WATER MANAGEMENT IN POLAND AND UKRAINE IN CONDITIONS OF DEVELOPMENT AND CLIMATE CHANGE

MONOGRAPH

Edited by

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Foreword

This publication is the result of the international cooperation of the **Department of Geoengineering and Water Management** of Cracow University of Technology (CUT) in Poland with the **Institute of Water Management and Environmental Engineering** of the National University of Water and Environmental Engineering (NUWEE) in Rivne (Ukraine). The cooperation of both research units dates back to 2016. It was initiated by the Marshal of the Małopolskie Province, who organised a study trip of the Polish group to Ukraine, combined with a joint conference of the Ivano-Frankivsk Oblast and the Małopolska Province for the exchange of experiences in the field of:

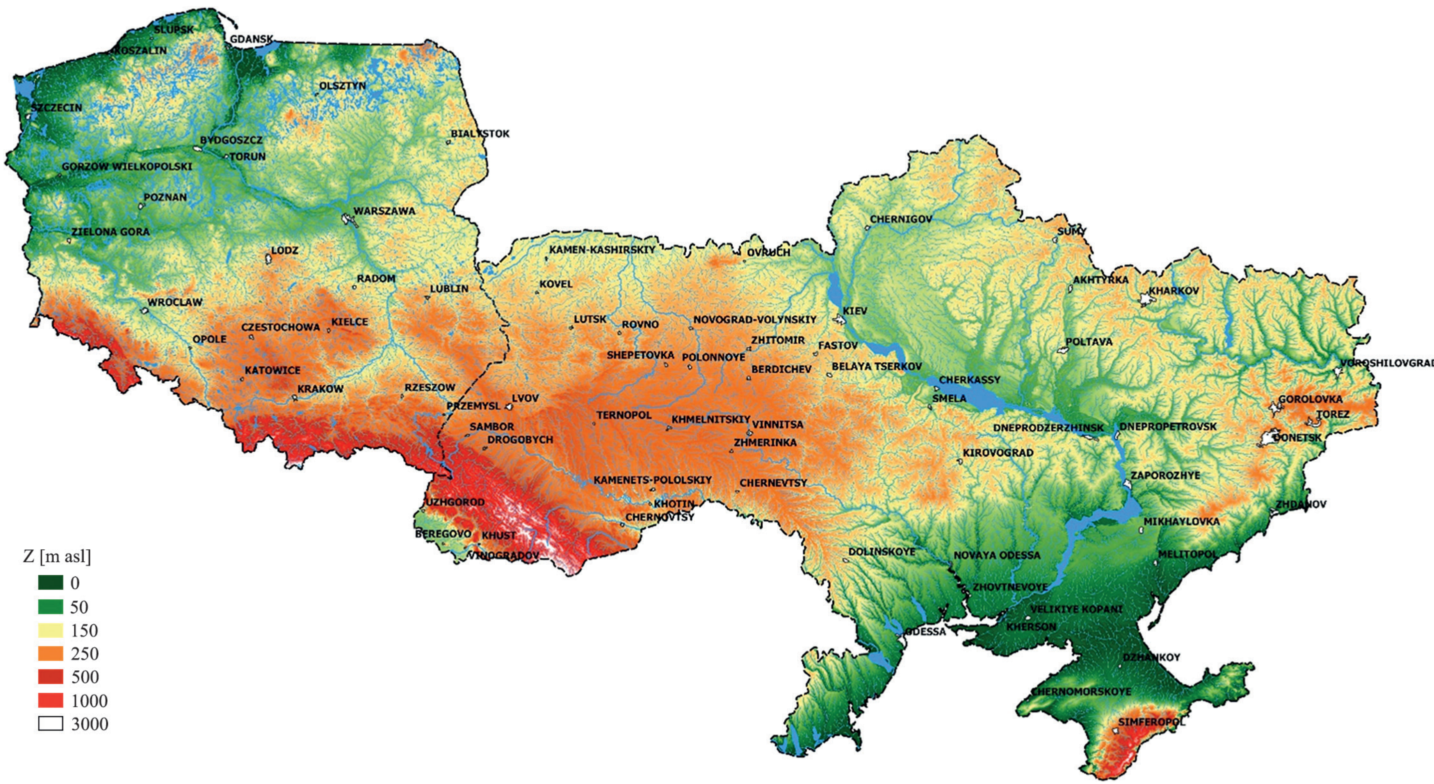
- flood protection and the development of flood protection infrastructure,
- management of waters belonging to regional governments in the Carpathian region and its outskirts in the Dnieper basin.

This event, the aim of which was to analyse the approach to water management, in the context of European requirements, resulted in direct contacts between both of our universities. More importantly, it has directed the discussion on the scope and organisational and legal form of scientific cooperation between both units.

The complementarity of the scientific and research bases of our units as well as similar research problems in the field of engineering and water management, located in different but geographically and hydrologically similar regions, led to the establishment of the substantive scope of this cooperation. This is related to the tasks of water engineering and management for the benefit of socio-economic development aimed at the modern and sustainable development of urban and rural centres. We are connected by the Western Carpathians and divided by sea basins. Our countries differ in terms of size and economic structure. Ukraine occupies nearly twice the area, and over 60% of this area is covered by chernozem and chestnut soils, which account for nearly 40% of the world's resources of these fertile soils. Ukraine is the breadbasket of Europe and many Asian countries, while the Polish economy is much more diverse.

The aim of the cooperation is the implementation of technological standards in the field of planning, design, implementation and maintenance of water and water facilities. Such standards meet the requirements of modern water policy under conditions of development and climate change.

In the last three years, the project entitled **E-mobility, Sustainable Materials and Technologies** (PPI / APM / 2018/1/00027 / U / 001) has become the formal basis for this cooperation. It has provided an opportunity for the research teams



The elevation map of the region covered by the analysis – the territories of Poland and Ukraine (own study) of both our units to cooperate. One of the main results of this cooperation is this two-part monograph on water management in both countries.

The water resources of each country are a strategic, vital, and natural resource that is of particular importance. They are a national treasure of each country, the basis of sustainable economic development. They provide all aspects of life and human economic activity, determine the possibilities of industry and agriculture development, sustainable developments of settlements, organisation of recreation, and health improvement of people.

From the entire surface of the planet, which covers an area of 510 million km^2, the world's oceans take up an area of about 70.8%. More than 98% of the world's water resources are mineralised waters that are poorly adapted for economic use. Only 0.3% of the total hydrosphere volume is available for commercial use (4.2 million km^2). The biggest part of the planet's population suffers from problems connected with water. Such as water scarcity, droughts, floods or low levels of water quality.

The water management systems of our countries – Poland and Ukraine, differ significantly, both in terms of the size and structure of water resources and also in terms of the administration and management system of water resources. Ukraine, aspiring to membership in the European Union, is trying to introduce certain requirements related to the protection of water resources in advance, preparing the basis for the implementation of the requirements of the Water Framework Directive and other related provisions. However, it is a long process and the direct correspondence of problematic issues remains at a certain level of generality.

The above conditions translated into the way of presenting and interpreting the issues and problems of water management in our countries in this publication. While maintaining the separateness of the Polish and Ukrainian parts of the monograph, one can compare the basic issues presented in Chapters 1, 2 and 3 of each part of the monograph. But even here, in Chapter 3 of the Polish part, the effects of climate change have been integrated with development, and especially with urbanisation, which is important for our country, while the Ukrainian part mainly deals with the effects of climate change.

Chapter 4 in each part of the monograph, devoted to selected problems of water management, was treated individually. In the Ukrainian part of the monograph, these problems were related to national conflict issues and problems. In the Polish part of the monograph, the focus is on regional issues in the upper Vistula basin.

Authors

LIST OF ABBREVIATION

EEA	European Environmental Agency
EEC	European Economic Community
EU	European Union
FHM	flood hazard maps
FRM	flood risk maps
FRMP	flood risk management plan
GWP	Global Water Partnership
GZWP	Major Groundwater Reservoirs (*Polish abbreviation*)
HELCOM	Baltic Marine Environment Protection Commission – Helsinki Commission
IMWM-NRI	Institute of Meteorology and Water Management – National Research Institute
IPCC	Intergovernmental Panel on Climate Change
IWRM	integrated water resources management
JRC	Joint Research Center
MaxPP	max water level (*Polish acronym*)
MGR	major groundwater reservoirs
MinPP	min drawdown level (*Polish acronym*)
MPC	maximum permissible concentration
NGOs	Non-Government Organisations
NHMS	National Hydrological and Meteorological Survey
NPP	full reservoir level (*Polish abbreviation*)
PFRA	preliminary flood risk assessment
PGI-NRI	Polish Geological Institute-the National Research Institute
PHS	Polish Hydrogeological Survey
POR	predicted operational resources
PPNW	Program for counteracting water shortages (*Polish abbreviation*)
RBMP	river basin management plan
RCP	Representative Concentration Pathways
RIVPACS	River Invertebrate Prediction and Classification System
RPBs	Rapid Bioassessment Protocols
RWMA	Regional Water Management Authority (*Polish abbreviation RZGW*)
SCW	artificial water bodies (*Polish abbreviation*)
SNQ	average annual minimum flow (*Polish abbreviation*)
SNq	average annual minimum flow per unit area (*Polish abbreviation*)

SSQ	average annual mean flow (*Polish abbreviation*)
SSq	average annual mean flow per unit area (*Polish abbreviation*)
SWH-PW	State Water Holding – Polish Waters
SZCW	heavily modified water bodies (*Polish abbreviation*)
UAP	Urban Adaptation Plan
V_c	total storage capacity
V_n	dead storage capacity
V_p	flood storage capacity
V_u	active (live) storage capacity
WFD	Water Framework Directive, Directive 2000/60/EC
WTO	World Trade Organisation

WATER MANAGEMENT IN POLAND IN CONDITIONS OF DEVELOPMENT AND CLIMATE CHANGE

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1. Water resources

The characterisation of water resources contained here includes surface water and groundwater to the extent necessary for water management tasks. Nevertheless, the description presents important features of water resources and their temporal and spatial variability.

Taking into account the water resources assessment criteria resulting from the transposition of the Polish legislation to the EU requirements, the text includes the traditional and formal detailed naming of resources according to their types. This applies primarily to the delineation of water bodies in accordance with the requirements of the Water Framework Directive [Official Journal of EU 2000], which are divided into:

- Inland surface waters and their catchments into surface water bodies, in which planning systems 2016–2021 [Journal of Laws 2016] and 2022–2027 [SWH-PW 2021] distinguished:
  - rivers,
  - reservoirs,
  - lakes,
  - coastal and transitional areas.
- Groundwater (including groundwater reservoirs) into groundwater bodies.
- Moreover, according to the qualification of anthropogenic intervention in relation to surface waters, a distinction is made according to the European nomenclature:
- natural bodies of water not subject to anthropogenic pressure which alter their hydrological regime and morpho-dynamic and/or physico-chemical status and, as a consequence, their biological status;
- heavily modified surface water bodies whose character has been significantly changed by physical human activity;
- artificial surface water bodies, mainly artificial water storage reservoirs, which are the result of human activity and, functioning under a different flow regime from their natural counterparts, achieve different physical, chemical and biological characteristics.

These classifications were assigned a corresponding typology of quantitative and qualitative status assessment. The quality status of surface waters, in addition to the physico-chemical assessment, is based on morphological and biological classification.

1.1. Rivers and lakes

Poland's political boundaries largely coincide with its hydrographic boundaries. Only 13% of our surface water resources are formed outside the national territory and only a few per cent runoff to neighbouring countries. Therefore, by determining the runoff, surface water resources can be determined. The average annual runoff of surface water from the territory of Poland including inflows from abroad in the period 2000–2017 was 58.5 km^3. However, in dry seasons, the level can fall to even below 40 km^3. The annual water resource per inhabitant is 1.6 thousand m^3, while in most European countries, this value is over 5 thousand m^3.

Poland is classified as a country with relatively low water resources, which is caused both by climatic factors (low precipitation) and hydrological conditions – part of the groundwater drains directly to the sea. This runoff from Quaternary formations alone is believed to be 24.8 m^3/s, which corresponds to the average flow of the upper Vistula above the mouth of the Przemsza River. Deficit areas include Wielkopolskie Lake District, especially Kujawy, part of the Mazowiecka Lowland and Podlaska Lowland and the uplands of Śląska and Kielecka. The Carpathians, the Sudetes and the northern part of the lake district belt are surplus areas. Surface water resources in Poland are characterised by high temporal and territorial variability, which requires the retention of a part of the surplus resources, especially in the south of the country.

Poland, a country with an area of 312 700 km^2, is located in the catchment areas of three seas: the Baltic Sea (99.7% of the country's area), the North Sea (0.1% of the country's area) and the Black Sea (0.2% of the country's area) [Statistics Poland 2020a]. The Polish part of the Baltic Sea catchment area consists of two basins of the largest rivers, Vistula and Odra, as well as five basins of smaller rivers, Ücker, Banówka, Świeża, Pregoła and Neman, and catchment areas of rivers flowing directly to the Baltic Sea.

The North Sea catchment area includes the Polish part of the Elbe basin (238 km^2), while the Black Sea catchment area includes the Polish fragments of the Danube basin (385 km^2) and the Dniester basin (233 km^2) [Statistics Poland 2020a].

Figure 1.1 presents the spatial location of the river basins.

In 2004, as part of the implementation of the WFD, the typology of Polish rivers also distinguished coastal and transitional waters in the area of the sea coast. This division is based on the level of salinity of these waters in the marine catchment area. It is worth noting that Poland's transitional waters include the two larger bays of the Baltic Sea: Gdańsk (with the Puck Bay and the Vistula Lagoon) – the mouth area of the Vistula, and Pomeranian (with the Szczecin Lagoon) – the mouth area of the Odra.

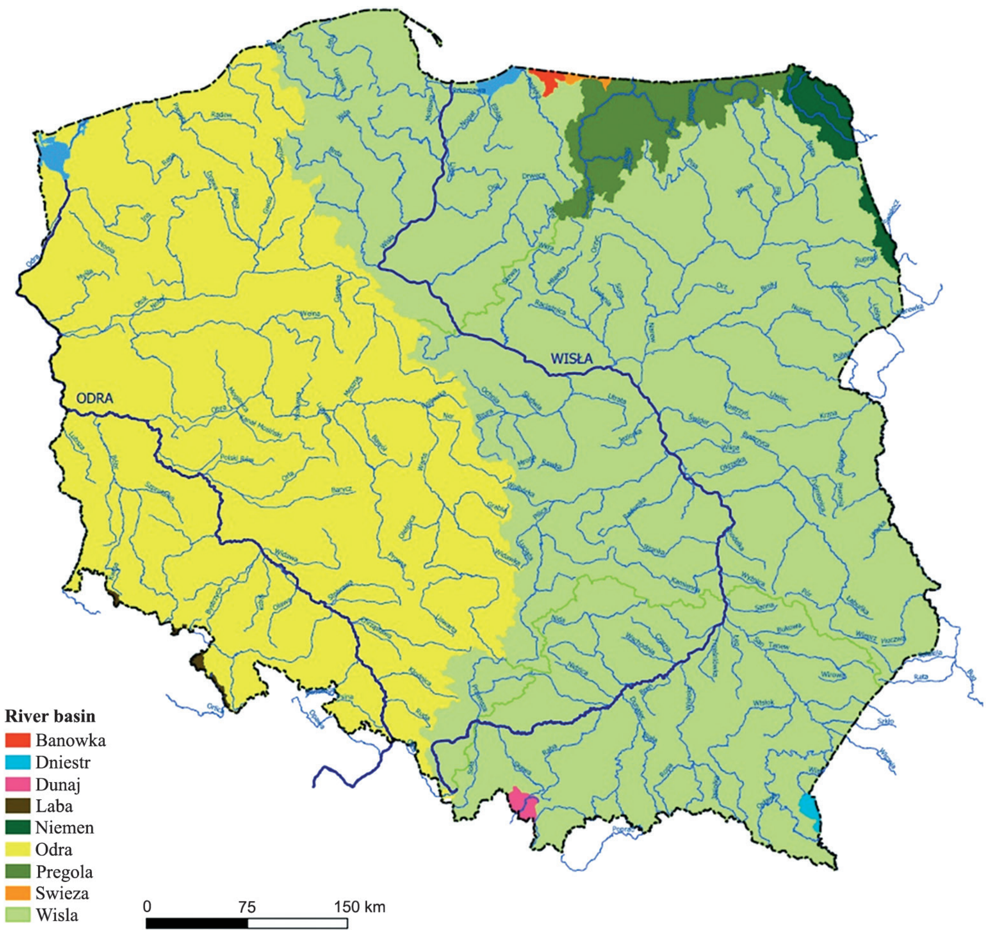


Fig. 1.1. River basin districts in Poland (own study based on www.kzgw.gov.pl)

Taking into account the current, correct typology of Polish rivers with the distinction of transitional and coastal waters, the corresponding division of Polish river basins into sea catchments and their numerical characteristics are provided in Table 1.1 and the data of larger Polish rivers and their basins are given in Table 1.2. However, in characterising and parameterising the physical characteristics of rivers and their river basins in Chapter 1.1.1, comprehensive reference was made to only the main rivers (Odra and Vistula) and their basins.

Table 1.1

Catchment areas and river basins including transitional and coastal waters

Catchment areas and river basins	Area in Poland in thousand km^2	Percentage share (%) of this area in the national area
Baltic Sea catchment area	**311.9**	**99.7**
Odra River Basin	106.1	33.9
The catchment area of the Szczecin Lagoon	2.5	0.8
Direct catchment area of the Baltic Sea	17.3	5.5
Vistula River Basin	168.7	54.0
Vistula Lagoon catchment area	14.8	4.7
Neman River Basin	2.5	0.8
North Sea catchment area	**0.2**	**0.1**
Elbe River Basin	0.2	0.1
The Black Sea catchment area	**0.6**	**0.2**
Danube River Basin	0.4	0.1
Dniester River Basin	0.2	0.1

Table 1.2

Larger rivers in Poland and their basins

River	Receiving water	Area of the river basin in Poland in km^2	Length of the river on Polish territory in km	Average runoff in m^3/s
Vistula	The Baltic Sea	183 176	1047	1080.0
Odra	The Baltic Sea	118 015	742	567.0
Warta	Odra	54 529	808	216.0
Bug	Narew	19 284	587	155.0
Narew	Vistula	53 873	448	313.0
San	Vistula	14 390	443	129.0
Noteć	Warta	17 330	388	76.6
Pilica	Vistula	9273	319	47.4
Wieprz	Vistula	10 415	303	36.4
Bóbr	Odra	5830	270	44.8
Łyna	Pregota	5719	190	34.7
Nysa Łużycka	Odra	2197	198	31.0

1.1.1. Rivers and their basins

On the basis that the Odra and Vistula river basins dominate in Poland (99.7% of the country's area), they are the main focus of attention.

Vistula River Basin

The area of the Vistula river basin is 193 911.1 km^2, of which 183 176 km^2 is within the boundaries of Poland and constitutes 58.5% of the country's area.

The Vistula river is entirely within the Polish territory and its sources are located on the western slope of Barania Góra in Beskid Śląski, at an altitude of over a thousand meters above sea level. The Vistula flows into the Gdańsk Bay. The river basin area is located in the south-east, east and north-east of the country.

The Vistula river basin is divided into four water regions:

1) the Little Vistula water region, comprising the catchment area of the Vistula river from its sources to the mouth of the Przemsza river;
2) the Upper Vistula water region, comprising the catchment area of the Vistula river from the mouth of the Przemsza to the mouth of the Sanna;
3) the Middle Vistula water region, comprising the catchment area of the Vistula river from the mouth of the Sanna to Korabniki;
4) the Lower Vistula water region, which includes the catchment area of the Vistula river from Korabniki to the mouth to the sea and the basins of the Przymorze rivers [SWH-PW 2021].

Table 1.3 shows the land use distribution across the Vistula basin. The land use structure is dominated by agricultural land, which accounts for about 66% of the total basin area. Forests and semi-natural ecosystems cover about 29% of the area, while anthropogenic and aquatic areas cover about 3% and 1.5% of the basin area, respectively.

Table 1.3

Land use in the Vistula river basin

Water region	Area of the river basin [km^2]	Land use [%]:			
		Agriculture	Forests and semi-natural ecosystems	Anthropogenic areas	Water areas of
the Little Vistula	3942.5	51.3	31.9	12.8	4
the Upper Vistula	43 109.3	60	35	5	0.9
the Middle Vistula	101 053.9	70	25	3	1
the Lower Vistula	35 070.1	61.1	32.3	2.7	4
Vistula River Basin	183 175.8	66	29	3	1.5

It can be observed that the use of the Vistula river basin area is distributed very similarly, but deviations are also visible.

The Little Vistula region is distinguished by the highest degree of industrialisation. This is related to the Upper Silesian Industrial Region, within which the region is located. Urbanised areas account for over 12% of the area.

The Middle Vistula region, on the other hand, is characterised by better conditions for agricultural production, which can be observed in the degree of utilisation of this area.

The Little Vistula region includes the catchment areas of the Little Vistula and Przemsza rivers. The Little Vistula catchment area is comprised of mountainous and foothill areas, while the Przemsza catchment area largely covers urbanised and industrialised areas.

The most important tributaries of the Vistula River in the Little Vistula water region are: Iłowinica, Biała, Pszczynka, Gostynia and Przemsza (second order watercourses). The total length of the hydrographic network of the Little Vistula catchment area is approximately 2130 km. The largest dam reservoirs in the region are Goczałkowice, Wisła Czarne, Kozłowa Góra, Łąka, Dziećkowice (the reservoir works only on the basis of water transfer from the Soła river). Underground recharge is predominant in most of the water region [SWH-PW 2021].

The Upper Vistula water region covers an area of 43 109.3 km^2 and includes the Vistula catchment area from below the mouth of the Przemsza river to the mouth of the Sanna river, including the Sanna catchment area.

In the last planning cycle, an additional division of the Upper Vistula Region into **the Upper-Western Vistula Region and the Upper-Eastern Vistula Region** was introduced. The Upper West Vistula water region covers an area of approximately 22 438 km^2. It includes the catchment area of the Vistula river from the cross section below the mouth of the Przemsza river to the mouth of the Sanna river without the catchment area of the Sanna river and without the catchment areas of the right-bank tributaries: Wisłoka with Brno, Trześniówka, Łęg and San. The Upper West Vistula water region covers an area of approximately 20 664 km^2. It includes the catchment areas of the following tributaries of the Vistula: the Wisłoka with the Breń, the Babulówka, the Trześniówka, the Łęg, the San and the Sanna. The region's major rivers include the Wisłok, San, Wisłoka, Tanew and Łęg.

The largest right-bank tributaries of the Vistula in this area are the San and the Dunajec (second order watercourses), the catchments of which comprise almost half of the area of the Upper Vistula water region. Other major right-bank tributaries are the Wisłoka, Raba, Soła and Skawa (second order watercourses). Among the largest left-bank tributaries of the Vistula river in the Upper Vistula region are the Nida and the Czarna rivers (second order watercourses). The total length of the region's hydrographic network is 23 800 km.

The largest dam reservoirs in the region are Chańcza, Tresna, Dobczyce, Czaniec, Świnna Poręba, Czorsztyn-Sromowce, Solina-Myczkowce, Rożnów--Czchów and Klimkówka.

An important element in the region is the Upper Vistula Cascade, which consists of six damming stages: Dwory, Smolice, Łączany, Kościuszko, Dąbie and Przewóz. The stages allow navigation on the section from the mouth of the Przemsza river to the Przewóz water stage. Most of the water region is dominated by surface recharge. In the area of the Carpathians, the share of surface feeding accounts for more than 65% of the total runoff; towards the north, the predominance of surface feeding is decreasing. In a small area, in the north-western and north-eastern part of the water region, there is a predominance of underground recharge [SWH-PW 2021].

The Middle Vistula water region includes the catchment area of the Vistula river from the mouth of the Sanna river to Korabniki. The largest right-bank tributaries of the Vistula river in this region are: Wieprz, Świder, Narew, Skrwa. The largest left--bank tributaries are: Kamienna, Iłżanka, Radomka, Pilica and Bzura (second order watercourses). The total length of the hydrographic network of the Middle Vistula water region is approximately 40 700 km. The largest dam reservoirs in the region are: Dębe Reservoir on the Narew river, Włocławek Reservoir on the Vistula river, Sulejów Reservoir on the Pilica river, Siemianówka Reservoir on the Narew river, Wióry Reservoir on the Świślina river, Nielisz Reservoir on the Wieprz river and Domaniów Reservoir on the Radomka river. Natural lakes with an area greater than 3 km^2 in the Middle Vistula region are: Śniardwy, Mamry, Niegocin, Wigry, Roś, Tałty, Nidzkie, Hańcza. In the water region, there are also non-drainage areas, mainly in young glacial areas, including the non-drainage catchment areas of lakes. The northern and southern parts of the water region are dominated by groundwater recharge, while the central part is dominated by surface recharge. The rest of the water region has a balance of surface and groundwater recharge [SWH-PW 2021].

The Lower Vistula Water Region includes the northern part of the Vistula basin below Włocławek to the mouth of the Baltic Sea and the catchment areas of the Przymorze rivers west of the mouth of the Vistula up to and including the Słupia river and east of the mouth of the Vistula up to and including the Pasłęka river. The main hydrographic and hydromorphological axis of the region is the Vistula valley. The Vistula river basin accounts for 70.3% of the total area of the Lower Vistula region. The remaining 29.7% of the area consists of the catchment areas of the Przymorze rivers. The area lies entirely within the catchment area of the Baltic Sea. The main rivers in the water region are the Vistula river with its main tributaries, the Brda, Wda and Drwęca (second order watercourses), the Słupia, Łupawa, Łeba, Reda rivers flowing directly into the sea as well as the Elbląg, Pasłęka, Bauda rivers flowing into the Vistula Lagoon (first order watercourses). The total length of the river network in the water region is 12 847.2 km, and the length of the Vistula river within the region is approximately 260 km. The water region is characterised by a significant number of natural water bodies. According to the Hydrographic Map of Poland, there are 2290 lakes and reservoirs in the region, with a total area of 1087.6 km^2. The largest natural water body in the analysed area is the Vistula Lagoon which is a transitional water body. The reservoir is only partly located within the borders of Poland and has a surface area of 328 km^2. Other large natural water bodies include: Lake Łebsko, Lake Jeziorak, Lake Gardno, Lake Żarnowieckie, Lake Charzykowskie, Lake Narie and Lake Druzno. In the water region, there are also areas without drainage located, above all, in the lake district part of the region. In addition, eleven artificial water reservoirs are located in the region, the largest of which are Koronowo in the Brda catchment, Żur in the Wda catchment and Pierzchały in the Pasłęka catchment [SWH-PW 2021].

Odra River Basin

The **Odra** river basin within the borders of Poland covers an area of 118 015 km, which accounts for 38% of the country's area. It covers south-western, western and north-western areas of Poland. In addition to the Odra river basin, the Odra river basin also includes the basins of the Rega, Parsęta, Wieprza and other rivers flowing into the Szczecin Lagoon and the Baltic Sea west of the Słupia mouth.

The total length of the Odra is 855 km, of which 742 km are within the Polish borders. The sources of the river are located on the territory of the Czech Republic in the Odra Mountains, in the south-eastern part of the middle Sudetes range, at an altitude of 634 m. The Odra flows into the Szczecin Lagoon. The Odra river basin area is characterised by asymmetry, with a large right-hand side and a small left-hand side.

The Odra changes its character along its course, initially, in the source section it is a mountain river. In its lower reaches it turns into a lowland river. The Odra is a navigable river from Kędzierzyn-Koźle to its mouth at Szczecin. It is a channelised river and there are twenty-four water stages along the 187 km-long section. Below Brzeg Dolny, the Odra is regulated by spurs. The river is connected to the Spree and Havel via a system of channels.

Due to the longitudinal gradient, the upper, middle and lower Odra are distinguished as follows (the average gradient of the Odra is 0.74‰):

1) The upper – from the riverhead to Koźle, the section length is 202 km, for the first 54 km the Odra has the character of a mountain river (gradient of 7.2‰), while in the Polish territory, the gradient is much lower (0.33‰).
2) The middle – from Koźle to the mouth of the Warta river, with gradients from 0.28 to 0.19‰, it has a length of 522 km.

3) The lower – from the mouth of the Warta river to the Szczecin Lagoon, with gradients of 0.05 to 0.001‰.

According to the regulation on river basin areas, the following water regions are distinguished in the Odra river basin region: Upper Odra, Middle Odra, Warta and separately its tributary of the Noteć River[1] (from 2022, the Noteć water region was separated in the Warta water region), Lower Odra and Przymorze Zachodnie.

Table 1.4 shows the distribution of land use across the Odra basin. The land use structure is dominated by agricultural land. The Upper Oder region is distinguished by its degree of anthropogenisation. These are regions located within the Silesian Province (The Upper Silesian Industrial Region, The Carboniferous Region of Rybnik), which are the most anthropogenically changed areas in the country.

Table 1.4

Land use in the Odra river basin

Water region	Area of the river basin [km^2]	Land use [%]:			
		Agriculture	Forests and semi-natural ecosystems	Anthropogenic areas	Water areas of
The Upper Odra	3830	60	23.5	15	1.3
The Middle Odra	39 299	60	25	5	1
Warta, including Noteć water region	54 480	63.5	31.2	3.7	1.5
	17 306	52,1	40,6	2,5	2,0
The Lower Odra and Przymorze Zachodnie	20 406	56	37	2.5	4.5
Odra River Basin	118 015	59.9	29.2	6.6	2.1

The Upper Odra water region includes the upper part of the Odra basin area from the state borders to the mouth of the Gliwice Channel. The most important right-bank tributaries of the Odra in the Upper Odra water region are the Olza, Ruda, Bierawka and Kłodnica, while the most important left-bank tributary is the Psina (second order watercourses). The total length of the hydrographic network of the Upper Odra water region is approximately 2125 km. Artificial water reservoirs are located in the water region, the largest of which are: the Dzierżno reservoir, the Rybnicki reservoir, the Pławniowice reservoir and the Dzierżno Małe reservoir. There is a balance of groundwater and surface recharge over most of the water region. Only in the north-eastern part of the Upper Odra water region does the groundwater supply predominate in the total runoff.

[1] Draft of the second update waters management plan in the Odra basin, Warsaw 2022.

The Middle Odra water region includes the section of the Odra river starting below the mouth of the Kłodnica river up to the mouth of the Nysa Łużycka river. The length of the river section in the Middle Odra water region is just over 430 km. The most important right-bank tributaries of the Odra river in the water region are: the Mała Panew, the Stobrawa, the Widawa, the Barycz and the Krzycki Rów (second order watercourses). The more important left-hand tributaries are: the Osobłoga, the Nysa Kłodzka, the Oława, the Ślęza, the Bystrzyca, the Kaczawa, the Bóbr and the Nysa Łużycka (second order watercourses). The total length of the hydrographic network of the middle Odra catchment area is 22 042 km. In the area of the Middle Odra water region, there are artificial water reservoirs, including: Leśna Reservoir, Bukówka Reservoir, Słup Reservoir, Nysa Reservoir and Kozielno Reservoir. The water region is dominated by areas with a balance of ground and surface recharge (ground 45–55%, and surface 45–55% of the total runoff). In a small area, in the northern part of the water region, there is a weak predominance of groundwater recharge. Within the Sudetes, there is mainly a weak predominance of surface feeding (groundwater 35–45%, surface 55–65% of the total runoff), while in the south-western part of the water region, there is a considerable predominance of surface feeding (groundwater up to 35%, surface more than 65% of the total runoff).

The Warta water region covers an area of 54 479.97 km², which is about half of the entire Odra river basin and gives it an asymmetry that is typical of this area, characterised by a large right-hand side and a small left-hand side. The region covers the catchment area of the river Warta from its riverhead to its confluence with the Odra river near Kostrzyn. The Warta is the longest tributary of the Odra river with a length of 793.5 km. The Warta catchment area borders to the west and south on the Odra river basin, of which it is a part, and to the east on the Vistula river basin. The larger rivers in the Warta water region include: the Noteć (from 2022 as separate water region), the Prosna, the Obra, the Ner and the Wełna (third-order watercourses) and the Drawa and the Gliwa (fourth-order watercourses). The total length of the hydrographic network is almost 17 950 km. In addition to the river network, the network of lakes is well developed, with their main concentrations in the three lake districts: Wielkopolskie, Lubuskie and Zachodniopomorskie. The lake district is also home to a number of drainage-free areas. Two artificial water reservoirs are located in the water region: Jeziorsko Reservoir and Poraj Reservoir.

The Noteć water region, separated from the Warta water region from 2022, covers an area of approximately 17 306 km^2. It covers the catchment area of the Noteć river from its sources to the estuary to the Warta river near Santok. The Noteć is the longest tributary of the Warta with a length of 391 km. The most important watercourses of the Noteć water region are: Noteć, Drawa and Gwda. The water region of the Noteć river is completely within one ecoregion. These are the Central Plains (100% of the region's area).

The Lower Odra and Przymorze Zachodnie water region covers a stretch of the Odra river measuring 219.4 km in length, beginning at the mouth of the Nysa Łużycka and ending at the mouth of the Odra into the Roztoka Odrzanska. The largest tributaries of the Odra in the water region are the rivers: the Pliszka, the Ilanka, the Myśla, the Kurzyca, the Słubia, the Rurzyca, the Tywa, the Płonia, the Ina, the Gunica (second order watercourses). The Lower Odra and Przymorze Zachodnie water region also includes the Baltic Sea catchment area. The most important watercourses of the Przymorze are the rivers: Rega, Parsęta together with Radwa, Czerwona and Wieprza together with its largest tributary Grabowa (first order watercourses). The total length of the hydrographic network of the Odra and Przymorze Zachodnie water region is approximately 7528 km. In addition, there are more than a thousand lakes in the Lower Odra and Przymorze Zachodnie water region, the largest of which are Lake Dąbie, Lake Miedwie, Lake Jamno and Lake Bukowo. As in the Warta water region, there are numerous areas without drainage in the lake district. The Szczecin Lagoon is also located here, a large part of which is within Polish borders (410 km^2, out of a total area of 687 km^2). The most important artificial water reservoirs in the water region are the Rosnowo reservoir, the Hajka reservoir, the Likowo reservoir, the Rejowice reservoir, the Żurawie reservoir and the Połczyn Zdrój reservoir.

1.1.2. Hydrographic network structure

A characteristic feature of the river network in Poland is the pronounced asymmetry of the **Vistula and Odra** river basins. Their right-hand tributaries are longer and better developed. The ratio of the left basin to the right basin of the Vistula is 27:73, and for the Odra it is 30:70. This is due to the general north-westerly slope of the land surface and the development of relief in the Tertiary and Quaternary periods. In southern Poland, the valleys are much older than in the north of the country, where the river network only became established at the end of the last glaciation, during the formation of the Baltic Sea. During the glaciations, due to the blocking of the runoff to the north, the water flowed westwards along the front of the glacier. With its recession, the waters changed direction, moving from latitudinal proglacial valleys towards the north, as evidenced by the characteristic bends in the course of the rivers (the Poznań Gorge of the Warta River).

