9-1.2%) also do not contribute to an intensive development of microbiological processes in the ground. Due to the aeration of the entire stream (the concentration of O2 in water is 1.5 mg / l), the anaerobic component of the destruction process of OM in the sediments is practically absent, the total destruction occurs predominantly by aerobic means (the total destraction was 45 and 47 mg C/m^2 at two sites). Thus, the contribution of bottom sediments to the process of decomposition of OM is small. The phosphorus flux from the bottom sediments also turned out to be insignificant - 0.3 mg P/m^{2}s (Figure 59).

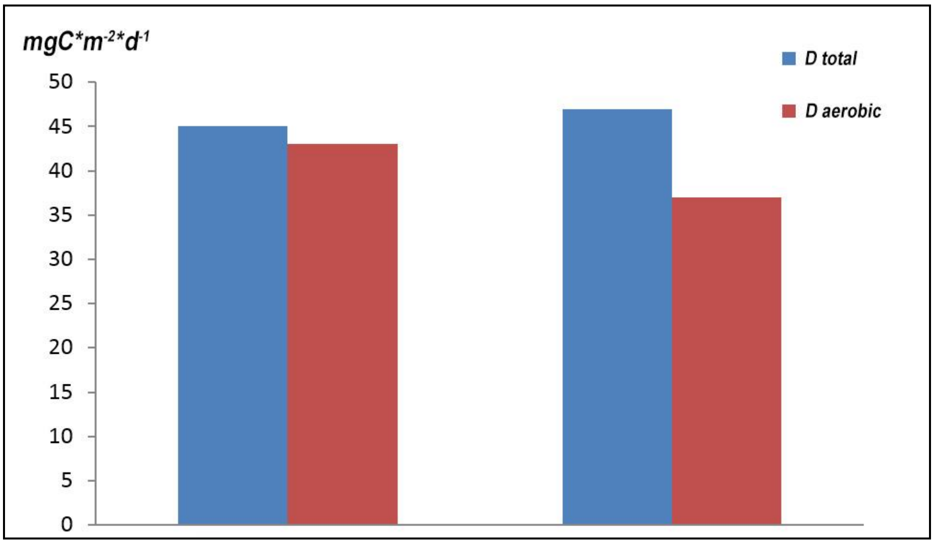

Figure 59. The ratio of total and aerobic destruction D of organic matter in bottom sediments of the Velesa river case study reach (left – upper location, right – downstream location)

5.3.7. Preliminary results of discriminating runoff sources using end-member mixing analysis

The objectives of the end-member mixing analysis done in the Velesa River basin (working package WP B-I-1) were to identify potential sources of water and hydrological interpretation of contributing geographical source waters specific to WD catchments. The preliminary results indicate (Figure 60) a significant variability of underground water sources. The chemical composition of these sources is determined by soil-formation processes and the underlying rocks. The identification and accounting of specific water sources in the EMMA-analysis will make it possible to give an objective assessment of the temporal dynamics in dominant runoff sources and flow paths. The score plot of the Principal Component Analysis PCA shows a spatial differentiation of water samples. Potential measured end-members (vertices of a triangle) form a mixing space. Stream water samples are located inside of this area (Figure 60).

