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International Commission
for the Protection
of the Danube River

Internationale Kommission
zum Schutz der Donau

Guidance Document on Managing Hazardous Substances Pollution in the Danube River Basin

Deutschland //// Österreich //// Česká republika //// Slovensko //// Magyarország //// Slovenija //// Hrvatska //// Bosna i Hercegovina //// Србија //// Crna Gora //// România //// България //// Moldova //// Україна

International Commission for the Protection of the Danube River

Acknowledgement

This document was developed in the framework of the INTERREG DTP Danube Hazard m³c project (DTP3-299-2.1), co-funded by the European Union Funds (ERDF, IPA, ENI) with the financial contributions of the partner states and institutions. The report was subsequently reviewed by the ICPDR Pressures and Measures Expert Group and the ICPDR Secretariat. The contribution of the national experts from the Danube countries is appreciated.

Technical coordination: Adam Kovacs

Imprint

Published by:

ICPDR – International Commission for the Protection of the Danube River

Document number: IC 272

Executive summary

Hazardous substances (HS) pollution is a significant water management issue in the Danube River Basin (DRB) that needs basin-wide pollution assessments and harmonized abatement measures through transboundary cooperation. Danube countries – under the auspices of the International Commission for the Protection of the Danube River – have made significant efforts to tackle HS pollution by conducting targeted monitoring campaigns, applying basin scale water quality models and implementing various control measures. Yet, chemicals are still found in the aquatic environment having ubiquitous persistent, bioaccumulative and toxic features and leading to failing good status of surface water bodies. Thus, further steps need to be taken towards a more "toxic-free" DRB, fully in line with the ambitions of the EU Green Deal.

Despite the substantial progress achieved in controlling HS pollution in the DRB, further efforts are needed in the future to sustainably manage the problem. Narrowing the information gap related to HS pollution is a key aspect, the state-of-the-art knowledge regarding monitoring and chemical emissions needs to be massively improved. Moreover, the water management sector has to adapt its policies and measures to reflect to the latest EU requirements and to establish an enabling regulatory framework that can support and control the implementation of these measures. In addition, in some Danube countries, substantial lack of institutional capacity, unclear responsibilities and insufficient intersectoral dialogue hinder the establishment of an efficient management. Furthermore, the pressure of climate change impacts on water quality management is rapidly growing, both high intensity rainfall events and drought periods may cause adverse effects if they are not counteracted by adaptation measures.

To appropriately address these challenges, institutions from Danube countries and beyond implemented the Danube Hazard m^{3}c project that aimed to contribute achieving a durable and effective transnational control and reduction of HS water pollution. It built on the three elements of water governance (measuring, modelling and management) complemented by capacity building and delivered valuable databases, technical tools and guidance documents linking science with policies.

With regard to policy making, Danube countries are advised to take actions in three fundamental areas, all representing an essential part of managing HS pollution.

1) Identify problematic substances by using harmonized approaches

- Jointly designate an updated list of river basin specific pollutants for the DRB, which have adverse effects on aquatic ecosystems in the basin and/or may negatively influence the extraction of drinking water from raw water and therefore they should be carefully monitored and controlled.
- Harmonize and jointly determine Environmental Quality Standards for the compounds of transboundary importance.
- Harmonize the immission monitoring programs as appropriate and share and discuss experiences with other Danube countries.
- Harmonize the analytical methods towards using standardized methods for the common parameters as appropriate and establish close cooperation on sharing knowledge and best practices.
- Promote and support using modern sampling devices and up-to-date monitoring techniques.

2) Build a sound knowledge base by developing emission inventories

- Develop consistent emission inventories for indicator substances, especially targeting the major point source emitters but also diffuse pathways that are difficult to monitor.
- Investigate diffuse emission inventories by applying catchment-scale water quality models. representing all relevant pathways, while maintaining the link to sources.
- Coordinate modelling assessments on the DRB-scale with national applications in synergistic manner.
- Support the application of modelling-based risk assessment at river basin scale to help optimizing the overall surface water monitoring process.
- Implement well-designed, investigative, emission-targeted monitoring programs for supporting the establishment of an emission inventory.
- Develop and use a harmonized, comprehensive transboundary database including HS concentrations in all relevant environmental media and emission pathways.
- Put emphasis on investigating contaminated sites, legacy emission stocks and specific pathways with limited information available.
- Collect supplementary data of high importance for the inventory development, especially for the modelling assessments.
- Provide free access to the monitoring and inventory data as well as on registered emitters.

3) Develop an enabling policy framework by regulatory, economic and advisory instruments

- Establish a dialogue and partnership among the relevant key sectors (e.g. water management, industry, agriculture) to seek mutually agreed actions to be jointly implemented.
- Proactively influence the regulatory process of chemical authorization and use restriction.
- Carefully examine the currently revised water legislations, adapt provisions and create national implementation programmes and make use of the opportunities of the new Common Agricultural Policy.
- Design program of measures in a harmonized and coordinated way in full compliance with all relevant water acquis, in line with the pollution control hierarchy and addressing both point source and diffuse emissions.
- Prioritize source and pathway control measures to prevent and minimize HS pollution that can be accompanied by transport control measures to further retain HS fluxes.
- Harmonize the respective emission standards for urban and industrial wastewater discharges.
- Set appropriate pollution fees for the major point source dischargers and consider applying penalties in case of non-compliance with the relevant legislations and introducing a charge on products containing HS.
- Apply the extended producer responsibility approach targeting the main polluters responsible for wastewater emissions.
- Develop an appropriate combination of direct payments and voluntary schemes for diffuse HS pollution arising from agriculture and land management.
- Provide economic incentives for developing and implementing up-to-date technologies and use eco-labelling of products that have been produced using environmentally appropriate methods and materials.
- Raise awareness and facilitate public dialogues to foster responsible use of chemicals and provide practical information and technical facilities for safe disposal of harmful substances at the local level.
- Create institutional capacity for further developing monitoring programs and databases on HS pollution using regional knowhow and for enhancing emission modelling as an operational tool for emission inventorying at national level.
- Strengthen technical and institutional capacity at both, administration and utility level in the wastewater management sector.

- Make advisory services and knowledge exchange platforms available for all farmers.
- Foster research and development to provide solutions for the HS pollution problem along with enhanced and accelerated dissemination of results and knowledge exchange among stakeholders and decision-making authorities.

The adequate combination of these mechanisms, tailored to the national needs and conditions, can contribute to establish a sound knowledge base and an enabling regulatory framework and to control and reduce HS pollution in the DRB more effectively. Nevertheless, it is strongly recommended to implement follow-up activities on managing HS pollution in the DRB by capitalizing the outcomes of the Danube Hazard m^{3}c project. These activities would offer additional capacity building possibilities on enhanced monitoring and modelling tools and would elaborate a new transnational action plan for future control of HS in the DRB reflecting to the remaining and emerging challenges.

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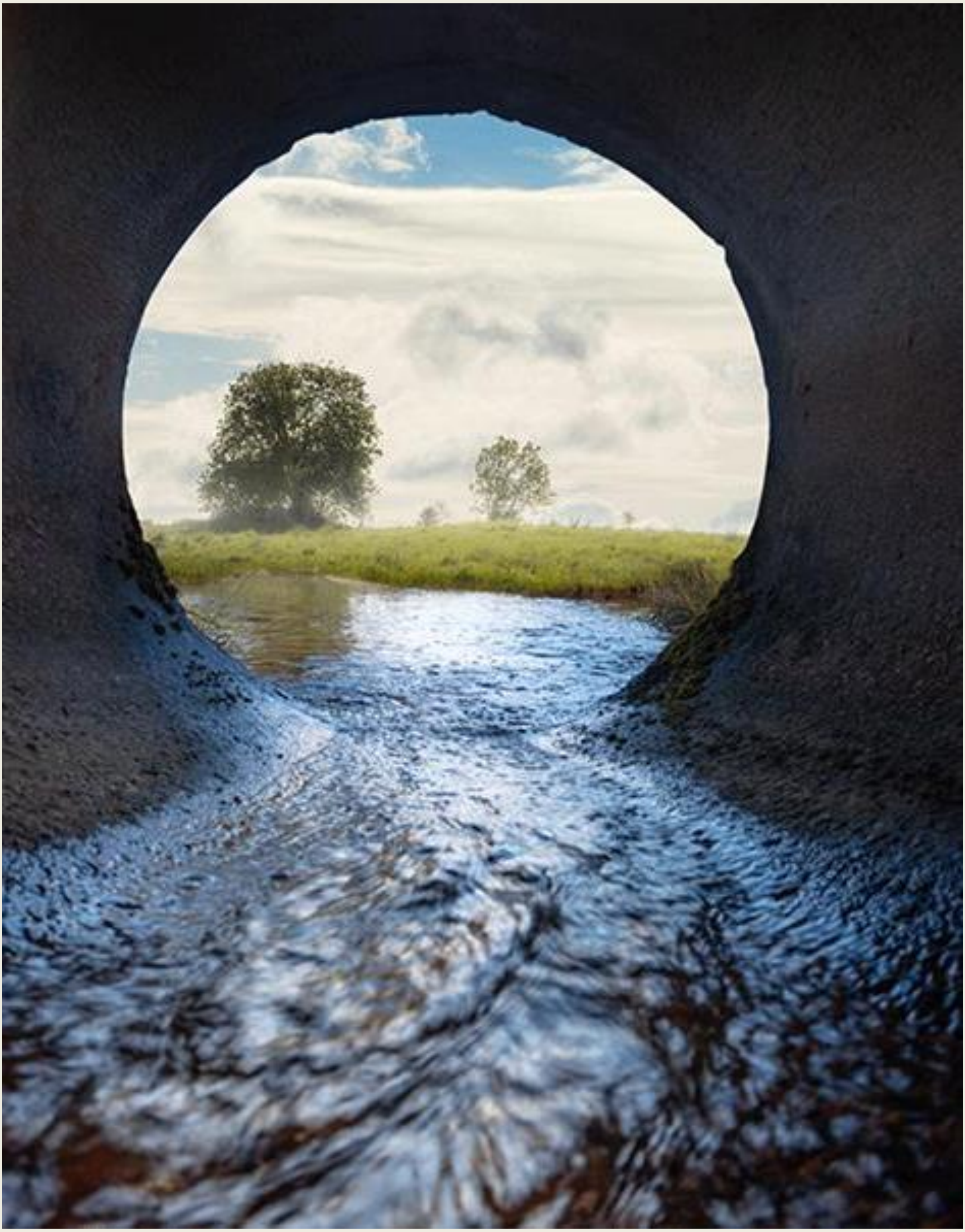
List of Abbreviations

As	Arsenic
BaP	Benzo[a]pyrene
BAT	Best Available Techniques
BpA	Bisphenol-A
CAP	Common Agricultural Policy
Cbz	Carbamazepine
Cd	Cadmium
CSO	Combined Sewer Overflow
Cu	Copper
Dcf	Diclofenac
DHm^{3}c	Danube Hazard m^{3}c
DHSM	Danube Hazardous Substances Model
DRB	Danube River Basin
DRBMP	Danube River Basin Management Plan
DWD	Drinking Water Directive
EC	European Commission
ECHA	European Chemicals Agency
EU	European Union
EQS	Environmental Quality Standard
EQSD	Environmental Quality Standards Directive
Hg	Mercury
HS	Hazardous Substances
IAS	Individual and other Appropriate Systems
ICPDR	International commission for the Protection of the Danube River
IED	Industrial Emissions Directive
IPM	Integrated Pest Management
JDS	Joint Danube Survey
MoRE	Modelling of Regionalized Emissions
Met	Metolachlor
MS	Member States
Ni	Nickel
NP	Nonylphenol
OP	Octylphenol
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead

PE	Population Equivalents
PFAS	Per- and Polyfluoroalkyl Substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PNEC	Predicted No-Effect Concentration
REACH	Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals
SPD	Sustainable Use of Pesticides Directive
SSD	Sewage Sludge Directive
Tcz	Tebuconazole
TNMN	Transnational Monitoring Network
RBMP	River Basin Management Plan
RBSP	River Basin Specific Pollutant
UWWTD	Urban Wastewater Treatment Directive
UWWTP	Urban Wastewater Treatment Plant
WFD	Water Framework Directive
Zn	Zinc

Part A – Context



1 Setting the scene

Hazardous substances (HS) pollution refers to contamination with harmful chemicals and substances of emerging concern that might be heavily toxic to or accumulative in living organism. They include both inorganic and organic pollutants such as heavy metals, arsenic, cyanides, hydrocarbons like mineral oil derivates, trihalomethanes, polycyclic aromatic hydrocarbons, per- and polyfluoroalkyl substances, surfactants, flame retardants, plasticizers, biphenyls, phenols, pesticides, haloalkanes, endocrine disruptors, pharmaceuticals, certain ingredients of personal care products, etc. HS can be emitted to water from both point and diffuse sources. Point source emissions are mainly related to wastewater discharges from households and industries as major pathways. Industrial facilities that process, utilise, produce or store HS can release them with wastewater discharges. Indirect dischargers are connected to public sewer systems and can transport contaminated industrial wastewater to the urban wastewater treatment plants (UWWTPs) if their own treatment system is not designed or inefficient for removing specific HS. Households and public buildings connected to sewer systems can also contribute to water pollution by emitting chemicals used in the course of daily routine via urban wastewater (e.g. compounds of personal care products, household chemicals, or pharmaceuticals). Although UWWTPs without specific removal technology for HS already remove a high share of undesired chemicals, they still release those chemicals into surface waters in significant amounts, which are neither degradable under standard treatment conditions nor are adsorbed to sludge. Often the technological scheme of the UWWTPs has to be specifically modernised and improved for removal of certain HS.