The density of the river network in Poland is differentiated both spatially and regionally. A very dense network is found in the mountains, for example, in the Carpathians up to 4.0 km/km^2 and in the Sudetes about 1.2 km/km^2, which is conditioned both by a large supply from precipitation and by varied relief and poorly permeable ground. The river network in the Lublin Upland is one of the rarest in Poland – less than 0.5 km/km^2 [Jokiel et al. 2017]. It is similar to other uplands, associated with significant rainwater infiltration, karst phenomena and a deep groundwater table. A rare river network occurs in areas covered by sandy sediments. In the lowlands, dense river networks occur on the impermeable ground.

1.1.3. Lakes

When we write about lakes, we usually refer to natural lakes, although in this context, it is also common to speak of dam lakes, i.e. water storage reservoirs. Water storage reservoirs are the subject of Chapter 1.2, and only natural lakes are discussed here.

In Poland, the number of natural lakes is not constant – it decreases systematically. This is due to the fact that lakes are bodies of water with a very different surface area (calculated from 1 ha) and depth. In 1954, 9296 lakes over 1 ha were identified and catalogued [Majdanowski 1954], and in forty years their number has decreased by as many as 2215, or over 11% [Choiński 2006]. This was caused by the rapid disappearance of the smallest lakes, as a result of their overgrowing and shallowing. Lakes disappear and turn into wetlands (marshes or peat bogs). In Poland, wetlands constitute 8% of the country's area. The largest areas are in the lake districts and in Polesie Lubelskie. Many wetlands are under protection. The most important of these are the Biebrza and Narew National Parks.

Polish lakes differ in their genesis of origin, which allows the following genetic types of lakes to be distinguished [Choiński 2006]:

- **moraine-dammed lakes**, formed in depressions of ground moraine or as a result of the obstruction of outflow by terminal or lateral moraine (Śniardwy, Mamry, Niegocin, Morskie Oko in the Tatra Mountains);
- **ribbon lakes**, occurring in places where meltwater flowing under the ice sheet has carved gutters (Hańcza, Drawsko, Wigry, Gopło, Jeziorak);
- **kettle holes**, so called post-glacial ponds created in hollows after the melting of ice blocks covered with moraine rocks (Głęboczek near Tuchola);
- **tarns**, on the site of former fern fields of mountain glaciers (Tatra and Giant Mountains ponds).

Other types of lakes found in Poland are:

- **coastal or littoral**, created by separating a former sea bay by a spit (Łebsko, Gardno, Jamno, Wicko);
- **delta lakes**, situated in the hollows of river deltas (Dąbie, Drużno);
- **karst lakes**, filling up sinkholes or karst funnels (Łęczyńsko-Włodawskie Lake District);
- **river or oxbow lakes** – traces of a former river bend.

Our country's lake level is relatively low at around 0.9%. There is considerable spatial variation in lake levels. The largest area is characterised by the Masurian Lake

District (4.1%) – especially the Great Masurian Lakes Region – 20%, Pomeranian Lake District (2.0%) and Wielkopolskie Lake District (1.5%). Figure 1.2 shows the spatial variation of lake percentage across the country.

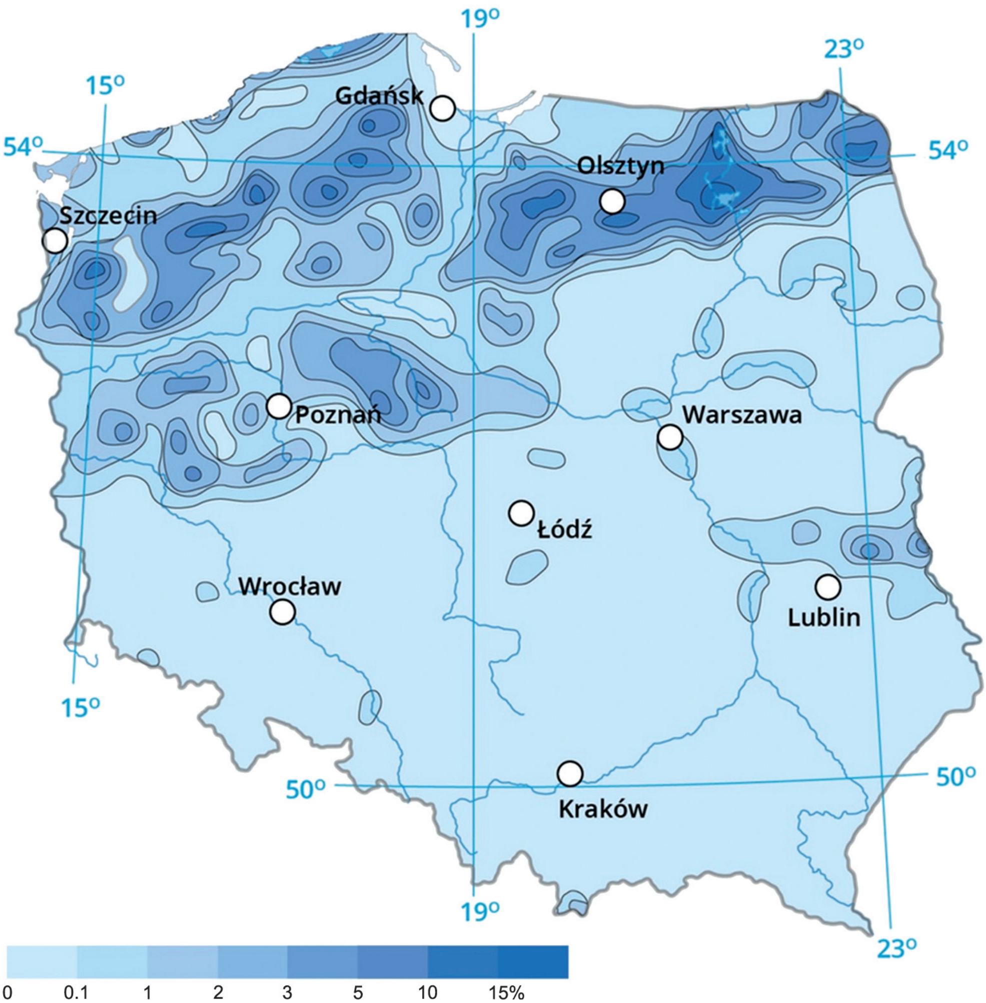


Fig. 1.2. Spatial differentiation of lake levels in Poland (https://zpe.gov.pl)

From the point of view of water management, lakes larger than 50 ha are the most important. There are about one thousand of them in Poland and they are the subject of systematic monitoring and the assessment of their condition. This is due to the role they play in water management, water supply and wastewater collection, fishing and recreation, and above all, in environmental terms.

The largest lakes in terms of surface area are located in the north of Poland, and the ten largest are presented in Table 1.5.

Table 1.5

The largest natural lakes in Poland

Lake	Province	Area in km^2
Śniardwy	Warmińsko-mazurskie	113.8
Mamry	Warmińsko-mazurskie	104.4
Łebsko	Pomorskie	71.4
Dąbie	Zachodniopomorskie	56.0
Miedwie	Zachodniopomorskie	35.3
Jeziorak	Warmińsko-mazurskie	34.6
Niegocin	Warmińsko-mazurskie	26.0
Gardno	Pomorskie	24.7
Jamno	Zachodniopomorskie	22.4
Wigry	Podlaskie	21.9

1.1.4. Surface water bodies

As stated in the introduction, surface water bodies are elements of surface waters identified for the purposes of water status assessment.

By type, surface water bodies are classified as:

– rivers,
– reservoirs,
– lakes,
– coastal and transitional.

In the current planning cycle of 2016–2021 [Journal of Laws 2016], a total of 4586 water bodies have been identified. Table 1.6 presents their basic generic division and number for the Vistula and Odra river basins. The number of water bodies planned for 2022–2027 is lower by about 40% [SWH-PW 2021].

Table 1.6

Overview of the river basin districts of the Vistula and Odra

Water region	Number of water bodies				
	rivers	reservoirs	lakes	transitionals	coastals
The Little Vistula	44	4			
The Upper – Eastern Vistula	208	4			
The Upper – Western Vistula	229	7			
Narew	229	1	162		
Bug	254	1	23		
The Middle Vistula	398	5	21		

table 6 cont.

The Lower Vistula	357	4	293	5	2
Total in the Vistula river basin	**1719**	**26**	**499**	**5**	**2**
The Upper Odra	142	5	1		
The Middle Odra	446	12	27		
The Lower Odra and Przymorze Zachodnie	270		109	2	2
Warta	279	2	124		
Noteć	135		166		
Total in the Odra river basin	**1272**	**19**	**427**	**2**	**2**
Total	**2991**	**45**	**926**	**7**	**4**

As can be seen, river and lake water bodies dominate in numbers. Lake water bodies comprise natural lakes with a water-surface area greater than 50 ha. Against this background, the number of water storage reservoirs eligible for assessment is marginal (5%).

1.1.5. Supply and surface runoff

Figure 1.3. shows the river network of Poland, including lakes and water storage reservoirs, against the background of the country's geographical regions, i.e. the structure of surface waters.

The supply of Polish rivers is dominated by a rain-snow regime. In addition, a groundwater supply is also present, which is of the greatest importance during periods of snow cover. The supply is marked by two periods of high water levels. The first maximum flow occurs in spring and is associated with snowmelt. The highest levels are associated with heavy summer rainfall (generally in July). The lowest water levels occur in winter. For part of the year, the rivers are frozen. Ice lasts longest in eastern Poland (about 80 days), i.e. in areas with a highly continental climate. The shortest ice period (about 10 days) is found in areas with a predominantly oceanic influence – the Baltic areas and the Silesian Lowlands.

A measure of the diversity of Poland's water resources is unit runoff from the main hydrographic areas. The average unit runoff in the 1951–1990 period in the Vistula basin was 5.54 $dm^3/s/km^2$ and in the Odra basin, it was 5.3 $dm^3/s/km^2$. The highest unit runoff characterises the catchments of the mountainous tributaries of the Vistula (12 $dm^3/s/km^2$), and the lowest, equal to 4 $dm^3/s/km^2$, the catchments of the rivers of the central lowlands, Kujawy and Wielkopolska. The highest annual average unit runoffs were recorded in the Tatras (more than 50 $dm^3/s/km^2$).

The total annual runoff provides a measure of the perennial water resources. In the period 1901 to 2014, this runoff was approximately 61.2 km^3. In the driest years (1954), the resource was only 37.6 km^3, while the record year in terms of runoff volume was 1981, when runoff was 90 km^3 [Gutry-Korycka 2018].

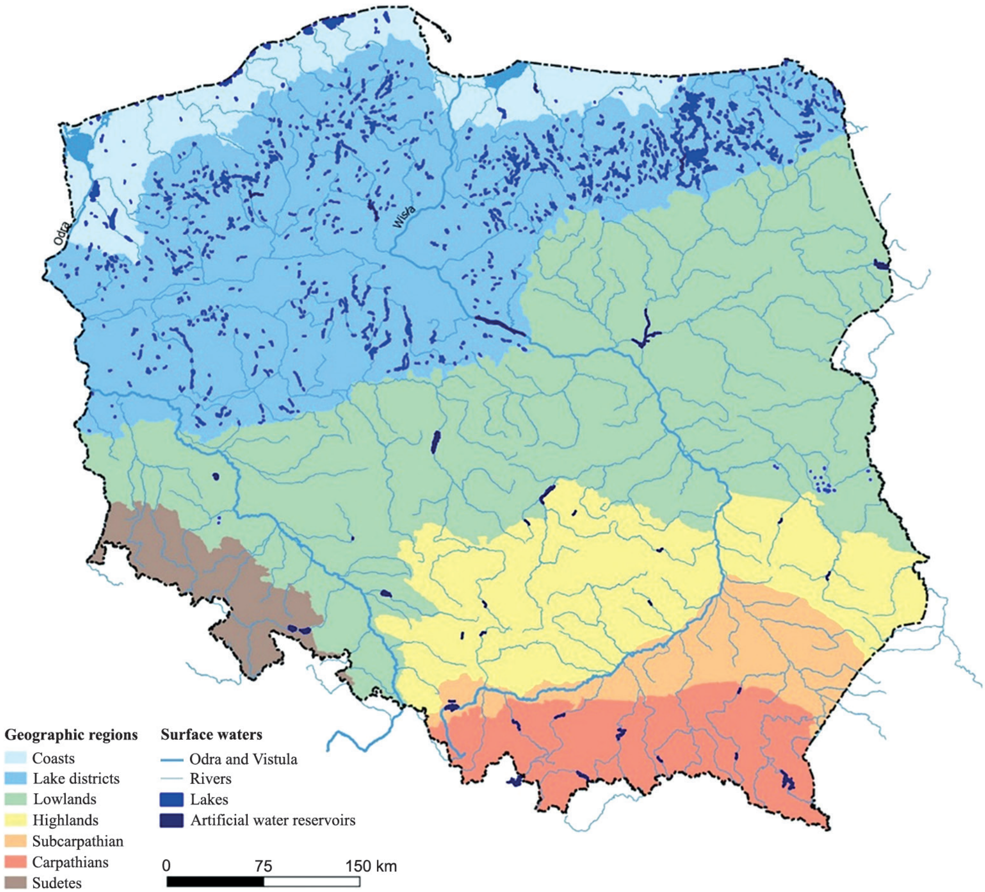


Fig. 1.3. Surface waters at the background of geographic regions in Poland

1.1.6. The use of surface water and related threats to its status

The list of functions, in addition to the primary one (environmental) that rivers and surface water in general perform in social, municipal and industrial terms, includes:

- water supply, including for energy purposes across the full range of energy sources;
- water, inland waterway transport (shipping function);
- hydropower engineering;
- irrigation of agricultural land;
- inland fishing;
- water and coastal recreation.

As mentioned earlier, the functions of the lakes are limited, besides environmental they have functions for water supply, inland fishing, occasional hydropower engineering and recreation.

The main Polish rivers, the Odra and Vistula – in sections, with reference to the above list, perform three basic functions – water supply, navigation and energy. Other functions are territorially differentiated, which is determined environmentally, hydrologically and historically. Table 1.7 presents further characterises of the use of rivers in this respect.

Table 1.7

Utilisation of the Vistula and Odra river basins
(own study based on[Statistics Poland 2020a, 2020b, 2020c])

Item	River function	Utilisation of the Vistula and Odra river basins
1.	**Inland transport (shipping)**	The national waterway network is a collection of distinct and qualitatively different navigable routes. Polish inland waterways are characterised by low operating parameters. The vast majority are routes of regional importance. In 2019, the national waterway network covered 3722 km, with 3513 km of navigable waterways actually used by shipping. In Poland, the average distance of navigable waterways per 1000 km^2 is 11,7 km. The basic river and channel network in Poland consists of the following waterways. In the Vistula river basin: ● rivers – Biebrza, Brda, Martwa Wisła, Nogat, Szkarpawa, Pisa and Vistula; ● channels – Augustowski, Bartnicki, Bydgoski, Elbląski, Jagielloński, Łączański and Żerański; ● lakes – Ruda Woda, Bartężek, Drużno, Jeziorak, Szeląg Wielki, Ewingi, Roś, lakes on the route of the Augustów and Elbląg channels, and the system of Mazurian lakes, including lakes connected by rivers and channels, from Roś Lake in Pisz to Mamry Lake in Węgorzewo and the side routes of Mikołajewskie Lake from Nidzkie Lake. In the Odra river basin: ● rivers – Nysa Łużycka, Noteć, Warta, Parnica, Odra Zachodnia, Odra Wschodnia and Regalica; ● channels – Gliwicki, Kędzierzyński, Ślesiński, Górnonotecki; ● dykes – Klucz-Ustowo and Parnicki; ● lakes – Dąbie and Gopło. The development of water tourism and recreation routes on smaller rivers (tributaries of the Vistula and Odra) is of local importance. In order to integrate it into the international system, it is necessary to regulate the main rivers.
2.	**Energetics**	The share of hydropower in electricity generation in Poland is approximately 1.5%. Energy resources are distributed as follows: ● Vistula 45.3%, ● Odra 9.8%,

table 1.7 cont.

		● Vistula and Odra river basins 43.6%, ● Rivers of Pomerania 1.3%. Between 2016 and 2020, the total hydropower generation remained at a similar level – 2000 GWh each single year, of which 50% is the output of large plants with a generating volume greater than 10 MW. Small power plants between 1 MW and 10 MW produce approx. 30%, while power plants of up to 1 MW produce only about 20%. Most hydropower plants are located in the southern part of Poland, where the lie of the land and hydrological conditions increase the hydropower potential.
3.	**Utility, municipal**	The volume of water abstraction by the economic sector has not changed significantly over the last 20 years. The proportions of water use are as follows: ● industry – 68%, ● municipal management – 23%, ● fishing – 9%. The main source of water supply for the national economy is surface water. Their intake in 2020 was 6.9 km^3, covering 80% of needs.

Threats to surface waters from the use of river, lake and reservoir waters are analysed and assessed as part of the assessment of the status of surface water bodies conducted for water management plans [Journal of Laws 2016; SWH-PW 2021]. The monitoring base and principles of this assessment are presented in Chapter 2. Here, the relevant factors influencing the risk of not achieving the environmental objectives due to anthropogenic impacts are defined and the results of the water status assessment are referred to.

The factors having the main influence on the anthropogenic risk of surface water are considered to be generic:

– hydromorphological pressures on water bodies that quantitatively alter the water resources and the geomorphological structure of the riverbed;
– pressures on the biological components of the aquatic ecosystem;
– pressures exerted on the physico-chemical elements and on the chemical state which determines the quality status in the traditional sense.

These are impacts primarily related to water use and protection from negative impacts in terms of:

– water supply (abstractions and transfers of water, discharges of urban, domestic and industrial waste water, as well as reservoir retention related to water supply);
– water and road transport within the river corridor and associated river regulation and development;
– hydropower, associated with damming and the discharge of polluted and heated water;

- agricultural use of the catchment area and uncontrolled discharge of associated pollutants;
- longitudinal and transverse structures (levees, longitudinal and transverse structures and reservoirs) to protect coastal areas against flooding.

Based on the results of quantitative monitoring and the criteria for the limit values of its indicators, the state of surface water bodies is assessed in the hydromorphological, physico-chemical, chemical and biological terms, followed by an integrated assessment of the ecological status of rivers and, in the event of water bodies, of their ecological potential. This provides the basis for:

- a baseline assessment of the risk of a water body not achieving good ecological status in the five-year period of the river basin management plan (RBMP);
- setting an action programme for this period to improve the situation;
- a list of water bodies for which there are justified derogations from the applicable quality requirements.

RBMP for the years 2016–2021 specified that prior to its implementation (as of 2013), 64% of water bodies in the Odra river basin were at risk of failing to meet environmental objectives, and 77% in the Vistula river basin, respectively. This is the vast majority of the area of both river basins. Unfortunately, under the second update, the draft water management plans for the Odra and Vistula river basins specify that, as of 2019, 95.4% of the water bodies in the Odra basin are at risk of failing to meet environmental objectives, and 94% in the Vistula basin are also at the same risk.

The fundamental issue concerns the reasons for this. The lack of implementation of most of the planned actions (more than 80%) was indicated as the main justification. Even acknowledging this explanation, the fundamental issue is that understanding and interpreting this disadvantage is made difficult because the assessment and its comparisons are accompanied by information chaos. It concerns information on the following changes that have occurred in the period between the last and the present RBMP update: (i) the change of boundaries of the water bodies and thus their number, (ii) the change of provisions on the criteria for assessing the chemical status of waters, (iii) the change of scope of monitoring, (iv) the changes in interpretation/scope of pressures on waters and treatment of some quality indicators in the assessment of the possibility of not achieving good ecological status.

The problem, however, is that not only has the intended improvement not taken place, regardless of the money spent on it, but conversely, there has been a significant deterioration in the condition of rivers and water bodies. This may undermine the credibility of the approach to both assessment and remediation measures particularly due to the following points:

- More than 23.3 billion PLN has been spent on the National Municipal Wastewater Treatment Program alone for the reduction of river pollution, between 2013 and 2018;
- Public perception reports visible symptoms of improvement in the state of the environment, including water.

This kind of situation should be explained in a transparent and understandable way, in an environmental, economic and social context. This state of affairs both undermines the credibility of the assessments themselves in a situation of a large social effort to improve the state of waters, and may also "immunise" social sensitivity to the assessments and, as a consequence, to the state of waters, assuming that regardless of how one acts, it still does nothing.

1.2. Artificial water reservoirs

1.2.1. Main storage reservoirs

Reservoirs began to be built in Poland mainly after the Second World War, when the country's rapid development and socio-economic needs for water emerged. This was due to an increase in water demand for the population in urban centres and industry, as well as the need to reduce flood damage in developed areas. Reservoirs in the western lands in the Odra basin started to be built more than 120 years ago and in the Vistula basin about ninety years ago, indicating a faster development of the western lands. The tasks to be fulfilled by the reservoirs under construction are: increasing the value of low flows in order to obtain a disposable resource for supplying water to the growing population and developing industry; building hydropower plants important for maintaining the efficiency of the country's energy system; maintaining the Odra waterway and protecting against flooding. Subsequently, reservoirs were also used for recreational purposes through the construction of resorts in the vicinity of their basins, which were regarded as compensation for the local population displaced by the basin. It was assumed that the reservoirs built would activate the development of the region in which they were located. There are more than 100 storage reservoirs in Poland, which can store a maximum of about 3423.4 million m^3 of water. The largest reservoirs are shown in Table 1.8. After a certain period of operation, water quality problems in the reservoirs closely related to pollutant runoff from the reservoir catchment area emerged. At present, therefore, there are operational problems with existing reservoirs associated with their ageing (eutrophication) and the need to repair reservoir damming structures in order to maintain the intended functions of reservoirs and the safety in the areas below them. However, the main focus will be on the experience of existing lar^{ge} reservoirs with volumes greater than 15 million m^3 as shown in Table 1.8.

Table 1.8

The largest artificial reservoirs in Poland [https://www.naukowiec.org/tablice/geografia/najwieksze-sztuczne-zbiorniki-i-stopnie-wodne_799.html]

Water reservoirs and dams	Location	Year of commissioning	Maximum volume [million m^3]	Maximum surface area [km^2]	Maximum accumulation or slope height [m]
Solina	San	1968	472.0	21.1	60.0
Włocławek	Vistula	1970	370.0	75.0	14.5
Czorsztyn-Niedzica	Dunajec	1997	231.9	12.3	54.5
Jeziorsko	Warta	1986	202.8	42.3	11.5
Goczałkowice	The Little Vistula	1956	165.6	32.0	13.0
Świnna Poręba	Skawa	2012	161.0	10.35	50.0
Rożnów	Dunajec	1941	160.7	16.0	31.5
Dobczyce	Raba	1986	141.7	10.7	27.9
Otmuchów	Nysa Kłodzka	1933	105.5	20.6	18.4
Nysa	Nysa Kłodzka	1971	102.5	20.7	13.3
Turawa	Mała Panew	1948	95.5	20.8	13.6
Tresna	Soła	1967	94.6	9.6	23.8
Dzierżno Duże*	Kłodnica	1964	94.0	6.2	11.2
Dębe	Narew	1963	90.0	33.0	7.0
Koronowo	Brda	1960	80.6	15.6	22.0
Siemianówka	Narew	1991	79.5	32.5	7.0
Sulejów	Pilica	1973	78.9	23.8	11.3
Mietków	Bystrzyca	1986	71.8	9.1	15.3
Dziećkowice*	water from the Soła	1976	52.5	7.1	14.5
Pilchowice	Bóbr	1912	50.0	2.4	46.7
Klimkówka	Ropa	1994	43.5	3.1	33.3
Kuźnica Warężyńska*	Czarna Przemsza	2005	42.0	4.7	2.3
Słup	Nysa Szalona	1978	38.4	4.9	19.1
Wióry	Świślina	2005	35.0	4.1	23.4
Pławniowice	Potok Toszecki	1976	29.1	2.4	3.3
Porąbka	Soła	1936	27.2	3.3	21.2
Topola	Nysa Kłodzka	2003	26.5	3.4	7.8

table 1.8 cont.

Chańczą	Czarna Staszowska	1985	23.9	4.7	12.8
Rybnik	Ruda	1972	22.0	4.7	11.0
Poraj	Warta	1978	21.1	5.1	12.0
Przeczyce	Czarna Przemsza	1963	20.7	4.7	12.5
Nielisz	Wieprz	1997	19.5	8.3	9.6
Kozielno	Nysa Kłodzka	2003	16.4	3.5	8.0
Żur	Wola	1929	16.0	3.0	15.5
Bukówka	Bóbr	1987	15.5	2.0	22.4
Kozła Góra	Brynica	1937	15.2	5.8	6.0
Leśna	Kwisa	1907	15.0	1.4	35.8

* a water reservoir using the excavation after the exploitation of sand.

These reservoirs have been assigned more than one task, most often several tasks with a hierarchy of implementation, for example, raising low flows, water supply, flood protection and hydropower. Only in the Odra river basin do single-purpose reservoirs exist and are associated with flood protection called dry reservoirs (Table 1.9).

Table 1.9

Dry storage reservoirs in the Odra catchment area (own study)

Item	Reservoir	Operation since	Volume million m^3	River/Stream
1.	Racibórz Dolny	2020	185.00	Odra
2.	Sobieszów	1909	6.74	Kamienna
3.	Cieplice	1909	4.95	Wrzosówka
4.	Mirsk	1910	3.92	Długi Potok
5.	Mysłakowice	1913	3.56	Łomnica
6.	Świerzawa	1911	1.90	Kamiennik
7.	Stronie Śląskie	1908	1.38	Morawka
8.	Krzeszów ×2	1906	1.13	Zadrna
9.	Kaczorów	1929	1.08	Kaczawa
10.	Bolków	1912	0.87	Nysa Szalona
11.	Międzygórze	1909	0.83	Wilczka

As one can logically assume, the preferred location for storage reservoirs was in mountain and submontane areas (Fig. 1.4), where there is a high or very high variability of flows in rivers and streams and it is not possible to provide a sufficiently large disposable water resource for the accepted tasks, and where there is the threat of sudden flooding. It should be added that the disposable water resource cannot be obtained from groundwater either as the bedrock can only store water in small quantities.

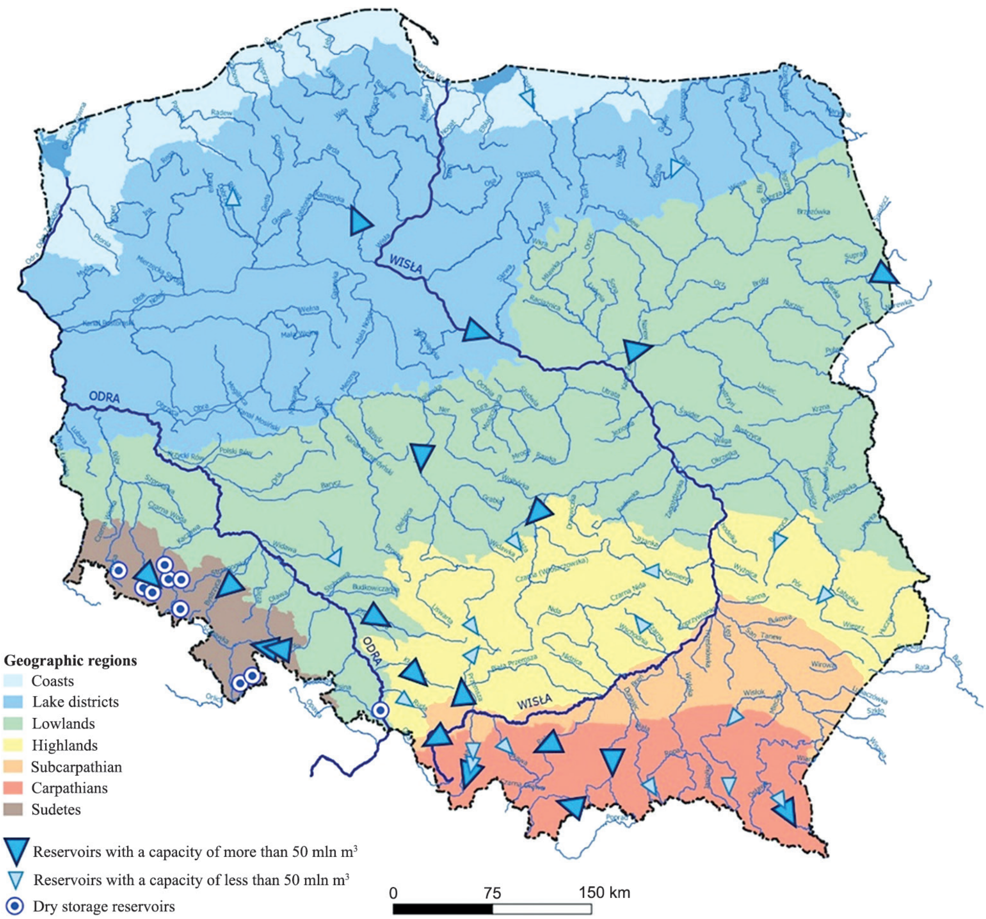


Fig. 1.4. Spatial location of large, medium and dry storage reservoirs in Poland (own study)

1.2.2. Reservoir retention functionality

In Poland, we mainly have multipurpose reservoirs, thus their total volume consists of three basic volumes related to specific tasks. These are the unusable, usable and flood volumes shown in Figure 1.5 and defined below.

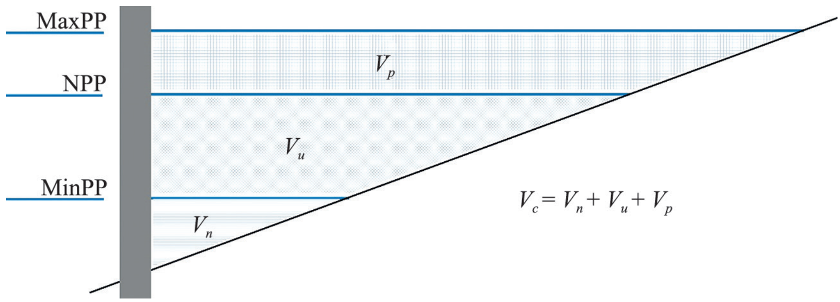


Fig. 1.5. Specific reservoir volumes and damming levels

These are the following volumes of the reservoir, calculated from the lowest ordinate of its bowl:

– The volume referred to as dead storage capacity (V_n) is determined by the minimum level of damming in the reservoir (MinPP) resulting from the technical possibilities of the operation of the facilities, for example, water intake, power supply of the power station, or the appropriate minimum quantity of water resulting from environmental criteria.
– The second specific volume is the active (live) storage capacity (V_u) determined by analysing hydrological data and the assumed purposes of water retention in the reservoir, for example, equalisation of flows and ensuring water abstraction of an appropriate value with an assumed quantitative and temporal guarantee.
– The third specific volume is the flood storage capacity (V_p), which is defined in relation to the possibility of lowering the culmination of floods with existing flood volumes. Often in Polish reservoirs, this volume (to MaxPP) has been limited by topographical or land-use possibilities and the high cost of obtaining it, which as a result, limits its effectiveness in reducing the culmination of the largest surges and necessitates the appropriate design of sluicing devices in reservoir dams and defining the principles of their control.

These volumes are related to the specific damming levels (Fig. 1.4) which are crucial for the determination of the parameters of individual hydraulic structures and for the dimensioning of the discharge facilities. The actual damming levels in the reservoirs fluctuate between NPP (full reservoir level) and MinPP (min drawdown level) during non-storm periods, resulting in temporarily different reservoir volumes. The values of these volumes are related to the hydrological conditions prevailing at a given time and to the water management conducted in the reservoirs.

When talking about reservoir retention, often too generally, for example in strategic or planning materials, only the total storage capacity (V_c) is used without reference to the individual types of reservoir retention volume. This is an oversimplification that hinders the realistic assessment of retention volumes in terms of function and, above all, does not reflect the problem that reservoir retention is intended to solve. This issue is addressed in detail in Chapter 4, which discusses problematic issues in the upper Vistula river basin.

The following examples can illustrate what issues need to be addressed in the analysis and assessment of reservoir retention:

1. The problem of assessing reservoir volume – specific reservoir volumes with different task hierarchies
   – Solina reservoir – the primary task of energy utilisation: V_c = 473 million m^3, V_n = 174 million m^3, V_u = 249 million m^3, V_p = 50 million m^3,
   – Dobczyce Reservoir – the primary task of supplying water to Cracow: V_c = 141.7 million m^3, V_n = 22.6 million m^3, V_u = 91.1 million m^3, V_p = 33.87 million m^3 (summer) and 22.56 million m^3 (winter).
2. Assessment of reservoir retention at the area scale
   A similar problem in the assessment of reservoir retention occurs when the total storage capacity (V_c) is related to the scale of the country, e.g. we have about 6.5% of the annual runoff from the area of Poland, while regionally, the reservoir retention is highly diversified and, for example, in the Upper Vistula catchment area, this indicator amounts to about 11.5%, including a large share of unusable retention in the Solina reservoir.
3. Allocation of reservoir retention
   It should be stressed that the location of reservoir retention should be viewed primarily in terms of well-founded needs, currently through the formulation of an overriding public purpose that cannot be achieved by more environmentally beneficial means. Reservation of reservoir locations is a complex and lengthy process and effects should be determined at different spatial and temporal scales.
4. Changes in the use of reservoir retention during the operational period
   After the political change in Poland, there was a significant decrease in demand for water, especially in large urban and industrial centres. This was caused by the reduction of water losses in transmission networks, the liquidation of water-intensive industries, the use of closed circuits in the installation of plants, and the saving of water by the population and industry. This raises the question of a new assessment of the use of reservoir volumes, particularly in the context of increasing needs for more permanent flood volume associated with the reduction of flood risk at a certain level.
5. Other tasks and problems
   The scale of problems in water management in the existing and planned reservoirs increases when new scenarios in the emergence of extreme phenomena and the ageing of reservoirs and high safety requirements are considered. The ageing of reservoirs creates threats to water quality, and the

systematic loss of usable and flood volume through the flooding of reservoirs with sedimented debris; furthermore, ageing hydraulic structures may limit, at least temporarily, the maintenance of fixed damming levels, which translates directly into reservoir volumes.

Storage reservoirs in Poland have been created through the construction of various types of dams, which is related to the development of hydrotechnical facility construction technology. These are mainly earth dams and much smaller concrete dams.