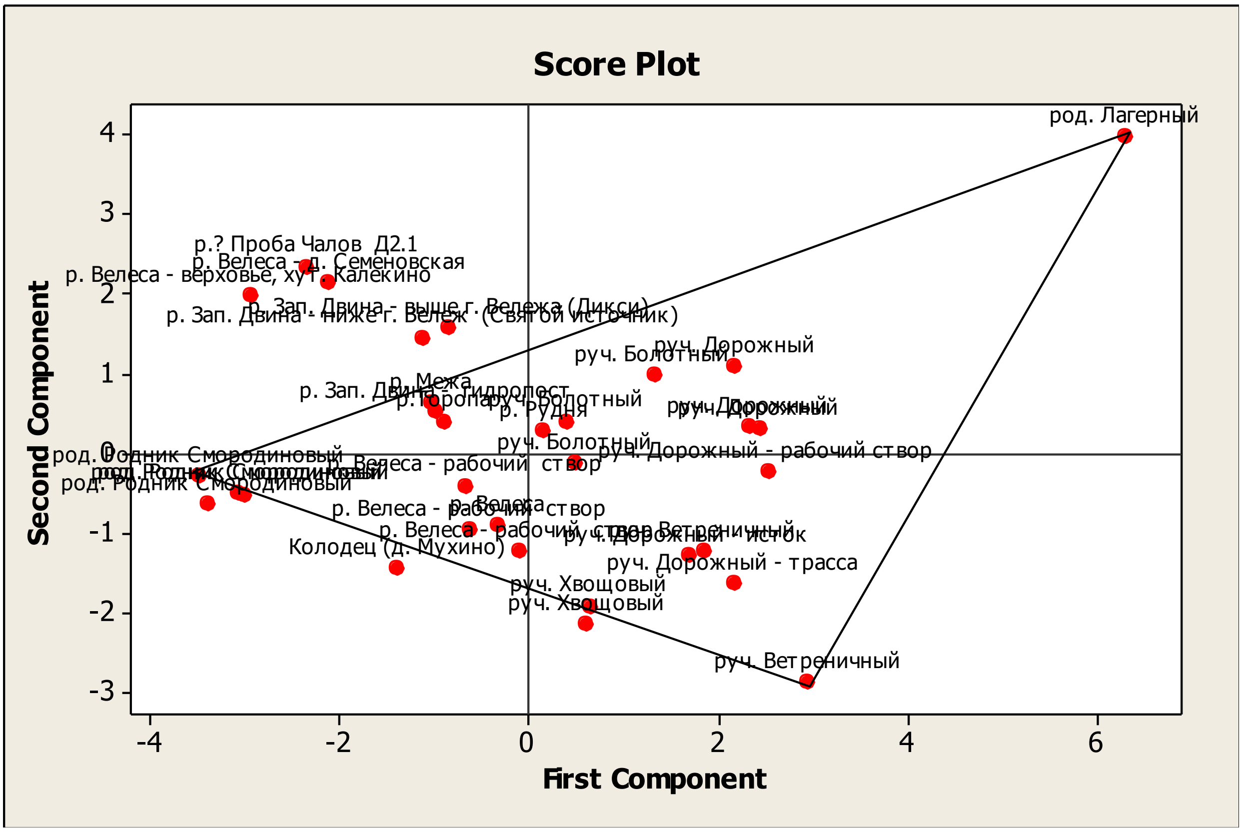

Figure 60. Result of the PCA analysis to discriminate water sources in Velesa Rive catchment

5.4. Conclusions

In this chapter we aim to present the concept of the pilot study, focusing on methodological aspects of the approach. The results of pilot study will be published in targeted papers. Some of the preliminary results of the pilot study have been already presented at international conferences:

1. Oral presentation at international conference "Międzynarodowe drogi wodne – bezpieczeństwo i rozwój" by Chalov S.R. "Investigation of short-term dynamics of river water turbidity" (Poland, Bydgoszcz, June 2018)
2. Oral presentation at the 2nd Baltic Earth Conference, The Baltic Sea in Transition by Pavel Terskii1, Alexey Kuleshov: "Water balance assessment using SWAT for Russian subcatchment of Zapadnaya Dvina River" (Helsingør, Denmark, June 2018)
3. Oral presentation at the Second International Young Scientists Forum on Soil and Water Conservation and ICCE symposium 2018 "Climate Change Impacts on Sediment Dynamics: Measurement, Modelling and Management" by V. Belyaev: "Application of sediment fingerprinting for establishing suspended sediment sources within the Velesa River basin" (Russia, Moscow, August 2018)
4. Poster presentation at the Second International Young Scientists Forum on Soil and Water Conservation and ICCE symposium 2018 "Climate Change Impacts on Sediment Dynamics: Measurement, Modelling and Management" by P.N. Terskii, A.A. Kuleshov, S.R. Chalov "Water balance and sediment load assessment using SWAT model. Case study on Russian subcatchment of the Western Dvina River" (Russia, Moscow, August 2018)

Results of the particular working packages of Pilot study were published in the following publications:

- Sergey Chalov. Consistency and uncertainty analyses of sediment transport monitoring in transboundary river: case study of the Western Dvina (Russian Federation, Belarus and Latvia) // Proceedings in Earth and Environmental Sciences.
- Pavel Terskii. Water balance assessment using SWAT model. Case study on Russian subcatchment of the Western Dvina River // Proceedings in Earth and Environmental Sciences.
- S.R. Chalov, A.S. Tsyplenkov. Short-term dynamics of river water turbidity // Geography and Tourism, Vol. 6, No. 1 (2018). DOI: 10.5281/zenodo.1314006