Diffuse emission pathways are substance-specific. Atmospheric deposition, surface run-off, combined sewer overflows (CSOs), erosion/sediment transport and subsurface flow are the main contributing routes. Urban systems, especially paved areas (deposited air pollutants, litter, roof and facade materials, particles or off-gases from road traffic), agriculture (pesticide, fertilizer and contaminated sludge application), contaminated sites (industrial areas, landfills, abandoned areas) and mining sites are the most important sources. Background geochemical loads can be considerable in specific regions where the parent rock layers naturally contain HS (e.g. metals). However, in many cases, the pollution had occurred in the past (historical pollution), its source can no longer be identified, and the emitted HS can accumulate in significant quantities in certain environmental media, mainly in the soil.

Due to the rapid development of the chemical industry that is continuously producing new compounds, their different and complex environmental behaviour, the long-lasting chronic toxicity of many of them, and difficult to analyse impact of the so called “chemical cocktail”, the whole mechanism of the HS pollution has not been fully understood so far. For this reason, the use of effect-based monitoring methods and effect-based trigger values get more and more attention, which are able to examine the water status by looking at complex toxic mechanism of compound mixtures.

HS can pose a serious threat to the aquatic environment and humans. Some of them are persistent, slowly degradable and can accumulate in the ecosystem (soil, unsaturated zone, river and lake sediments or in biota like fish or mussels). Depending on their concentration and the actual environmental conditions, they can cause acute (immediate) or chronic (latent) toxicity. They can deteriorate habitats and biodiversity and also endanger human health via drinking water or fish consumption as many of these chemicals are carcinogenic, mutagenic, interfere with the endocrine system or reproduction, or teratogen. They usually affect one or more of the vital systems of the living organism, like nervous, enzymatic, immune, reproductive, muscular systems or directly target the cells, exerting also genotoxic and mutagenic activities. They can alter proteins, impact cells, tissues and different organs, negatively influencing individual organisms or entire populations. As many pollutants tend to attach to organic matter, they may build up in individual organisms (bioaccumulation) or even in the food web (biomagnification). Moreover, some of the pollutants can attach to soil and sediment particles and can be subject to subsequent resuspension and dissolution. Therefore, HS pollution is considered as local/regional or even basin-wide water quality problem, which could even impact entire ecosystems, and dealing with this problem usually requires long-term actions and complex sets of measures.

Managing HS pollution needs an enabling regulatory framework, a sound knowledge base on the emissions, sufficient institutional and technical capacity at the relevant organizations, an appropriate combination of source, pathway and transport control measures and strong public awareness.

1.1 Policy context

In the broader policy context, the Zero Pollution ambition, as one of the key commitments of the European Union (EU) Green Deal[1], provides a sound policy framework for managing HS pollution. The Zero Pollution vision for 2050 is to reduce air, water and soil pollution to sufficiently low levels that are no longer considered harmful to human health and natural ecosystems, creating a toxic-free environment. The Zero Pollution Action Plan[2] sets key targets to be achieved by 2030 to speed up reducing pollution at source. These targets include inter alia improving water quality by reducing waste, plastic litter at sea (by 50%) and microplastics released into the environment (by 30%), improving soil quality by reducing nutrient losses and chemical pesticides' use by 50% and significantly reducing waste generation (e.g. residual municipal waste by 50%). It also emphasizes the need for a more effective implementation of the pollution management hierarchy based on the precautionary principle, giving the priority to preventive actions, followed by reduction measures and remediation.

In addition, the objectives and actions of the EU Chemicals Strategy for Sustainability[3], and the EU Strategic Approach to Pharmaceuticals in the Environment[4], linked to the EU Pharmaceutical Strategy[5], are to be considered for the future management of chemicals and pharmaceuticals in the Danube River Basin (DRB). The EU Chemical Strategy aims to better protect citizens and the environment while boosting innovation for safe and sustainable chemicals. The main actions of the Strategy include banning the most harmful chemicals in consumer products (allowing their use only where essential and non-substitutable with safer alternatives), accounting for the cocktail effect of chemicals when assessing risks from chemicals, phasing out the use of per- and polyfluoroalkyl substances (PFAS) in the EU (unless their use is essential) and boosting the investment and innovative capacity for development, production and use of chemicals that are safe and sustainable by design, and throughout their life cycle. The EU Strategic Approach to Pharmaceuticals in the Environment is complementary to the EU Pharmaceutical Strategy, which focuses on availability, affordability, sustainability and security of supply of pharmaceuticals, as well as enabling innovation and establishing links with the actions of the EU Strategic Approach regarding environmental aspects of production, use and disposal of medicines where applicable. The EU Strategic Approach calls for actions to address the environmental implications of all phases of the lifecycle of (both human and veterinary) pharmaceuticals, from design and production through use to disposal. The key actions include increasing awareness and promoting prudent use of pharmaceuticals, supporting the development of pharmaceuticals less harmful to the environment and promoting greener manufacturing, improving environmental risk assessment and expanding environmental monitoring and improving waste management.

Management activities concerning HS pollution are legally determined for the EU Member States (MS) through several EU directives and regulations, fully in line with the implementation of the Water Framework Directive[6] (WFD), the main EU regulatory instrument for water management. The purpose of the WFD is to protect and enhance the status of inland surface waters, transitional waters, coastal waters and groundwater, and to ensure sustainable use of water resources and that all waters meet 'good status' by 2027 at the latest.

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[1] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - The European Green Deal, COM/2019/640 final.

[2] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Pathway to a Healthy Planet for All. EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', COM/2021/400 final.

[3] Communication from the Commission to The European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment, COM/2020/667 final.

[4] COM (2019) 128 Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee on the European Union, Strategic Approach to Pharmaceuticals in the Environment.

[5] Communication from the Commission to The European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Pharmaceutical Strategy for Europe, COM/2020/761 final.

[6] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

For surface waters, good status is defined as good ecological status/potential and chemical status, whereas for ground waters good chemical and quantitative status must be reached. The WFD assigns water management to river basins rather than administrative borders and requires the elaboration of river basin management plans every 6 years. It provides the backbone of the relevant national water policies and sets the framework conditions for a harmonised implementation of various measures at the national level. With respect to HS pollution, the WFD obliges countries to achieve good chemical status based on the list of 45 priority substances. Good chemical status is defined in terms of compliance with all the Environmental Quality Standards (EQS) established for the priority substances at European level. Moreover, the directive requires that the EU MS identify pollutants of regional or local relevance (the River Basin Specific Pollutants, RBSPs), especially considering the ones listed in WFD Annex VIII, and provide respective EQS values, establish appropriate monitoring schemes and implement regulatory measures for them. Compliance with the EQS of the RBSPs is to be evaluated for the ecological status. Measures aiming to control HS pollution have to be included in the programs of measures of the river basin management plans.

The Environmental Quality Standards Directive[7] (EQSD) sets the respective EQS values for the priority substances of the WFD and mandates EU MS to phase out priority hazardous substance emissions and to reduce priority substances releases. EU MS should monitor sediment and biota in order to carry out a long-term trend analysis of those priority substances that tend to accumulate. Moreover, an inventory of emissions, discharges and losses of all priority substances has to established and periodically updated. The current version of the Directive also introduced biota standards for several substances and lays down provisions to improve the efficiency of monitoring and the clarity of reporting with regard to the ubiquitous persistent, bioaccumulative and toxic substances. Furthermore, a Watch List mechanism is in place to effectively identify substances of greatest concern, to gather information on emerging pollutants by targeted EU-wide monitoring and to support the prioritisation process in future reviews of the priority substances list. EU MS have to monitor the substances on the list at least once per year for up to four years. The list has been updated[8] in 2022 by adding 7 additional substances.

In October 2022 the European Commission (EC) adopted a proposal[9] to revise the list of priority substances in surface water and groundwater. For surface waters, twenty-five substances with well-documented adverse effects on nature and human health are proposed for addition to the existing list of priority substances including a standard for total pesticides. On the other hand, four existing priority substances are proposed for removal from the list, and another for integration into the new PFAS group, and eight already-regulated “other pollutants” have been re-designated as priority substances. The EC has also proposed to update quality standards for 16 substances already on the list, mainly to make standards stricter because of evidence indicating a higher risk than originally identified. Moreover, a mandatory Watch List mechanism will be introduced for groundwater bodies and new groundwater pollutants with EU-wide quality standards will be added to the former pollutant list used for assessing chemical status of groundwaters.

Implementation of the WFD requires the compliance with a set of water related legislation as basic measures. The Urban Wastewater Treatment Directive[10] (UWWTD) is driven by water quality protection and precautionary aspects and specifically focuses on the sewer system and wastewater system development. EU MS are obliged to establish sewer systems and UWWTPs at least with secondary (biological) treatment or equivalent other treatment at all agglomerations with a load higher than 2,000 population equivalents (PE). In case an agglomeration bigger than 10,000 PE is located in an area sensitive to eutrophication or its catchment area, tertiary treatment (nutrient removal) must be introduced. Since the Black Sea was significantly suffering from eutrophication in the late 1980ies, the receiving coastal areas have been

[7] Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council.

[8] Commission Implementing Decision (EU) 2022/1307 of 22 July 2022 establishing a watch list of substances for Union-wide monitoring in the field of water policy pursuant to Directive 2008/105/EC of the European Parliament and of the Council (notified under document C(2022) 5098).

[9] Proposal for a Directive of the European Parliament and of the Council amending Directive 2000/60/EC establishing a framework for Community action in the field of water policy, Directive 2006/118/EC on the protection of groundwater against pollution and deterioration and Directive 2008/105/EC on environmental quality standards in the field of water policy, COM(2022) 540 final.

[10] Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment.

designated by Romania as a sensitive area under the UWWTD, requiring more stringent treatment technology than secondary treatment at least at the medium-sized and large UWWTPs (>10,000 PE) in the EU MS of the entire DRB, being the relevant catchment area of the Black Sea northwest Shelf. In addition, the UWWTD also states that individual and other appropriate systems (IAS) as exceptions shall be used to locally collect (and treat) wastewater if constructing a wastewater collection system is economically not feasible or did not result in environmental benefit. However, IAS must provide the same environmental protection as the required collection and treatment systems would deliver.

In October 2022, the EC published a proposal[11] for revision of the UWWTD which requires significant additional efforts for pollution control in urban wastewater management until 2040. According to the proposal, sewer systems and UWWTPs will be needed for all agglomerations above 1,000 PE. Quaternary treatment for the removal of HS will have to be introduced at all UWWTPs above 100,000 PE as well as above 10,000 PE in areas with risk of failing to achieve the respective EQSs. The extended producer responsibility approach will have to be used for products, which lead to discharges of HS into urban wastewater. Elaboration of integrated plans will be required to handle pollution from stormwater overflows and urban rainwater runoff for all agglomerations above 100,000 PE as well as above 10,000 PE in case of risk of failing the respective EQSs. In January 2024, the European Commission reported the closure of the provisional political agreement between the European Parliament and the Council on the Commission's proposal revising the UWWTD. The agreed text was formally adopted by Parliament in April 2024.