Reservoirs and their facilities are subject to monitoring. The scope of reservoir monitoring is described in Chapter 2. In addition, water quality studies in reservoirs are conducted as part of a regional monitoring network, which is obligatory for reservoirs with a volume greater than 40 million m^3, and local monitoring for other reservoirs.

As part of a complete assessment of water quality in reservoirs, the following are performed:

– the identification of pollution sources,
– the assessment of water quality in reservoirs,
– the assessment of the vulnerability of the reservoir to eutrophication,
– the assessment of the quality of bottom sediments.

The main problem from the point of view of the economic tasks that the reservoirs perform is the eutrophication of the retentate water, the degree of threat of which is assessed on the basis of observation of phosphorus concentrations.

The extent of monitoring for assessing the technical condition of dam structures depends on the importance class of the structure and is described in detail in the operating instructions for each dam. At a basic level, it consists of observation networks and includes observations of structure deformations and filtration phenomena in the structure, its foundation and its surroundings. On the basis of the monitoring data and other surveys conducted periodically, an assessment of the technical condition of the structure is prepared and its operational safety is assessed. On the basis of this assessment, the scope of renovation and the modernisation of structures is determined and recommendations are made. It should be emphasised that maintaining a structure in at least a good technical condition means at the same time maintaining the designed reservoir volumes and meeting the requirements of the water management of the reservoir.

1.2.3. Small storage reservoirs

In Poland, there are many small storage reservoirs with a more even spatial distribution than large reservoirs. They have only a local impact, and attributing to them the character of multi-tasking at the design stage is difficult to accept according to task and economic efficiency criteria. It is therefore necessary to ask the question about the purpose of building small reservoirs in the context of assessing the effectiveness of retention and the problems we want to solve or reduce. The established environmental criteria generally do not support the construction of a large number of small reservoirs as they worsen the ecological status of the watercourses on which they are built and the effects of this type of retention are insufficiently justified.

In this situation, once again, we need to look at the problem of retention in more detail than just generally stating that it is needed. While it is true that small reservoirs mitigate the effects of drought, and sometimes the culmination of floods, we must be aware that the level of this retention does not protect us from extreme hydrological phenomena. This is due to the fact that their volumes are too low and difficult to control so as to increase their efficiency in the mentioned range. Taking into account environmental requirements and future hydrological scenarios, water retention in small reservoirs in combination with micro-retention and natural retention should play an important role in the environment by mitigating the effects of drought. The quantitative assessment of the effects of this retention is not defined today in relation to the probability of the occurrence of hydrological phenomena and also to the spatial scale, thus we mainly remain with the qualitative assessment of the effects of this retention.

1.2.4. Concluding comments

Polish reservoirs conduct water management on the basis of operating instructions updated even every five years, and on the basis of meteorological and hydrological forecasts prepared by IMWM NRI, including inflows to the reservoir. This enables better use to be made of available reservoir volumes, particularly in large reservoirs where permanent experienced staff can flexibly control the runoff and water intake. Control during floods in small reservoirs, especially in mountainous areas, is very difficult, and usually the overflows of these reservoirs are constantly open and prepared for the passage of floods. In normal periods (periods with the absence of floods), reservoir management is the responsibility of the reservoir owners or administrators (the vast majority of large reservoirs belong to the State Treasury). During periods of high tide, the control of runoff can be influenced by emergency managers considering the regional or supra-regional situation.

With regard to the reservoir retention planned for the coming years and in the medium-term horizon:

- Dry reservoirs for local flood protection and small retention reservoirs are indicated for implementation in water management plans (updated RBMP);
- A number of polders are planned in the flood risk management plans (updated FRMP) to support flood protection with existing levees;
- The Programme for the Construction of International Class Waterways on the Odra and Vistula Rivers from 2019 adopted in Poland will require the

construction of large-capacity reservoirs to maintain the required conditions for navigation throughout the year. This problem is currently a major research and design challenge.

The planned numerous small storage reservoirs should be treated at this stage of programming as potential locations to be verified and indicated for implementation in subsequent stages of investment preparation.

It is important in this process to develop good practices in the construction and management of reservoirs and polder retention.

1.3. Groundwater

Groundwater is a complex structure both vertically and horizontally, depending on the geological structure. Due to the shape of the terrain in Poland, one can distinguish lowland regions (coastlands, lake districts, lowlands) and upland-mountain regions (highlands, sub-Carpathian basins, Carpathians, Sudetes), which have a band system with latitudinal orientation [https://www.pgi.gov.pl/dokumenty-pig-pib-all/psh/psh-materialy-informacyjne/informatory-psh/4719-informator-psh-2017-gzwp/file.html].

1.3.1. Geological structures and water-bearing media

Along the country's southern border stretches a belt of mountains and foothills, the Sudetes in the west and the Carpathians in the east. The genesis and geological evolution of these mountains are different. The Sudetes were formed during the Variscan orogeny. Much later, in the Mesozoic, they were penetrated and during the uplift of the Carpathian Mantle, they were pushed up as seamounts. The orographic Sudetes are largely composed of crystalline rocks, while the Carpathian Mountains are young mountains belonging to the Alpids and therefore the mantle layers are dominated by Jurassic to Neogene flints. The most water-bearing structures here are the gravel and sand filled alluvial valleys of the larger rivers. In the area of the Sudetes, most water-bearing structures are connected with the Permian-Cretaceous basins. In their foreland, large groundwater resources exist in buried river valleys existing before glaciations, in the Pliocene and Pre-Pleistocene [Staśko 2002; Staśko et al. 2007].

From the Upper Silesian Upland in the eastern part of the Silesian-Cracow Upland, there is a belt of uplands continuing eastwards through the Małopolska Upland to the Lublin Upland and further on through the Volhynian-Podilian Upland into the region of Ukraine beyond the country's borders. The landscape is dominated by undulating and hilly terrain, and the tributaries of the Vistula and Odra rivers start their course from their sources on the uplands. In the upland areas Mesozoic sediments, mainly Cretaceous and Jurassic, occur on the surface or under a thin layer of Cenozoic, Paleozoic and older Mesozoic water-bearing strata have been locally documented in Upper Silesia and the Świętokrzyskie Mountains. In the middle of the country, from Belarus in the east to Germany in the west, stretches a belt of flat or undulating relief and low-lying terrain classified as the Polish Lowland.

In the north of Poland, before the Baltic coast, there is a belt of lake districts with a varied young glacial relief. It is dominated by deposits of the Cenozoic period, mainly Pleistocene, which reach their greatest thickness, locally exceeding 200 m, in the structures of buried valleys and pre-valleys. In this part of the country, coastlands, lake districts and lowlands belts can be distinguished, all of which are included in the lowland hydrogeological province.

The terrain of Poland was strongly transformed and finally formed by the Scandinavian glaciations. The area occupied by the youngest glaciation of the Vistula river occupies almost half of the country in the north. Figure 1.6 shows the main hydrogeological units and structures of Poland.

There are differentiated water-bearing media in the country – fractured, pore, pore--seep and fractured-karst aquifers – which at the regional scale are a combination of the distinguished types. The mutual overlapping of water-bearing media in the vertical profile and the facio-lithological differentiation of sediments in the plan enables the occurrence of multilayer structures/aquifer systems (multi layer aquifer systems). The coastlands, lake districts and lowlands are dominated by the groundwater-rich pore media of the Cenozoic, usually separated into hydrogeological structures of the Pleistocene and older aquifers of the Neogene and Palaeogene. In the subsoil of the Cenozoic, ordinary waters were locally found in sandy layers and in series of marls, limestones and gezes classified as Cretaceous and Jurassic. In many places, Mesozoic aquifers are threatened by brine ascensions, and in the coastal zone, they are also threatened by seawater ingress. The uplands are dominated by fractured and locally fissured karst aquifers, in the vicinity of which, sandy aquifers are found, for example, those formed in buried Pleistocene valley structures. Buried river valley structures from the late Pliocene and Pleistocene became the main water-bearing structures in the foreland of the Carpathians and Sudetes. In many places, they have been filled in with a series of gravels, silts and coarse sands. They are distinguished by their high water conductivity and high renewability of groundwater resources. In the southern part of the Lublin, Małopolska and Silesian-Cracow uplands, older Triassic and Palaeozoic aquifers also occur. Geologically, the Carpathian range coincides with the Carpathian foredeep and is filled mainly with Miocene molasse sediments from the Carpathians, which were finally uplifted in the Neogene. Over a large area, it preserves relict seawater and salt water from the leaching of a series of chemical and evaporative sinkholes. The mountain ranges of the Carpathians and the Sudetes are distinguished by scarce groundwater resources and are dominated by fracture and pore-cracking media, developed mainly in blowholes, weathering and tectonic fractures [Motyka 1988]. The only water-bearing structures in the Sudetes are the Middle Sudeten Trough and the Outer Sudeten Trough.

Fig. 1.6. Main hydrogeological units and structures of Poland (own study)

1.3.2. Exploitable groundwater resources

Groundwater is a very important part of the water supply system as over 70% of the Polish population uses it as the main source of drinking water. Extensive hydrogeological investigations were conducted to determine its quality and availability, which enabled the selection of Major Groundwater Reservoirs, i.e. areas with the highest water-bearing capacity and abundance. According to the State Hydrogeological Service (PSH), the main groundwater reservoirs are geological structures or their fragments showing the highest water bearing capacity and abundance in the hydrogeological regions, which are currently or may become the main source of water supply for the inhabitants.

Figure 1.7 shows the location of the Major Groundwater Reservoirs against the background of geographical regions.

There are currently 131 identified Major Groundwater Reservoirs. For each reservoir, PHS prepares documentation to the extent consistent with applicable law and methodology or an addendum to existing documentation, a map of the protection areas together with the identification of recommendations for the management of these areas (if the reservoir required protection), a mathematical model and a GIS documentation database.

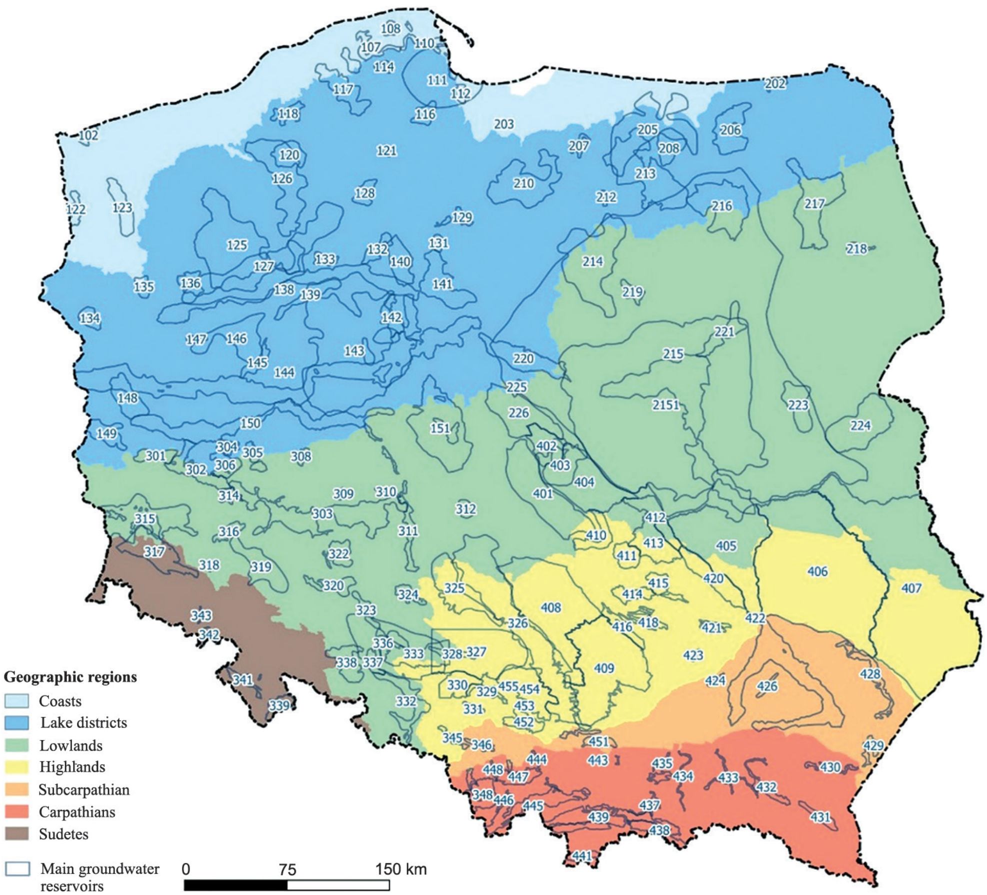


Fig. 1.7. Main groundwater reservoirs in comparison with geographical regions (own study)

The Polish Hydrogeological Survey periodically identifies and determines, as of 31 December of a given year, the amount of ordinary groundwater resources that can be developed. It is the sum of the disposable resources. For example, according to such documentation, as of 31.12.2021, the sum of disposable resources was **29 million m³/d** and prospective resources **5 million m³/d**, resulting in a total of up

Table 1.10

List of established exploitable resources of ordinary groundwater in Poland in 2020, by provinces
(https://www.pgi.gov.pl/psh/materialy...)

No.	Voivodships	Area km^2	Exploitable resource						
			In total [m^3/h]		resource module m^3/h/km^2	state of exploitation resources [m^3/h] from			
			As of 2020.12.31	increase-decrease in 2020 r.		Quaternary deposits	Neogene-Paleogene deposits	Chalk deposits	older
	In total	312 685	2 104 888.68	21 288.28	6.73	1 383 700.99	225 230.40	293 170.32	22 864.42
1.	Dolnośląskie	19 948	94 200.55	903.99	4.72	62 895.70	21 509.85	3906.36	5888.65
2.	Kujawsko-Pomorskie	17 970	196 285.36	5216.20	10.92	149 396.63	34 400.93	9694.90	2792.90
3.	Lubelskie	25 114	149 908.73	2223.02	5.97	25 150.88	12 999.11	110 929.44	829.30
4.	Lubuskie	13 984	95 291.20	506.10	6.81	88 360.76	6902.44	14.00	0.00
5.	Łódzkie	18 219	178 616.78	2684.66	9.80	69 801.24	11 059.41	63 891.57	33 864.56
6.	Małopolskie	15 144	80 777.38	4266.12	5.33	45 433.90	9998.39	13 517.76	11 827.34
7.	Mazowieckie	35 598	266 047.06	432.70	7.47	21162561	17 472.37	26 592.83	10 356.25
8.	Opolskie	9412	59 713.79	496.50	6.34	25 782.10	15 791.05	2056.00	16 084.64
9.	Podkarpackie	17 926	61 139.00	678.07	3.41	53 939.14	5390.01	1619.76	190.09
10.	Podlaskie	20 180	79 078.97	80.97	3.92	76 975.87	2047.10	44.00	12.00
11.	Pomorskie	18 293	169 294.15	1678.55	9.25	140 864.20	16 244.55	12 160.40	25.00
12.	Śląskie	12 294	110 335.21	-300.97	8.97	24 984.90	2655.59	4889.69	77 805.03
13.	Świętokrzyskie	11 672	62 888.18	108.45	5.39	7 071.84	5343.60	15 342.72	35 130.02
14.	Warrnińsko-Mazurskie	24 203	131 759.53	75.63	5.44	124 627.03	7022.30	148.20	18.00
15.	Wielkopolskie	29 826	196 889.88	1652.54	6.60	117 728.20	48 957.10	26 874.19	3351.84
16.	Zachodniopomorskie	22 902	172 656.89	585.75	7.54	159 042.99	7436.60	1488.50	4688.80

to **34 million m^3/d of usable groundwater resources in Poland** [https://www.pgi.gov.pl/psh/zadania-psh/8886-zadania-psh-zasoby-wod-podziemnych.html].

From an economic (business) point of view, the analysis of water needs and consumption, including groundwater, is performed on an administrative basis. Above, the exploitable groundwater resources are presented quantitatively in Table 1.10 in the province.

1.3.3. State of groundwater resources

In accordance with formal requirements, a periodical assessment of the status of groundwater resources is conducted within the framework of the management plans divided into groundwater bodies. These are area units which include groundwater

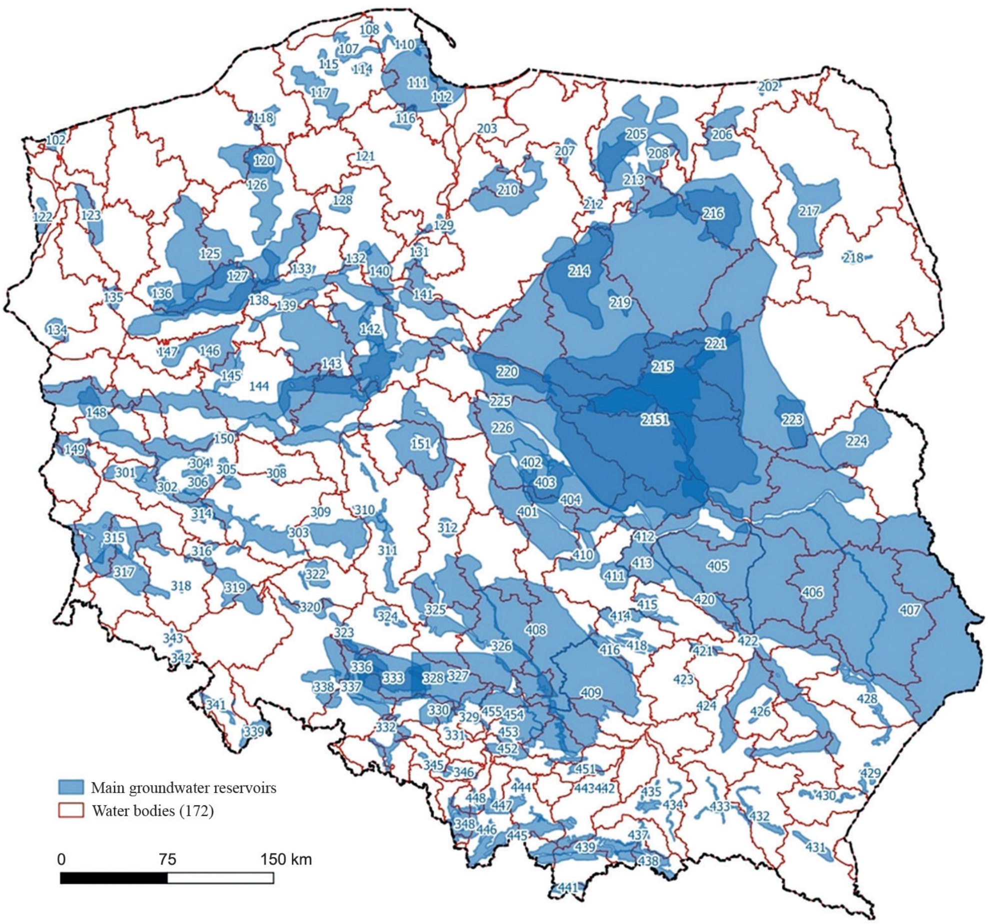


Fig. 1.8. Division of Poland into 172 groundwater bodies at the background of the main groundwater reservoirs (MGR/GZWP) (own study)

that occurs in aquifers with porosity and permeability that allow abstraction for public water supply or flow rates that are significant for shaping the desired status of surface water and terrestrial ecosystems. A significant groundwater flow is a flow which, if not achieved at the interface between a water body and a surface-water or terrestrial ecosystem, would result in the significant deterioration of the ecological or chemical quality of surface water or significant damage to a terrestrial ecosystem directly dependent on groundwater. Groundwater abstraction which is significant in terms of the supply of drinking water to the population is an abstraction which averages more than 10 m^3/d or which supplies at least fifty people.

The Polish Hydrogeological Survey prepares the geological and hydrogeological characteristics of groundwater bodies.

It analyses pressures and impacts on groundwater that result in impacts on its quantitative status and chemical quality. Currently, the area of Poland is divided into 172 groundwater bodies (Fig. 1.8).

Fact sheets for groundwater bodies developed by The Polish Hydrogeological Survey are published at https://www.pgi.gov.pl/psh/zadania-psh/8913-zadania-psh-jcwpd.html. Each description includes the following elements: geological characteristics (stratigraphic assignment, lithological description, geochemical type of rock formations), hydrogeological characteristics (type of aquifer, average filtration

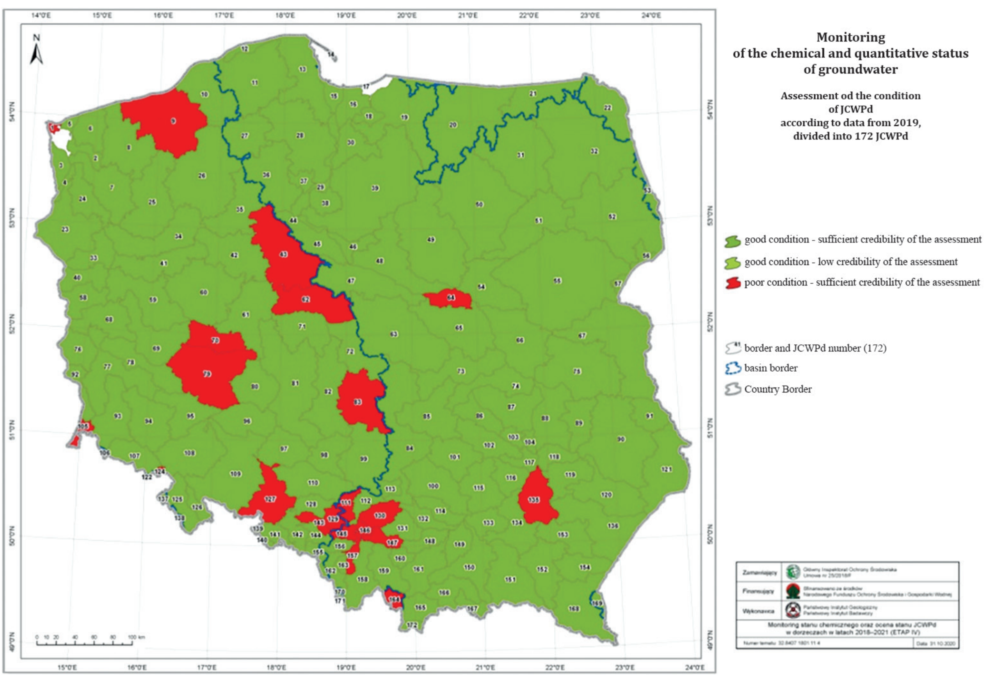


Fig. 1.9. Assessment of the status of the groundwater bodies according to 2019 data by 172 water bodies (report on the assessment of the status of water bodies..., PGI NRI 2020)

coefficient, average thickness of aquifers, number of aquifers included in the water body) and characteristics of the overburden of the aquifer.

The assessment of groundwater status conducted by the Polish Geological Institute and the National Research Institute in 2020 showed that an overall good rating could be attributed to 151 groundwater bodies, representing 91.6 of the country's area, and a poor rating to only twenty-one groundwater bodies, representing the remaining 8.4 per cent of the country's area, as shown in Figure 1.9.

It is worth noting here that the assessment of groundwater status differs markedly in favour of the assessment of surface water resources (see Chapter 1.1).

2. Organisation and approach to water management in Poland

2.1. Institutional arrangements of water management

Water management is one of thirty-five branches of government administration and, according to Article 11 of the Act on branches of government administration, covers the following issues [Journal of Laws 1997]:

1) the shaping, protection and rational use of water resources;
2) the maintenance of inland surface waters owned by the State Treasury together with the technical infrastructure related to these waters, including structures and water facilities;
3) inland waterways maintenance;
4) flood protection, including the construction, modernisation and maintenance of water facilities protecting against flooding and the coordination of undertakings aimed at protecting the state against flooding;
5) the functioning of the state hydrological and meteorological service and the state hydrogeological service, with the exception of groundwater quality monitoring issues;
6) international cooperation in border waters within the scope of the tasks assigned to the department;
7) defining the terms and conditions for the collective supply of water intended for human consumption and the collective disposal of waste water.

The minister in charge of water resources management is responsible for creating policy on water resources management (currently, in 2022, it is **the Minister of Infrastructure). The State Water Holding – Polish Waters** is responsible for the implementation of the policy. Water resources are managed in a hydrographic system (this principle was introduced more than twenty years ago, in 1997). Polish Waters have a hierarchical structure based on the division of the country's area into river basins, water regions and drainage basins. The description of the organisation of Polish Waters and competences of individual organisational units is discussed in the next subchapter (Subchapter 2.2).

The main tasks of the minister in charge of water management include the aforementioned shaping of the directions of the state water policy as well as:

- coordinating the implementation of public tasks in water management, including by issuing guidelines and instructions to the President of Polish Waters on how to perform the tasks;
- fulfilling obligations arising from international agreements on water management to which the Republic of Poland is a party;
- supervising, controlling and evaluating the activities of Polish Waters;
- supervising the activities of the state services – the state hydrological and meteorological service, the state hydrogeological service and the state service for the safety of damming structures.

The Minister's auxiliary apparatus is the Ministry of Infrastructure, where water management is the responsibility of the Ministry: Department of Water and Inland Navigation and Department of Water Management Adjudication and Control.

The Minister of Infrastructure, apart from the department "Water Management", manages other departments of government administration: transport and departments closely related to water management, maritime economy and inland navigation. The minister responsible for water management closely cooperates, with regard to the objectives and tasks of water management, with the following ministries, among others [Journal of Laws 1996]:

- The Ministry of Interior and Administration, which is responsible for crisis management, the protection of public safety and order, as well as for preventing and dealing with the effects of natural disasters. The Minister of Interior and Administration is subordinated to the Commander-in-Chief of the State Fire Service (SFS), which performs most of the above-mentioned tasks together with SFS units.
- The Ministry of Climate and Environment, responsible for, inter alia, climate and sustainable development issues, protection and shaping of the natural environment, monitoring compliance with environmental protection requirements and studying the state of the environment, as well as geology and forestry. The Minister of Climate and Environment, inter alia, is in charge of:
  - The Chief Inspector of Environmental Protection, who conducts state environmental monitoring, including monitoring of the state of water resources.
  - The General Director for Environmental Protection – which is the central body of government administration responsible for nature protection and control of the investment process.
  - Polish Geological Institute – National Research Institute also acting as the state geological service and the state hydrogeological service (groundwater monitoring).
  - National Fund for Environmental Protection and Water Management and provincial funds for environmental protection and water management financing tasks.

- The Ministry of Health, with respect to the requirements to be met by water used for supplying the population with water intended for consumption and bathing sites – the Chief Sanitary Inspector supervises the quality of drinking water and bathing waters.
- The Ministry of Agriculture and Rural Development for the protection of waters against pollution by nitrates from agricultural sources (preparation of good agricultural practices).
- The Ministry of Development and Technology with respect to the requirements and conditions for planned development and the planned development of areas located in areas of special flood hazard.

The diagram below (Fig. 2.1) presents the main entities responsible for water management in Poland together with their main tasks.

The primary legal act regulating water management is **the Act of 20 July 2017 – Water Law** [Journal of Laws 2017b], its scope and adopted solutions are the result of many years of legislation and proven practice (Water Law Acts of 1974 and 2001), European Union legislation and also the profound reform of water management that this act introduced. The Water Law implements the following EU Directives:

- Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy Water Framework Directive;
- Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, Flood Directive;
- Directive 2008/105/EC of 16 December 2008 on environmental quality standards in the field of water policy;
- Directive 2006/118/EC of 12 December 2006 on the protection of groundwater against pollution and deterioration;
- Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment;
- Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, Nitrates Directive;
- Directive 2006/7/EC of 15 February 2006 concerning the management of bathing water quality;
- Directive 2008/56/EC of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

The main findings and objects of regulation of the Water Act 2017 relate to:

- **Water ownership** – waters of the territorial sea, internal sea waters, inland flowing waters and groundwaters are owned by the State Treasury and are public waters, only standing waters in a ditch or pond which is exclusively

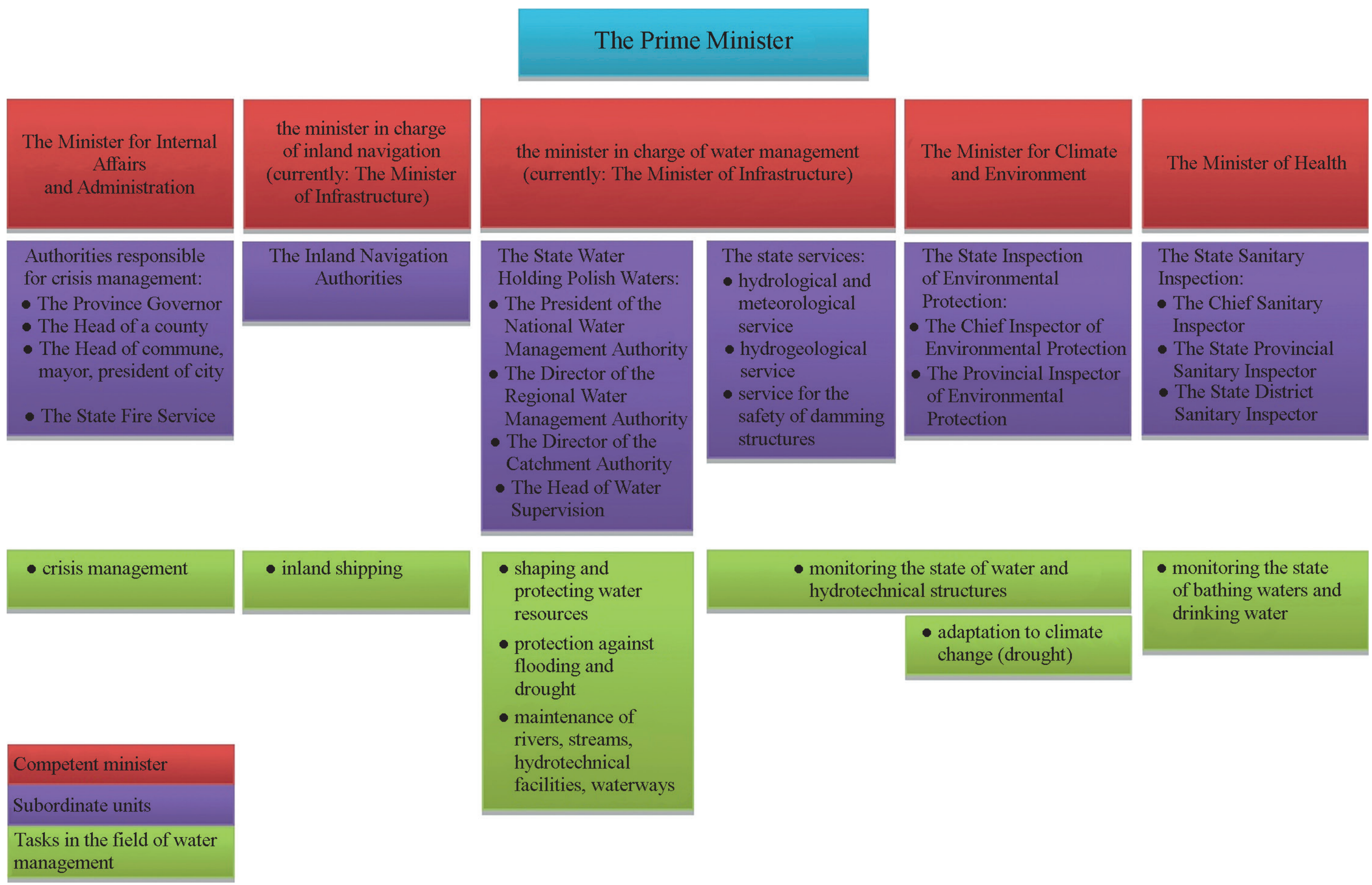


Fig. 2.1. Organisation of water management in Poland

rainwater or groundwater, located within the boundaries of a property are private property of the owner of that property. Ownership rights in relation to public inland waters are exercised by the State Water Management Company Polish Waters, and in the case of marine waters by the minister in charge of maritime economy.

- **Water use** – the 2017 Water Law maintains the division, which has been in place since 1962, between free-of-charge and non-administratively-decreed common and ordinary water use and special water use regulated by water-law consents. It has introduced a new category of usually chargeable water services consisting of providing households, public entities and business entities with the possibility to use water beyond the scope of common water use, ordinary water use and special water use.
- **Water protection** – almost the entirety of the provisions concerning the objectives and principles of water protection, environmental objectives, criteria and means of assessing the status of surface and groundwater and the environmental status of marine waters are the result of implementing into water law the provisions of EU directives – the Water Framework Directive, Directive 2008/105/EC on environmental quality standards, Directive 2006/118/EC on the protection of groundwater, Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, the Marine Strategy Framework Directive. The section "Water Protection" also regulates issues related to municipal wastewater treatment – the provisions in this area are the result of many years of experience in the creation and implementation of the National Municipal Wastewater Treatment Program and the implementation of Directive 91/271/EEC on urban wastewater treatment.
- **Flood risk management** – the responsibility for flood protection has been defined, establishing Polish Waters as the main entity responsible for the protection of people and property against flooding caused by public waters, according to the provisions of the Floods Directive, flood protection shall be conducted with consideration of flood hazard maps, flood risk maps and flood risk management plans, The Act contains general principles for the preparation of the aforementioned planning documents, as well as regulating their connection with planning and spatial development documents, including the participation of Polish Waters in agreeing plans and administrative decisions as regards development and land use in areas at particular risk of flooding.
- **Counteracting the effects of drought** – in accordance with the provisions of the Water Law, this is a task of governmental and self-governmental administration bodies and the Polish Waterways, which should be implemented on the basis of the plan for counteracting the effects of drought, which is prepared by Polish Waters.