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Annex 1

PRINCIPAL INTERNATIONAL AND NATIONAL LEGISLATION IN WATER SECTOR

I. Relevant international laws and regulations in the water sector

1. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy" (Water Framework Directive).
2. Directive 2007/60/EC on the assessment and management of flood risks (Flood Directive).
3. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (Nitrates Directive).
4. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment.
5. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption (Drinking Water Directive).
6. (Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC (Bathing Water Directive).

II. Relevant Polish laws and regulations in the water sector:

1. *Act on inland navigation (2000).*
2. Environment protection Law (2001).
3. Act on fishing (2004).
4. Act on Inland fishing (1985).
5. Act of 18 July 2001 Water Law (Journal of Laws 2015, item 469, as amended).
6. Act of 20 July 2017 New Water Law (Journal of Laws 2017, item 1566), in force as of 1 January 2018, excluding some provisions, as defined by the act.
7. Act of 3 October 2008 on Sharing Information and Protecting Environment, Participation of the Citizens in Environment's Protection and Environmental Impact Assessments, item 1227, as amended).
8. Regulation of the Council of Ministers of 29 March 2013 on detailed scope of River Basin Management Plans (Journal of Laws 2013, item 578).
9. Regulation of the Council of Ministers of 14 November 2016 amending the regulation on detailed scope of River Basin Management Plans (Journal of Laws 2016, item 1973).
10. Regulation of the Minister of Environment of 19 July 2016 on the form and way of monitoring bodies of surface and underground water (Journal of Laws 2016, item 1178).

11. Ordinance of the Minister of the Environment of November 21, 2013 amending the ordinance on the forms and methods of monitoring of uniform bodies of surface and groundwater (Journal of Laws of 2013, item 1558).
12. Regulation of the Minister of Environment of 21 July 2016 on the classification of bodies of surface water and environmental quality standards for priority substances (Journal of Laws 2016, item 1187).
13. Regulation of the Minister of Environment of 21 December 2015 on the criteria and assessment of the status of the bodies of underground water (Journal of Laws 2016, item 85).
14. Act of 27 April 2001 Environmental Protection Law (Journal of Laws 2001 no. 62, item 627).
15. Act of 16 April 2004 on Nature Protection (Journal of Laws 2004, no. 92, item 880).
16. Act of 7 June 2001 on Collective Supply of Water and Collective Waste Disposal (Journal of Laws 2001, no. 72, item 747).

III. Relevant Belorussian laws and regulations in the water sector:

1. Law of the Republic of Belarus №1982-XII, 26.10.1992.
2. Water Code of the Republic of Belarus (2014).
3. National Plan of Actions on rational use of natural resources and environment protection in the Republic of Belarus for 2006-2010 years.
4. Water Strategy until 2020.
5. National Sustainable Development Strategy for the period up to 2020.
6. State Programme for water supply and sanitation “Clear water”.
7. State Programme for Development National Monitoring System of Environment in the Republic of Belarus for 2011-2015 years.

IV. Relevant Latvian laws and regulations in the water sector:

1. Environmental Protection Law (Latvia).
2. Law on Water management (2002).
3. Law on Water management Services.
4. Fishery Law.
5. Forestry Law.
6. Law on Environmental Impact Assessment (Latvia) (2005).
7. Law on Environmental Protection (Latvia).
8. Law on Pollution (2001): implementation of Council Directive 96/61/EC.
9. Waste Management Law.

10. Regulation No. 118 (2002): “Regulations regarding the Quality of Surface Waters and Groundwaters”.
11. Regulation No. 34 - "Regulations regarding Discharge of Polluting Substances into Water" (2002).
12. Regulation No. 736 - "Regulations Regarding a Permit for the Use of Water Resources"; (2003).
13. Regulation No. 857 - "Regulations regarding Procedures for Ascertaining of Groundwater Resources and Criteria of Quality" (2004).
14. “Regulations on the Protection of Water and Soil against Pollution with Nitrates from Agricultural Sources”, Cabinet of Ministers Regulations No.531, (2001).
15. “Regulations Regarding Utilisation, Monitoring and Control of Sewage Sludge and the Compost thereof”, Cabinet of Ministers Regulations No.362 (2006).