The Industrial Emissions Directive[12] (IED) dictates that national authorities need to ensure that pollution prevention and control measures at the largest industrial installations within the regulated industrial activities are up-to-date with the latest Best Available Techniques (BAT) developments. The industrial plants covered by the IED must have a permit with emission limit values for polluting substances to ensure that certain environmental conditions are met. Recently, the EC adopted proposals[13] for revised measures to address pollution from large industrial installations. The expected changes include more effective permits with tighter permit controls, supporting innovation for frontrunners to identify novel pollution control solutions, supporting industry's circular economy investments taking into account energy use, resource efficiency and water reuse, fostering synergies between depollution and decarbonisation and covering more installations (e.g. large-scale intensive livestock farms, extraction of industrial minerals and metals and large-scale production of batteries) and enhancing data transparency and public access to environmental information.

Other EU legal documents like the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals[14] (REACH), the Plant Protection Products Regulation[15] or the Biocidal Products Regulation[16] aim to minimize the release of harmful chemicals in order to protect human health and the environment while improving the functioning and competitiveness of the related industries and markets. To comply with these regulations, companies must identify and manage the risks linked to the substances they manufacture and market in the EU. For instance, they lay down rules for the authorisation of products containing dangerous chemicals and regulating their placing on the market, enforce substitution or exclusion of certain substances, ensure the safe application of products containing dangerous chemicals and prescribe emission limits for the HS. Recently, the European Chemicals Agency (ECHA) released updated recommendations[17] to improve

[11] Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment, COM(2022) 541 final.

[12] Directive 2010/75/EU of the European Parliament and the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

[13] Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, COM/2022/156 final/3.

[14] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

[15] Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC.

[16] Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products.

[17] https://echa.europa.eu/-/echa-updates-recommendations-to-improve-reach-registrations.

REACH registrations that will help companies to comply with REACH requirements and ensure the safe use of chemicals. Moreover, the ECHA published a proposal[18] on restricting around 10,000 per- and PFAS. It aims to reduce PFAS emissions into the environment and make products and processes safer for people.

The Mercury Regulation[19] covers the full life cycle of mercury by prohibiting the export of mercury and its compounds, the manufacture and trade of various mercury products, the use of mercury in certain industrial processes and by ensuring appropriate management of mercury waste. Moreover, the new proposal for revision[20] sets out rules to prohibit the use, manufacture and export of dental amalgam and the manufacture and export of mercury containing lamps.

The Drinking Water Directive[21] (DWD) ensures all water intended for human consumption can be consumed safely and makes all possible efforts to protect human health, control and monitor drinking water quality, provide information for the public and improve access to drinking water. The DWD sets strict water quality standards, tackles emerging pollutants of high concern, applies a preventive approach to reduce pollution at source by introducing a risk-based approach ("from source to tap") and establishes a Watch List mechanism to monitor the potential presence of selected chemicals throughout the whole water supply chain.

The release of agricultural chemicals is controlled by the Sustainable Pesticides Directive[22] (SPD) by reducing the risks and impacts of pesticide use on human health and the environment and emphasizing the use of Integrated Pest Management (IPM). EU MS are obliged to draw up a National Action Plan to implement a set of actions including inspection of pesticide application equipment, prohibition of aerial spraying, protection of the aquatic environment and drinking water, limitation of pesticide use in sensitive areas, trainings on pesticides use, awareness raising on the risks of pesticides and reporting on poisoning incidents. IPM promotes environmentally friendly application of pesticides based on all available information and tools and prefers low pesticide input methods, the least harmful practices and products and low or non-chemical and natural methods.

The EC also adopted a proposal[23] for a new Regulation on the Sustainable Use of Plant Protection Products (transforming the current Directive into a Regulation), aiming at achieving EU wide targets to reduce by 50% the use and the risk of chemical pesticides as well as the use of the more hazardous pesticides by 2030, in line with the key strategies of the EU Green Deal. The main actions include national reduction targets to be set by the EU MS within defined parameters to ensure that the EU wide targets are achieved, new measures to ensure that all farmers and other professional pesticide users practice IPM, a ban on all pesticides in sensitive areas such as urban green areas, protected areas and ecologically sensitive areas, national targets to be set by the EU MS to increase the use of non-chemical pest control methods and obtaining independent advice on alternative methods by farmers to ensure greater uptake of non-chemical pest control methods. However, in November 2023, the European Parliament voted to reject the proposal and the European Commission announced in February 2024 that the Regulation would be withdrawn.

The Proposal for the Directive on Soil Monitoring and Resilience[24] aims to ensure that all soils are in healthy condition by 2050, in line with the EU Zero Pollution ambition. The proposal provides a harmonised definition of soil health by a set of soil parameters to be respected including metals and organic compounds, and puts in place a comprehensive and coherent monitoring framework. Moreover, it lays down rules on sustainable soil management and remediation of contaminated sites along with their transparent mapping.

[18] https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal.

[19] Regulation (EU) 2017/852 of the European Parliament and of the Council of 17 May 2017 on mercury, and repealing Regulation (EC) No 1102/2008

[20] Proposal for a Regulation of the European Parliament and of the Council amending Regulation (EU) 2017/852 of the European Parliament and of the Council of 17 May 2017 on mercury as regards dental amalgam and other mercury-added products subject to manufacturing, import and export restrictions.

[21] Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption.

[22] Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides.

[23] Proposal for a Regulation of the European Parliament and of the Council on the sustainable use of plant protection products and amending Regulation (EU) 2021/2115, COM(2022) 305 final.

[24] Proposal for a Directive of the European Parliament and of the Council on Soil Monitoring and Resilience, COM (2023) 416 final.

The introduction of the WFD and the SPD into the Common Agricultural Policy (CAP) post 2020 will support their implementation and the achievement of their specific objectives. The new EU CAP[25] provides a multi-pillar financing mechanism to help farmers overcome the challenges linked to soil and water quality, biodiversity and climate change, environmental challenges and societal expectations. The suggested regulation comprehends increased ambitions towards environmental and climate protection. EU MS are obliged to make a greater overall contribution to the achievement of the climate- and environmental objectives compared to the previous programming period. In total, 40% of the CAP budget will have to be climate- and environment-relevant and support biodiversity objectives. The post-2020 CAP envisages requiring all EU MS to prepare a CAP Strategic Plan, where specific objectives would have to be achieved through targeted actions for improving the economic, social and environmental performance of the agricultural sector and rural areas. The new conditionality system would link farmers' income support to the application of environment- and climate-friendly farming practices. Moreover, agri-environment-climate commitments and eco-schemes would also be important elements of the CAP Strategic Plans and would support farmers in maintaining and enhancing sustainable farming methods going beyond mandatory requirements and relevant conditions.

The progressive development of the urban wastewater sector increases the quantities of sewage sludge that requires disposal. The Sewage Sludge Directive[26] (SSD, currently under revision) seeks to encourage the use of sewage sludge in agriculture and simultaneously regulates its use in such a way as to prevent harmful effects on soil, vegetation, animals and human beings. Detailed recording is required on the circumstances of sewage sludge application in agriculture and a set of limit values for concentrations of heavy metals in sewage sludge intended for agricultural use and in sludge-treated soils is assigned. Therefore, implementation of the SSD helps to avoid HS pollution by restricting the application of contaminated sludge to agricultural fields.

1.2 Rationale

According to the DRB Management Plan (DRBMP) Update 2021[27], numerous measures have been implemented in the DRB over the last two decades to control pollution including HS (e.g. high-level treatment of urban wastewater, implementation of BAT at industrial sites and applying best management practices in agriculture). On top of these, Danube countries have taken important steps to close knowledge gaps on HS pollution by compiling updated emission inventories, conducting targeted campaigns on UWWTP inflow and effluent analysis, organizing specific monitoring campaigns such as the Joint Danube Surveys (JDS) and supporting scientific investigations on basin-wide emission modelling and chemical analysis, such as the SOLUTIONS project[28] and the Danube Hazard m^{3}c (DHm^{3}c) project[29].

Despite the substantial progress achieved in narrowing the information gap related to HS pollution, the state-of-the-art knowledge needs to be improved in the future to appropriately manage the problem. The sources of HS pollution, the pathways via which they enter water bodies and their fate and behaviour in the environment are still not fully understood. Only scarce information is available on point source emissions from industrial and wastewater inventories and the understanding on diffuse emissions from agriculture, urban areas and historical polluting activities is very limited. Therefore, further efforts are needed to close knowledge gaps on the monitoring of HS in surface waters and to identify which priority substances and other emerging chemicals are of basin-wide relevance. Moreover, the information gap on the emission sources contributing to HS contamination of the surface waters should be narrowed.

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[25] Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013.

[26] Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture.

[27] ICPDR (2021): Danube River Basin District Management Plan Update 2021.

[28] https://cordis.europa.eu/project/id/603437.

[29] http://www.interreg-danube.eu/approved-projects/danube-hazard-m3c.

Although a number of measures has been taken for the progressive reduction of priority substances discharges, for phasing-out emissions of hazardous ones (including banning at EU level) and to control RBSPs, these pollutants are still found in the aquatic environment having ubiquitous persistent, bioaccumulative and toxic features and leading to failing good status of surface water bodies. Thus, measures to address HS releases should be further implemented in the urban and industrial wastewater management and agricultural sectors.

Moreover, the national legislations are facing challenges since many of the water management related EU legislations have been revised in line with the EU Green Deal and its related strategies such as the Zero Pollution Action Plan. While keeping the environmental and climate objectives ambitious, the revision process will likely bring challenges for water management by tightening the requirements and/or extending the scope of numerous water-related regulations for urban wastewater treatment, industrial technology implementation and pollution control, integrated pest management, agricultural measures, chemical monitoring and reaching good chemical status. These new aspects and targets arrived at a time of energy insecurity, dramatically rising prices, heavy market fluctuations and scarcity of chemicals and other essential materials. The combination of these factors represents a huge task for constructing, operating and maintaining new UWWTPs and thoroughly adapting and upgrading existing ones to achieve new limits of HS discharges, reduction of greenhouse gas emissions and energy neutrality. It also represents a significant challenge for the massive extension of monitoring and chemical analyses required by the new Directives. The water management sector has to adapt its policies and measures to reflect to the latest EU requirements and to establish an enabling regulatory framework that can support and control the implementation of these policies.

In addition, in some Danube countries, substantial lack of institutional capacity, unclear responsibilities, insufficient intersectoral dialogue and knowledge gaps regarding monitoring data and chemical emissions hinder the establishment of an efficient management. On the top of this, climate change impacts need to be taken into consideration, in particular the heavy rainfall events and the prolonged droughts with low flow conditions, causing high river loads and increased in-stream concentrations, respectively.

1.3 Objectives

Despite a significant risk of failing to achieve good chemical status for many water bodies in the DRB because of pressures related to HS pollution, controlling this kind of pollution is heavily underrepresented in the DRBMPs and national plans, mostly owing to substantial knowledge gaps, lack of system understanding and deficiencies in institutional capacity regarding both the identification of sources and pathways of pollution and implementation of effective management options. To improve this situation and to respond to the above-mentioned shortcomings, the ICPDR publishes this policy paper that draws upon the findings and policy recommendations of the DHm^{3}c project (see project output T3.3[30]), representing a collaborative effort between the project and ICPDR experts.

This paper recommends sound policy instruments and effective measures to protect aquatic environment against HS emissions for decision makers in the water management policy field. It offers Danube countries support for the preparation and implementation of their tailor-made national water management policies concerning HS pollution. The guidance will act as a strategic policy framework providing consistent approaches into which the Danube states are encouraged to integrate their individual national methods. It lays down the basis for planning measures subject to individual adjustments according to national conditions.

This document encompasses management level assessments and recommendations to be potentially incorporated into the upcoming DRBMPs and national RBMPs. This includes recommendations for a HS management strategy and a catalogue of mitigation measures including a qualitative assessment of their potential effects. It also includes an assessment of the “state-of-the-art” understanding obtained on the issue of HS pollution in the DRB, in addition to an overview of the relevant data and knowledge gaps and suggestions on how to overcome them. Thus, it can potentially contribute to achieve an effective and harmonized management of HS water pollution in the DRB, based on the prioritization of measures at transnational level and on the simultaneous consideration of specific territorial needs.

[30] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/b5cd57dd83262010f0756c758a16d8c9797d0ce7.pdf.