- **Water authority and entities responsible for water management** – the act defines the minister responsible for water management as the chief authority of government administration responsible for water management. It specifies their responsibilities and tasks, including the supervision of Polish Waters and state services: the state hydrological and meteorological service, the state hydrogeological service and the state service for the safety of damming structures. It establishes the tasks of state services and the principles of their financing (from the state budget). The main entity responsible for the implementation of the state policy on water management is the State Water Holding – Polish Waters, which consists of the following organisational units: National Water Management Authority with its headquarters in Warsaw; regional water management authorities with headquarters in Białystok, Bydgoszcz, Gdańsk, Gliwice, Cracow, Lublin, Poznań, Rzeszów, Szczecin, Warsaw and Wrocław; catchment authorities and water supervision facilities and their bodies; the President of the SWH Polish Waters; directors of regional water management authorities; directors of catchment management authorities; heads of water supervision facilities. The Water Law lists the tasks performed by individual units in the hierarchical structure of Polish Waters. A consultative and advisory body of the minister in charge of water management, the State Water Management Council, and consultative committees as consultative and advisory teams in water regions were also established.
- **Principles and economic bases for the functioning of Polish Waters and management of State Treasury property** – the act specifies principles of the financial management of Polish Waters, including the main sources of revenue and economic instruments for water management: fees for water services, increased fees, charges for the use of inland waterways, legalisation fee for water equipment made without water-legal consent, the annual fee for the use of land covered with public waters, revenues from the disposal of real estate, the annual fee for the use of a fishing area, revenues from fees and contracts for inland fisheries. The act defines the construction of water service charges for most types of water services consisting of a fixed and a variable fee, the principles for their calculation and the maximum fee rates for individual water services and economic activities.
- **Principles and instruments of water management** – the basic tools of water management are regulated planning, water management information system, water management control, water monitoring and water permits. The act lists twelve planning documents, including seven for inland waters (river basin management plans, flood risk management plans, drought management plan, water maintenance plans, preliminary flood risk assessment, flood hazard maps, flood risk maps) and five for marine waters, and defines their

objectives, scope and procedures for creation. It provides for the creation of an information system for water management and for collecting and making available information on water management. It regulates the principles and scope of water management control, as well as the responsible authorities and their tasks – Polish Waters, directors of maritime offices, State Sanitary Inspectorate, Environmental Protection Inspectorate. Objectives, the method and scope of water monitoring and bodies responsible for conducting it are the responsibility of the Environmental Protection Inspectorate, the state hydrological and meteorological service and the state hydrogeological service. One of the most important instruments for water management is the water permit, granted mainly by issuing a water permit, a water permit assessment or accepting a water permit application. The act specifies the principles for issuing water-legal permits, activities and investments that require a water-legal permit and notification, the Polish Waters authorities competent for permits, issuance procedures, the scope of applications and the water-legal report; it also regulates the issues of expiration, withdrawal and the limitation of water-legal permits.

2.2. Financing water management in Poland

Most water management tasks are of a public nature, meeting the basic needs of inhabitants and economic entities, such as providing water for the population and the economy, water protection and protection against floods and droughts. Their implementation is mainly entrusted to Polish Waters, as a public entity responsible for water management (protection against flood and drought, the maintenance of state assets including rivers, streams and hydrotechnical facilities) and local governments (water supply and sewage treatment). Both Polish Waters and local governments implement these tasks from a number of sources relying on funds from budgets (central, provincial and municipal), they use funds from EU programmes and environmental funds, and reach for other sources such as bank loans and credits.

One of the main objectives of the water reform introduced by the 2017 Water Law was to improve the financing of water management, and the most important economic instrument on which the new financing system is based is water service charges. According to the Explanatory Memorandum to the draft Water Law, charges for water services were to account for 49% in 2017, 64% in 2020, and in the final year of analysis in 2026, even 73% of the total revenue of Polish Waters [Godyń 2020]. The premise of the reform was to shift the burden of funding from the central budget to funds from water service charges. The three years of operation of the new funding system show that this target has not been achieved, although in 2020, the level of revenue from water service charges is around 50% of the total revenue, which is a significant result compared to the first two years 2018–2019, where the revenue was around 30%. The lower than originally planned level of revenue from water services was the result of a significant reduction in tariffs. Data on the financing of the operating costs of Polish Waters for the period 2018–2020 according to the data from the budget execution for 2018–2020, the Budget Act of 2021 and the draft budget for 2022 are presented below in Table 2.1.

Table 2.1

Revenues and operating costs of Polish Waters in 2018–2022

Specification	2018	2019	2020	2021	2022
	[PLN thousands]				
REVENUE	**1 206 309**	**1 585 979**	**1 412 499**	**1 577 244**	**1 515 753**
1. Income from operations, including:	416 657	538 574	785 096	467 046	526 937
Income from water services	*416 657*	*525 396*	*705 953*	*410 000*	*442 830*
Charges for the use of inland waterways			*1131*	*1081*	*1335*
Annual fees for use of land under water			*8361*	*7499*	*8540*
Legalisation fees			*1240*	*1138*	*1100*
Income from disposal of real estate			*16 611*	*8372*	*12 401*
Income from participation			*18 291*	*9841*	*14 680*
Income from inland fishing agreements			*6334*	*6911*	*6485*
Fees for water permits			*12 190*	*10 630*	*9686*
Income from business activities		*12 883*	*15 848*	*10 583*	*29 641*
Other		*295*	*137*	*991*	*239*
2. Subsidies from the state budget	657 860	910 434	419 736	951 224	827 761
3. Funds from other public finance entities	104 690	27 986	116 770	27 452	25 029
4. Other income	27 102	108 985	87 786	127 841	136 026
OPERATING COSTS	**1 031 440**	**1 451 750**	**1 578 386**	**1 908 409**	**2 102 909**
Depreciation	*230 435*	*388 488*	*461 793*	*450 586*	*714 550*
Materials and energy	*53 721*	*54 847*	*51 074*	*92 346*	*73 362*
External services	*270 799*	*451 563*	*415 913*	*710 279*	*634 399*
Remuneration and related expenses	*340 659*	*426 827*	*444 049*	*470 567*	*531 085*
Other expenses	*135 826*	*130 025*	*205 556*	*184 631*	*149 513*

Note: years 2018–2020 – actual incomes and expenses according to data from the implementation of budget laws, years 2021–2022 – planned incomes and expenses according to data from the budget law for 2021 and the draft budget for 2022.

In addition to the current costs of maintenance of assets and operation of the units of Polish Waters, investment expenditure is also incurred on the implementation of new water management facilities or the modernisation of existing facilities. Data on the financing of the investments of Polish Waters for the period 2018–2022 is presented below in Table 2.2.

Table 2.2

Appropriations for property expenditure of Polish Waters in 2018–2020

Specification by type of source of financing	2018	2019	2020	2021	2022
	[PLN thousands]				
Subsidies from the State Budget, including expenses resulting from strategic documents and maintenance of the Treasury assets (hydrotechnical facilities, rivers)	311 537	304 466	14 572	37 100	0
EU investments (EU funds)	348 411	789 909	543 383	1 085 838	690 995
Funds from environmental protection funds (National Fund for Environmental Protection and Water Management, Regional Fund for Environmental Protection and Water Management)	11 026	11 192	8040	8661	2377
Investments financed by loans	0	0	680 000	0	0
Own funds of Polish Waters	1281	88 642	177 796	384 733	428 086
Total property expenses	**672 255**	**1 194 209**	**1 166 267**	**1 526 332**	**1 134 259**

Note: years 2018–2020 – actual incomes and expenses according to data from the implementation of budget laws, years 2021–2022 – planned incomes and expenses according to data from the budget law for 2021 and the draft budget for 2022.

The investments conducted by Polish Waters are mainly the construction and modernisation of water devices – flood embankments, storage reservoirs, water falls and the execution of the regulation and development of rivers and streams. As mentioned above, Polish Waters are not the only entity implementing water management tasks, a number of tasks in the field are performed by local governments and business entities, particularly in the field of water supply and sewage disposal and treatment.

Polish Waters are a major investor, for example, in 2020 they spent PLN 1012 million on hydrotechnical investments. However, these expenditures represent less than 13% of the total water management investments, a summary of capital expenditures for all types of water management investments is presented below in the table (Table 2.3). In 2020, capital expenditure was over PLN 7952 million, of which PLN 5276 million is spent on wastewater treatment plants and sewerage networks, PLN 1654 million on water intakes, supply and treatment stations, and PLN 1012 million on hydrotechnical investments (reservoirs, stages, levees, regulation).

Table 2.3

Expenditures and material effects of water management investments in 2000–2020
(own study on the basis of [Statistics Poland 2021])

Investment types	2000	2005	2010	2015	2019	2020
Investment expenditures [million PLN]						
Municipal wastewater treatment plants	1162	839	1626	1445	1283	1182
Sewage networks	1902	2464	5241	4832	4472	4094
Water circulation systems	46	46	21	7	9	11
Water intakes and systems	852	863	1798	1230	1435	1272
Construction and modernisation of water treatment plants	197	292	709	522	482	383
Water reservoirs and falls	206	335	441	631	922	516
Regulation and management of rivers and mountain streams	155	109	223	469	126	218
Flood embankments and pump stations	244	117	393	442	259	278
Total	**4763**	**5065**	**10 454**	**9580**	**8987**	**7952**
Tangible effects of investments						
Municipal wastewater treatment plants [dam^3/d]	1098	123	122	213	56	55
Sewage networks (sewage disposal) [km]	4758	5417	8462	7961	4225	3364
Rainwater drainage networks [km]	343	352	837	866	633	593
Water treatment [dam^3/d]	173	147	128	75	43	95
Water supply network [km]	7837	5576	6271	4599	3023	2739
Water reservoirs [hm^3]	8.1	51.9	0.2	1.5	1.4	185.9
Regulation and management of rivers and mountain streams [km]	205	280	299	232	38	52
Flood embankments [km]	204	78	110	240	25	69

It is worth noting the collapse of the funding system in recent years, which is evident in the data presented in Figures 2.2 and 2.3. Expenditure in 2016–2018 was around 50% of that in 2013–2015, having declined to levels seen a decade ago. The collapse is mainly due to the adopted model of investment financing (Fig. 2.4 and 2.5), which is largely based on EU funds and depends on the activity of investors in obtaining funds, as well as government policy in this area. Cyclical changes in the disbursement of EU funds coincide with the periods of successive budget perspectives.

In addition, during this period, the functioning of water management was affected by political changes resulting from parliamentary elections. In the event of investments in water and sewage management, this also coincided with the completion of a number of investments included in the National Municipal Wastewater Treatment Program, which was to be completed just by the end of 2015. In the event of hydrotechnical investments, the overall decrease in investment outlays (in addition to the reduction in foreign funding) was clearly influenced by the reduction in funding from the state budget and provincial budgets.

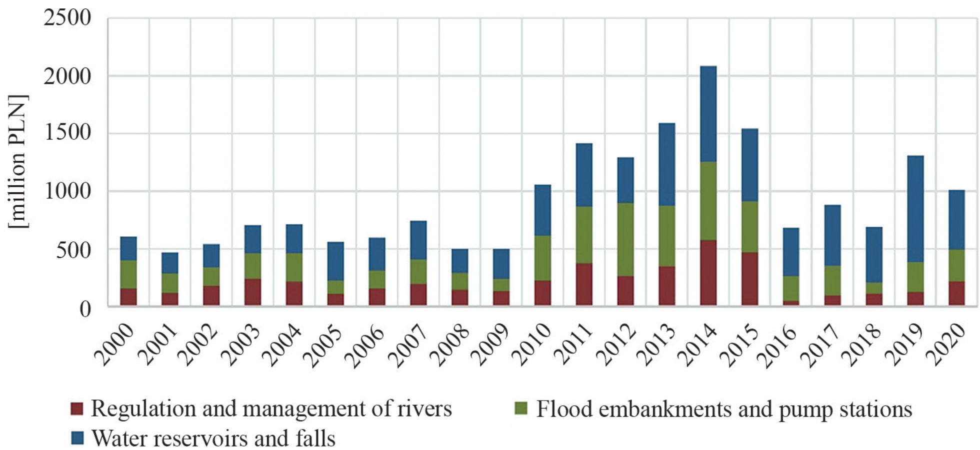


Fig. 2.2. Hydrotechnical investment expenditures (own study on the basis of [Statistics Poland 2021])

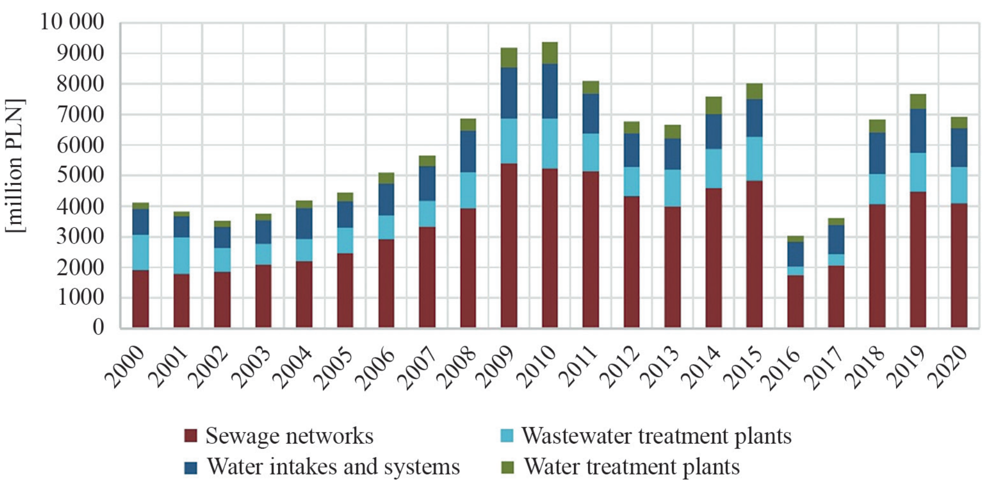


Fig. 2.3. Investment expenditures on water supply and wastewater treatment (own study on the basis of [Statistics Poland 2021])

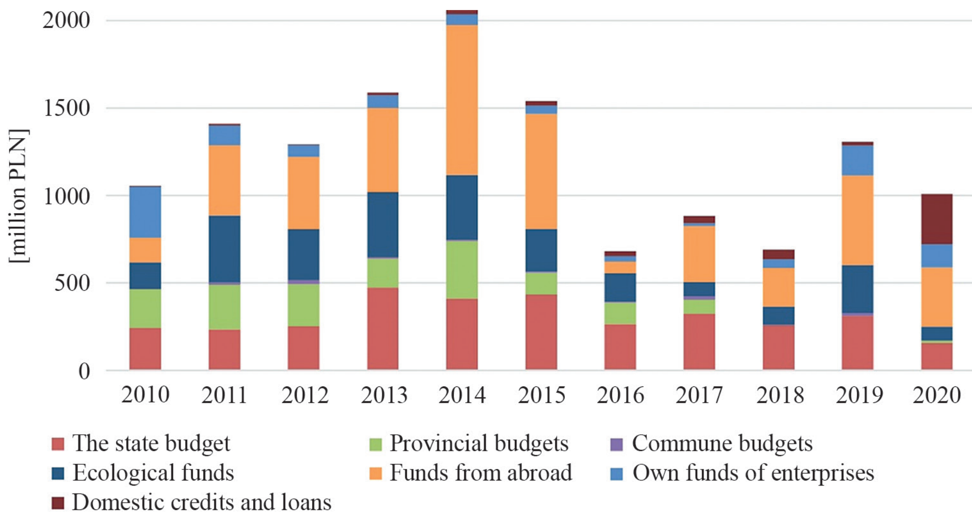


Fig. 2.4. Sources of funding for hydrotechnical investments (water reservoirs, river regulation, flood embankments and pumping stations) (own study on the basis of [Statistics Poland 2021])

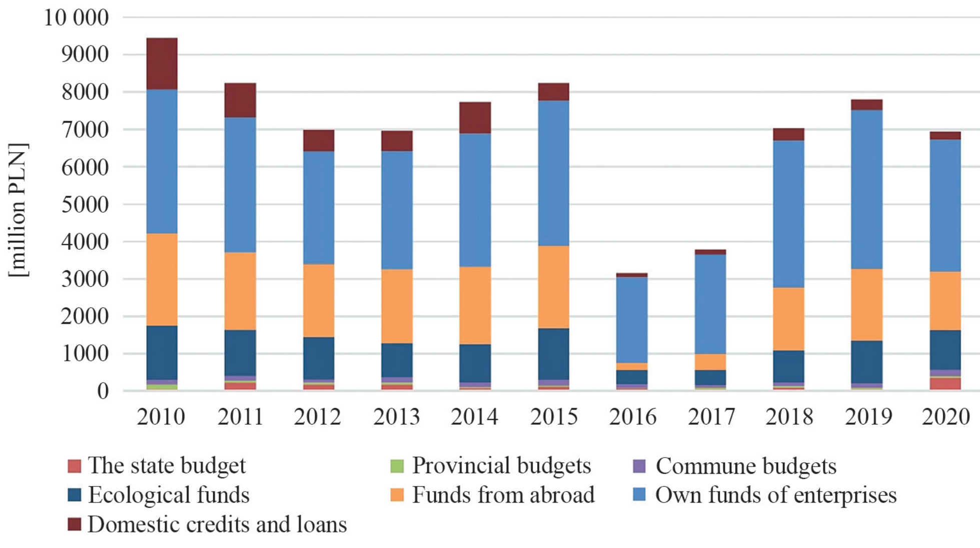


Fig. 2.5. The sources of financing investments in water supply and wastewater treatment (water intakes, treatment plants, water supply networks, wastewater treatment plants, sewage networks) (own study on the basis of [Statistics Poland 2021])

The data presented in the charts cover only three years (2018–2020) of operation of the new organisational and financial system, the introduction of which was supposed to ensure stable sources of funding for water management, including investments [Balcerowicz et al. 2021]. So far, in the financing of hydroelectric investments, it has not even been possible to reach the funding levels of ten years ago. The reduction in funding from the central budget and the lack of funding from provincial budgets (from which the now defunct provincial boards of drainage and water facilities were funded) resulted in a drastic reduction in investment, despite the urgent priority works to improve flood safety planned in the flood risk management plans to be undertaken in 2016–2021. Thus, the first years of the new funding system have not yet had the expected effect, but an overall assessment of such profound changes in water management will only be possible over the next few years.

2.3. Water management in river basins

Water resources management is implemented with consideration to the division of the country into **river basin areas, water regions and catchment areas**. In the territory of Poland, the following nine river basin areas have been distinguished for management purposes (Subchapter 1.1):

- **the Vistula river basin area which** includes, in addition to the Vistula basin situated within the territory of the Republic of Poland, the basins of the Słupia, Łupawa, Łeba, Reda and other rivers flowing directly into the Baltic Sea east of the Słupia mouth and also those flowing into the Vistula Lagoon;
- **the Odra river basin area** includes, in addition to the Odra basin located within the territory of the Republic of Poland, the basins of the Rega, Parsęta, Wieprza, Ücker and other rivers flowing directly into the Baltic Sea west of the Słupia river mouth and also those flowing into the Szczecin Lagoon;
- **seven river basin areas: Dniester, Danube, Banówka, Elbe, Neman, Pregoła, Świeża**, covering parts of international river basins situated in Polish territory.

Within the river basin areas, **water regions** have been identified and further divided for management purposes into **catchment areas** (Regulation of the Council of Ministers on catchment areas, which will assign them to the relevant water regions according to the hydrographical division of the country [Journal of Laws 2017a]).

The implementation of public tasks related to water management is entrusted to **the State Water Holding – Polish Waters**. Polish Waters have a hierarchical, 4-tier structure that is, with regard to area, based on the above hydrographical division of the country [Zaleski et al. 2021]:

I. central unit: National Water Management Authority, seated in Warsaw, which coordinates the work of the 2nd level;
II. eleven Regional Water Management Authorities with headquarters in Białystok, Bydgoszcz, Gdańsk, Gliwice, Cracow, Lublin, Poznań, Rzeszów, Szczecin, Warsaw and Wrocław, coordinating 3rd and 4th level works;
III. fifty catchment authorities;
IV. 330 water supervision facilities.

The boundaries of the areas and the seats of the Regional Water Management Authorities and the Catchment Authorities are shown on the map below (Fig. 2.6).

Fig. 2.6. Areas of operation of organisational units of Polish Waters (https://www.kzgw.gov.pl/index.php/pl/jednostki-organizacyjne/mapa-obszarow-dzialania)

The President of the National Water Management Authority is a higher authority in administrative proceedings than the Director of the Regional Water Management Authority. The National Authority performs planning and programming tasks as the most important water management planning documents are prepared at the river basin scale, while the plans that are prepared at the region level are under the supervision of the National Water Management Authority. The supervision of regional boards also includes the implementation of the investments and tasks entrusted to them. The prepared plans, together with other information concerning the water environment, are made available, inter alia, through an information system operated by the National Water Management Authority and the Hydroportal.

The most important tasks of the National Water Management Authority are:

- preparation of draft planning documents and their updates (river basin management plans, preliminary flood risk assessment, flood hazard maps, flood risk maps, flood risk management plans, drought management plans, environmental objectives for marine waters, programme for the protection of marine waters);
- co-authoring the National Municipal Wastewater Treatment Program, with the minister in charge of water management and its updating;
- operating the water management information system and the Hydroportal;
- the implementation of sustainable water management measures, including the achievement of environmental objectives in river basin areas;
- supervising the planning and implementation of investments in water management and tasks related to the maintenance of water and hydrotechnical facilities;
- conducting administrative cases in which the President of the Polish Waters acts as a higher-level authority in administrative proceedings.

Regional Water Management Authorities operate in the areas of water regions, perform water management tasks implemented at this level, plan, coordinate and supervise the implementation of tasks at the level of regions and basins. Regional boards also perform planning tasks by preparing documentation necessary to draw up plans in river basin areas.

The most important tasks of the regional boards are:

- managing cases concerning water permits (water permits and water permit assessments for investments that may have a significant impact on the environment, in closed areas, for the construction of flood-protection structures, for water transfers, etc.) and other decisions provided for in the Water Law Act, director of the Regional Water Management Authorities;
- preparation of draft planning documents and their updates (lists and characteristics of water bodies, the identification of anthropogenic impacts on water status, economic analyses of water use, etc.);
- planning of water maintenance tasks, projects related to the restoration of ecosystems degraded by the exploitation of water resources and the maintenance of inland waterways, which are then performed at a lower level by the catchment boards;
- supervising the activities of the catchment managements in this respect;
- undertaking measures to balance the quantity and quality of surface and groundwater;
- undertaking measures to provide water of sufficient quantity and quality for human, industrial and agricultural uses;

- acting as the regulatory authority for the approval of tariffs – prices and rates of charges for water and sewage in municipalities;
- collecting, processing and transmitting information for spatial planning and crisis management centres and cooperating with governors in the development of the provincial crisis management plan;
- analyse the reports of the municipalities on the implementation of the National Municipal Wastewater Treatment Program;
- providing opinions and consultations on a number of decisions, legal acts and planning documents, e.g. concerning bathing waters, protective zones of water intakes, spatial planning documents and decisions, and waste management plans, mainly with regard to their connection with water management.

At the level of the catchment boards, responsibility for the maintenance of waters, including dikes, inter-dikes and inland waterways is implemented. The catchment boards plan and conduct water management investments and ecosystem restoration projects as well as conservation measures in public waters that result from the Natura 2000 plans. They are the competent authority for water permits and for issuing a number of administrative decisions under water law. The catchment boards also manage matters relating to water service charges, increased charges, dues and other payments.

At the lowest level in the water boards, tasks of maintenance and operation of water facilities are performed. Due to their number (330 supervisor facilities), they are the most accessible to the parties, thus they accept applications for water permits and other decisions provided for in the water law. As far as water permits are concerned, they are also the competent authority for matters relating to water permit notifications, which include activities that may affect water resources.

2.3.1. Planning

The purpose of planning in water management, according to the Water Law, is:

- achieving or maintaining a good status of water and water-dependent ecosystems and protecting, enhancing and preventing further deterioration of aquatic, terrestrial and wetland ecosystems;
- improving water resources;
- promoting sustainable water use based on the long-term protection of available water resources;
- reducing the inputs of substances and energy which may have a negative impact on the waters or the ground;
- improving flood protection and combating the effects of drought.

The achievement of the above-mentioned objectives requires the programming of appropriate measures, which is realised by preparing the following planning documents (concerning inland waters):

1) river basin management plans (RBMP),
2) flood risk management plans (FRMP),
3) drought effects counteracting plan,
4) water maintenance plans,
5) preliminary flood risk assessment (PFRA),
6) flood hazard maps (FHM),
7) flood risk maps (FRM).

River basin management plans (RBMP) and flood risk management plans (FRMP) are plans resulting from EU directives, which member states are obliged to produce within a certain scope and timeframe and send to the European Commission. The principle of **iterative** planning has been adopted, planning documents are subject to cyclical review and update (every six years) – the planning and implementation cycle includes state identification, scheduling and action plan setting, implementation and monitoring, and implementation review, evaluation and re-planning [Godyń et al. 2021].

The most important plans in the field of water management are **the river basin management plans, as their task is to establish the principles of formation**, protection and use of water resources, as well as to develop a programme of measures which will ensure the achievement and maintenance of a good condition of all waters and ecosystems dependent on them. The following planning documents are prepared for the RBMP:

– the characterisation of bodies of water, indicating artificial and heavily modified bodies of water and bodies of water which are at risk of failing to meet environmental objectives;
– the identification of significant anthropogenic impacts and the assessment of their influence on surface water and groundwater status;
– the identification of impacts of changes in groundwater levels;
– lists of protected areas (e.g. designated for public water supply, bathing waters, sensitive to eutrophication from urban sources);
– economic analyses related to water use;
– water monitoring programmes;
– lists of emissions and concentrations of priority substances and other substances which cause water pollution.

On the basis of the above documents, and on the basis of the results of water monitoring and the review of the implementation of measures from the previous planning cycle, programmes of measures for individual water bodies and protected areas are developed, which aim to ensure the achievement of the established environmental objectives.

The catalogue of corrective actions includes both technical and supporting non-technical measures, which, if appropriately selected for each waterbody, will allow:

– the achievement of the environmental objectives by 2027 for the water bodies for which a good status has not been established,
– the maintenance of a good status in the water bodies that have achieved good status.

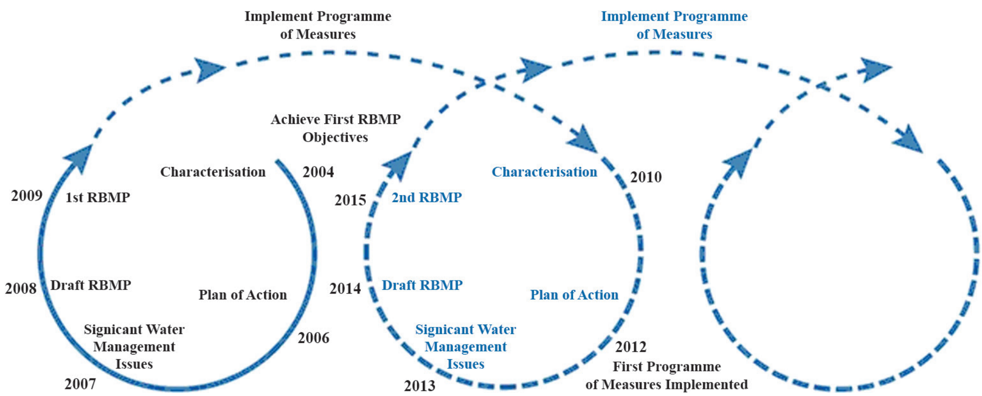


Fig. 2.7. The process of preparing water management plans for river basin areas (Scottish Government 2007)

RBMP also lists water bodies for which a derogation from the attainment of environmental objectives is established (e.g. postponement in time or setting lower values to be met), but this needs to be justified by a lack of technical feasibility or disproportionately high costs or natural conditions.

According to the latest draft of the RBMP update, measures for river water bodies *focus on* [SWH-PW 2021]:

○ restoring the permeability of rivers for fish migration,
○ restoring the connection between the riverbed and the inundation areas in the river valley,
○ improving the morphological (habitat) conditions in the riverbed and the water flow to improve living conditions for aquatic organisms,
○ improving water quality and reducing the input of pollutants from agriculture, municipal and industrial wastewater,
○ meeting the requirements necessary for natural protected areas.

Measures for reservoir and lake water bodies are also of a similar nature, with the main actions being to reduce the inflow of pollutants, restore permeability and improve habitat conditions. The catalogue of measures includes a number of technical measures in the field of municipal management (mainly further implementation of the National Municipal Wastewater Treatment Program) and measures such as the elimination of migration barriers, the construction of culverts, the restoration of biotopes, re-naturalisation measures and other measures. With regard to non-technical measures, their catalogue is also very broad and provides for educational and information activities, as well as control activities concerning: agricultural activity (nitrate contamination, good agricultural practice), water management, including reviews of water permits, the verification of commune and district environmental protection programmes. In contrast, measures to achieve environmental objectives in groundwater bodies are mainly non-technical, including the development of resource documentation.

RBMP is the basic planning document in the field of water resources management, its findings serve to shape and protect water resources on the river basin area, it also establishes the principles of water resources management. The developed measures are to achieve or maintain at least a good condition of waters and ecosystems dependent on waters and to ensure the possibility of using waters for the population and the economy. An important effect of the RBMP measures is to reduce the amount of pollutants, including priority substances, which may have a negative impact on waters and ecosystems dependent on them. RBMP also includes measures resulting from other water management plans, ensuring the improvement of flood safety and counteracting the effects of drought.

The most important planning document for flood protection is **the flood risk management plan (FRMP)**. Flood risk management plans are the final outcome of the entire flood protection planning process, which also includes: preliminary flood risk assessment (PFRA), flood hazard maps (FHM) and flood risk maps (FRM). The flood risk management plan identifies **the best strategies for flood risk reduction** [Godyń et al. 2021]. All these documents are produced in six--year cycles and are subject to review and update as part of subsequent cycles – as shown in Figure 2.8.

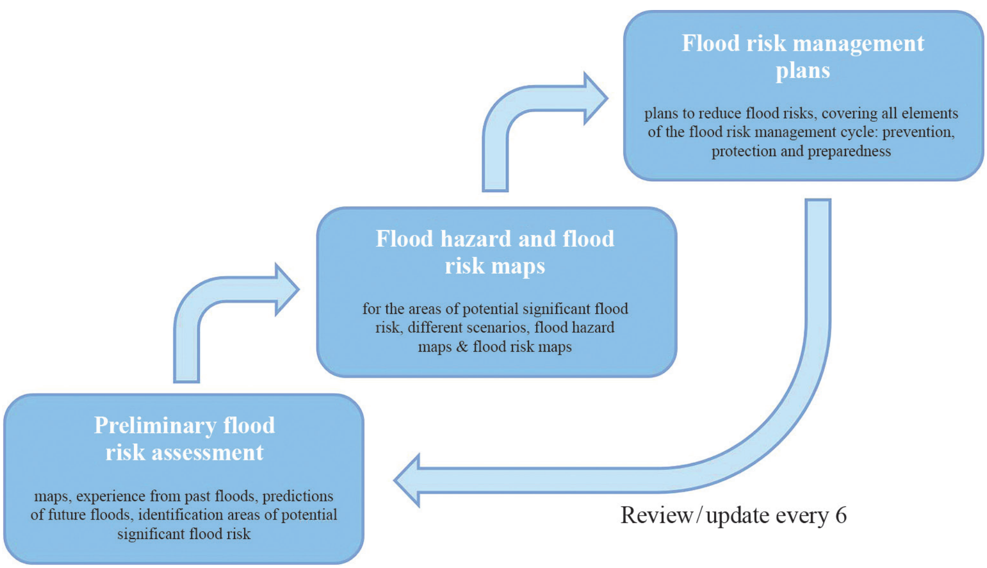


Fig. 2.8. Planning cycle in flood risk planning (Flood risk management planning in Finland…)

The preliminary flood risk assessment, as its name implies, identifies, on the basis of historical data, areas that have experienced flooding and for which further analyses are required in order to accurately estimate the flood hazard and risk. Such an estimate is conducted by means of mapping analyses and flood modelling in the areas delineated in the preliminary flood risk assessment, which results in the production of flood hazard maps defining the extent of flooding and water depths and flood risk maps defining the risk (number of inhabitants at risk, types of buildings, potential losses).

For the areas at risk of flooding thus identified, flood risk management plans and flood risk reduction measures shall be developed. The selection of measures in the FRMP shall depend on the level of risk in the area concerned and the specific characteristics of the site, the applicability of technical and non-technical solutions, and the objective – the desired reduction in the level of risk in the area concerned. The planning of appropriate measures shall be conducted by means of the option analyses of flood risk reduction strategies (modelling of different technical and non-technical solutions and their impacts on flood risk). Options shall be subjected to an economic assessment of their effectiveness through a cost-benefit analysis and a comprehensive multi-criteria analysis that considers the impacts/effects of the options from the economic, social, environmental and flood risk management perspective. The environmental analyses/criteria shall take into account, inter alia, the impact of the planned measures on the environmental objectives related to the achievement of good status of water and water-dependent ecosystems. The main steps in producing analyses for flood risk management plans are shown below in Figure 2.9.

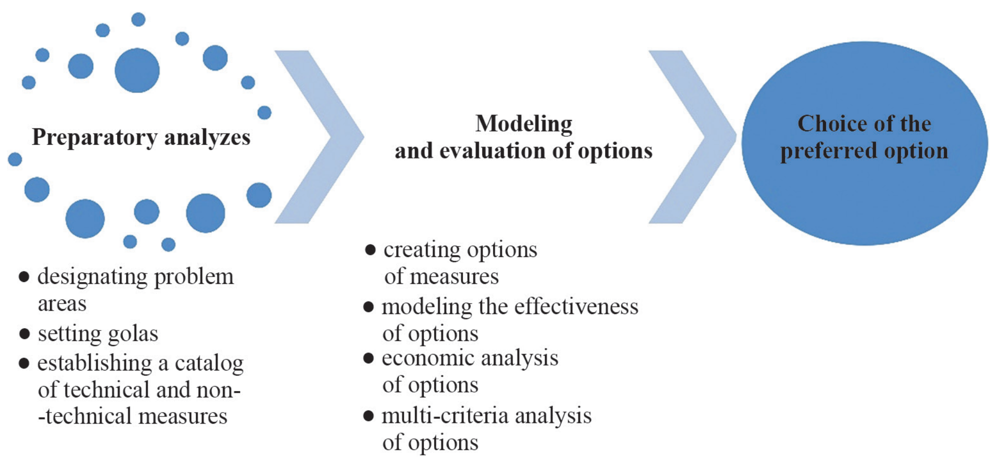


Fig. 2.9. The main steps in the development of the flood risk management plan (Godyń et al. 2021)

Up until 2022, the following plans have been prepared:

- River basin management plans RBMPs:
  - The first was completed in 2011.
  - The first update of the plans occurred in 2016.
  - The second update of RBMPs was prepared as part of the third planning cycle from 2016 to 2021. As part of the work, the following were reviewed and updated: lists of protected areas, identification and analysis of pressures and impacts, environmental objectives. Furthermore, draft water management plans were developed (public consultation was completed in 2021, the consideration of comments and creation of final versions will occur in December 2022), including the development of a set of actions necessary to achieve the environmental objectives.
- Flood risk management plans:
  - The first planning cycle was PFRA 2011, FHM and FRM 2015.
  - The second planning cycle – updating documents and maps: PFRA 2018, FHM and FRM 2019, FRMP drafts were developed in 2020–2021 (public consultation was completed in 2021 and consideration of comments and creation of final versions will occur in December 2022).

2.3.2. Monitoring and assessment of the status of the water resources

Water management – particularly with regard to the shaping and protection of water resources – and water use require water monitoring that provides information on water status and its changes. Surveys and assessments of water status are the basis for planning measures necessary to improve its status and to protect it against pollution, including eutrophication caused by pollution from agriculture and industrial pollution by substances particularly harmful to the aquatic environment.