IV. Relevant Russion Federation laws and regulations in the water sector:

1. Water Code (2006).

IV. Relevant Ukrainian laws and regulations in the water sector:

2. Law of Ukraine “On Hydrometeorolgical Activity” № 443-XIV, 18.02.1999.
3. Law of Ukraine “On Environmental protection” № 1264-XII, 25.06.1991.
4. Order of the State Hydrometeorlogical Service “List of criteria of high and extremely high pollution of the Environment which are used in the system of Hydrometeorological Service” (№ 75, 31.05.1993.
5. Decree of the Cabinet of Ministers of Ukraine “On approval of the Provisions of the State Environmental monitoring system” (№ 391, 30.03.1998).
6. Decree of the Cabinet of Ministers of Ukraine “On approval of the Order of the State monitoring of water” (№ 815, 20.07.1996).
7. Order of the State Emergency Service of Ukraine “On preparation and providing of operational and regime information concerning pollution of the Environment” (№ 777, 23.12.2013).
8. Order of the State Emergency Service of Ukraine “On changes to the Algorithm of preparation, processing and submitting by hydrometeorological organisations, institutions of the State Emergency service of Ukraine the regime information concerning pollution of the Environment” (№ 451, 16.09.2016).
9. Water Code of Ukraine. Decree of the Supreme Council (Verkhovna Rada), № 2013/95-BP (current version 04.06.2017).
10. Decree of the Cabinet of Ministers of Ukraine “On approval of the Order of the state water cadastre management” (№ 413, 08.04.1996). Current version of 07.06.2017.
11. Order of the State Emergency Service of Ukraine “On approval of Methodological recommendations on the state water cadastre management concerning chapter “Surface water” (№ 609, 03.12.2015).

12. Order of the Ministry of Ecology and Natural Resources of Ukraine "On approval of the List of polluting substances for determination of chemical status of surface and ground water bodies and ecological potential of artificial or heavily modified surface water body" (№ 45, 06.02.2017).
13. Law of Ukraine "On assessment of Environmental impact" (№ 2059-VIII, 23.05.2017, in force).
14. "Methodology of ecological assessment of surface water quality by related criteria" (approved by the Order of the Ministry of Environmental Protection and Nuclear Safety of Ukraine № 44, 1998).
15. Normative document "Environmental protection and rational use of natural resources. Organization and performing of observations of surface water pollution" (KND 211.1.1.106-2003). 61) "List of maximum allowable concentrations and roughly safe levels of impact of harmful substances for the fishery water objects". Approved by the Ministry of Fisheries of the USSR (№ 12-04-11, 09.08.1990). Legal status of this document is prolonged by the Order of the Ministry of Emergency Situations of Ukraine (№ 1128, 20.08.2011).

Annex 2

MONITORING PROGRAMS

Surface water monitoring program of RosHydroMet (Russian Federation)

Monitoring station rank (category)	Frequency			
	Daily	**Each ten days**	**Monthly**	**Each hydrological seasons**
1	Temperature, DO, conductivity, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main (2-3) trace contaminants concentrations, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main ions, trace contaminants concentrations, visual observations, nitrogen (nitrites, nitrates, ammonia), phosphorus, silicium, petrochemicals, SSAS, phenols, pesticides, heavy metals
2	Visual observations	Temperature, DO, conductivity, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations	Temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main ions, trace contaminants concentrations, visual observations, nitrogen (nitrites, nitrates, ammonia), phosphorus, silicium, petrochemicals, SSAS, phenols, pesticides, heavy metals
3	na	na	Na / available only during high water events	Extended program: temperature, pH, DO, conductivity, sediment concentrations, BOD, COD, main ions, trace contaminants concentrations, visual observations, nitrogen (nitrites, nitrates, ammonia), phosphorus, silicium, petrochemicals, SSAS, phenols, pesticides, heavy metals **Short program (allowed):** Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations
4	na	na	na	Temperature, pH, DO, conductivity, sediment concentrations, BOD, trace contaminants concentrations, visual observations

NOTE: surface water monitoring programs and lists of parameters of Poland, Belarus and Ukraine are presented in Metadatabase file (see separate Excell file attaced)