2 Summary of HS pollution in the DRB

2.1 Current status and trends of water quality

The DRBMP Update 2021 provides an overview on the current situation of the chemical status of the surface water bodies in the DRB. Good chemical status (overall status in water and biota) was achieved for 36.0% of the water bodies. For priority substances in water, good chemical status was reported for 67.7%. After neglecting the ubiquitous substances, the percentage of good chemical status was slightly increased to 73.8% but a significant portion of data is still missing. For priority substances in biota, good chemical status was not achieved in any water body. Despite the fact that a great portion of data for biota is still missing, the impact of ubiquitous substances on the chemical status in biota is significant: without data for brominated diphenyl ethers and mercury, good chemical status in biota was achieved for 28.2%. Looking to the future, about 30% of the surface water bodies are at risk of failure to achieve good status by 2027 because of HS pollution.

Current chemical river pollution monitoring accomplished in the framework of the **JDS4** was focused on target analysis of the WFD priority substances and on RBSPs. In addition to that, few emerging chemicals from the EU Watch List were investigated. The strategy to overcome the limits of classical target analysis included wide-scope chemical target screening and non-target screening approaches in combination with effect-based monitoring which are on the threshold to become regular tools for WFD-compliant monitoring. A handful of diverse target screening methods were applied during JDS4 focusing on several thousands of compounds. Hundreds of compounds were detected. This comprehensive use of screening techniques enabled their comparison to be made, and interlaboratory trials and training for the Danube laboratories to be completed. Acquiring this huge dataset from screening methods (>2,600 substances from wide-scope target screening, >65,000 substances used for suspect/non-target screening and altogether >300,000 results) made it possible to perform prioritisation of pollutants in water, biota, sediment, wastewater and groundwater (using the prioritisation framework of the NORMAN Association[31]) leading to specification of tens of substances with the proven most adverse effects to the Danube ecosystem.

Target screening of 2,608 substances was performed on all JDS4 surface water samples. The results of the screening have shown the presence of 495 substances with concentrations above their limit of quantification in at least one sample. Out of these, 53 substances exceeded their toxicity threshold value (Predicted No-Effect Concentration, PNEC or EQS) in at least one sample. From the current WFD priority substances (not considering the proposed new list), only 3 (PFOS, cybutryne and cypermethrin) were on the list. Additionally, six former or current WFD surface water Watch List substances were on the list (erythromycin, imidacloprid, 17beta-estradiol, thiacloprid, diclofenac and ciprofloxacin). These six compounds together with the 44 new substances are the potential 50 candidates for the RBSPs in the surface water compartment of the DRB and their presence in the basin should be carefully monitored.

The list was dominated by:

- **pesticides** (nicosulfuron, terbuthylazine, 2,4-dichlorophenoxyacetic acid, fipronil, metazachlor, allethrin, fenthion, bentazone, metolachlor, cybutryne, imazamox, 2,4-dichlorophenol, dazomet, pethoxamid, methoprene, spinosyn A, pyrethrin I) and their transformation products (1,3,5-triazin-2(1H)-one, 4-((1,1-dimethylethyl)amino)-6-(ethylamino)-, desethylterbuthylazine),
- **pharmaceuticals** (anticonvulsant carbamazepine – also a marker of pollution from wastewater, alpha-blocker telmisartan, antipsychotic ziprasidone, immunosuppressive and anti-inflammatory 7-hydroxymethotrexate, candasertan against high blood pressure, antibiotic vancomycin and dicloxacillin; and drug against osteoporosis raloxifene),
- **personal care products** (antiseptic cetylpyridinium, antiseptic and disinfectant benzododecinium, fragrance 6-acetyl1,1,2,4,4,7-hexamethyltetralin),
- **surfactants** (N,N-dimethyldodecan-1-amine, cis-1-(3-chloroallyl)-3,5,7-triaza-1-azoniaadamantane),
- **PFAS compounds** (perfluorooctanesulfonamide),

[31] https://www.norman-network.net/.

- **biocides** (antibacterial product benzyl hexadecyl dimethyl ammonium, disinfectant miristalkonium),
- **novel flame retardants** (2-ethylhexyl diphenyl phosphate (EHDP), 3,3',5,5'-tetrabromobisphenol A),
- **plasticisers** (bisphenol A bis(3-chloro-2-hydroxypropyl)ether (BADGE*2HCl)) and
- **industrial chemicals** (4-(1,1,3,3-tetramethylbutyl)phenol, 2-ethylhexyl-2-cyano-3,3-diphenylacrylate, hexa(methoxymethyl)melamine, 2,4-dichlorobenzoic acid).

2.2 Investigations on HS emissions at river basin scale

First time ever, a tailor-made catchment scale water quality model called **Danube Hazardous Substances Model (DHSM)** was applied for the entire DRB in the framework of the DHm^{3}c project to quantify emissions and river loads for selected HS. The model is based on the methodology[32] developed in the SOLUTIONS project and has been adapted to the DRB conditions and river basin management purposes based on experiences from pilot-scale investigations. The DHSM has been implemented for the entire DRB and for the following 17 target chemicals, which represent relevant sources and pathways, are relevant for the International Commission for the Protection of the Danube River (ICPDR), national and regional authorities in the basin, and can be actually detected and measured:

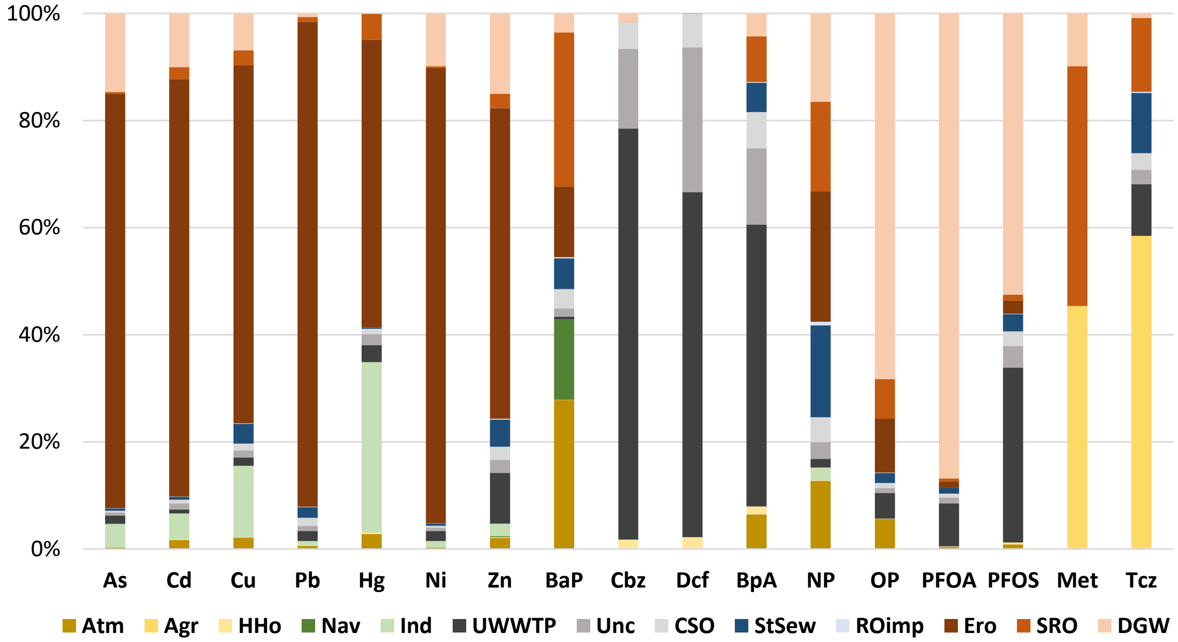
- Metals: arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn).
- Benzo[a]pyrene (BaP) as one of the Polycyclic Aromatic Hydrocarbons (PAH).
- Pharmaceuticals: carbamazepine (Cbz) and diclofenac (Dcf).
- Industrial chemicals with wide dispersive use: bisphenol-A (BpA), nonylphenol (NP) and octylphenol (OP).
- PFAS: perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS).
- Pesticides: metolachlor (Met), a herbicide in agriculture and tebuconazole (Tcz), a fungicide used for wood preservation.

In the framework of the DHm^{3}c project, available measurement results on HS concentrations back to 2008 were collected for surface water, groundwater (sub-surface water), topsoil, atmospheric deposition, stormwater outlet and UWWTP effluents from the Danube countries. This was supplemented by the project's own measurements carried out in pilot catchments. The results of the extensive data collection are available in the DHm^{3}c Inventory in a harmonized form, which provided a sound database for the modelling (see the project output T1.1[33]). In addition, the modelling was based on various global datasets (e.g. population, settlement type, roads network), European-scale or DRB-specific datasets (simulated hydrology, industrial dischargers, UWWTPs) and information taken from the international literature.

The relative proportion of the main emission pathways are presented in **Figure 1**. The emissions are subdivided according to the pathways into direct emissions to surface waters (atmospheric deposition, the spraying of pesticides in agriculture, households not connected to centralized wastewater collection systems, industry and inland navigation), emissions from mixed sewer systems (UWWTP effluents, sewer systems not connected to UWWTPs and CSOs) emissions from urban runoff (separated rainwater collection systems and uncollected runoff from paved surfaces flowing into surface waters) and emissions from soil (surface runoff from permeable surfaces, soil erosion, agricultural drainage flow and groundwater flow). It is noted that the discharges to surface waters from current mining (insofar as not included in the industry sources inventory) and historic mining could not be quantified on the basin scale and therefore had to be left out of the inventory.

[32] van Gils, J., Posthuma, L., Cousins, I. T., Brack, W., Altenburger, R., Baveco, H., van Wezel, A. (2020). Computational material flow analysis for thousands of chemicals of emerging concern in European waters. Journal of Hazardous Materials, 397(April), 122655, https://doi.org/10.1016/j.jhazmat.2020.122655.

[33] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/cbdd805c7a3a73ad0a4c4b2fa362fc135eaab556.pdf.



Atm: Atmospheric deposition directly to surface waters; Agr: Direct emissions to surface waters from agriculture (spray drift); HHo: Direct emissions to surface waters from unconnected households; Nav: Direct emissions to surface waters from navigation; Ind: Direct discharges to surface waters from industry; UWWTP: Emissions from treated domestic wastewater collected in sewers; Unc: Emissions from wastewater collected but not connected to a UWWTP; CSO: Combined sewer overflows; StSew: Emissions from separate storm water collection systems (in urban areas); ROimp: Direct runoff from impermeable surfaces to surface waters (outside urban areas); Ero: Soil erosion; SRO: Surface runoff from permeable surfaces; DGW: Agricultural drainage + Groundwater (subsurface flow).

Figure 1: Relative proportion of emission pathways for target compounds

The metals show a wide spectrum of sources and pathways. They are important today, but they had been used in the past in even larger quantities - partly uncontrolled. Metals were emitted by the flue gases of combustion plants (coal-fired power plants, waste incinerators), they are present in built-in materials (roads, roofs, buildings, structures, vehicles), and were widely used in gasoline (lead) and fertilizers (cadmium) whose impacts can be still observed. Consequently, pollution over several decades has accumulated in the environment, mainly in soils, from where metals were washed into the surface and underground waters over time.

For metals, the combined soils related pathways provide the largest contribution (typically 70% or more). Contributions > 10% occur for industry discharges (Cu, Hg) and UWWTPs (Zn). The spatial results for zinc show emission gradients probably controlled by terrain and hydrology gradients that drive the soil related pathways. A second important driver may be the spatially variable historical pollution in soils. In most places the soil related pathways may be dominant. Locally, direct sources may be dominant (atmospheric deposition on large lakes, industrial point sources). In other places, the contribution from wastewater may be dominant (from mixed sewers collecting wastewater and urban stormwater) or from stormwater and CSOs.

Benzo[a]pyrene is emitted by incineration (combustion plants, household heating), but it is usually transported over short distances in the atmosphere (in contrast to mercury, which can even cross a country or larger areas). Benzo[a]pyrene quickly settles and accumulates attached to particles. For benzo[a]pyrene the modelling results show large contributions from surface runoff (29%) and from direct atmospheric deposition (28%), with noticeable contributions from navigation and erosion (> 10%). The spatial results for benzo[a]pyrene show high emissions in large lakes and larger rivers, and in places with high local atmospheric deposition and high rainfall (e.g. in Slovenia). Locally high atmospheric deposition may be attributed to nearby industrial and domestic incineration or intensive combustion engine traffic. Often, surface runoff or erosion and sub-surface flow are dominant pathways. In many places direct sources are dominant (atmospheric deposition on large lakes, inland navigation in larger rivers). Occasionally, stormwater and CSOs or wastewater dominate.