Surveys and assessments of surface water status, groundwater status, environmental status of marine waters and water status of protected areas are conducted within the framework of state environmental monitoring.

State environmental monitoring is conducted on the basis of a programme – the current *Strategic Environmental Monitoring Programme for 2020–2025* was developed by the Chief Inspector of Environmental Protection and approved by the Minister of Climate in 2020 [GIOŚ 2020a]. The principles of monitoring in terms of the research and assessment of water status are regulated by the Water Law Act and its implementing regulations [Polish Official Gazette 2019; Journal of Laws 2019, 2021a, 2021b], which transpose EU legislation, mainly including the requirements of the Water Framework Directive.

State monitoring is conducted by the Inspectorate for Environmental Protection. The bodies responsible for state environmental monitoring are the Chief Inspector for Environmental Protection, who supervises and coordinates the implementation of tasks of state environmental monitoring and also performs tasks at the national level, and the provincial environmental protection inspectors, who perform tasks at the provincial and local level. In addition, as far as water condition monitoring is concerned, studies and assessments are conducted by the state hydrological and meteorological service (studies of hydrological and morphological water elements) and the state hydrogeological service (studies and assessments of groundwater condition with regard to physicochemical and quantitative elements).

Within the framework of state environmental monitoring, water quality monitoring is distinguished, which includes:

- the surface water quality monitoring subsystem:
  - tasks relating to the study and assessment of surface water quality:
    - studies on the state of rivers, including dam reservoirs,
    - studies on the state of lakes,
    - studies on the quality of bottom sediments in rivers and lakes,
    - studies on the status of transitional and coastal waters,
    - observations of hydromorphological elements for the classification of ecological status/potential of surface waters,
    - regional and river basin assessments of biological, physico-chemical, hydromorphological and chemical elements,
    - monitoring of priority substances,
    - assessment of the eutrophication of waters,
  - programmes that are implemented as a result of environmental conventions and international agreements signed by Poland:
    - monitoring of rivers flowing into the sea and the Kaliningrad area for the HELCOM Pollution Load Compilation programme,
    - monitoring of transboundary waters,
- groundwater quality monitoring:
  - studies on the chemical status of groundwater bodies,
  - development of comprehensive assessments of the status (chemical and quantitative) of groundwater bodies,
  - development of assessments of groundwater pollution by nitrates,
- Baltic Sea monitoring.

2.3.3. Structure of the surface water monitoring network

The subjects of monitoring are surface waters in separated so-called surface water bodies (total number of 5643), among which the following types of surface water bodies are distinguished: river waters (3116), reservoir waters (45), lake waters (1067), coastal waters (4) and transitional waters (7). There are four types of monitoring of surface water bodies: diagnostic, operational, research and protected areas.

Diagnostic and operational monitoring aims to provide information allowing assessment of the status of surface water bodies and meeting the basic environmental objective of the Water Framework Directive, which is to achieve at least a good status. Research monitoring is conducted in order to clarify the reasons for the failure to meet the environmental objectives if the data and information from the diagnostic and operational monitoring are insufficient. The monitoring of protected areas shall aim at assessing the fulfilment of the additional requirements established to meet the environmental objectives for protected areas:

- used for the supply of water intended for human consumption,
- intended for recreational use, including swimming,
- sensitive to eutrophication caused by pollution from urban sources,
- located in Natura 2000 sites and other protected areas dependent on surface water quality,
- intended to protect aquatic animal species of economic importance.

Surveys and assessments of surface water status are conducted at measurement and control points and monitoring does not cover all water bodies. The location of the points is based on water lists, updated water body characteristics and emission inventories. The measurement network used for diagnostic monitoring enables the study and assessment of water status in each river basin area.

The assessment of surface water status shall be conducted by assessing:

- **the ecological status** (ecological potential if the water is artificial or heavily modified) of surface water bodies on the basis of analyses of biological elements and supporting physico-chemical and hydromorphological indicators;
- **the chemical status** of bodies of surface water based on an analysis of results of measurements of chemical pollutants, including so-called priority substances.

2.3.4. Structure of the groundwater monitoring network

The subject of monitoring is 174 groundwater bodies, in accordance with *the Update of the monitoring programme for groundwater bodies in the river basin system for 2020–27*, the following types of groundwater monitoring are conducted [PGI-NRI 2020a]:

- chemical status monitoring,
- quantitative status monitoring,
- research monitoring.

The observation and research network for groundwater monitoring in the period 2022–2027 includes 1396 points for the monitoring of the chemical state and 1098 points for the monitoring of the quantitative state.

The monitoring of the chemical status of the water bodies is conducted through:

1) diagnostic monitoring of chemical status, with the aim of:
   - ✓ the completion and verification of the procedure for the assessment of anthropogenic impacts,
   - ✓ the provision of information to assess long-term trends due to both changes in natural conditions and anthropogenic impacts.
2) operational monitoring of chemical status, with the aim of:
   - ✓ the assessment of the chemical status of water bodies identified as being at risk of not achieving the environmental objectives specified for them,
   - ✓ the identification of significant and sustained upward trends in pollutant concentrations due to anthropogenic impacts.

The quantitative status monitoring of a water body is established in order to assess the quantitative status of the water body, including the determination of the reserves of available groundwater resources and the analysis of the location of the groundwater table for each body of water.

Research monitoring of water bodies or parts thereof are established in order to achieve the following objectives:

1) an explanation of the reasons for failure to achieve the environmental objectives established for the relevant water bodies in so far as the explanation of the reasons is not possible on the basis of data and information obtained from measurements or investigations conducted as part of the monitoring of the quantitative status or the monitoring of the chemical status of the water bodies;
2) the identification of the type, concentration and extent of the pollution if there has been or there are indications that there is a risk of pollution of the water body;
3) the identification of the extent of any significant deterioration in groundwater levels that would entail a risk that the environmental objectives for the relevant watercourse will not be achieved.

3. The impact of development and climate change on water resources

International experience to date indicates that the socio-economic and environmental impacts of climate change should be analysed in the context of development, particularly development pressures on water resources. Only this approach can realistically assess the impact of climate change on water resources. However, at this stage, it is not only in Poland that the effectiveness of analyses and evaluations in this field is low due to the fact that: he general recognition of the problem is known, but the detailed regional and local approach to the issue is still an open problem.

In this section of the monograph:

– summarized the results of research on the level of climate change and their impact on the dynamics of surface water runoff in Poland against the background of European analyzes and assessments;
– reference is made to the impact of development and development pressures on changes in the structure and regime of runoff;
– an approach to climate change adaptation in urban (highly urbanised) areas for the protection of water resources is presented as part of the Urban Adaptation Plans to climate change in Poland.

3.1. The level of climate change and assessment of its impact on surface water dynamics in Poland

The following data sources were used here:

1) European Environmental Agency databases [EEA 2021] and national meteorological and hydrological data sources;
2) JRC Technical Report *Impact of changing climate, land use, and water usage on Europe's water resources*, published by the European Commission in 2018, EUR 29130 EN [JRC 2018];
3) A monographic study entitled *Climate change and its impact on selected sectors in Poland*, published under the editorship of Z.W. Kundzewicz, O. Hov and T. Okruszko [Kundzewicz et al. 2017], prepared as part of the CHASE-PL project (Assessment of Climate Change Consequences for Selected Sectors in Poland) realised under the Polish-Norwegian Research Cooperation programme, led by the National Centre for Research and Development.

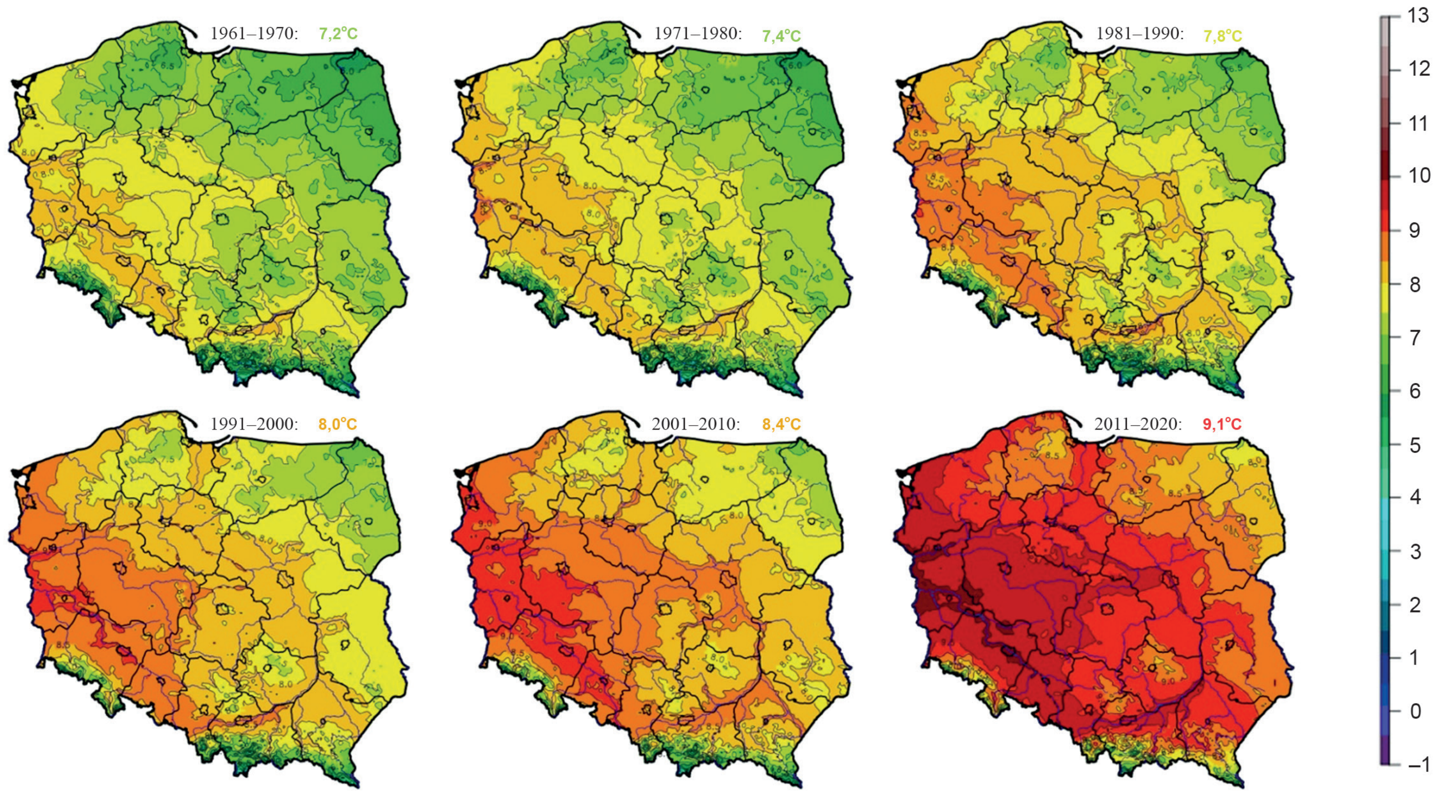


Fig. 3.1. Average annual temperatures in Poland in the following decades, taking into account their spatial distribution throughout the country (https://naukaoklimacie.pl of 20.02.2022)

The source of anticipated changes in the dynamics of surface water runoff is climate change, the primary measure of which is an increase in average air temperature. It is affected by seasonal and local variations in air temperature, which result in changes in humidity and consequently in precipitation dynamics. This sequence of events creates significant natural hazards associated with water scarcity (droughts) and water excess (floods).

The first questions relating to this issue concern the reality and level of significance of changes in annual average air temperature, so as to dispel doubts about the real risks of climate change.

The analyses of meteorological data conducted in Poland unequivocally confirm a systematic increase in air temperature over the last 60 years. According to online data [https://danepubliczne.imgw.pl, https://naukaoklimacie.pl], the average air temperature in the area of Poland in that period increased from 7.2°C (the decade of 1961–1970) to 9.1°C (the decade of 2011–2020).

This increase is not evenly distributed, as the thirty-year period between 1961 and 1990 was a period of low urbanisation and industrial sources of high carbon dioxide emissions. During this period, the average air temperature in the following three decades increased from a value of 7.2°C to a value of 7.8°C.

The following thirty years, 1990–2020, was a period of social and economic transformation in our country, accompanied by an intensive development of urbanisation, including a significant increase in the length of roads – mainly express roads – and an increase in wheeled transport for the carriage of goods, as well as a significant intensification of agriculture and agricultural processing. During this period, in thirty years the average air temperature in the following three decades, increased from a value of 8.0°C to a value of 9.1°C.

Apart from other mainly natural factors that influence periodic changes in air temperature, it is impossible to deny the fact that we are observing systematic climatic changes that have been triggered by the development of civilisation. This is also evidenced by the changes in the spatial distribution of this temperature in the regional structure of Poland which accompany changes in average air temperature.

This is shown in Figure 3.1. It shows that the average increase in air temperature in successive decades is accompanied by a change in the spatial structure of air temperature variation. There is a definite reduction in areas with temperatures below 7°C or even 8°C. This includes mountainous areas in the south of the country as well as lake regions in the north and east of the country.

As can be seen in Figure 3.1, the maximum area temperatures in the western part of Poland have exceeded 10°C and even 11°C in the last decade. This is a distinct difference from the past. Until now, according to observations made since the nineteenth century, the average annual temperature generally did not exceed 10°C locally. Only in 1934, when the average annual temperature in Poland reached 9°C, did Wrocław, Szczecin, Poznań and Zielona Góra record an average annual temperature of 10.0–10.2°C.

The consequence of the above-mentioned changes in air temperature are changes in the dynamics of surface-water runoff, caused mainly by the increasing frequency of rapid and high short-term precipitation, especially in urban areas, as well as the increasing number of days with high air temperature during the year, which has an impact on the worsening hydrological droughts in n an increasingly large part of the country. For example, Figure 3.2 shows a systematic increase in the number of days with a mean air temperature above 30°C with the decadal moving average. In the thirty-year period between 1961 and 1990 (the period before intensive urbanisation), the average annual number of days with such high temperatures was 3.5 days, and in the decade between 2011 and 2020, it reached 10.4 days.

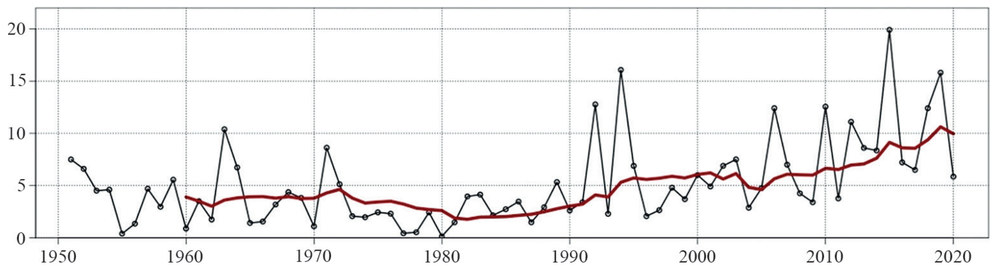


Fig. 3.2. Number of days with maximum daily temperature T_{max} >= 30°C in 1951–2020 and 10 year moving average (https://naukaoklimacie.pl, 20.02.2022)

This has a significant negative impact on Polish agriculture and requires intervention and long-term actions to reduce the effects of drought [NIK 2020].

However, as in other countries, we are interested in predicting the effect of climate change on surface water runoff conditions over the coming decades, the 2070 and 2100 horizons. Such projections of change in European and global analyses have been based on projections of the increase in mean annual air temperature under conditions of the implementation of development scenarios forcing a limitation of greenhouse gas radiation to a certain level of radiation, measured in W/m^2. These are the so-called RCP (*Representative Concentration Pathways*) scenarios recognised by the Intergovernmental Panel on Climate Change (IPCC) as representative for analysis and forecast assessments for European regions. The projection results contained in recent reports [JRC 2018] are based on analyses of two out of a base of four RCP (*Representative Concentration Pathways*) scenarios considered by the Intergovernmental Panel on Climate Change (IPCC) to be representative of current economic opportunities. These are scenarios RCP 4.5 and RCP 8.5 which set the estimated radiative forcing by greenhouse gases in the year 2100 to values not exceeding 4.5 and 8.5 W/m^2, respectively.

The reference period for assessing the impacts of climate change for these scenarios is 1981–2010. A thirty-year projection of global change from 2071 to 2100 was analysed, assuming a pessimistic RCP 8.5 scenario. It is assumed that by as early as around 2040 (analysis period 2026–2055) there will be a global average air temperature increase of 2°C, and between 2071 and 2100, the temperature will rise to 3–4 and locally even 6.2°C.

Below, Figure 3.3 for these conditions presents the increase in mean annual precipitation over the period (2026–2055) when the global temperature increase reaches 2°C.

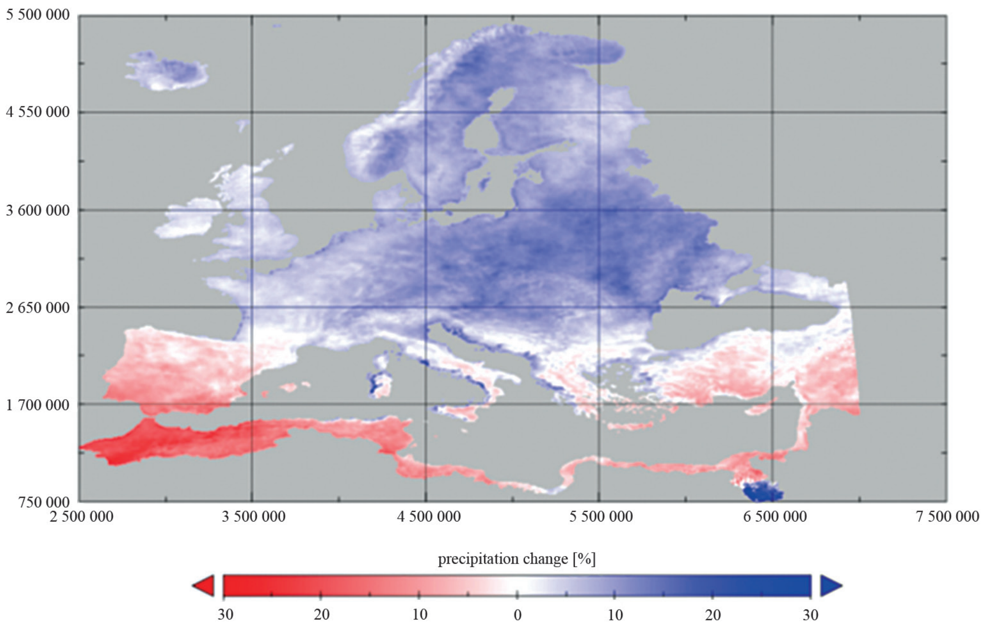


Fig. 3.3. Projection of changes in mean annual precipitation over Europe with a 2°C increase in global air temperature (JRC 2018). Color red – precipitation decrease, blue – precipitation increase

This projection was quoted from the Technical Report *Impact of changing climate, land use, and water usage on Europe's water resources* [JRC 2018], and was derived from eleven forecasting models as an average result from these forecasts.

As can be observed from this illustrative projection map, Poland lies in an area of increase in average annual precipitation of between 5% and even 20%. The entire country shows an increase in precipitation. Changes in our country can be expected to be in line with the European average in terms of values, with higher growth in the southern regions.

These changes correspond to the percentage changes in mean stream (fluvial) flows shown in Figure 3.4.

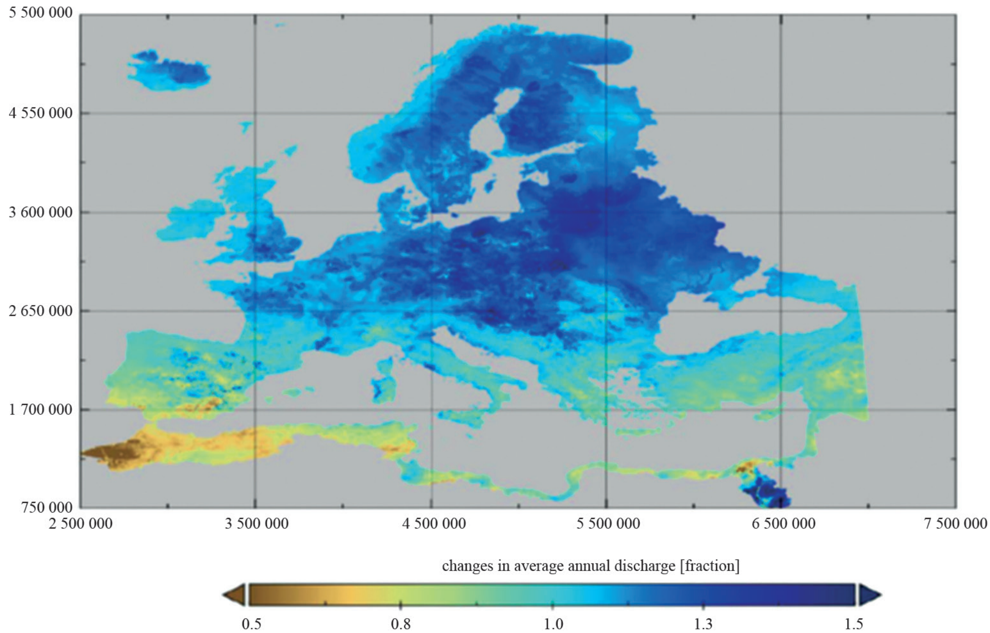


Fig. 3.4. Projection of the change in mean stream flow (fluvial) for a climate with an increase in air temperature of 2°C compared to the historical period 1981–2010. Values above 1 indicate increases in stream flow and water availability and values below 1 indicate decreases (JRC 2018)

As shown in Figure 3.4, the central belt of Poland's lowlands does not show much change. In contrast, a significant increase in stream flow is predicted in the northern and southern areas, which also means an increase in high flow values and a decrease in low flow values. Consequently, this will have a significant impact on flood risk, as shown in Figure 3.5 for the two instances of increased mean air temperature. The southern and western parts of Poland will be subject to a much higher flood risk.

The above data were confirmed by national, detailed analyses, as part of the CHASE-PL project *Assessment of the consequences of climate change for selected sectors in Poland* [Kundzewicz et al. 2017]. Below, Table 3.1 shows the key results of the projections of temperature and precipitation changes in our country for the two RCP scenarios, RCP 4.5 and RCP 8.5.

As can be seen, the prospect of an increase in average air temperature, both annual and seasonal, is inevitable and corresponds to the predicted global scenarios in this respect. This will significantly worsen the drought problems in Poland. Already, the number of days with highest and high air temperatures has nearly tripled compared to the previous period. Long dry periods occur and there is a growing problem of so-called heat islands in cities. At the same time, the development of urban agglomerations contributes to the deepening of this phenomenon. Without appropriate measures to limit the impact of climate change on the increase of the impact of heat islands as well as measures to limit the impact of urban development on the adverse changes in water relations in the medium and long term, these adverse processes will worsen.

Table 3.1

Summary of projected mean annual changes in air temperature and precipitation over Poland, under RCP 4.5 and RCP 8.5 scenarios, in the horizons 2021–2050 and 2071–2100 (Kundzewicz et al. 2017)

Time horizon	Scenario	Winter December–February	Spring March–May	Summer June–August	Autumn September–November	Annual
(a) Temperature changes (°C) – DD projection						
2021–2050	RCP 4.5	+1.2	+1.0	+1.0	+1.1	+1.1
		(+0.4; +1.9)	(+0.6; +1.7)	(+0.7; +1.4)	(+0.6; +1.6)	(+0.7; +1.4)
	RCP 8.5	+1.6	+1.3	+1.1	+1.3	+1.3
		(+0.5; +2.5)	(+0.9; +2.0)	(+0.7; +1.3)	(+0.6; +1.8)	(+0.8; +1.8)
2071–2100	RCP 4.5	+2.5	+2.0	+1.7	+1.8	+2.0
		(+1.1; +3.3)	(+1.1; +2.8)	(+1.3; +2.3)	(+1.4; +2.4)	(+1.4; +2.5)
	RCP 8.5	+4.5	+3.2	+3.1	+3.5	+3.6
		(+3.8; +5.3)	(+2.5; +4.0)	(+2.5; +3.9)	(+2.7; +4.2)	(+3.0; +4.1)
(b) Evolution of precipitation (%) – DD projection						
2021–2050	RCP 4.5	+8.4	+7.6	+3.8	+5.6	+5.9
		(+2.4; +16.5)	(+2.0; +14.0)	(+2.3; +8.8)	(+2.3; +13.8)	(+3.54; +9.2)
	RCP 8.5	+13.2	+10.5	+4.7	+6.8	+8.0
		(+6.0; +22.0)	(+0.5; +22.9)	(+0.2; +11.0)	(+1.0; +15.0)	(+5.0; +11.0)
2071–2100	RCP 4.5	+18.4	+14.8	+4.0	+6.5	+9.7
		(+12.0; +27.0)	(+7.0; +23.0)	(+7.0; +12.0)	(0.0; +12.0)	(+6.0; +13.0)
	RCP 8.5	+26.8	+26.4	+5.2	+13.1	+15.7
		(+18.0; +35.0)	(+16.0; +39.0)	(-5.0; +15.4)	(-0.6; +25.0)	(+9.0; +23.0)

The percentage increase in average annual precipitation is clearly seasonally differentiated, shifting the highest values towards the winter months. Nevertheless:

- an increase in average precipitation between 5.9% and 8.0% in the 2050 perspective and between 9.7% and 15.7% in the 2100 perspective is conducive to a significant increase in flood risk as well as an increase in frequent, rapid and short-term precipitation in urban areas;
- the high percentage increase in precipitation in spring, summer and autumn represents a potential increase in the flood risk of less frequent floods caused by torrential precipitation which usually covers significant areas of the country.

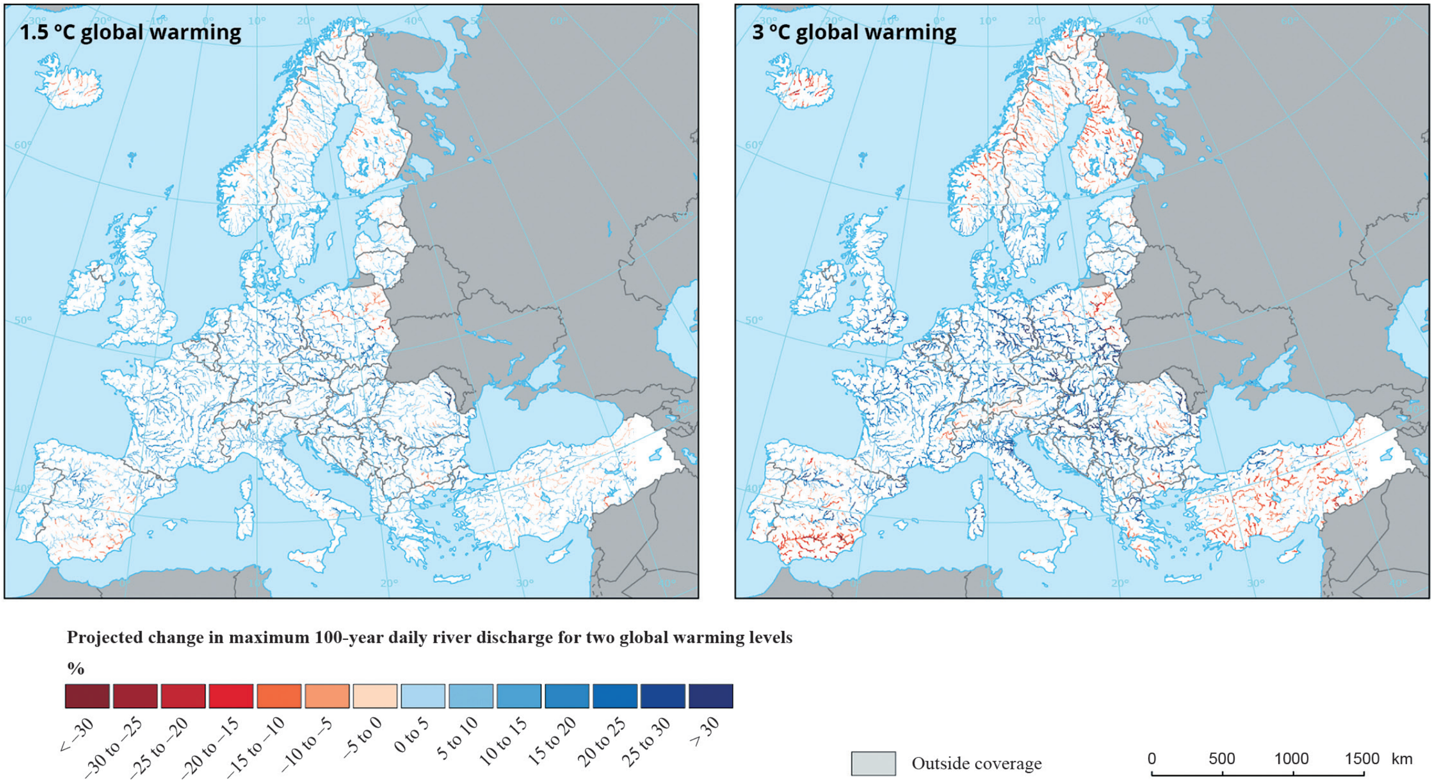


Fig. 3.5. Relative change in maximum 100-year daily river discharge for two global warming scenarios (1.5°C and 3°C) (https://www.eea.europa.eu/data-and-maps/indicators/river-floods-3/assessment, 20.02.2022)

Figure 3.5 shows global scenarios for the increase in intensity of 100-year floods for two values of the increase in mean air temperature. As can be seen, the area of Poland varies in this respect. In both instances, an increase in flood intensity is mainly observed along the Vistula and Odra, and highest in the south of the country. This is justified by the regional specificity of Poland. Drought-prone areas will dominate in central and north-eastern Poland.

3.2. The impact of development pressures on the structure and discharge regime of water

Urbanisation is the second factor that has a significant impact on the adverse change in the structure and regime of water runoff. It causes an increase in surface runoff due to a reduction in the natural infiltration of rainwater. This results in a significant acceleration and increase in the volume and culmination of surface storm water runoff. On the other hand, during dry periods, it causes hydrological lows to deepen. This is schematically shown in Figure 3.6.

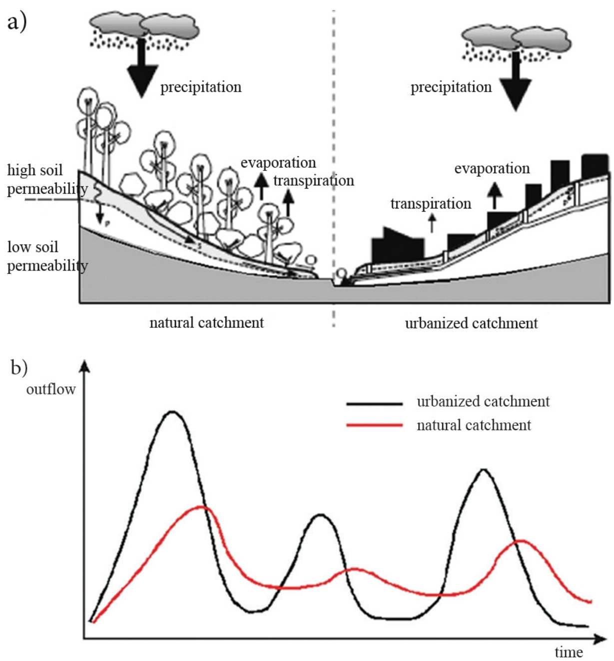


Fig. 3.6. Result of urbanisation pressure: a) changes in water relations, b) effect of changes in rainwater runoff

Urbanisation is associated with land use change and development not only in urban areas but also in suburban areas and under conditions of road development.

This generates pressure on the runoff structure due to the sealing of the catchment area as a result of reduced soil infiltration of precipitation as well as reduced plant evapotranspiration through the reduction of green areas. An additional factor accelerating the runoff is the canalisation of rainwater and the discharge of its excess directly into river receivers.

Both phenomena, excess and deficient runoff, are unfavourable and dangerous. However, recent years have shown that with the intensification of heavy rainfall, the lack of effective storm water drainage has become a serious problem. Figure 3.7 presents the effect of the percentage sealing of the catchment area on the increase in the rainfall-runoff coefficient, ranging from lowest (occurring every two years) to highest (occurring once every 100 years), corresponding to a probability of 1% of the event. These are the results of American research in areas subjected to urbanisation, for soil types C and D. In Polish nomenclature, this corresponds to clay and silt soils with below-average permeability (C) and low permeability (D), facilitating the generation of surface runoff under precipitation conditions.

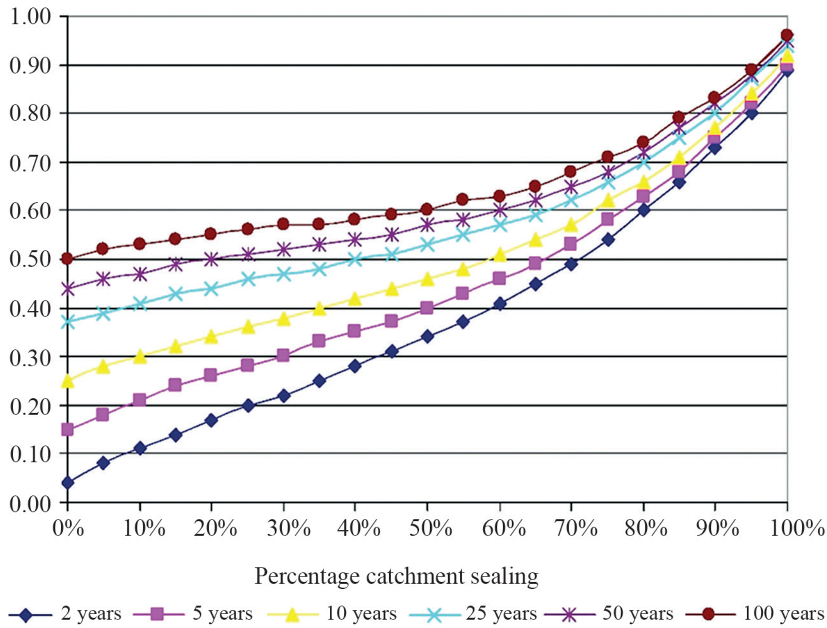


Fig. 3.7. Influence of percentage catchment sealing on runoff coefficient for specific precipitation characteristics for category C and D soils (Godyń et al. 2021)

As can be seen, for the highest rainfall, the runoff coefficient increases by a factor of two, but for average and lower rainfall, this increase reaches multiples of 3–5, which is a very serious problem. The level of the sealing of catchment areas in urban areas varies, on average, from 40% to 75%.