For investigated pharmaceuticals, only contributions from households could be quantified. Wastewater related pathways therefore contribute >90% to the emissions. The spatial results for carbamazepine show highest emissions to water in places with high population and a high connection rate to sewers. As country-specific emission factors have been applied, some differences between countries can be observed. UWWTPs are the dominant pathway, except for areas with low connection rates to sewers, where household releases to soil possibly supplemented by re-used sewage sludge find their way to the surface water via sub-surface flow. The release of pharmaceuticals due to veterinary use could not be quantified.

The use of PFOS in products has already been banned, but there are still many products currently in use in households and accumulated in the so-called stock of long-living goods, from which they will be still released over the coming years. For PFOS, households are an important source and wastewater is a relevant pathway (37%). Subsurface flow is an important pathway, too (53%). The modelling results show an east-west gradient in the emissions, caused by an assumed correlation of emission factors and soil concentrations to population density and Gross Domestic Product. Also, population centres show high emissions. In many places the erosion and subsurface flow pathway is dominant, as a result of accumulation in soils. In drier areas, the wastewater pathways dominate. Near larger water surfaces, direct atmospheric deposition dominates.

For the other investigated industrial chemicals, a diverse spectrum of pathways exists. For Bisphenol-A, households are an important source and wastewater is an important pathway (67%). Subsurface flow is an important pathway, especially for PFOA (87%). For nonylphenol, stormwater is an important pathway (17%). For both phenols erosion contributes significantly (>10%).

For the investigated pesticides, important pathways are direct losses to surface water during application in agriculture (45-58%) and surface runoff (14-45%). For metolachlor, subsurface flow is relevant (10%). For tebuconazole there are significant contributions (>10%) from stormwater and WWTPs, due to the use as a biocide. The spatial results for metolachlor reflect the use in agriculture. In most places, surface runoff or direct emission by spray drift are the dominant pathway. Locally, this is subsurface flow.

A comprehensive assessment of the investigated emission sources and pathways, the spatial distribution of the emissions, a scenario analysis and a model documentation are presented in the project output T3.2[34].

2.3 Knowledge gaps and other shortcomings

The DHm^{3}c project, for the first time ever, implemented a targeted monitoring programme including surface waters and related emission pathways, created a basin-wide database with the concentration of a broad range of substances in these compartments integrating data from own monitoring program and diverse pre-existing national and other project-related data. Building on the gained information, an up-to-date basin scale emission model was applied to set up a basin-wide emission inventory of selected HS. This knowledge coupled with an in-depth review of existing national policies, serves as a sound basis to formulate recommendations for future policies for the Danube countries to manage transboundary HS pollution in an efficient way. Despite these advances, several shortcomings and knowledge gaps have been identified that need to be considered in the future for strengthening the management of HS pollution under increasing environmental and climate pressures and public expectations.

Lack of harmonized monitoring

The project clearly showed that despite the significant efforts on national level, a basin-wide strategy for HS monitoring in water bodies and emission pathways is missing. The available data differ among countries regarding selected substances, analytical methods, considered pathways and environmental media. Transboundary activities like the Danube Transnational Monitoring Network[35] (TNMN) or JDS are very valuable initiatives in this respect, but while TNMN is focused on regular monitoring of the main surface waters in the DRB but includes only a restricted number of HS (missing many of the relevant organic ones), JDS provides information on a wide spectrum of chemicals but only to a restricted geographical extent and at

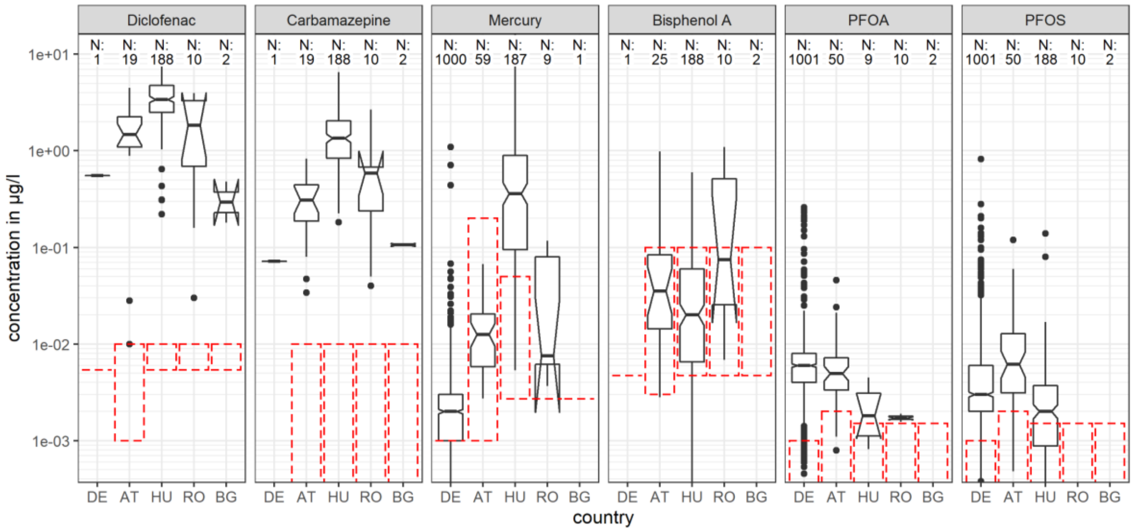
[34] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/18559bdc251b21a7cc79e3411435d0ce11782680.pdf.

[35] http://www.icpdr.org/wq-db/.

singular events in every six years. As hazardous substance pollution stems from the whole basin and enters water bodies via multiple pathways, which sometimes show a highly dynamic behaviour, these initiatives can only complement and enrich but not fully replace national monitoring programs and their harmonization as proper basis for a basin-wide management.

Lack of substance specific data from sources and pathways

Substance specific data are the backbone of an emission inventory for HS. First of all, there is an urgent need for country specific information on production and use volumes of HS. Valid calculations of emission factors highly depend on this information. Emission modelling of pesticides for instance is not able to provide a solid emission inventory if applied volumes are not known. Some countries in the basin made significant efforts in monitoring of UWWTP effluents, groundwater or soil contamination. Similar information from other countries is missing, which hampers the differentiation of regional emission factors (**Figure 2**).



Statistically significant differences can be observed between Germany (DE), Austria (AT) and Hungary (HU) for PFOS, PFOA and Mercury and between AT and HU for Diclofenac and Carbamazepine. Small sample sizes or missing data hamper the comparison for other countries. Red dashed bars represent level of quantification values of the labs.

Figure 2: Statistical evaluation of substance concentrations in UWWTP effluents

Generally, only very little information is available on HS concentrations in surface runoff from urban areas and streets leading to emissions into surface waters via rain sewers as well as via CSOs. This clearly constrains the validity of representation of this emission pathway in the emission inventory.

Lack of access to existing data

Another aspect that has been recognized during the implementation of DHm³c project and the development of the basin-wide database is that some data (e.g. concentrations in soil, groundwater, surface waters or wastewater) do exist on regional or national scale but are not accessible for further use such as integrated risk assessments or transnational emission modelling. In some cases, transfer of data is associated with high costs or administrative hurdles. In other cases, data have not been delivered for further use in the project without explicitly communicated reasons or are simply not available for anyone but the relevant authority or data holder. Another critical barrier was the unclear data licensing, which makes their use difficult from a legislative perspective. Reasons for restrictions in data accessibility have to be better understood to remove barriers for data sharing and to develop a new culture of communication, data exchange and fair licensing in the basin. This would allow making a better use of the existing information and supporting an advanced level of HS pollution control.

Lack of inventory of contaminated sites

A significant lack of information is related to contaminated sites. With respect to metal pollution of rivers, it mainly concerns former or still active mining sites, which are potential major point sources. First attempts have been made to create an inventory, but discharge volumes are not available on a basin scale. A currently emerging topic is the PFAS-contaminated sites, which mainly locally but potentially also on catchment level may significantly contribute to water quality deterioration. Contaminations are mostly related to landfills of municipal waste and firefighting training grounds, where PFAS containing foams have been used. The identification of such contaminated sites recently started in some countries such as Germany and Austria, but even there the information on such potentially contaminated sites is still scarce.

Lack of knowledge and data on emissions from stocks of legacy substances

In the case of metals, current emissions are dominated by the contribution of soil-related pathways, which transport metals accumulated in soil over the past decades into surface waters. A similar situation exists for the “legacy” substances PFOS and PFOA, which are causing concern throughout Europe and beyond. For water management, the time scales associated with the wash-out of such legacy substances after cessation of non-essential emissions are of key importance. In the case of metals, the share of the "natural" background, the emissions that eventually remain after releases by human activity have been minimized and stocks have washed out, is uncertain. In some European rivers, downward trends of metal concentrations are observed. Resolving this knowledge gap requires the collection and analysis of harmonized data in surface waters, soils and groundwater over longer periods of time.

Lack of precision of emission modelling

Looking at modelling results from pilot catchments and from the basin-wide model, it becomes clear that for some parameters concentrations and loads in surface waters can be modelled reasonably (e.g. pharmaceuticals, PFOS, PFOA, some metals), while for others the model performance needs to be improved. A main modelling problem occurs when input data do not represent the regional situation (e.g. for pesticides), either because data are missing or because the extrapolation of data from other regions does not work due to regional specificities. Another reason is the insufficient understanding of the behaviour of a substance (e.g. pharmaceuticals) leading to uncertainties in the modelled transport processes (transformation, degradation, adsorption, settling etc.). The only way to improve model performance is to increase system understanding based on pilot investigations driven by a high level of data availability.

Lack of institutional capacity to use emission modelling as operative tool in administration

While emission modelling for nutrients has a thirty-year history in the DRB, the same for HS is lagging behind. Looking at implementation of national RBMPs, only Germany, Austria and Hungary have already used modelling tools for the WFD status assessment and have included a quantification of emissions via diffuse pathways into the assessment. Via capacity building trainings and workshops the DHm^{3}c project has succeeded to increase interest and understanding of regional and national authorities for the development of emission inventories using emission models, yet the operative and self-dependent implementation on national level is one step further.

Part B – Strategy

3 Policy recommendations

Policies controlling HS pollution need to build on three fundamental elements. They should first establish an appropriate monitoring system to identify the problem, including a well-designed and harmonized monitoring program, modern equipment for measuring and a well-structured open access database. Secondly, they need to develop a comprehensive emission inventory to determine the main pollution sources and pathways and to quantify the pollution fluxes within the catchments. Finally, they have to put in place appropriate control measures to minimize pollution, targeting the main sources and pathways.

3.1 Problem identification and need for harmonization

Monitoring approaches of the Danube countries, the evaluation of the measurements and the related data management need to be better harmonized. On the top of the obligations regarding the monitoring of the priority substances, Danube countries should designate together an **updated list of RBSPs for the DRB**, which are intensively used and problematic for the waters in the basin and therefore they should be carefully monitored and controlled. This list should be determined by harmonizing the existing lists of potential Danube RBSPs derived by the JDSs and national lists of RBSPs. The list is to be subject to regular updates based on future scientific investigations. Danube countries should jointly discuss and decide what substances need to be added to or potentially removed from the list.

It is suggested to harmonize and jointly determine the **EQSs** for the compounds of transboundary importance (Danube RBSPs) based on total or bioavailable concentration values in water as well as concentrations in sediment and biota, as appropriate. The potential reasons for applying major differences in the EQS values at national level need to be investigated in depth.

Danube countries may consider harmonizing the **immission**[36] **monitoring programs** as appropriate**.** In the first step, detailed descriptions are required from each country for each type of monitoring programs, indicating the aim of the programs and number of HS, why certain priority substances are missing, where the sampling points are, what the monitoring frequency is, etc. This information should be then shared and discussed at an appropriate forum of the Danube countries such as the ICPDR.

Danube countries are advised to harmonize the **analytical methods** towards using standardized methods for the common parameters as appropriate. For several priority substances in different matrices (sediment, fish, crustacean or mollusc) no standardized analytical methods are available and countries develop their own methods of analysis. In these cases, close cooperation on sharing knowledge and best practices among countries is highly beneficial. Harmonized analytical methods for measuring the concentrations of HS subject to monitoring in the DRB would improve the level of consistency and comparability among the different countries and could reduce costs and time needed to implement the monitoring programs.

It is strongly recommended to promote and support using modern sampling devices and up-to-date monitoring techniques. Two complementary and necessary **monitoring approaches** need to be widely applied for the overall assessment of emerging substances and thus to ensure a long-lasting management of these pollutants: i) non-target screening for the identification of unexpected substances and ii) effect-based bioassays for toxicological assessments focusing on the impacts of mixtures of HS on ecosystems.

More details on the current national policies and the need for harmonization can be found in the DHm^{3}c project output T3.1[37].

3.2 Knowledge base development

In many river basins, including the DRB, emission inventories for marker substances are currently lacking, especially with respect to diffuse sources of pollution. However, developing a comprehensive and sound knowledge base is a prerequisite towards an effective control of HS pollution. On one hand it should include

[36] Amount (concentration) of a pollutant present in the environmental compartment.

[37] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/e5303ecfba680e4d0c2d296a75d163dae6d29f27.pdf.

consistent emission inventories for indicator substances, especially targeting the major emitters such as industrial facilities, UWWTPs, mining sites (especially for metals) and contaminated sites (landfills or former firefighting grounds) associated with legacy pollution (e.g. PFAS) but also diffuse pathways such as erosion, surface runoff or groundwater flow that are difficult to monitor. **Diffuse emission inventories** should be based on catchment-scale water quality models with appropriate emission factors, representing all relevant pathways, while maintaining the link to sources. These models are able to trace back water emissions to pathways and sources and can assess the impact of measures on water status and their efficiency to reduce emissions. Moreover, they can be used to predict the impacts of climate change on chemical pollution by taking into account hydrological implications under changing climate.

Danube countries are advised to adopt and further maintain **chemical emission models** such as the DHSM or the Modelling of Regionalized Emissions[38] (MoRE) developed in the framework of the DHm^{3}c project that can be used at both basin-wide and national level. Elaborating models in a harmonized way would ensure that an assessment on the DRB-scale can be coordinated with national applications in synergistic manner so that they together could offer a profound basis for successful basin-wide management of HS pollution.

Application of **modelling-based risk assessment** at river basin scale can help optimizing the overall surface water monitoring process. Emission monitoring, modelling and inventory development can reduce the immission monitoring costs by orienting surface water monitoring to those water bodies where the pollution pressure is significant. They can also help focusing monitoring efforts on new and problematic compounds for which little knowledge is available. Danube countries are encouraged to make use of the modelling tools for supporting risk assessments that will likely be required by the EU water legislation such as the revised UWWTD.

Further information on the models can be found in the DHm^{3}c project outputs T2.2[39], T3.2 and T4.5[40].

On the other hand, there is a strong need for **emission[41] targeted monitoring efforts** throughout the DRB over longer periods, focusing on a limited number of substances. Well-designed **investigative monitoring programs** for supporting the establishment of an emission inventory should be started at national level at least where there is already an identified problem or pollution risk is relevant. These programs should be harmonized in the DRB using agreed protocols and analytical methods. Moreover, it is recommended to develop and use a harmonized, comprehensive **transboundary database** including HS concentrations in all relevant environmental media and emission pathways, taking into account that relevant pollution sources could be located beyond national borders. For some pathways (wastewater effluents, runoff, soil and groundwater contamination), data availability is uneven across the DRB, in some countries data collection and monitoring are lagging behind that needs to be addressed. In addition, targeted efforts are needed to narrow major knowledge gaps related to specific pathways. Information on diffuse emissions from rainwater sewer outlets or CSOs is very scarce in the DRB. Very little information is available on the contaminated sites (location, volume of substances).

Moreover, specific river load monitoring campaigns should be implemented to support the **calibration and validation** of the emission model that addresses both the spatial and temporal variability of water quality. To support this effort on the basin-wide level, the organic indicator substances mentioned before should be considered for inclusion in the TNMN of ICPDR. In addition, the database should contain certain spatial, statistical and environmental data on at least regional level that are of high importance for the inventory development (e.g. land use, population, river discharge, production and use volume of the investigated substances).

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[38] Fuchs, S.; Kaiser, M.; Kiemle, L.; Kittlaus, S.; Rothvoß, S.; Toshovski, S.; Wagner, A.; Wander, R.; Weber, T.; Ziegler, S. (2017): Modelling of Regionalized Emissions (MoRE) into Water Bodies: An Open-Source River Basin Management System. Water 2017, 9, 239, https://doi.org/10.3390/w9040239.

[39] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/52b44806c4c7637a97f77af4f9476a043bbcee60.pdf.

[40] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/5b8c3f3faaabc8ae6593568893ee2ef47171d532.pdf.

[41] Amount (flux) of a pollutant that is emitted from the source.

A great example for developing a **consistent database** is the inventory elaborated within the DHm³c project. More information on the DHm³c transboundary database and the harmonized and cost-effective monitoring approach can be found in Output T1.1, T1.2[42] and T4.5.

The suggested actions to develop an emission inventory are presented in **Figure 3**:

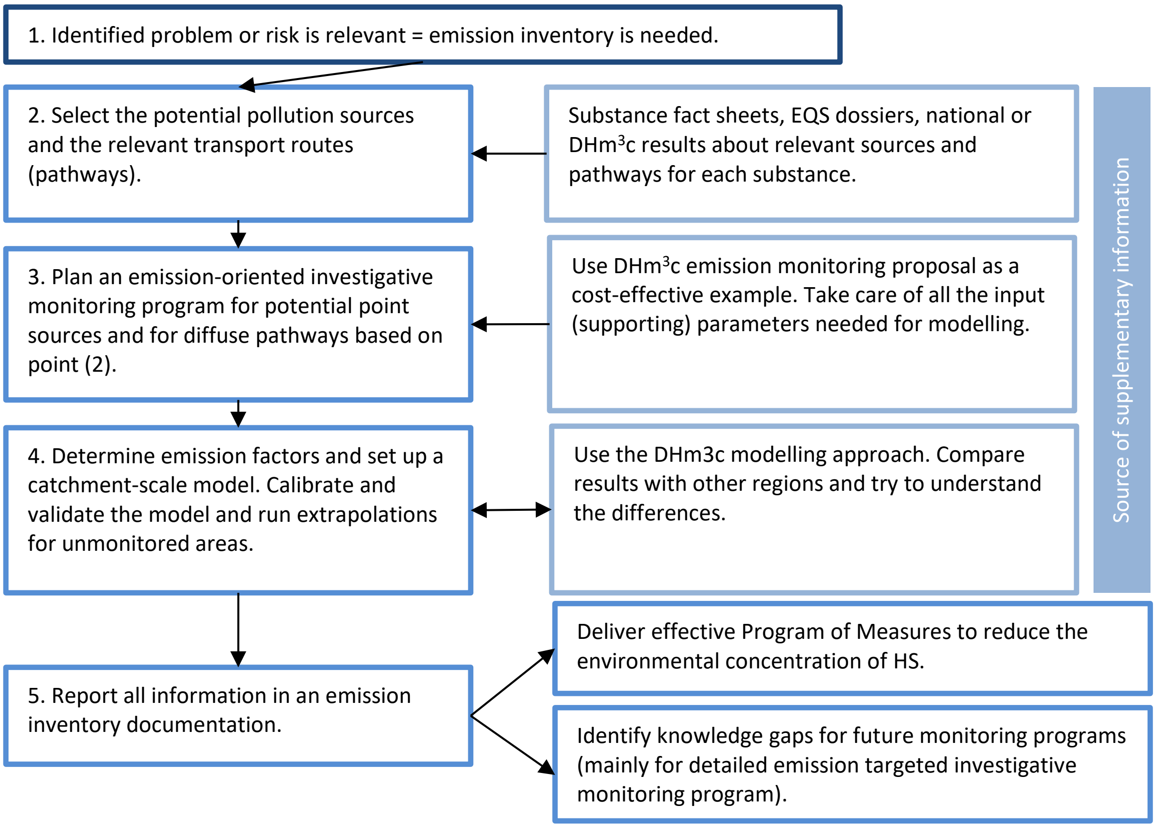

Figure 3: Development of emission inventories

These data would provide a good **empirical basis and system understanding** for the modelling (e.g. data for determining emission factors or validating the model), for identifying the emission sources with acceptable confidence but also for the selection of the most-effective combination of measures. A list of indicator substances for emission inventories has to be carefully selected and established at the basin-wide level based on thorough discussions and consensus. All relevant pollutant groups should be represented in the inventory.

Danube countries are advised to prepare common rules for monitoring and assessing the discharges from **combined sewers**[43] via CSOs. The estimation (i.e. quantification) of pollution contribution of the CSOs would significantly improve the management of HS in urban water management.

Importantly, **free access** to the monitoring and inventory data as well as on registered emitters should be provided. The database should allow public and cross-institutional availability of data and metadata without major administrative and data licensing burden and easy tracking of the presence or frequency of occurrence of all relevant HS. This will facilitate the harmonization of monitoring of the HS, especially for the wastewater discharges of specific industrial sectors.

[42] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/56/72fa696c253bc2f72312970f80fc3dc1eafa5f6f.zip.

[43] Combined sewer systems - that carry wastewater and stormwater in one pipe - become overwhelmed by excess stormwater and overflow into streams.

3.3 Policy tools

Future water management efforts on HS pollution should change the paradigm by shifting the focus from substances to pathways through:

- defining **"priority pathways"** instead of priority pollutants because water management interventions are directed at some critical pathways and have less impact on regulatory frameworks related to chemicals' admission or use;
- defining **"marker substances"** for these priority pathways since too many substances are in use.

Control strategies and Programs of Measures addressing HS pollution should include three different aspects:

- **Regulatory provisions** to prevent or control HS pollution focus on certain technological standards and measures.
- **Economic instruments** used as an alternative to the command-control regulations or in combination with them utilize economic incentives based on the polluter pays principle, the beneficiary pays principle or cost sharing.
- Finally, **soft measures** including education, awareness raising, capacity building and knowledge exchange are also a vital part of the HS management strategies.

The adequate combination of these mechanisms, tailored to the national needs and conditions, can contribute to establishing an enabling regulatory framework and to control and reduce HS pollution in the DRB more effectively.

Regulatory provisions

Danube countries should establish a **dialogue and partnership** among the relevant key sectors (e.g. water management, industry, agriculture) to seek mutually agreed actions to be jointly implemented. Efforts have to be made to strengthen coordination, consistency and complementarity between all relevant sectorial policies and funding schemes to ensure that they work in an integrated way and in good synergy. This includes taking environmental knowledge and planning tools (e.g. RBMPs) into closer consideration to support the design of relevant and effective sectorial policies at national level.

Water management sector should proactively influence the regulatory process of **chemical authorization** and use restriction in order to set obligations to the producers on limiting or banning the use of certain persistent substances and to strengthen the inspection mechanism over the production chain.

Danube countries should carefully examine the currently **revised water legislations** and establish a **proper regulatory framework**. Sufficient institutional capacity needs to be ensured for proper implementation, policy adaptation and compliance control. Strengthening the coordination between the WFD and other relevant water acquis is highly important to achieve an effective management. In particular, the proposal for the revised UWWTD, IED, EQSD and DWD are of great importance since they will bring ambitious new requirements that need to be transposed into the national legislation and implemented afterwards. This will require the careful adaptation of the obligatory technical standards and measures, discharge prohibitions, emission limits, monitoring requirements and reporting obligations. Moreover, it should be supported by national implementation programmes along with a financial plan concerning the necessary investments, prioritization of actions, project time schedules, potential funding sources and the way of funding.

Water management sector should design, implement, monitor and control specific **programs of measures** to reduce HS pollution in all relevant sectors and for all relevant pathways. These measures should be designed in a harmonized and coordinated way in full compliance with all relevant water acquis and in line with the pollution control hierarchy (see Chapter 4). Since the emissions of various substance groups (pharmaceuticals, cosmetics, pesticides, metals, industrial chemicals) are related to different sources and pathways, programs of measures should be tailored at least according to the main substance groups. They should target the most relevant pollution sources and pathways by addressing both point source and diffuse emissions and setting up appropriate combinations of potential measures.

Danube countries should make use of the **CAP post 2021** for controlling pesticides pollution. The introduction of the WFD and the SPD into the conditionality will support their implementation and the achievement of their specific objectives as direct support of farmers has a stronger link to compliance with water legislation than before. Moreover, voluntary measures like eco-schemes and rural development interventions can promote low or no pesticide input practices and agri-environmental measures to help farmers to overcome the challenges related to protecting soil and water quality, safeguarding biodiversity and adapting and mitigating against climate change impacts by supporting environmentally friendly practices, organic farming and sustainable innovations.

It is recommended to harmonize the respective **emission standards** for urban and industrial wastewater discharges. When setting emission limit values for polluting substances, competent authorities should consider all relevant substances that may be emitted. A better harmonization, especially concerning the list of monitored HS and their emission standards used in specific industrial processes would facilitate the implementation of the integrated approach for protection of the surface water bodies in the DRB and the application of the "polluter pays" principle. Besides effluent concentrations, the absolute mass load of the pollutant (e.g. expressed in kg/month or kg/year) needs also to be taken into account when setting industrial emission standards.