Urbanisation is a factor with an impact on water relations as old as the history of urban development. However, the intensity of development has increased many times in recent decades. This is accompanied by intensifying climate change which, when integrated with development pressures, is creating unprecedented water problems. This applies to both the excess and the lack of water.

The level of urbanisation, for global uniformity, is measured worldwide by the percentage of the population living in urban areas. However, given the current scope and pace of development, urbanisation is an advanced economic process. As mentioned, in the sphere of development, it concerns not only urban development but also municipal and transport infrastructure.

In Poland, a noticeable increase in urbanisation has been recorded since the late 1990s. Notwithstanding the fact that the population living in urban agglomerations remains at around 60%, the intensity of development is high and rising. This is primarily related to the development of the cities' technical infrastructure.

Systematic European analyses, the results of which are included in the JRC Technical Report *Impact of changing climate, land use, and water use on Europe's water resources* [JRC 2018], indicate that urbanisation pressures will continue. Forecasts to 2050 show an increase in the urban population relative to non-urban areas. This also applies to Poland. Figure 3.8 shows the result of this prediction, on a grid with a resolution of 25 km × 25 km. The population increase of urban areas at the expense of that of others is clearly indicated. As can be seen, in Poland,

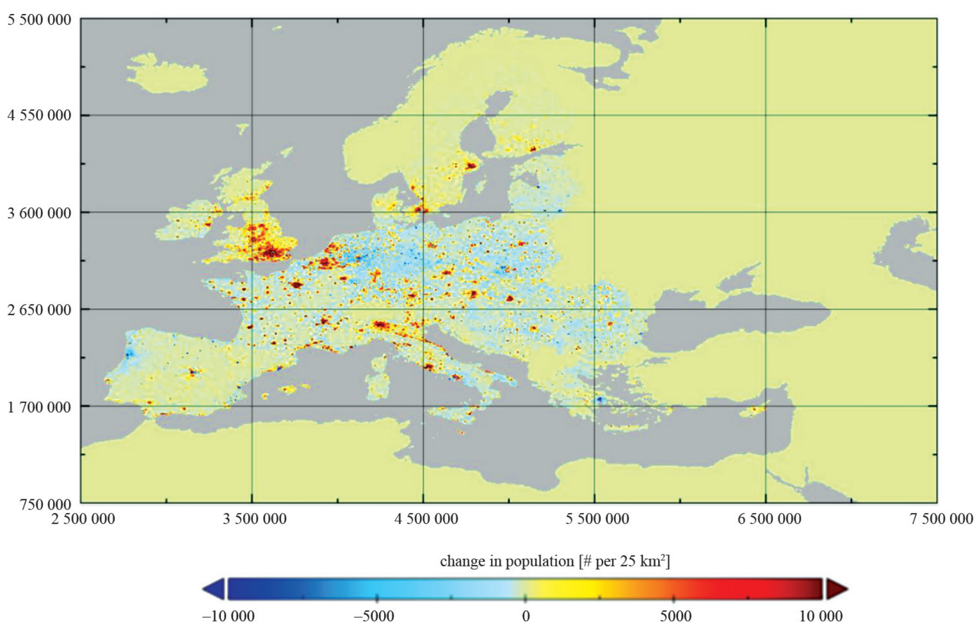


Fig. 3.8. Projected area-based population change in the European Union countries by 2050 (JRC 2018)

the main trans-local migrations mainly concern the southern and central areas of the country.

In the southern part, it is mainly the south-eastern Carpathian area associated with the Little and Upper Vistula basins. In this area, in addition to concentrated urbanisation (large and medium-sized cities) there is historically established and developed dispersed urbanisation in landslide-prone areas (see Figure 3.9). This generates additional flood risks.

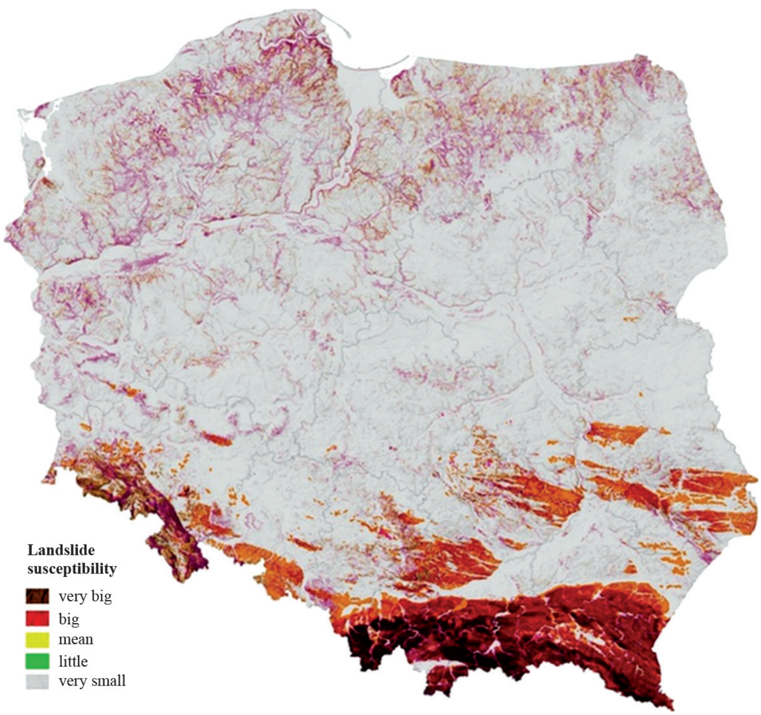


Fig. 3.9. Landslide susceptibility structure of Poland (PGI-NRI 2015)

In urban areas, and mainly within cities, the conditions for increasing flood risk have changed and continue to change. In addition to the threat from rivers, the threat from direct surface runoff of heavy precipitation has significantly increased and continues to increase. These are generally short-lived, often localised rainfall events with maximum intensities significantly higher than what has been historically recorded. However, their daily totals exceed even 300 mm. This is a problem of many Polish cities, measured by the growing number of interventions necessary to reduce flooding and its consequences. Figure 3.10, on the example of Cracow, shows the initial stage of flooding/submergence of a tunnel road in the city centre due to the impossibility of draining storm runoff through the city sewer system.

Fig. 3.10. Cracow, tunnel in the Pawia Street area, 5 August 2021

As recommended by the Floods Directive [EU 2007], which has been implemented into Polish legislation [Journal of Laws 2017b] in the form of Flood Risk Management Plans, it recommends the identification of precipitation floods. Precipitation floods occur throughout the country, but significant negative impacts are recorded primarily in larger cities.

For the purposes of the 2022–2027 FRMP, as part of the revision of the Preliminary Flood Risk Assessment – PFRA [SWH-PW 2018], an attempt was made to identify historical precipitation floods for thirty-nine cities with a population of more than 100 000. These include the following cities: Białystok, Bielsko-Biała, Bydgoszcz, Bytom, Chorzów, Częstochowa, Dąbrowa Górnicza, Elbląg, Gdańsk, Gdynia, Gliwice, Gorzów Wielkopolski, Kalisz, Katowice, Kielce, Koszalin, Cracow, Legnica, Lublin, Łódź, Olsztyn, Opole, Płock, Poznań, Radom, Ruda Śląska, Rybnik, Rzeszów, Sosnowiec, Szczecin, Tarnów, Toruń. It appeared that homogeneous data with a uniform structure for the period 2010–2017 were only data on fire brigade interventions. These are only selective data on the basis of which a general risk assessment cannot be made.

In addition, precipitation floods are mostly small-scale events. The conducted analyses show that the vast majority of interventions concern incidents that cover an area of at most a few hundred square metres: between 28% and 87% of interventions concern an area of up to 100 m^2, and between 72% and 97% of interventions concern areas of up to 300 m^2.

Table 3.2 summarises the results of these analyses for the cities with the highest number of fire brigade interventions during precipitation floods.

Table 3.2

The ten cities in alphabetical order with the highest number of fire brigade interventions and high precipitation flood risk classification between 2010 and 2017 (SWH-PW 2018)

City	Number of fire brigade interventions	Category of local threat according to the State Fire Service				
		Small	Local	Medium	Large	Disaster
Elbląg	178	10	165	1	2	0
Kalisz	541	17	519	4	1	0
Konin	225	6	218	1	0	0
Koszalin	63	8	55	0	0	0
Cracow	**2211**	**1435**	**763**	**8**	**2**	**3**
Olsztyn	229	19	209	1	0	0
Poznań	863	75	787	1	0	0
Rzeszów	854	27	824	3	0	0
Warsaw	**3183**	**1043**	**2129**	**10**	**1**	**0**
Zielona Góra	417	143	272	2	0	0

The lack of a wider uniform database on precipitation floods, as in previous planning periods, has eliminated the assessment of this risk in the 2022–2027 FRMP.

Coupled with the lack of a uniform and sufficiently broad data base on the consequences of the threat of rising air temperatures, especially in urban areas, it was decided to analyse the impact of climate change and urban adaptation planning separately.

3.3. An approach to climate change adaptation in urban areas

Taking into account the fact that the problem concerns mainly urbanised areas, and especially urban areas, the main problem that must be solved in the first place was the adaptation of cities to climate change.

Between 2017 and 2018, Climate Change Urban Adaptation Plans (UAPs) were implemented in Poland, for forty-five large cities – over 90 000 inhabitants.

The summary document [Ministry of Environment 2018] covers forty-four cities, but Warsaw has such a plan, developed in a separate procedure. The methodologies for these studies were released in 2013, and their implementation was entrusted to teams working with the authorities of these cities.

The plans are based on an assessment of the impact of meteorological and climatic risks on the city's sectors/areas, including: water and wastewater management, public health, transport, energy, land use, high intensity land use, biodiversity, tourism and cultural heritage. Heat, frost, intense rainfall and storms, urban flooding, flooding, seaward flooding, drought, windstorms, landslides and rising sea levels were considered as threats.

Heat hazards were referred to all sectors and other hazard types were selectively referred to selected sectors/areas. Each UAP document has the following implementation structure:

- the extent to which the implementation team cooperates with the city authorities and the community,
- the assessment of the city's spatial sensitivity to climate change,
- the risk analysis related to the hazards,
- the assessment of the city's sensitivity to climatic and hydrological risks,
- the selection of adaptation options to reduce risks and their impacts, now and in the future,
- the draft plan for adapting the city to climate change together with an assessment of its impact on the environment.

When analysing UAPs, it is impossible not to notice that their standard varies. There are specific documents that deal exhaustively with both the assessment of risks and adaptation recommendations for their mitigation, which covers several major cities. The remaining documents are of a much more or very general nature and are only a preliminary indication for further proceedings. This is mainly due to the fact that the basis for the qualification of flood risks was:

- assessments obtained through a survey and the opinion of the local administration supported by experts (working groups appointed by the local government),
- a review of available studies.

Depending on the determination of the local authority, qualifications with very different levels of description and accuracy of assessment were obtained. Unfortunately, in most instances, they will prevent the identification of threat mechanisms.

There is also a lack of consistency in defining some of the risks and their level of assessment. This is especially true of the risk of rainfall and flooding. This issue is characterized below.

The main source of urban flooding is heavy precipitation. Urban flooding occurs when the urban drainage system is unable to receive and safely discharge rainwater.

Urban flooding can have two different causes:

- direct flooding/flooding by surface water from rainfall,
- flooding/flooding by surface water from overloaded drains or stormwater drainage.

Urban floods are classified as precipitation floods, the mechanism of which is related to the inefficiency of the drainage system, including sewer failures. In this situation, the threat of intense precipitation should be reasonably linked to urban flooding.

In turn, floods are associated with either river flooding or the impact of sea level rise within cities. The documents addressed the impact of sea level rise separately and only in relation to water and wastewater management and biodiversity. The term ‘flooding’ has, in turn, been used interchangeably with the term ‘urban flooding’ in several instances of cities. Furthermore, the UAP document was not sufficiently integrated with the documentation of historical and potential floods within the flood risk management plans (FRMP).

In summary, Urban Climate Change Adaptation Plans have many advantages but also disadvantages with regard to their potential for practical implementation in risk reduction, such as:

- Lack of standardised descriptions (definitions) of floods and their sources; *the result: classification of hazards as intense precipitation and storms, urban flooding and floods – interchangeably without description and definition*.
- Free treatment of the required scope of the study and its level of detail; *the result: it is not possible to standardise the scope and level of information and thus the comparative assessment of cities*.
- Identification of adaptation measures at a high level of generality; *the result: a failure to link their results to the complex mechanisms of urban flooding development. Rather, it is a significant social incentive to act*.

In this manner, only a limited basis for programme activities has been obtained in relation to the diagnosis and strategies and plans for reducing the causes and consequences of urban flooding. It is necessary to develop works in this area carried out by city boards, but on the basis of a strategic approach and implementation standards set at the national level.

3.4. Conclusion

It is necessary to develop in Poland, as in many European countries, a strategic approach to mitigating the current and future risks associated with the negative impact of climate change. This applies mainly to developing urban centres and to the two main threats: (1) an increase in summer temperatures and the associated increase in heat islands in intensely built-up areas, and (2) an increase in the frequency and intensity of precipitation and associated urban flooding [Arden, Jawitz 2019].

Limiting the formation of heat islands and combating their effects requires the introduction of a systematic temperature monitoring network linked to the current local rainfall monitoring system. This will enable the analysis of the movement of air masses and pollutants, which will facilitate the identification of the level of risk and the location of the most endangered places.

In the event of urban flood risk reduction, it is important to have a good understanding of the diverse and complex mechanisms of their formation in urban centres. These mechanisms, especially in large Polish agglomerations located on large rivers, combine the following elements:

– sealing the site with a complex stormwater drainage pattern of old combined sewers and newer stormwater drains,
– a complex system of rainwater discharge to receiving water bodies, "breaking" catchment boundaries,
– the location of storm discharges in the main channel of the river, which results in the need to close them during periods of higher water levels and surges, which most often accompany heavy precipitation,
– unfavourable elevation of the built-up river valley – closed off by dikes or city boulevards on one side and by the upland towards the city limits on the other.

In both instances, the effective mitigation of these risks and their impact on the current and future safety and proper development of the city requires the expansion and restoration of lost rainwater retention to be integrated with the drainage system and spatial planning. This is the key to success and must be linked to the use of such captured rainwater to support the development of green spaces. However, this requires, in addition to strategic regulations, the development of local and multi-scale conceptual studies.

Against this background, the institutional consultations of the draft resolution of the Council of Ministers on the creation of the Program for Counteracting Water Schortages (short Polish abbreviation: PPNW)[2] should be welcomed with optimism. The main text of the PPNW program was made public in December 2021. Consultations in 2022 concern the PPNW with appendices including packages of the retention measures in the areas of: (i) restoration of rivers and wetland ecosystems; (ii) small retention reservoirs, other hydrotechnical facilities and protection of existing micro-retention facilities; (iii) afforestation, tree plantings and protection of areas periodically flooded areas; (iv) protection of outflow from agricultural areas; (v) implementation of municipal plans for adaptation to climate change.

The basic PPNW document contains a valuable diagnosis of the state of water resources and its prospects for the years 2030–2050, developed on the scale of water regions, taking into account the impact of climate change, in the scope of:

– water status and water balance in the context of both the guarantee of the availability of water resources and the potential of an inviolable resource,
– the condition and potential of surface and underground retention along with the assessment of its sensitivity to the negative effects of climate change,

[2] Draft (June 20, 2022) of the resolution of the Council of Ministers on the adoption of the "Program for counteracting water scarcity for the years 2022-2027 with a perspective until 2030": https://www.gov.pl/web/premier/projekt-uchwaly-rady-ministrow-w-sprawie-przyjecia-programu-przeciwdzialania-niedoborowi-wody-na-lata-2022-2027-z-perspektywa-do-roku-2030.

based on the interpretation of monitoring results produced on the basis of a homogeneous and relatively dense measurement network.

This will reduce the impact of climate change on the state of water resources throughout the country, and in urban areas, it will accelerate the creation of retention solutions with much higher efficiency than before.

4. Selected research problems in the upper Vistula catchment area

The data and characteristics of the upper Vistula basin presented in Subchapters 4.1–4.3 were taken mainly from the study entitled *The current state and planning for the development of water management in the Upper Vistula basin – basic problems* [Nachlik et al. 2001], carried out by the team of the Department of Geoengineering and Water Management of the Cracow University of Technology as a result of many years of cooperation with the water authorities of this region. These data close the multi-year period 1981–2000, but are fully consistent in terms of genres and areas. The quantitative changes that took place in the next two decades, 2001–2020, were emphasised. However, these periodic differences do not change the relative area characteristics, they only change the total parameters (up to 10%) that characterise this part of the Vistula river basin. This study forms the basis for the formulation of water threats and, consequently, a detailed approach to solving water management problems and related conflict issues at the interface between risk reduction and socio-economic development.

Significant and current problems regarding the flood risk (Subchapter 4.4) were also developed on the basis of the own projects of the Department of Geoengineering and Water Management, prepared under the supervision of A. Bojarski and E. Nachlik.

4.1. General characteristics of the catchment area

The catchment area of the Little and Upper Vistula River covers an area of 51 515 km^2, including 48 036 km2 within Poland. According to the administrative division, the area includes the following provinces:

- Śląskie in 37.6% of its area,
- Małopolskie in 100% of its area,
- Świętokrzyskie in 64.6% of its area,
- Podkarpackie in 100% of its area,
- Lubelskie in 11.2% of its area.

In the system of catchment area administration and management, the catchment area region of the Little and Upper Vistula is subordinated to the Regional Water Management Authorities in Gliwice, Cracow and Rzeszów. In the further part of this publication, the catchment area of the Vistula closed by the cross-section in Zawichost (below Sandomierz) will be referred to as the upper Vistula catchment area. It is a historical name representing the area of a part of the Vistula river basin from its sources to the Zawichost section.

The map (Fig. 4.1) shows the territorial extent of the provinces and Regional Water Management Authorities against the background of the upper Vistula catchment area and its main tributaries.

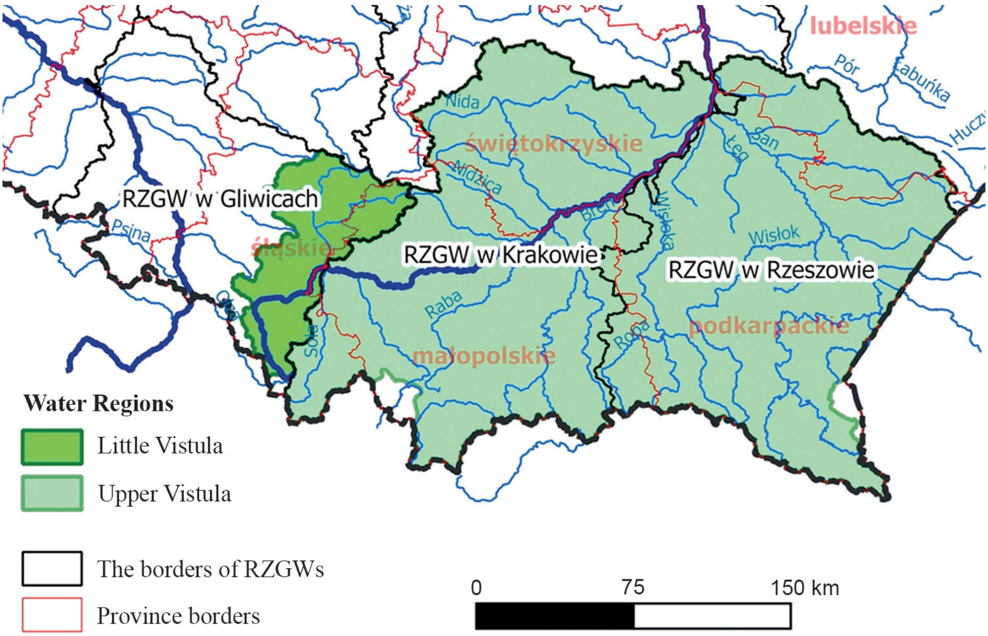


Fig. 4.1. Boundary of the Little and Upper Vistula catchment area on the background of administrative borders of provinces, areas of the Regional Water Management Authorities (own study)

The analysis of land use in the upper Vistula catchment area in comparison with the country (Table 4.1) shows the following regularities:

a) The land area per inhabitant in this part of the Vistula river basin is significantly lower than the national average, and within the basin, this indicator varies by almost five times. The lowest values are recorded in the following provinces: Śląskie – 0.25 ha/1 inhabitant and Małopolskie – 0.47 ha/1 inhabitant;
b) indices of permanent buildings in rural and urbanised areas and of agricultural land in the Śląskie and Małopolskie provinces are higher than the national average.

Currently, as of 2021, these characteristics have changed to some extent [Statistics Poland 2021]. This mainly applies to changes as compared to 2000 in the scope of:

- an increase by 0.6% in the share of agricultural land, by 1.4% in the share of forest land and by 0.07% of ecological land in the total area of the country,

- a decrease in the share of land under water by 0.6%, by 0.9% of built-up and urbanised land, and by 0.5% of other land and wastelands in the total area of the country.

Table 4.1

Land use structure in Poland and in provinces in the upper Vistula basin (Nachlik et al. 2001)

Area	Total area [ha]	Area per 1 inhabitant [ha]	Percentage land use in different categories [%]					
			Agricultural land	Forestry land, wooded land and shrub land	Inland waters	Developed and urbanised land	Ecological land	Other land and wasteland
Poland	**31 268 500**	**0.81**	**59.3**	**29.1**	**2.7**	**6.6**	**0.03**	**2.3**
Małopolskie province	1 514 410	0.47	59.3	30	1.7	7.7	0	1.4
Podkarpackie province	1 792 628	0.84	52.9	38.2	1.6	6.4	0	0.9
Śląskie province	462 196	0.25	52.2	31.9	2.2	11.4	0	2.2
Świętokrzyskie province	754 103	0.88	63.6	27.9	1.2	6.3	0	1
Lubelskie province	280 180	1.4	68.8	22.8	1.5	5.6	0.05	1.2
the upper Vistula basin	**4 803 517**	**0.56**	**60.4**	**29.6**	**1.6**	**7.1**	**0.01**	**1.3**

In individual voivodships, the changes in the share of built-up and urbanized land, which have the greatest impact on changes in water relations, are varied. Declines were recorded in the following provinces: Małopolskie (by 0.9%), Podkarpackie (by 1.2%), Świętokrzyskie (by 1.4%) and Lubelskie (by 1.5%). However, in the Śląskie Voivodeship, there was an increase in the built-up and urbanised area by 0.9%.

However, analysing in detail the impact of buildings on the significant increase in flood risk in urbanised areas, a conclusion can be drawn that in large cities, in the last twenty years, there has been an intensification of urban development resulting in a marked increase in the sealing of the ground surface.

The topography of the river basin area causes that in its southern submontane and mountainous part, there are restrictions in the area's development due to high, steep mountain and submontane slopes, which are sometimes threatened by landslides.

Table 4.2 presents indicators characterising the water balance in the upper Vistula catchment area.

Table 4.2

Water resources in the upper Vistula basin in comparison with the country (Nachlik et al. 2001)

	Measurement unit	Annual precipitation [10^3 m^3]	Annual runoff [10^3 m^3]	Groundwater resources [10^3 m^3]	Surface [km^2]	Population [thousand]	Annual water resources per inhabitant [m^3/inhabitant]
Poland	-	189 573	approx. 62 000	approx. 7 350	312 685	38 660	1794
	%	100	100	100	100	100	100
The Little and Upper Vistula Basin	-	30 183	14 500	2290	48 035	8568	1960
	%	15.9	23.4	14.3	15.4	22.2	109

The surface outflow and exploitable groundwater resources of the upper Vistula river basin constitute over 20% of Poland's resources, while the area of this basin constitutes 15% of the country's area. The average value of these resources per inhabitant evens out and amounts respectively to 1794 m^3 in the country and 1960 m^3 in the upper Vistula area, but is less favourable in the upper Vistula catchment area due to spatial differentiation of resources and intensive development of this area. For surface resources, these indicators have similar values and are respectively: 1637 m^3 and 1692 m^3. These figures cannot be interpreted literally, as the country's surface water resources vary from year to year, ranging from 60 to 140% of their average value. The corresponding fluctuations in the surface water resources of the upper Vistula are lower but are also apparent.

According to the general seven-grade classification of water availability used in the world, Poland belongs to countries with very low water availability (1000–2000 m^3/inhabitant during a year). In European terms, our level of water availability is less than 40% of the average.

This brief characterisation of average values does not reflect the essence of problems related to the formation of water resources in the upper Vistula catchment area. It only indicates that the region has unfavourable (in relation to national averages) regional conditions in their management. Only a spatial and temporal analysis of the structure of the Vistula River water resources makes it possible to identify the types of threats, their causes and location, as well as other conditions occurring in this area.

4.2. The role of water resources in social and economic development, in accordance with the principles of sustainable development

Sustainable development is the human use of the biosphere (including water resources) conducted in such a manner as to derive the greatest possible sustainable benefit from current production and harvesting, while preserving the potential of the biosphere to meet the needs and aspirations of future generations.

Shaping the development of the upper Vistula catchment area requires, above all, the proper use of the potential and resources that the region possesses and the elimination of threats to them. An important role in this is performed by water management, which gathers all conscious and intentional human interactions with water resources. The purpose of this impact is to satisfy biological, social and economic needs and prevent damage to these resources. Biological and socio-economic needs include:

- supplying water of appropriate quality to urban and rural populations, agriculture, industry, services and other areas of the national economy, which simultaneously involves the discharge of water after use,
- protecting water resources from pollution and overuse,
- protecting against the harmful effects of rivers and streams, mainly from flooding, land flooding, erosion processes (including on agricultural land), sediment accumulation, abrasion of reservoir banks, etc.,
- protecting against the effects of water shortages during periods of drought,
- using water for water transport, hydropower, leisure and tourism.

In determining a strategy to achieve these objectives, a number of prerequisites must be considered that define the possible room for manoeuvre and guide specific actions.

The prepared development strategies of individual provinces (Śląskie, Małopolskie, Świętokrzyskie, Podkarpackie and Lubelskie) cover the problems of water management. It is generally seen through the following perspectives:

– water and wastewater management, in the context of basic infrastructure,
– environmental protection, in the context of the formation and use of water resources,
– flood protection, in the context of improving quality of life.

All in all, these issues, as well as all others, are subject to the principles of coherence of regional development and spatial planning forecasting, assuming continuity of the strategic planning process. This means, in fact, the continued development of water management as a field shaping the use of water resources and protection against the risks they pose (floods and droughts).

In the provincial development strategies, the priorities in water management were adjusted to the needs of a given region or province and on this basis, a hierarchy of tasks was established. In general, these correspond to the views of the water management community; the detailed development plans should clarify the terms of reference.

4.3. Assessment of the status of water management in relation to the water resources of the basin

4.3.1. Surface water resources

The river network and surface water bodies of the upper Vistula catchment area as well as the control water gauge cross-sections of the basin are presented in Fig. 4.2.

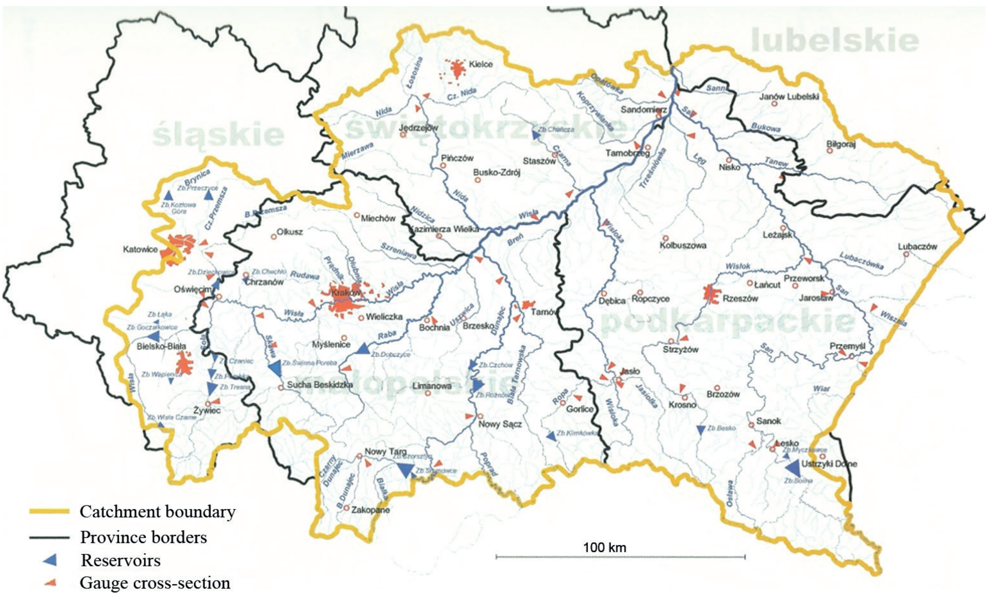


Fig. 4.2. River network of the upper Vistula, storage reservoirs and major water gauge cross sections (Nachlik et al. 2001)

The quantitative and spatial assessment of water resources was presented for the conditions in force until 2000, which is a reference point for problem analysis in the field of water management tasks.

There are many definitions of surface water resources. Here, the following two basic definitions are used:

Potential resources – determined by the average annual mean flow SSQ [m^3/s] or the corresponding unit outflow SSq [$dm^3/s/km^2$] per unit area of the considered catchment (see Fig. 4.3). A measure of the global value of these resources during the year is the annual runoff, calculated in [m^3] – also see Table 4.2.

Real resources – defined by the average annual minimum flow SNQ [m^3/s] or the corresponding unit outflow SNq [dm^3/s/km^2] (see Fig. 4.4). Assuming a high guarantee of secured needs, it is assumed that these are the resources at the disposal of water management. If so, the actual level of use of the resource must consider preserving a certain proportion of it for the needs of the river's natural environment (flora and fauna) and the requirements of fisheries management, water tourism and landscape protection. This part of the resource in a given section of the river is determined by the so-called "inviolable flow", which is assessed individually depending on local conditions. In this situation, the balance of real resources has been conducted on the basis of SNQ, and the assessment of their value in the context of the level of resource utilisation and the resulting shortages has been characterised, with consideration to areas where the preservation of an inviolable flow of a sufficiently high value is essential.

Average annual specific runoffs vary from about 6 dm^3/s/km^2 in the northern part of the upper Vistula catchment area, to 15 dm^3/s/km^2 in the Carpathians and even 20 dm^3/s/km^2 in their highest parts. In the upper Dunajec catchment area, SSq varies from 15 in Podhale to 50 dm^3/s/km^2 high in the Tatras. By contrast, the average low unit runoff SNq ranges from 1.5 in the northern part of the area to 3.0 and over 10 dm^3/s/km^2 in the highest elevations.

Fig. 4.3. Potential water resources – according to average specific runoff SSQ (Nachlik et al. 2001)

Fig. 4.4. Real water resources – according to average annual minimum flow SNQ (Nachlik et al. 2001)

Table 4.3

Structure of water resources of the upper Vistula river (own study)

River	Water gauge cross-section	Catchment area [km²]	SSQ [m³/s]	SNQ [m³/s]
1	2	3	4	6
Vistula	Skoczów	297	6.1	0.4
	Goczałkowice	738	9.7	0.8
	Nowy Bierun	1748	21.9	3
	Pustynia	3912	43.3	18
	Dwory	5312	62.1	22.4
	Smolice	6796	83.4	27.8
	Tyniec	7524	91.7	30.8
	Sierosławice	8999	105.7	35.6
	Popędzynka	10 704	123.3	39.4
	Jagodniki	12 058	138	47.5
	Karsy	19 817	219	65.4
	Szczuoin	23 901	242	74.8
	Sandomierz	31 847	303	83
	Zawichost	50 732	449	120

table 4.3 cont.

Przemsza	Jeleń	1996	18.7	11.4
Soła	Oświęcim	1386	22.2	3
Skawa	Zator	1154	16.4	3.3
Raba	Proszówki	1470	17.6	3.1
Dunajec	Żabno	6735	84.3	18.7
Wisłoka	Mielec	3915	35.6	6.06
San	Radomyśl	16 824	134	35.3

The upper Vistula catchment area is characterised by a significant irregularity of runoff, measured by:

a) ratio of high flows with probability of exceeding 1% ($Q_{1\%}$) and the average annual mean flow (SSQ) at a given control cross-section; maximum values of this index are: 20–40 for Przemsza, and 60–120 for The Little Vistula and Carpathian tributaries of Vistula;
b) ratio of the mean annual flow module MO to the mean low flow module MN – the maximum values of this indicator are: 3–4 for the Przemsza River and 6–18 for The Little Vistula river and the Carpathian tributaries of the Vistula river;
c) the annual non-uniformity of average low flows across months and seasons.

This means problems associated with both high flood risk and difficulties in water supply during periods of low flows.

Relating the above data on the average and the lowest flow in the Zawichost cross-section – the control for the Upper Vistula basin, to the values from the last two decades 2002–2020 calculated according to the IMWM-NRI data [https://danepubliczne.imgw.pl/], it should be stated that there has been a decrease in the value of these characteristic flows. In the last twenty years, the SSQ value decreased by 9.1% and reached 408 m^3/s, and the lowest value of the SNQ flow in the Zawichost section decreased by 18.3% and reached 98 m^3/s.

This is undoubtedly related to the periodic long-term variability of the runoff in this basin, but most of all to the adverse impact of both climate change (see Chapter 3) and changes in the use and management of this part of the basin (see section 4.2).

4.3.2. Surface water retention status

Artificial retention is a treatment to support natural retention, which over the last 100 to 200 years has been largely reduced by changes in land use. These changes are up to 50% and are mainly due to the expansion of land occupied by construction and communication infrastructure at the expense of forests, agricultural land and grassland.

Forestry areas are the most important for natural retention in the upper Vistula river basin. The spatial distribution of forestry resources is shown in Figure 4.5. Forested retention helps to even out low flows, so it is important to protect and develop wooded areas. Reservoir retention in the upper Vistula catchment area is characterised in Table 4.4.