Countries may consider implementing regulatory measures to oblige producers and major chemical users to cooperate on conducting **emission targeted monitoring**. Sampling municipal and industrial wastewater effluents (pharmaceuticals, industrial chemicals) or agricultural soils (pesticides) aiming at contributing to an emission inventory, where other compounds need to be analyzed than those listed in permits or standards, would help narrow knowledge gaps on HS pollution.

Economic instruments

Competent authorities should set appropriate **pollution fees** for the major point source dischargers. They should provide evident stimulus for the facility operators to decrease the emission of a specific hazardous substance through wastewater discharge. A more harmonized approach in defining the way of calculating the pollution fees, assessing the specific contribution of each hazardous substance and the corresponding risk to the environment would improve the level of control and would provide equal background for applying the "polluter pays" principle. Pollution fees should be used in combination with emission limit values. While the latter ensures that no major environmental damage can occur by setting a maximum limit for emissions, the fees should encourage polluters to go beyond basic standards and to further reduce pollution.

Penalties should be considered in case of non-compliance with the relevant legislations such as technological deficiencies, exceeding emission limits, failing reporting obligations or incomplete information disclosure on the use of chemicals. The penalties should be proportionate and dissuasive.

Introducing a **charge** via authority taxation on products containing HS may be considered. Although companies may increase product prices in response to the tax, the potential negative publicity and the changing customer preference towards less harmful products may encourage manufacturers to substitute problematic substances with environmentally friendly ones.

In case of urban wastewater discharges, the **extended producer responsibility** approach should be applied, targeting the main polluters responsible for the emissions and shifting economic responsibility towards producers. Producers who contribute to water pollution should also contribute to the costs of the pollution abatement (e.g. quaternary wastewater treatment) based on the quantity and toxicity of HS in their products.

For diffuse HS pollution arising from agriculture and land management, an appropriate **combination of direct payments and voluntary schemes** needs to be developed. While direct payments as income support are to be provided based on compliance with basic standards related inter alia to water management (e.g. soil protection, sustainable use of pesticides), voluntary schemes provide an opportunity to financially compensate and support efforts that go beyond the basic requirements and implement agri-environment-climate measures and integrated rural development. Voluntary measures should be financially attractive, practicable and acceptable for farmers but also effective at reaching the desired environmental objectives.

Providing **economic incentives** for developing and implementing up-to-date technologies and substituting harmful substances could be an effective tool towards sustainable approaches. This could be achieved by tax reductions or investment supports.

Eco-labelling of products that have been produced using environmentally appropriate methods and materials should be widely used to promote safe products and to encourage the public to choose them.

Public authorities are an important purchaser of certain goods. By using the **Green Public Procurement** instrument, they could promote consumption of more sustainable products and incentivise industry sectors to invest in development of environmentally friendly technologies and products.

Authorities should introduce appropriate rules and procedures for **compensating** individuals or the public that are substantially affected by HS pollution. It has to be ensured that they have the right to claim and obtain compensation for the occurred economic, environmental and social damage from those found responsible for the damage.

Soft measures

Awareness raising and public dialogues should be fostered to pave the way towards acceptable solutions and necessary compromises in the spirit of cooperation. Raising public awareness on the negative effects of chemicals on the environment and human health to foster responsible and realistic use of chemicals in the daily life is extremely important towards behavioural change of the public. Moreover, communities should be provided with practical information and technical facilities for safe disposal of harmful substances at the local level.

Water management sector should develop **capacity building** activities at the administration level. This should be related to the use of water quality modelling for river basin management planning at both national and transboundary level, and to the development of consistent monitoring efforts and emission inventories. Additional efforts are needed at the national authorities of all Danube countries to create institutional capacity for further developing the necessary monitoring programs and databases on HS pollution using regional knowhow and for enhancing emission modelling as an operational tool for emission inventorying at national level.

In wastewater management, countries need to ensure that the necessary **technical and institutional capacity** is available at both, national and local level so that the necessary investment projects can be smoothly implemented. At the level of water authorities, the regulation and control over the implementation issues are important aspects that need appropriate knowledge. At utility level, well-developed trainings targeting the operation and maintenance of wastewater infrastructure are crucial to ensure not only a qualified workforce but also efficient and sustainable wastewater treatment, including advanced technologies for removing chemicals. Countries are encouraged to develop national wastewater management training programs and curricula.

In agriculture, **advisory services** and knowledge exchange platforms should be made available for all farmers. Establishing an appropriate advisory system may help farmers to make management decisions, to understand environmental aspects and to adjust the production technologies to the special local conditions of each individual farm. A farmer receiving personal advice is more likely to understand e. g. the conditionality obligations and will thus more readily comply with them. In the same way farmers might be more open to opportunities and possible advantages of (voluntary) agri-environment programmes and thus will more readily participate in them. Advisory services should aim at improving both the farmer's professional skills and economic performance but also at minimizing chemical emissions to the environment and safeguard water quality. Appropriate combination of top-down (consultation with advisors or facilitators) and bottom-up (exchange of practices among farmers and cooperation) systems should be developed and supported.

Research and development to provide solutions for the HS pollution problem should play an important role in the implementation of the WFD. Enhanced and accelerated dissemination of results and knowledge among stakeholders should be facilitated efficiently, making use of all available up-to-date technologies (including internet-based and digital technologies), advanced equipment and modern devices. Best practice examples could be communicated e.g. by demonstration events and practical workshops.

Capacity building should be accompanied and supported by proper **education and curricula**. Professional education should integrate environmental aspects in an appropriate manner. High-level education institutes (universities, colleges) should organise and offer education in the field of integrated water resources management, combining traditional water management and environmental engineering. Monitoring and modelling of HS pollution should receive a strong emphasis in the lecturing program.

Knowledge transfer among decision-making authorities to present and exchange up-to-date knowledge and experiences should be organized on annual basis. Tailored international workshops, training courses and conferences might be a good platform to stimulate knowledge transfers among the Danube countries.

4 Recommendations on sustainable measures

4.1 Guiding principles for measure implementation

Measures should be implemented in accordance with the **pollution control hierarchy**, represented by an inverse pyramid (see **Figure 4**).

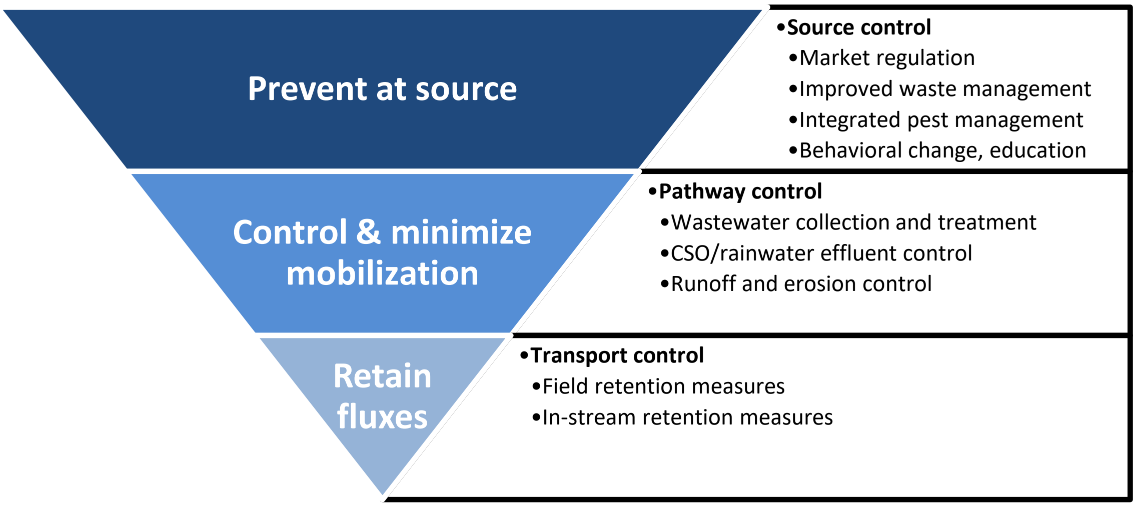

Figure 4: Pollution control hierarchy

Priority should be given to **prevention at the source** to avoid the unnecessary release of harmful chemicals. This can be ensured by **banning or limiting the production** and **market placing** of certain hazardous chemicals but also **improved waste and pest management** can play an important role to reduce the release of these substances. **Legacy pollution** from mining sites, landfills and former firefighting grounds gets more and more attention. In such cases well designed **remediation technics** for soil and groundwater might need to be applied. Moreover, behavioural change of people, **education** and awareness raising in society are also crucial to ensure the reasonable and responsible use of chemicals in daily life.

Since many of the chemicals are widely used and their presence cannot be prevented, **measures controlling the emission pathways and the mobilization of pollutants** are of utmost importance for water management. Appropriate/advanced **treatment** of municipal and industrial wastewater, **best available techniques** at industrial sites, controlling **CSOs and rainwater inlets**, **water retention in urban areas**, **reducing runoff** and **soil loss** from the field by constructional measures and best management practices are the most important interventions.

Finally, the **chemical fluxes can be further retained** by applying retention measures both on the field and in the river. **Buffer zones, green infrastructure measures, wetlands and floodplains** are great examples of these measures, which have other positive impacts on the water status such as water retention, flood mitigation, climate change adaptation and preserving biodiversity. Nevertheless, they should not be considered as primary nature-based treatment facilities replacing source or pathway control measures.

4.2 Toolbox for source, pathway and transport control measures

A catalogue of measures is provided below that categorizes measures and actions according to the mechanism they control. The listed source, pathway and transport control interventions should be appropriately combined for a particular substance or group of substances according to national/regional needs and conditions.

Source control

Use regulation

In view of the continuous introduction of increasing numbers of chemicals, use regulation (control at source) is important. That is why implementation and enforcement of the REACH, the Plant Protection Products Regulation and the Biocidal Products Regulation in EU MS should have high priority. In non-EU MS likewise, chemical use regulation needs to be prioritized. Especially the REACH regulates the use of HS in products and calls for consideration of the whole life cycle of these products. Chemical products should be designed based on a sustainable concept that reduces or eliminates the use of HS over the whole life cycle of the product, as it is stipulated in the “safe and sustainable by design” criteria that is currently being developed at the EU level.

Usage regulation is evidently not sufficient, as substances causing problems in water systems have entered the market also in areas where full implementation of the related Regulations has already been realized. This is to a certain degree unavoidable, for example in the case of pharmaceuticals where positive health effects often outweigh adverse environmental effects. The same situation applies to certain products and technologies, where the use of specific hazardous substance cannot be efficiently avoided under the current technological state of art. Investing in innovative research and development should though aid solving these problems that is supported by the current EU political agenda (e.g. through the Horizon Europe[44] funding).

Improved solid waste management

Many HS are stored in our “technosphere”, as they are used in in textiles, construction materials, “long-living” consumer products, etc. This includes already banned or severely restricted HS, such as PFOS, flame retardants, pesticides/biocides, mercury and cadmium. Careful management of solid waste avoids leakages to surface waters and soils of such HS. Strict bans and controls on illegal dumping are needed. Selective collection of HS by the public (free and easily accessible), such as the collection of paints, solvents, oils, medicines, pesticides used in retail gardens, household cleaners, car tires, electronic waste, etc. can have a strong positive effect. Re-use should have preference over landfilling and incineration when possible.

Measures to reduce the emissions to soils

Present emission levels via soil related pathways are controlled by a build-up of HS concentrations in soils over longer periods caused by various emissions to soils. These emissions stem from atmospheric deposition and from agriculture practices (fertilizer use, distribution of manure), with smaller contributions from domestic wastewater in areas without sewer systems and from the re-use of wastewater and/or sewage sludge. While measures taken to reduce emissions to soils are not expected to have a direct effect, they are nevertheless beneficial on the long run. This concerns the reduction of emissions to atmosphere (e.g. BAT requirement for industries like waste incineration plants and coal-fired power plants), the reduction of metal content of fertilizers and animal fodder, the reduction of the application of contaminated wastewater and/or sludge in agriculture and the construction of sewer systems.

Best management practices for pesticides

Best management practices for pesticides need to be promoted to minimize environmental losses while maintaining the desired pest control in agriculture. This includes pesticide application to the crop and at accurate rate, careful monitoring of the pest build-up to ensure timely control, the use of modern spraying machinery and effective techniques to reduce the risk of spray drift, novel seed treatment to decrease the need for field application of chemicals, filling sprayer tanks on organic biobeds, using low volume sprayer tank cleaners and proper disposal of excess chemicals and tank washings.