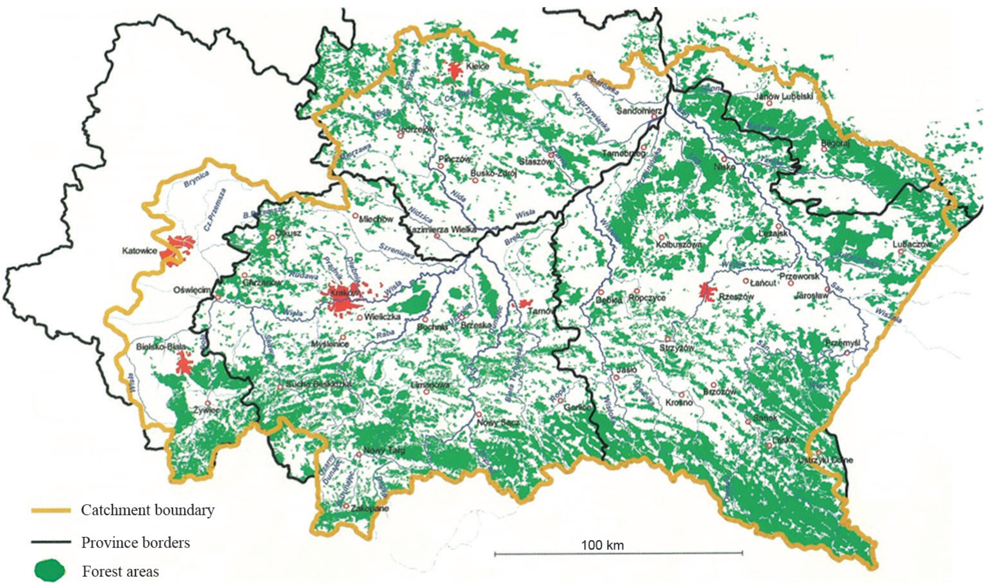


Fig. 4.5. Forestry areas in the upper Vistula catchment area (Nachlik et al. 2001)

Table 4.4

List of main storage reservoirs in the upper Vistula catchment area (own study)

Item	Reservoir	River	The year of commissioning	Volume [million m^3]		
				utility	flooding	total
1	Solina	San	1968	249.00	50.00	473.00
2	Czorsztyn	Dunajec	1995	132.8	63.3	231.90
3	Goczałkowice	The Little Vistula	1956	111.70	45.30	165.60
4	Rożnów	Dunajec	1942	44.80	86.00	171.30
5	Dobczyce	Raba	1986	91.10	*S: 33.87 W: 22.56	141.74
6	Tresna	Soła	1967	59.50	35.35	94.04
7	Dziećkowice	Post-treatment	1979	48.30		52.50
8	Klimkówka	Ropa	1994	33.0	8.00	43.50
9	Porąbka	Soła	1936	19.47	4.58	27.19

table 4.4 cont.

10	Chańcza	Czarna Staszowska	1984	15.50	6.90	24.50
11	Przeczyce	Czarna Przemsza	1963	16.60	2.95	20.74
12	Besko	Wisłok	1978	13.97	5.63	15.38
13	Kozłowa Góra	Brynica	1939	10.95	2.25	15.30
14	Czchów	Dunajec	1955	6.00		12.00
15	Łąka	Pszczynka	1981	7.50		11.20
16	Myczkowce	San	1962	5.40	1.00	10.00
17	Sromowce	Dunajec	1995	5.14		6.70
18	Wisła Czarne	The Little Vistula	1972	1.61	2.95	5.06
19	Czaniec	Soła	1966	1.16		1.32
20	Chechło	Chechło	1937	0.70		1.20
21	Wapiennica	Wapiennica	1932	1.00		1.10
22	Świnna Poręba	Skawa	2012	122.00	24.00	161.00
Total				997.20	372.08	1686.27

* S – summer flood volume; W – winter flood volume

4.3.3. Groundwater resources

Standard groundwater

The main aquifers are located in the upper Vistula catchment area, within the following hydrogeological units:

- Carpathian folded massif,
- pre-Carpathian sinkhole,
- the Upper Silesian trough,
- the Cracow monocline,
- Miechowska trough,
- Świętokrzyskie folded massif,
- Lubelskie trough.

Hydrogeological units form Usable Groundwater Levels. These are groundwater deposits with regional resource modules above 5 $m^3/d/km^2$, potential well yields above 5 m^3/h and favourable quality parameters.

The fragments of hydrogeological units with the highest water resources have been named Main Groundwater Reservoirs (MGR). This term is understood to mean basins that meet the following criteria:

- the potential yield of the well is more than 70 m^3/h,
- the capacity of the intake is greater than 10 000 m^3/d,
- there is a favourable usable water quality.

In deficit areas, designated MGR may correspond to lower, individual quantitative criteria. On the basis of the aforementioned criteria, 49 MGR were identified in the upper Vistula river basin. Their location is shown in Figure 4.6.

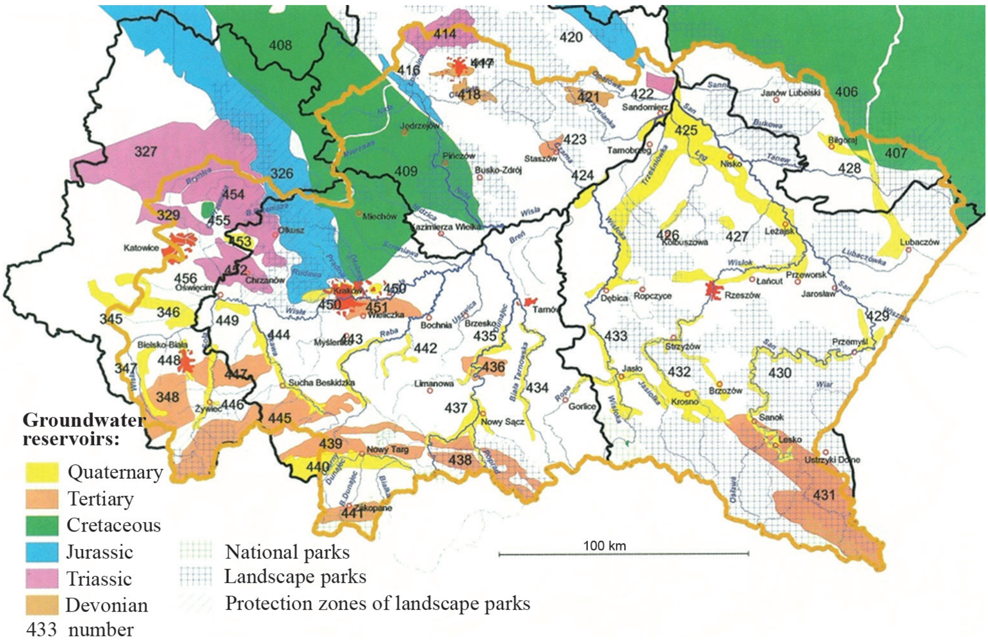


Fig. 4.6. Major groundwater reservoirs in the upper Vistula catchment area against the background of protected landscape areas (Nachlik et al. 2001)

A quantitative measure of groundwater resources is the estimated amount of their disposable (operational) resources. This value is expressed in thousands of cubic metres per day and as an abundance module in millimetres of groundwater layer per year. These values vary from 3 to 1330 thousand m^3/day, with no threat to the quantitative status due to exploitation.

4.3.4. Mineral groundwater used in spa therapy

In Poland, the richest region in terms of the number of occurrences of underground therapeutic waters and their curative properties is the area of the southern part of Małopolskie province. Waters of a curative nature are found in spas such as Krynica, Muszyna, Piwniczna, Rabka, Swoszowice, Szczawnica, Wieliczka, Wysowa, Wapienne, Złockie and Żegiestów Zdrój. There are two spas in Świętokrzyskie province (Busko Zdrój and Solec Zdrój) and two in Śląskie (Ustroń and Goczałkowice), while in Podkarpackie, there are four (Polańczyk, Horyniec, Iwonicz Zdrój and Rymanów Zdrój).

The location of spas in the upper Vistula catchment area is shown in Fig. 4.7. Out of the total number of forty-four spas in Poland, twenty-one (48%) are located in the upper Vistula catchment area.

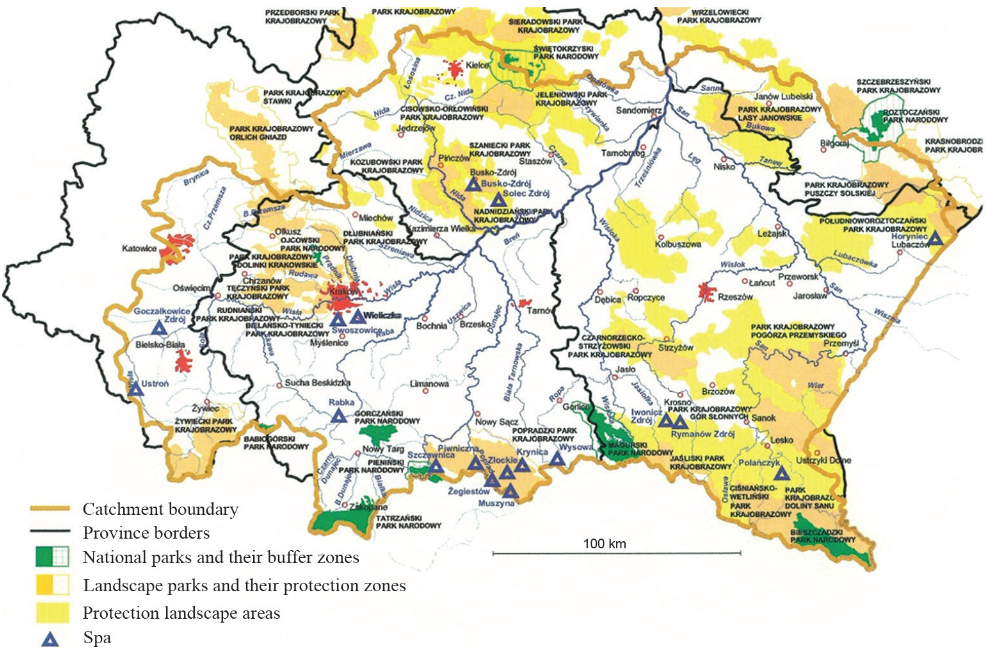


Fig. 4.7. Areas of protected landscape and the location of spas in the upper Vistula catchment area (Nachlik et al. 2001)

4.3.5. Water resources quality

Until 2000, the quality condition of the water resources in the Upper Vistula basin was generally considered to be poor. This assessment concerned both the Vistula River itself and its main tributaries [Nachlik et al. 2001].

After the implementation of the WFD and as a result of the implementation of a very large number of wastewater treatment plants, including in small towns, and in the conditions of limiting the discharge of salt water from mines, the quality condition of this part of the basin improved significantly.

The requirements of WFD and monitoring conducted in accordance with its recommendations, broadly presented in Chapter 2, still indicate the need for significant measures in this respect to achieve good ecological status of surface waters and good chemical status of groundwaters, also in the Upper Vistula catchment area.

4.4. Flood hazard problems and the effectiveness of the flood protection system in the upper Vistula catchment area

Against the background of numerous water management tasks in the upper Vistula catchment area, the problem of flood protection is presented below as one of the issues related to extreme weather events. Regardless of the increasing risk of drought, the flood risk in the Upper Vistula basin dominates and remains the source of the highest damage and material losses.

Since the floods of 1997, much research has been devoted to reduce this risk. It was intensified after the disastrous floods of 2010. This publication presents only part of the results of these studies in the context of assessing the effectiveness of the flood protection system. It was considered that the experience of catastrophic floods enables good recognition of the problems and allows for a better understanding of the problems and effects, which translates into the correct formulation of the strategy for further actions and should be used for the work on the concept of the modernisation of the system.

4.4.1. The existing flood protection system in the Upper Vistula catchment area

The flood protection system in the Upper Vistula catchment area consists of the main storage reservoirs with their permanent flood reserves as defined in Table 4.3 and their location as shown in Fig. 4.2 as well as the flood dikes as shown in Fig. 4.8. The system is also completed by sections of regulated rivers and streams described in section 1.1.

Flood dikes in the upper Vistula catchment area have been built since the mid nineteenth century, considering the historical circumstances when the upper Vistula catchment area was divided between the three partitioned states and the Vistula itself was a border river. By 1918, the end of World War I, the right embankment of the Vistula below Cracow and above the mouth of Przemsza (Austrian and Prussian partitions) had been built almost completely. The dike crest rows were adjusted to the recorded catastrophic flood of 1813.

The left-bank area below Cracow was diked after a flood in 1934. A number of sections of dikes built earlier were also upgraded during this period. The width of the Vistula's big waterbed was reduced by the construction of dikes from about 4 km to about 1.5 km to often 0.7–1.1 km.

The level of technology and safety regulations in force at the time were significantly different from current requirements. It should be added that the dikes were originally designed to protect mainly agricultural areas, but are now intensively developed.

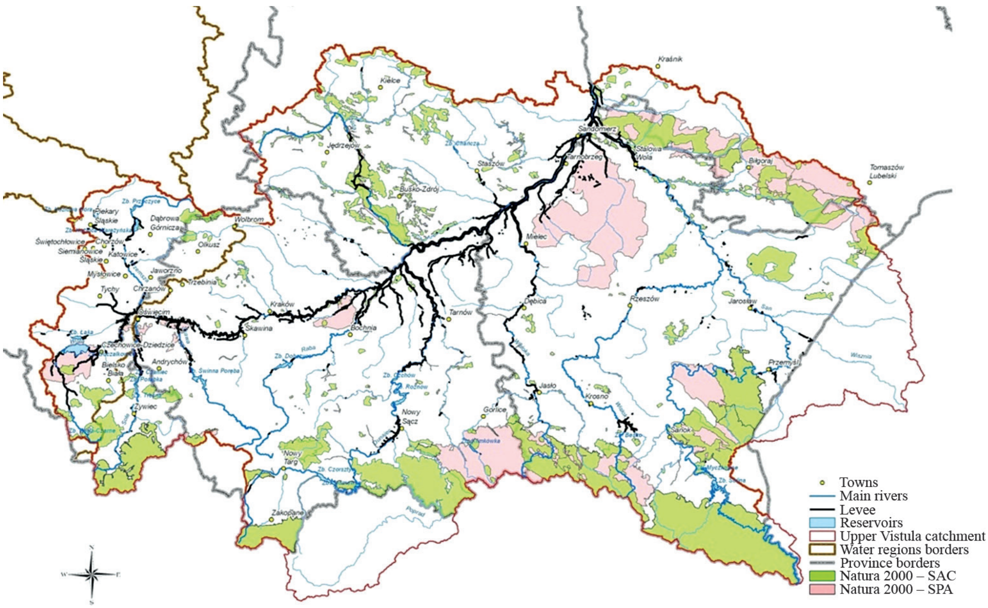


Fig. 4.8. Flood dikes, storage reservoirs and Natura 2000 protected areas in the Upper Vistula catchment area (Bojarski et al. 2012)

In the years 1960–1990 mostly sectional dikes were built on the Vistula's tributaries, especially on the estuarial sections. The total length of the dikes in the upper Vistula catchment area is approximately 2470 km.

After a major flood in 1997, work began on modernising the dikes, which was mainly realised by local government units. Work was conducted in an ad hoc and uncoordinated manner (mainly flood damage repair) and a systemic approach only started after 2009. We currently have flood hazard maps (FHM) and flood risk management plans (FRMP) where the approach to dike upgrading is combined with an assessment of the effectiveness of existing reservoir retention and planned polder retention. Another element to be considered is the assessment of the variable capacity of river channels and the area between dikes, where low and high vegetation should be preserved for natural reasons. Dike crest rows are defined in relation to flows with a certain probability of occurrence, which is related to the value of the protected area.

Dikes fulfil their function when their technical condition is at least satisfactory. In this respect, periodic surveys are undertaken to conduct technical condition assessments. Failure to implement proper maintenance of the inter-basin has resulted in severe overgrowth (Fig. 4.9 and Fig. 4.10) and highly variable flood flow conditions along the length of the rivers.

Fig. 4.9. State of the Vistula river bed and its inter-bed – Budziska town (own study)

Fig. 4.10. State of the Vistula river bed and its inter-bed – Sandomierz (own study)

This problem poses a threat to dikes as it contributes to localised uncontrolled damming of the water table and the formation of a water velocity field conducive to erosion and accumulation phenomena. The highly developed vegetation within the dikes is home to animals that dig their burrows in the dikes or their substrate. The constriction of the big water channel by dikes and regulatory buildings leads to unfavourable erosion and accumulation phenomena, which develop most intensively in periods of high floods. They can endanger not only protective structures but also engineering structures located in the cross-section of the aggressive water flow. Examples of the scale of erosion and accumulation phenomena are shown in Figures 4.11 and 4.12.

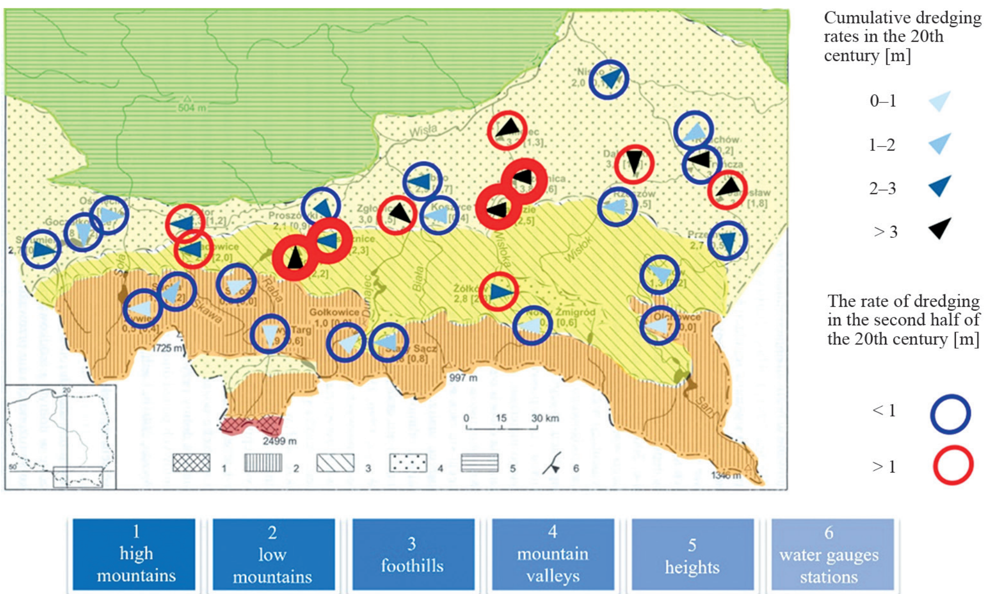


Fig. 4.11. Erosion of Carpathian riverbeds in the upper Vistula catchment area (Bojarski et al. 2009)

From the above description it can be observed that the protective functions of dikes are determined by many factors that are most often poorly defined and deviating from the design arrangements. A look at the flood protection system through an analysis of the experiences of catastrophic floods is particularly important in order to provide guidelines for preparing effective methods of modernising the system. This view is presented below.

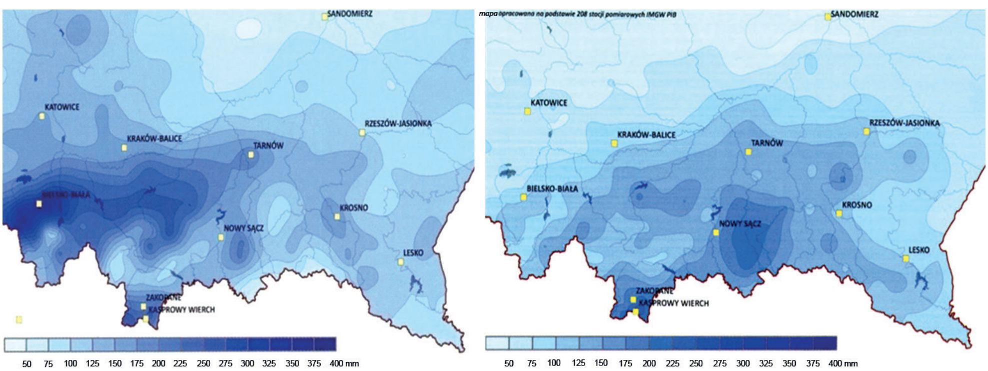
Fig. 4.12. Accumulation processes in the Vistula riverbed in the section: Tarnobrzeg–Sandomierz (own study)

4.4.2. Flood hazard and the effectiveness of the flood protection system in 2010

The characteristics will necessarily be based on two selected areas of the Vistula river, where the greatest problems occurred and their nature varied in terms of scale and the type of problems. The situation concerns the city of Cracow and the Sandomierz region.

4.4.2.1. Precipitation scenarios and flood characteristics

Precipitation scenarios generating catastrophic floods on the Vistula in 2010 are presented in Fig. 4.13. Important for the formation of the surge are the catastrophic scale of the precipitation, its spatial distribution and the direction and dynamics of its movement. In the first period (15–20 May), precipitation maxima occurred in the region of the highest source part of the catchment area and generated floods with very high culminations both in Cracow and Sandomierz. The second wave of precipitation occurred eighteen days after the first. Precipitation maxima occurred in the Dunajec catchment which generated another very high culmination in the Sandomierz cross-section. The second surge in Cracow was relatively low.



Precipitation from May 15 to 20 Precipitation from May 30 to June 4

Fig. 4.13. Meteorological situation shaping the inundation in the Upper Vistula catchment area in 2010 (Cebulak et al. 2011)

The characteristics of the floods in Cracow and Sandomierz are presented in Figures 4.14 and 4.15. It should be noted that the parameters of the surge waves were influenced by the used flood storage in the reservoirs and the retention resulting from the numerous dike failures shown in Fig. 4.16.

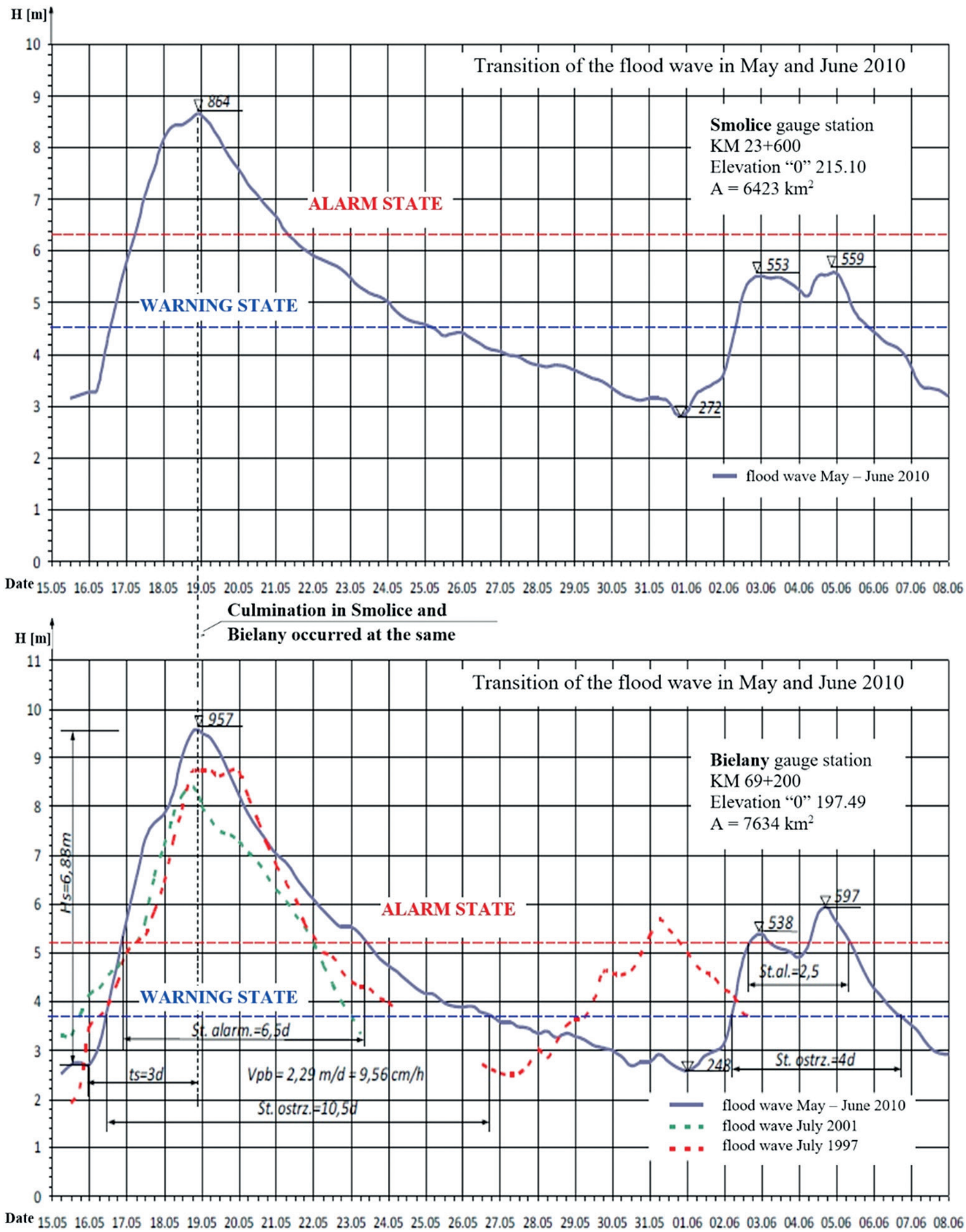


Fig. 4.14. The characteristics of the flood wave in 2010 at the Smolice and Cracow Bielany water gauge cross-sections and in July 2011 and July 1997 at Cracow Bielany (Bojarski et al. 2017)

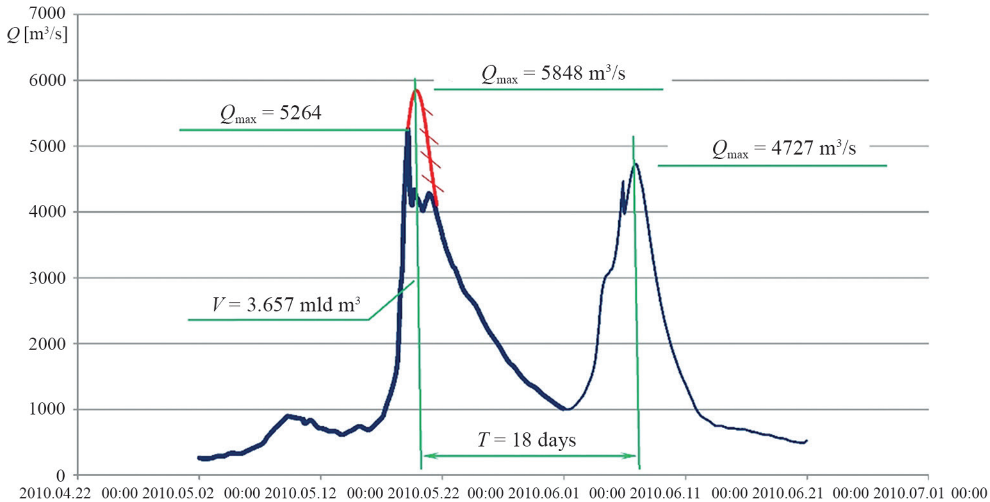


Fig. 4.15. Flood wave 2010 – Sandomierz water gauge
(own study)

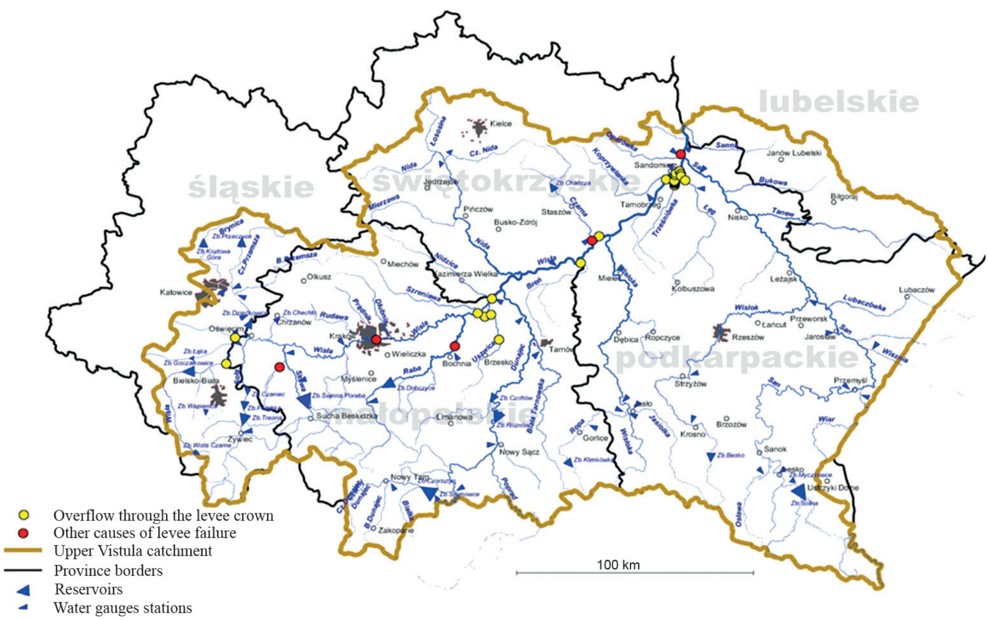


Fig. 4.16. Failures of flood dikes during the catastrophic flood in 2010
(Bojarski et al. 2015)

4.4.2.2. Passage of surge waves in Cracow and their consequences

In Cracow, the value of the culminating flow of the surge wave was about 2300 m^3/s and caused backflows on the Vistula tributaries in Cracow (Fig. 4.17). This was a flow with a probability of $Q_{1\%}$. The flood protection facilities in Cracow and some engineering structures presented in Fig. 4.17 were designed for the higher flow $Q_{0.1\%}$ and the 100-year flow $Q_{1\%}$ was supposed to be the safe flow for the city (Fig. 4.18).

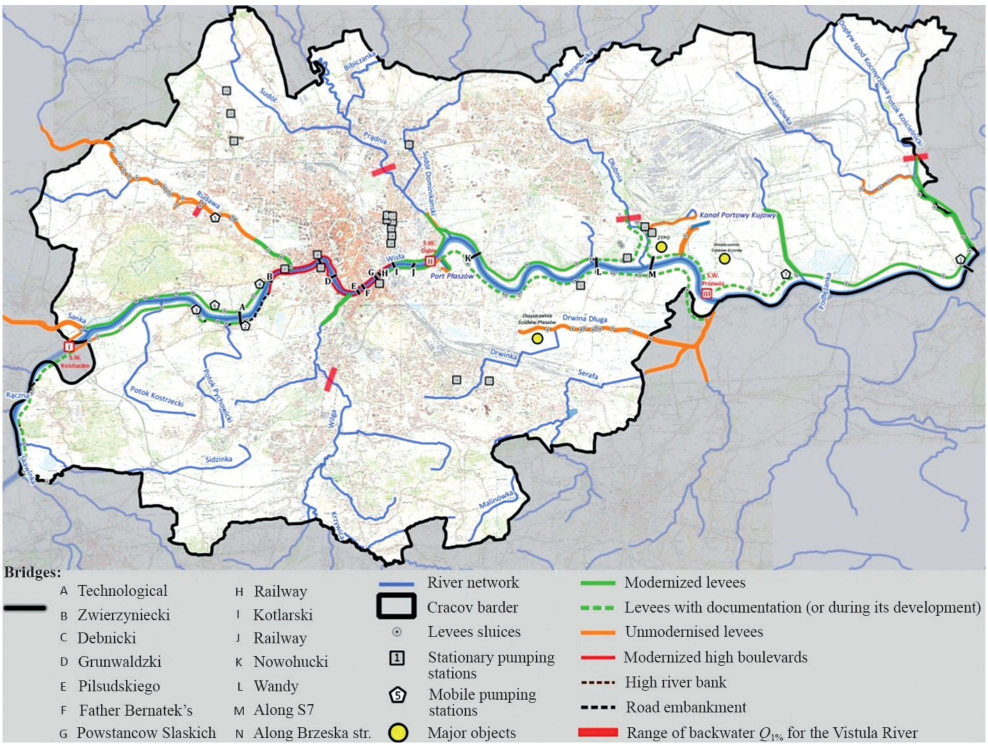


Fig. 4.17. Flood protection system in the area of the City of Cracow and its modernisation status (Bojarski et al. 2017)

In fact, the following problems have occurred:

– water accumulation on the Dębnicki Bridge structure and the beginning of flow restrictions on the Dąbie Level (Fig. 4.19),
– flooding of storm overflow outlets of the Vistula river for a long period of time (Fig. 4.19) and in many parts of the city in the zones of outflows of the Vistula tributaries in Cracow (Fig. 4.17),
– stability of low Vistula boulevards and a threat to the stability of levees and high boulevards in the city centre, high erosion and accumulation of debris in the zone of the Dębnicki bridge and Vistula bend (Fig. 4.20),

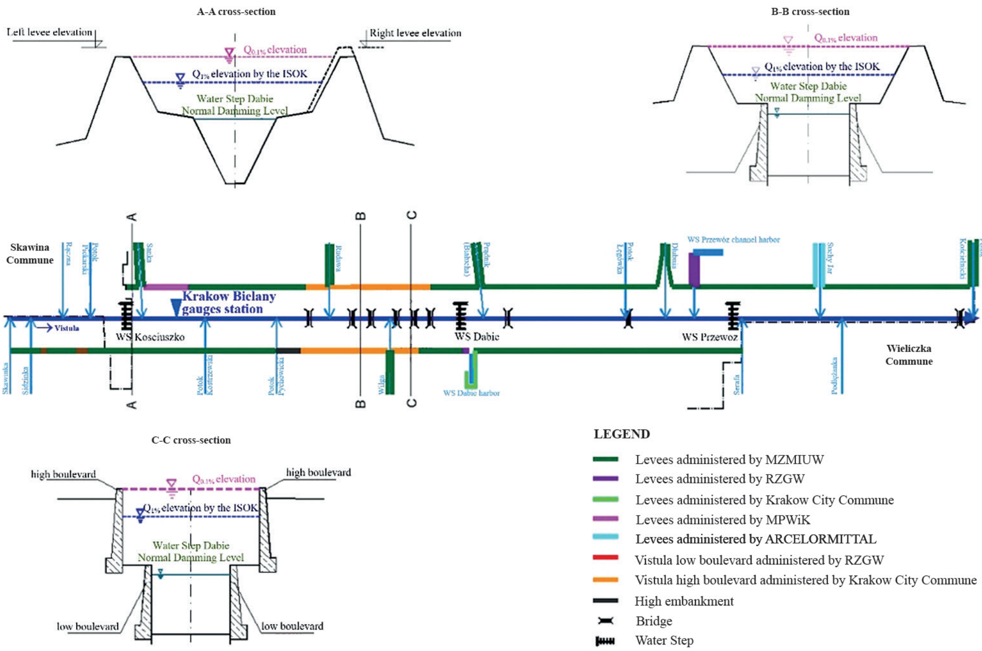


Fig. 4.18. Flood protection facilities and engineering structures in the Cracow area. State of levee administration in 2010 (Bojarski et al. 2017)

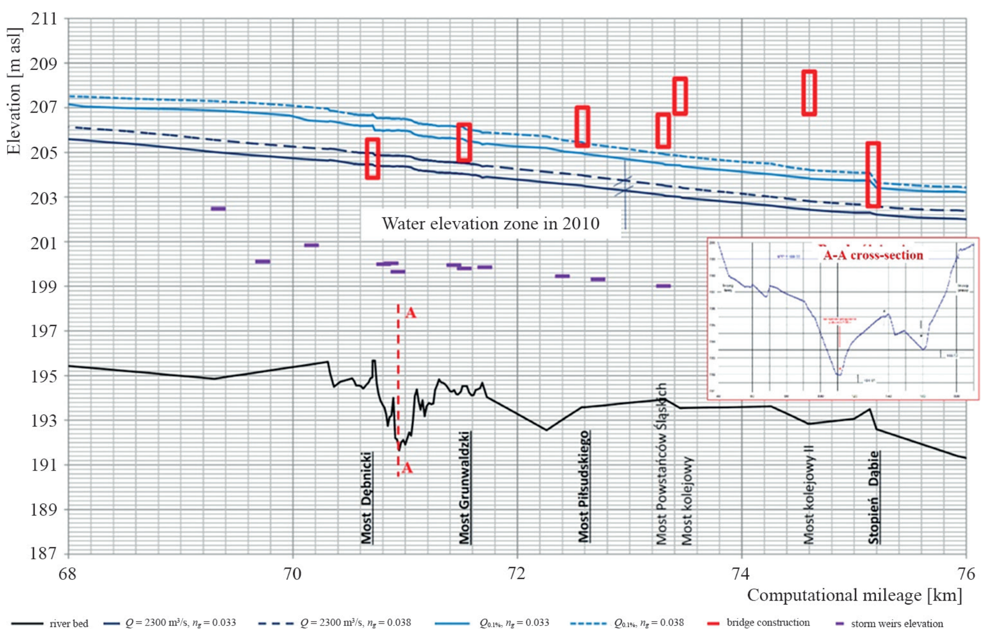


Fig. 4.19. Profile of the Vistula river in the Cracow section with calculated water table and Q_{2010} and deformations of the river bed after the 2010 flood (Bojarski et al. 2015)

Pic. 1. Debnicki Bridge – right bank

Pic. 2. Setion below the Debnicki Bridge – right bank

Pic. 3. Setion above the Debnicki Bridge – failure of the low boulevard

Pic. 4. Levee crown crack in the area of Wioslarska Street

Fig. 4.20. Flood in 2010. Consequences of a flood event in Cracow – examples (Bojarski et al. 2015)

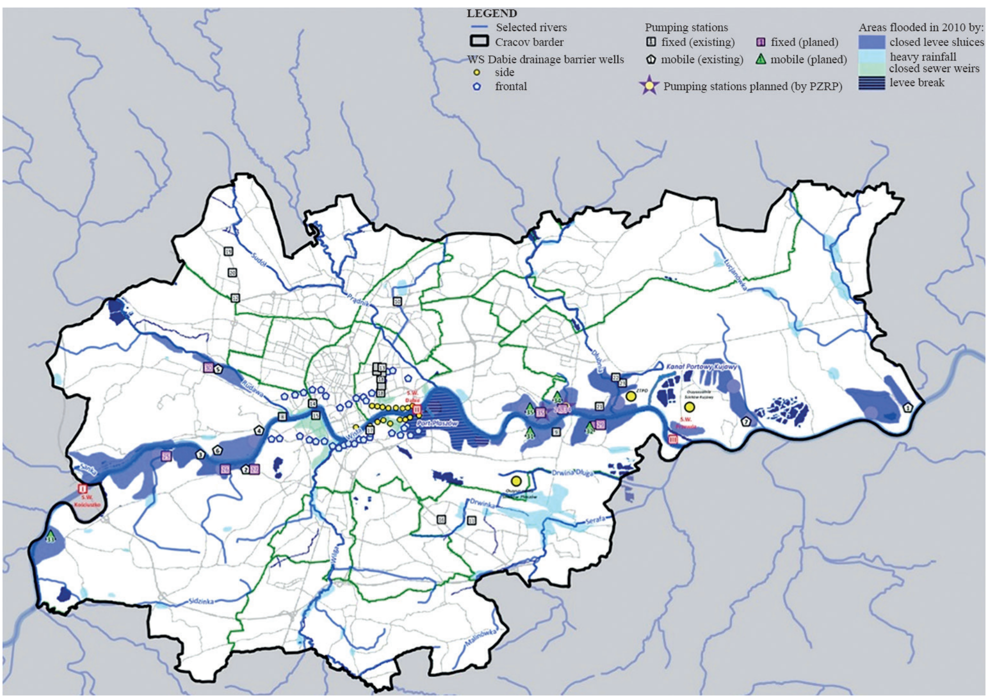


Fig. 4.21. System of existing and planned drainage pumping stations in Cracow against the background of flooding during the flood in 2010 (Bojarski et al. 2017)

– longitudinal crack of the upgraded levee (Fig. 4.20),
– flooding of areas outside the levees, usually at the location of levee sluices (Fig. 4.21),
– failure of the dike in the Płaszów Port (Fig. 4.21) and flooding of part of the city.