[44] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en.

Integrated pest management
IPM is a low-pesticide-input pest management approach. Pesticides application should be avoided as much as possible by crop rotation, adequate cultivation methods and balanced fertilization and irrigation. Application of pesticides should be based on careful pest monitoring which makes use of all available information, tools and methods. The use of pesticides should be kept only to levels that are economically and ecologically justified and which have minimal risk to human health and the environment. Sustainable biological, physical and other non-chemical methods must be preferred against chemical methods if they provide satisfactory pest control.

Organic farming
Organic farming should be introduced and promoted especially in areas important for drinking water supply, as organic farming in many cases has been proved as a powerful and efficient tool to safeguard groundwater quality. Organic farmers do not apply soluble mineral fertilizers and synthetic pesticides.

Integrated rural development
In the so called disadvantaged agricultural areas (land with limited productivity, natural constraints or unfavourable social conditions) integrated rural development approaches should combine all relevant available resources to safeguard sustainable agriculture, aesthetic landscapes, high nature value and biodiversity. Extensive grassland management, low-input agriculture, maintaining traditional agricultural and landscape forms, land use conversion towards semi-natural or natural types, wetland and floodplain reconnection and management are great examples for rural development measures that keep chemical inputs very limited.

Remediation of contaminated sites
Remediation of contaminated sites to prevent the pollution of surface waters either via surface or subsurface pathways is also an essential measure. In case of legacy pollution from former landfills, industrial sites or firefighting grounds, remediation techniques for cleaning up soil and groundwater might be necessary. Especially for PFAS that are subject of these types of pollution, efficient measures are still under development.

Avoidance of use of tar containing materials
PAH emissions can be reduced by avoiding the use of tar-based products for example in road surfaces and on ships' hulls.

Pathway control

Construction of sewer systems
Construction of wastewater collection systems in areas where they are not yet available is an ongoing activity in the DRB. Due to the construction of wastewater collection systems, a larger share of the generated wastewater reaches receiving surface waters, with certain treatment. Therefore, this development tends to increase emissions to surface waters of HS present in domestic wastewater and wastewater from smaller commercial areas. In addition, stricter control of (illegal) stormwater and wastewater discharges to sewer systems can help reducing HS pollution.

Decoupling of stormwater collection systems
The decoupling of stormwater collection systems from wastewater collection systems may have different and opposite effect on HS emissions. On one hand, the decoupling reduces CSOs and reduces the loading to UWWTPs, which will result in lower emissions of HS present in wastewater. On the other hand, the decoupling also reduces the stormwater volume that passes UWWTPs and therefore increases the emissions to surface waters of HS present in stormwater

Construction of conventional UWWTPs
The emissions of HS present in domestic wastewater can be abated by the ongoing implementation of conventional treatment (biological treatment, nutrient removal). Though not all HS are effectively removed in conventional UWWTPs, even a limited removal will directly benefit surface water systems.

Advanced wastewater treatment
Advanced fourth/quaternary level treatment, that can more effectively remove for example pharmaceuticals and compounds in cosmetics, is now under consideration in many countries and in some countries (Switzerland, Germany) already under implementation. They target at hardly or not biodegradable substances by advanced oxidation, adsorption or filtration steps. Advanced level treatment has been included in the proposed revision of the UWWTD. An important aspect is the operationalization of the polluter pays principle to cover the associated investments and operational costs. It is worth noting that after fourth level treatment there are several possibilities for the utilization of treated water (e.g. irrigation, replenishment of water in sensitive or protected waters), which is now not possible in many cases, mainly because of the chemicals.

As some HS partly end up in sewage sludge, the careful management of the sludge is important. Using sewage sludge with HS content in agriculture may increase health and environmental risk therefore the importance of source control for sludge management is extremely high.

Constructing small scale wastewater treatment facilities
Individual houses or small urban communities at whose scale construction of centralised conventional sewage collection and treatment systems is financially and/or technically disadvantageous should be equipped with appropriate small treatment facilities that are more cost-efficient and affordable. Adequate individual facilities (watertight storage tanks, septic tanks with infiltration fields, small domestic treatment plants and units) provide sufficient collection and treatment performance that allows discharging treated wastewater into small recipient water bodies or the soil.

Control of industrial discharges
The control of industrial discharges can be an important measure to reduce HS emissions. Such discharges enter often directly to surface waters, and an investment to avoid them or reduce them has a high environmental benefit. Emissions must be kept to a minimum during industrial production processes by BAT-compliant operation of facilities.

Increased storage in combined sewers
Measures to reduce CSOs, for example by providing more storage or improved management of available storage, are beneficial. Such measures reduce the volumes of wastewater being discharged to surface waters without full treatment. It is possible that climate change will cause increasing CSO volumes as a result of more and heavier rainstorms.

Retention and filtration of CSOs and stormwater collection systems
Measures to enhance HS retention at CSOs and stormwater collection systems will reduce these emissions in case substances can be removed by sedimentation with particles or by filtration. Such measures could be storage and retention basins, filtration ponds, etc. Contaminated sludge from such systems should be adequately managed.

Green Cities and Sponge Cities
Measures to improve water retention and to combat the urban heat island effect in response to climate change also have an effect on HS emissions. Such measures provide storage and infiltration capacity, will reduce the collected stormwater volumes and therefore also reduce HS emissions via stormwater.

Erosion control
Eroded soil particles can carry adsorbed pesticides, heavy metals and other micro pollutants that can enter water bodies with sediment transport on the field. Soil management & erosion control practices such as conservation tillage, contouring, contour strip-cropping, terracing, crop cover, crop restriction on sensitive fields, crop residue mulching are important measures to reduce soil loss from the fields. They provide protection for soils against the erosivity of rainfall and runoff and also reduce the soils surface's erodibility. Moreover, they help maintaining soil structure and infiltration rate. Establishing grass cover on bare soil (e.g. between plantation rows) surfaces and avoiding over-grazing of pastures should be considered to maintain soil protection.

Runoff control
Green and high diversity natural landscape elements that reduce evaporation losses from soils and increase infiltration into soils (vegetation barriers and field borders from trees and/or bushes, grass cover on bare soil

surfaces) offer favourable interventions to improve water-holding capacity of the soil, to preserve local water balance and available soil moisture and to reduce surface runoff.

Transport control

Buffer zones

Buffer strips with natural perennial vegetation (trees, bushes and/or grass) and without fertilizing and pesticides application should be introduced along water courses and/or on the edge of agricultural fields to act as a filtering barrier especially against HS emissions via soil erosion and surface runoff. They can trap eroded soil particles or adsorb dissolved pesticides as runoff passes through the buffer strip. They can also effectively prevent direct inputs via sprayers. Buffer strips may provide other ecosystem services like acting as habitats or increase the aesthetic value of landscapes.

Measures to reduce connectivity between the soil systems and rivers

For some HS, soil related pathways like erosion of topsoil, drainage flows and groundwater flows are responsible for a large share of the emissions to surface waters. Measures to reduce transport between the adjacent soil systems and rivers can be expected to directly reduce such emissions. Grassed depressions, vegetated waterways, inundation/sedimentation ponds, storm water reservoirs, constructed wetlands as well as reconnected wetlands and floodplains represent transport controlling and water storing measures that capture and retain runoff and sediment transport. In this way, they can temporarily store excess water of wet periods for periods with lack of precipitation to compensate water deficit in response to climate change, retain sediment and pesticides before entering water bodies and reduce downstream soil erosion and pesticides washout.

4.3 Estimated effect of measures

A qualitative assessment is provided in **Table 1** on the potential effect developments and measures on HS emissions to surface water.

Table 1: Effects of measures on HS emissions

Development or measure	Pharma-ceuticals	Industrial chemicals	Pesticides	Metals	PAHs
Use regulation	+	++	++	+	+
Improved solid waste management	+	+	+	+	+
Reduction of emissions to soil	(+)	(+)	(+)	(+)	(+)
Best management practices for pesticides	o	o	++	o	o
Integrated pest management	o	o	++	o	o
Organic farming	o	o	++	+	o
Integrated rural development	o	o	++	++	+
Remediation of contaminated sites	o	++	+	+	+
Avoidance of use of tar-based products	o	o	o	o	+
Construction of sewer systems	--	--	-	--	-
Decoupling of stormwater collection systems	+	+/-	+/-	+/-	+/-
Construction of conventional UWWTPs	+	+	+	++	+
Advanced wastewater treatment	++	++	+	+	+
Small scale treatment facilities	+	+	+	+	+
Control of industrial discharges	o	+	o	++	o
Increased storage in combined sewers	+	+	+	+	+
Retention of CSOs and stormwater systems	+	+	+	+	+
Green Cities and Sponge Cities	o	+	+	+	+
Erosion control	+o	o	+	++	++
Runoff control	+o	o	+	++	++
Buffer zones	+o	o	+	++	++
Reduced connectivity between soil and rivers	+o	o	+	++	++

++ probably significant positive effect (decreasing emissions), + positive effect with small or unknown significance (decreasing emissions), -- probably significant negative effect (increasing emissions), - negative effect with small or unknown significance (increasing emissions), +/- positive or negative effect, o not relevant, or no effect expected, () indicates a time delay between measure and expected effect.

5 Follow-up activities

5.1 Follow-up regional workshops and capacity building events

Due to the changing policy context, the organizations responsible for water quality management in the DRB are facing a huge challenge and have multiple concrete needs. This also concerns candidate non-EU states due to the ongoing or planned processes of transposition of EU legislation, and due to their commitments as ICPDR contracting parties. National laboratories need support to strongly improve and harmonize the procedures and methods for the chemical analysis of new priority substances and to achieve extremely low limits of quantification and detection due to the new strict standards in surface and ground water. They require additional equipment, know-how and capacity building for cost-efficient monitoring.

Furthermore, Danube countries require adequate tools and increased know-how for efficient data management, processing and analysis and for emission modelling to implement the newly required risk assessment approaches, to quantitatively assess the trade-offs between multiple targets and to evaluate complex scenarios to account for several external factors, including climate change, energy crisis, inflation and raw materials scarcity.

Danube countries are advised to organize national and/or regional capacity building events on enhanced monitoring and modelling tools. National organizations urgently need such tools for policy decision and implementation in their territories. The institutional capacity to bring these tools to a fully operative level in most Danube countries is still to be strengthened and key organizations need support to implement all the necessary steps and to adapt them to their specific territorial needs. This would simultaneously support them in the generally much needed process of digitization.

5.2 Follow-up regional project

The new complex policy changes and external pressures require a new transnational action plan for future control of HS in the DRB. The DHm^{3}c project has developed the first HS inventory database for the DRB, a pathway-oriented HS emission model for selected pilot regions and a transnational source-oriented HS emission model. Conceived prior to the changes in policy and the recent crises, the transnational database and model, despite being very valuable tools, need to be adapted to meet the present and future needs of the ICPDR for assessment and policy development in the DRB. The new complex dimension of problems and targets requires a fundamental revision and thorough extension of both tools. These enhanced tools would offer a great opportunity to update the chemical pressure assessment in the DRB and to support transnational measure implementation. Moreover, a comprehensive evaluation of the implications of the new targets and challenges for each national territory and for the DRB as a whole is needed to prioritize and coordinate actions and measures by considering different national initial conditions, resources and possibilities. The action plan could also serve as basis for the development of the future DRBMPs by providing substantial contribution to the Joint Program of Measures to be implemented by the Danube countries.

Since January 2024, Danube countries have been implementing a follow-up transboundary project that will deliver the above-mentioned action plan along with the updated technical tools and their assessment results. The project proposal called Tethys[45] builds upon the DHm^{3}c Project. Tethys aims to tackle hazardous substances water pollution through a holistic set of activities that will develop, test and provide national organizations and the ICPDR with fit-for-purpose, target-oriented and cost-efficient procedures, workflows and tools. The developed solutions will be harmonized at DRB scale and will be adjusted to the national specificities of the Danube countries. The planned approach will cover all required steps from monitoring and chemical analysis, through data management and processing to emission modelling and risk assessment. By the end of the project, DRB countries will have fit-for-purpose strategies to prioritize resources allocated to monitoring and to select the most appropriate techniques and procedures to generate a solid data basis for HS emissions inventories, including specific pathways underrepresented so far.

[45] https://interreg-danube.eu/projects/tethys.