4.4.2.3. Passage of surge waves in Sandomierz and their consequences

During the first flood in the Sandomierz region, the water surface elevation exceeded the crest of the right levee and as a result, the levee was washed out (Fig. 4.22). The effects of the Vistula levee washout and the value of water outflow through

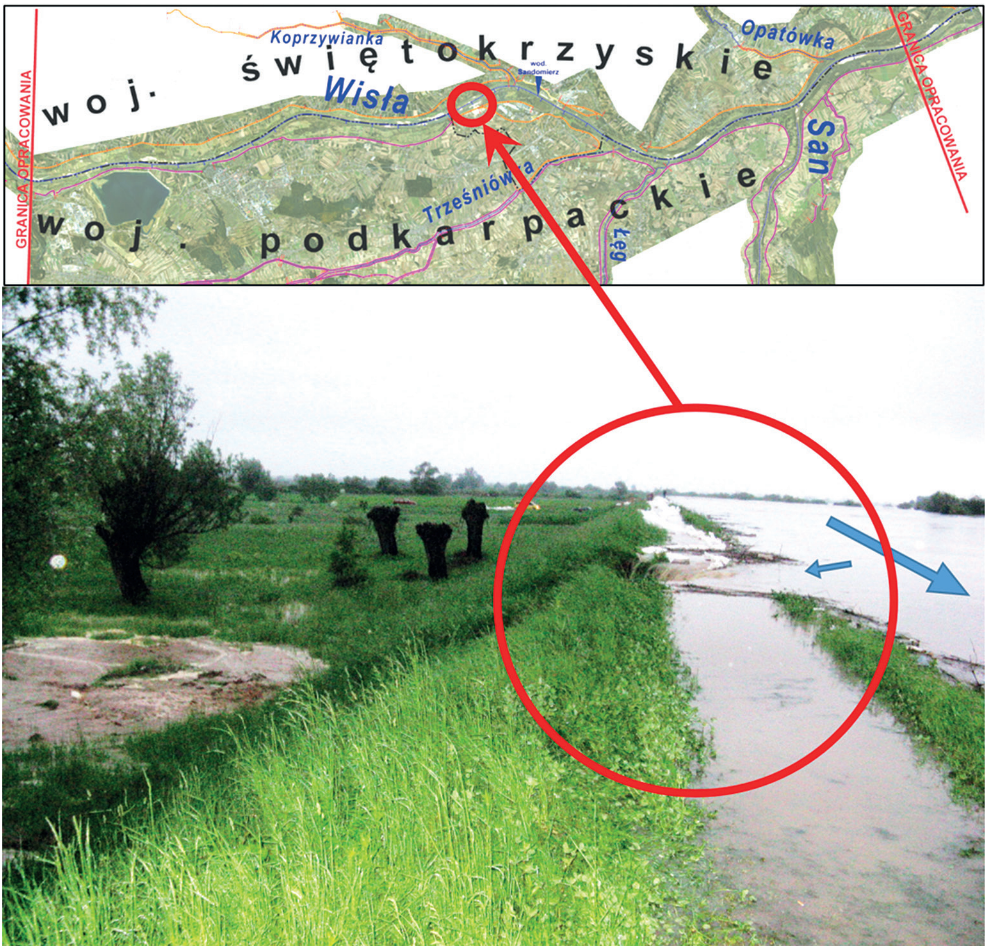


Fig. 4.22. Existing flood protection infrastructure in the Sandomierz area and the location of the first failure of the Vistula levee (own study)

the gap caused subsequent levees failures on the right-bank Vistula tributaries Trześniówka and Łęg (Fig. 4.23). Despite such a large extent of failure in the river junction and the reduction of flood culmination forced by it, further failures of levees occurred below Sandomierz on the left levee of the Vistula and its tributary, Opatówka (Fig. 4.23).

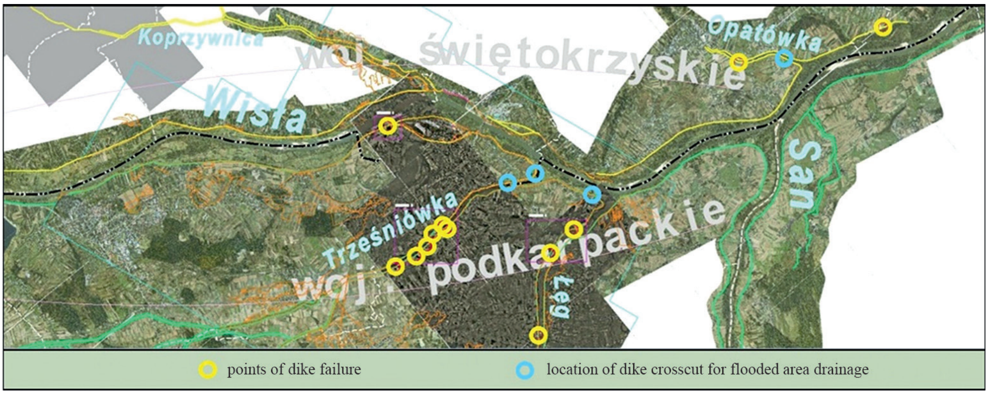


Fig. 4.23. Location of levee breaks on the river: Vistula, Trześniówka (both levees) and Łęg (left levee) as well as the dewatering cross-cuts of the levee in 2010 (own study)

The scale of the extensive damage caused was primarily due to the washing out of the Vistula levee and its bedrock over a length of about 150 m. The outflowing water brought out about 250 000 m^3 of material from the river bed and area between levees. The lake created outside the levee had a volume of about 160 million m^3 and its maximum depth was 5 m.

The analysis of the causes of the failure showed that:

- In areas located in the lower parts of the catchment area there are more flood risk scenarios and this should be considered when locating polder retention for areas already insufficiently protected by levees.
- At very high flows, there was a significant influence of vegetation in the channel (Fig. 4.24) on the velocity field, the length-varying contribution to the flow of the channel and between levees favouring the formation of local accumulations, and uncontrolled erosion and sedimentation phenomena.
- There are enormous problems with levee failures in the river's nodal areas, especially when the levees are high. Permanent pumping stations are shut down by flooding and even the most powerful mobile pumping stations cannot pump out millions of cubic metres of water in a short period of time. In such cases, levee cuts are made at the lowest points of the terrain as soon as the water in the river is lowered. It is also becoming urgent to secure (to close) the sites of failures and crosscuts so that the next flood wave does not endanger the protected areas (so as not to allow next flood wave to get out

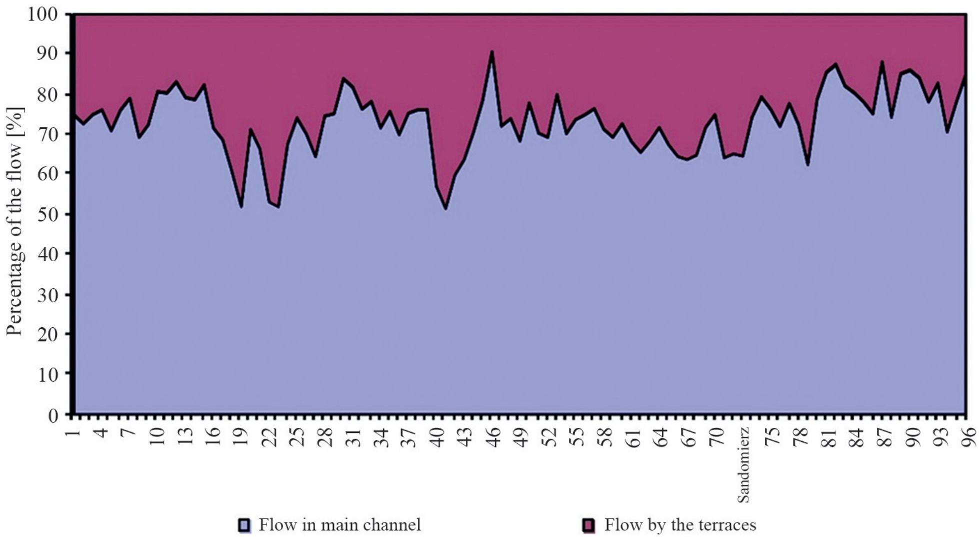


Fig. 4.24. Determination of the capacity of the Vistula river bed in the Sandomierz area, divided into the main channel and terraces covered with vegetation of different intensity for flow rate Q_{2010} (own study)

to the area outside the embankments). Such a situation was in Sandomierz in 2010 (Fig. 4.15).

An assessment of the causes of failure and the scale of flood damage in 2010 in Sandomierz also provided guidelines for the directions of modernisation of the existing flood protection system in the river junction near Sandomierz. The recorded uncontrolled phenomena of erosion and accumulation at the existing high levees clearly indicated actions towards limiting the values of maximum flows in this section of the Vistula and related to this is the further increase of the height of the levees. The search for adequately large and controlled polder retention to effectively reduce maximum flows in the threatened section was indicated. A further indication was to maintain control over vegetation development between levees in relation to planned safe flows.

4.4.3. Effects of the 2010 flood reduction by storage reservoirs

Table 4.5 shows the effects of selected storage reservoirs during the 2010 floods.

The assessment of the performance of multi-purpose storage reservoirs during high surges is usually not straightforward. The effects of flood reduction in selected reservoirs presented in Table 4.5 clearly indicate this, although they show effects only in the dam section. The performance ratings of the individual basins are as follows:

– The Goczałkowice reservoir showed a 56% reduction in flood culmination but used 79% of its flood capacity and significantly exceeded its non-harmful flow.
– The Tresna reservoir on the river Sole with a high flood potential achieved a reduction rate of only 25% with a flood capacity utilisation of 72% and an exceedance of the harmless flow value.
– The Dobczyce reservoir achieved a reduction effect of 48% but unfortunately with the use of emergency capacity after exceeding the MaxPP. This case provides guidance for the preparation of an assessment of the technical condition of reservoir dams allowing for such exceedances.
– The Czorsztyn and Rożnów reservoirs are located on the Dunajec river with the highest flood potential in the upper Vistula catchment area. As can be observed, they performed at a very high level of efficiency. The Czorsztyn reservoir has reduced culmination to the value of harmless flow, i.e. to 250 m^3/s, and the Rożnów reservoir only by 15%, using 80% of its flood capacity. This example clearly shows the importance of precipitation scenarios and the development of a river network that favours high volume surges, which significantly reduce the effectiveness of wave culmination reduction for the same flood capacities in reservoirs.

Table 4.5

Reductions in floods in 2010 in selected reservoirs (source: Regional Water Management Authorities in Cracow) examples (Bojarski et al. 2012)

Reservoir	Max inflow [m^3/s]	Max outflow [m^3/s]	Max outflow / *Q* harmless [-]	Reduction [%]	Use of flood reserve [%]
Goczałkowice	516	226	226/60	56	79
Tresna	988	746	746/335	25	72
Dobczyce	1150	600	600/300	48	124 – overcapacity
Czorsztyn	654	250	250/250	62	34
Rożnów	2000	1700	1700/1200	15	80

The answer to the question of what was the extent of the reduction effect along the length of the river has no simple answer without performing appropriate simulations on numerical models using reliable and detailed data. In general, it should be noted that the developed river network substantially limits this range. This means that in a flood protection system composed of levees and storage reservoirs, it is not only the volume of the waves and the corresponding retention but also the location of this retention that is important.

4.4.4. Summary

The presented selected problems of flood protection in the upper Vistula catchment area in the context of a catastrophic flood and the results of the analyses and experience gained indicate that there are still many problems to be solved and how important a rational approach verified by real problems and effects from the period of the catastrophic flood is. Flood protection systems are expected to demonstrate both local and regional effectiveness. Experience shows that the scope of problems increases when we move from qualitative descriptions of problems to quantitative descriptions and from planning studies to design studies. The quality of the output data including its consistency is always a very important factor. In the methodological field, the interpretation of both the output data and the obtained results of calculations and analyses is very important.

In presenting the experiences and results of the analyses from the catastrophic flood, it is important to point out how complex it is to evaluate the effectiveness of flood protection systems on a spatial scale and how important the experiences of historical floods are. Before considering the modernisation of the flood protection system in a situation with not only many solutions but also with limitations, it is very important to have a strategy and to justify the choices made.

Currently, tasks in water management are prepared and implemented based on the type and scope of planning presented in Chapter 2. Some of these plans have been updated, as recommended by the WFD, every six years. The development and implementation of these plans requires the systematic training of specialists so that the expected results in the existing and expanded water management systems are satisfactory. We remind you that the final effects include the processes of planning, implementation and operation. Each of these stages must take into account an interdisciplinary approach, growing requirements resulting from climate change, environmental requirements and multi-faceted security.

WATER MANAGEMENT IN UKRAINE IN CONDITIONS OF DEVELOPMENT AND CLIMATE CHANGE

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1. Water resources

Ukraine's water objects cover 24.2 thousand km^2, which is 4.0% of its total territory (603.7 thousand km^2). These objects include rivers, lakes, reservoirs, ponds, canals, and others. The territory of Ukraine does not have a very dense river network (average value – 0.34 km/km^2), there are no large natural reservoirs and poor groundwater reserves. The marshes, which were a natural regulator of river water, are now half--dried. Thus, Ukraine's aquatic natural resources are, first and foremost, local and transit flows of rivers, water reserves of lakes, artificial reservoirs, and underground horizons.

In Ukraine, traditionally, water was considered and used only as an economic resource for industrial and agricultural production, electricity generation, and for the discharge of wastewater, which eventually led to the exhaustion of the natural and ecological potential of water resources. The integration of Ukraine into the European Economic Community (EEC) and the World Trade Organisation (WTO) and the signing of an association agreement with the European Union, implies the formation and implementation of a balanced water policy of Ukraine according to the Sustainable development goals. The WTO's environmental requirements are intended to reduce the negative anthropogenic impact of economic activity on the environment and human health. Ukraine aligns its national water development strategy with the requirements of the EEC, the WTO and international commitments on sustainable development in general and environmental and aquatic in particular. So today, water is not only regarded as a natural resource, it also has pronounced social importance. This is why providing our citizens and economic sectors with quality water are one of the priorities of the Ukraine socio-economic policy.

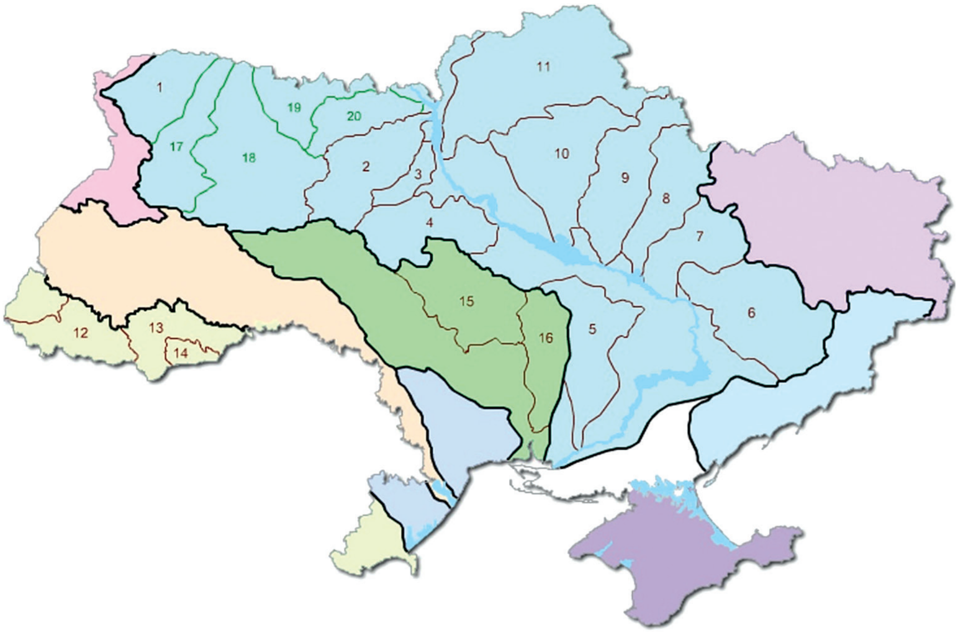
The rational use of water resources, the harmonisation of relations between man and nature, the protection of the environment – these issues are among the most pressing problems of today because they affect every inhabitant of the planet since the future of all mankind depends on their future.

1.1. Rivers (area, river basin, discharges, levels, water quality)

The hydrological network of Ukraine is genetically and functionally integrated into nine basins that differ in the catchment areas and water management activities. These are the Dnipro, the Western Bug, the Dniester, the Southern Bug, the Siverskyi Donets river basins, the Azov, the Black Sea, the Danube, and the Crimean river basins (Fig. 1.1). Given the issues of balanced water use, a brief description of the basins of the main rivers of Ukraine is given below.

Water resources of river runoff that are formed in Ukraine amount to about 200 km^3, but in low-water years, resources are reduced to 130 km^3.

One of the main hydrological characteristics is the average long-term runoff or annual runoff rate. In the water management plan, runoff determines the potential water resources of the river basin and is also the starting value in determining the runoff of the estimated security.



1st level river basin; 2nd level river basin; 3rd level river basin

– Dnipro River Basin:

1. Pripyat River Basin;
2. Teteriv River Basin;
3. Irpin River Basin;
4. Ros River Basin;
5. Ingulets River Basin;
6. Samara River Basin;
7. Orel River Basin;
8. Vorskla River Basin;
9. Psel River Basin;
10. Sula River Basin;
11. Desna River Basin;
17. Styr River Basin;
18. Goryn River Basin;
19. Ubort' River Basin;
20. Uzh River Basin.

– South Bug River Basin:

15. Synyukha River Basin;
16. Ingul River Basin.

– Danube River Basin:

12. Tysza River Basin;
13. Prut River Basin;
14. Seret River Basin.

– Dniester River Basin
– Vistula River Basin (Western Bug)
– Don River Basin (Seversky Donets'k)
– Black Sea River Basin
– Azov River Basin
– Crimean River Basin

Fig. 1.1. River basins in Ukraine

Figure 1.2 presents the average annual runoff modules. The Carpathian rivers are characterised by costs of 20–30 dm^3/s/km^2, for the rivers of the Crimean mountains – 4.0–5.0 dm^3/s/km^2. In the north of Ukraine, the most common values are 3.0–6.0 dm^3/s/km^2, and on the southern this module are reduced to 0.5 dm^3/s/km^2. The increase in runoff is also characteristic of the Donbas and Azov rivers due to the pumping of mine water and incoming water from the Siversky Donets – Donbas channel.

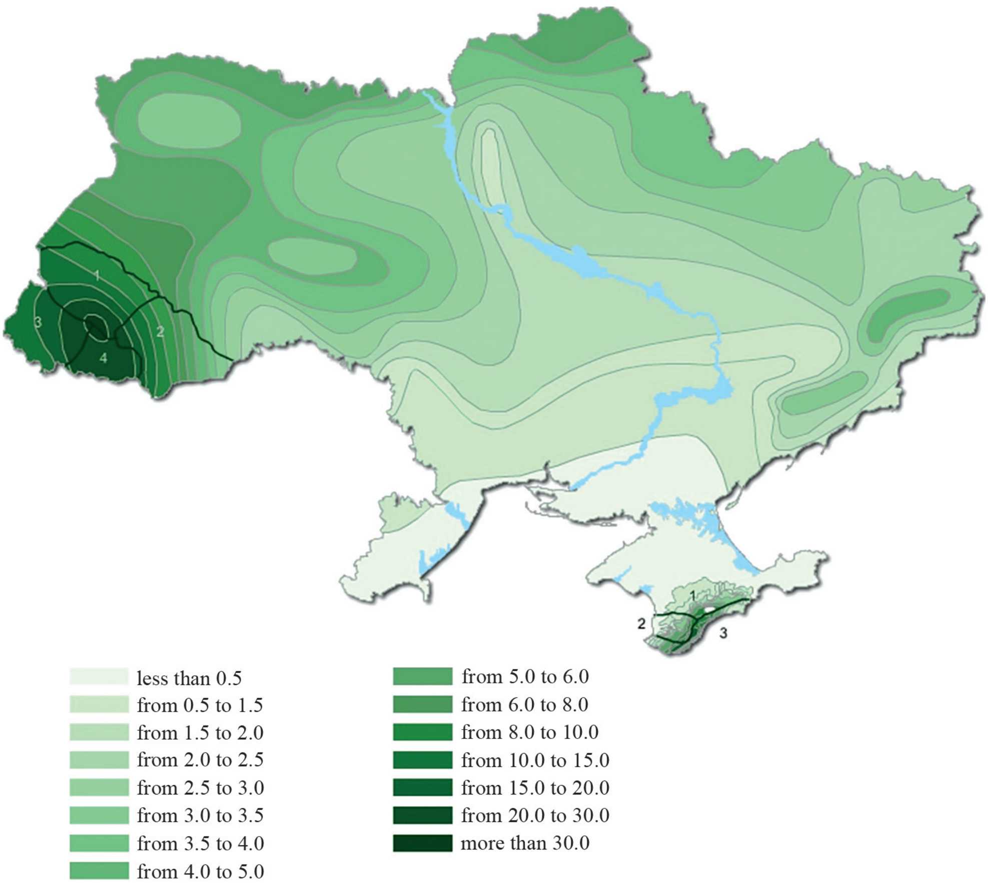


Fig. 1.2. Average annual runoff modules (litres/sec per km^2)

When determining the runoff rate, the coefficients of variation and asymmetry are always calculated. The coefficient of variation shows the deviation of costs from the average and depends primarily on climate sustainability and increases in its aridity. Therefore, the coefficient of variation is greater for southern rivers that have a more uneven regime, and smaller for rivers in the northern part of the territory that have correspondingly smaller fluctuations in the runoff. Moreover, for the same districts, the coefficients of variation of runoff for individual seasons may have different meanings, because runoff formation in different seasons is influenced by different factors. Thus, in an area with favourable groundwater conditions, the summer runoff, which is formed mainly by this source, may have a small coefficient of variation, and the spring runoff, which is formed depending on the nature of snow accumulation, may be greater for the same area. Therefore, the coefficient of variation in Polissya region is mainly 0.4–0.5, in the south, it reaches 0.8–1.0, and the flow variability in the Carpathians is somewhat less.

An exception to the general rule is the Donbas and Azov rivers, which have a relatively stable flow and the main factor of these features is the additional flow of water from mines, canals, and waterways, rather than natural features.

The asymmetry coefficient characterises the degree of asymmetry of the series of random variables considered relative to its average value. The asymmetry coefficient varies widely, from 1.0–1.5 to 3.0–3.5. The values of the coefficients of variation and asymmetry are given in Table 1.1.

Table 1.1

Long-term characteristics of the Ukraine annual river flow

River profile	The catchment area, km^2	Average long-term value		The coefficient of variation	The coefficient of asymmetry
		water discharge, m^3/s	runoff modules, dm^3/s/km^2		
1	2	3	4	5	6
Vistula River Basin					
Western Bug – Kamianka Buzka	2350	12.4	5.28	0.41	0.78
Poltva – Busk	1440	7.65	5.31	0.42	1.10
Rata – Mezhirichya	1740	8.03	4.61	0.47	0.83
Danube River Basin					
Prut – Ungheny	15 200	89.80	5.91	0.31	1.08
Tisza – Vylok	9140	216.0	23.6	0.29	0.00
Prut – Chernivtsi	6890	74.40	10.8	0.48	0.82
Latorytsia – Mukacheve	1350	23.4	17.2	0.37	0.60
Cheremosh – Usteryky	1500	25.50	17.0	0.35	1.50
Dniester River Basin					
Dniester – Zalishchaky	24 600	225	9015	0.32	0.65
Dnister – Halych	14 700	156.00	10.5	0.32	0.67
Lomnytsya – Perevozets	1490	23.8	16.0	0.40	0.83
Seret – Chortkiv	3170	12.1	3.82	0.23	0.84
Smotrich – Tsybulivka	1790	4.42	2.47	0.40	080

table 1.1 cont.

Southern Bug River Basin					
Southern Bug – Olexandrivka	46 200	85.6	1.85	0.37	0.67
Synyukha – Synyuhin Brid	16 700	27.5	1.65	0.45	0.80
Savranka – Osychky	1740	2.41	1.39	0.42	1.0
Velyka Vys – Jampil	2820	3.54	1.26	0.56	1.40
Yatran – Pokotylove	2140	4.19	1.96	0.46	0.87
Chorny Tashlik – Tarasivka	2230	3.32	1.49	0.63	1.60
Ingul – Novogorozhena	6670	8.77	1.31	0.75	1.66
Gromokliya – Mykhailivka	1410	0.73	0.52	0.94	2.05
Dnipro River Basin					
Dnipro – Kyiv	32 800	1370	4.18	0.26	0.25
Stochid – Lyubeshiv	2970	11.4	3.84	0.67	1.97
Sluch – Sarny	13 300	45.5	3.42	0.54	1.35
Uzh – Korosten	1450	3.29	2.27	0.72	1.71
Teteriv – Zhytomyr	5270	14.2	2.69	0.54	0.95
Desna – Chernihiv	81 400	323	3.97	0.31	0.87
Seim – Mutino	25 600	100	3.91	0.37	0.90
Ros - Korsun-Shevchenkivskyi	10 300	21.8	2.12	0.42	0.93
Psel – Sumy	7770	25.7	3.31	0.34	0.81
Khorol – Myrhorod	1748	3.65	2.09	0.52	1.17
Vovcha – Vasylivka	11 600	8.90	0.77	0.93	2.25
Basavluk - Katerino Natalivka	1050	0.74	0.70	0.87	1.95
Ingulets – Olexandero-Stepanivka	1400	2.32	1.66	0.69	1.28
Seversky Donets River Basin					
Seversky Donets – Zmiiv	16 600	45.5	2.74	0.42	1.09
Seversky Donets – Lysychansk	52 400	105	2.00	0.47	0.83
Oskol – Kupyansk	12 700	38.8	3.06	0.40	1.06
Aydar – Belolutsk	2250	5.61	2.49	0.60	1.28
The River Basins of the Azov Region					
Obytichna – Prymorsk	1300	1.71	1.32	0.71	1.52
Berda – Osipenko	1620	2.71	1.67	0.55	1.26
Kalmius – Primorske	3700	8.29	2.24	0.48	0.64
Kalchik – Mariupol	1250	1.55	1.24	0.66	1.56
Krynka – Blagodatne	1690	4.08	2.41	0.62	1.23
Crimea rivers basin					
Salgyr – Simferopol	321	1.47	4.58	0.44	1.30
Kacha – Suvorove	525	1.57	2.99	0.53	1.30
Alma – Chervonoarmijske	607	1.21	1.99	0.43	0.20

The Dnipro River Basin. This is the largest river in Ukraine with a catchment area of 293.0 thousand km^2 (the total area is 504.0 thousand km^2). Its total length is 2201 km, including 1121 km in Ukraine. The average annual discharge is 42.5 km^3.

The Dnipro catchment area is formed in the marshy forests of the Valdai Hills of Russia in the north of the Smolensk region. From its origins to the border between Ukraine and Belarus, the Dnipro laid its riverbed in the southwestern direction and crossing the border, in the area north of Orsha, Vitebsk region, the river lays along the 30° meridian to Kyiv. In the valley section from Kyiv to Dnipro, the Dnieper River flows in the south eastern direction, downstream, to the city of Zaporizhzhya, and flows in the submeridial direction, and in the lower reaches to the confluence with the Black Sea, the Dnipro flows to the southwest. In the northern and central parts of Ukraine, the Dnipro river basin is of considerable size (including the basins of the Pripyat and Desna rivers), which is twelve times its size. Administratively, there are sixteen regions within the basin. There are 180 cities, 363 settlements, and 15 650 villages, housing about 21.3 million people.

The Prypyat River Basin. This is one of the largest tributaries of the Dnieper. The area of the basin is 121 thousand km^2. The length of the river is 775 km, including 261 km in Ukraine. The source of the Prypyat River is located on the eastern slope of the weakly pronounced Main European Watershed in the village of Golyadin in Volyn. The Prypyat Valley at the top is poorly defined, the lower is clearer. The floodplain is developed throughout, and the alluvial terraces are fragmented. At the bottom, the width of the floodplain reaches 10–15 km. The upper reaches of the stream are 20–40 m wide, the average is 50–70 m wide, 100–250 m lower, and 4–5 km at the confluence with the Kyiv reservoir. River nutrition is mixed. The slope of the river is 0.08 m/km.

This Vistula River Basin. This is an international water basin, the area of which in Ukraine covers 12.6 thousand km^2. It occupies the far western part of the Ukraine territory, the proper right-bank part of the basin of the large Western Bug River, and part of the middle San River. The source of the Western Bug River is in the village Verhobuzhi of the Zolochiv district of the Lviv region, on the low-mountain Voroniaky hill. In Ukraine, it flows through the territory of the Lesser Polesie and the Nadbuzka Upland, as well as along the western edge of the Polissia lowland. The Western Bug flows into the artificial Zegrze Lake in Poland (the Baltic Sea basin). The total length of the river is 772 km, 392 km in Ukraine. The catchment area of the basin is 73 500 km^2 (11 205 km^2 in Ukraine). The slope of the river is 0.3 m/km. It is a plain river with a marshy floodplain, winding river bed, and numerous old riverbeds. The average annual water flow varies over the length of the river from 1.12 (Sasiv village) to 29.5 m^3/s (Sokal). The rural population in the Western Bug basin uses groundwater for water supply.

The water regime is characterised by a prolonged spring flood, a short-term summer mean water, which is disturbed by rain floods and almost annual autumn rises in water levels.

Dniester River Basin. This is a transboundary water system covering the southwestern part of Ukraine and the eastern part of Moldova. The upper Dniester and its leak belong to Ukraine. The Dniester River is located on the slope of the Carpathian Mountains (Rozluh village, Lviv region) near the border between Ukraine and Poland. The absolute height of the leak is 760 m. Below the Old Sambir, the Dniester River flows out of the mountains and acquires features of the Semi--mountain river. The width of the river is increased up to 30 m, depth – up to 1.0 m. Its total length is 1352 km, 912 km within Ukraine. The catchment area of the basin is 72 500 km^2, of which 73% or 53 450 km^2 is within Ukraine. The average slope of the river is 0.65 m/km. On the upper reaches, there is a mountain river with a deep canyon-like valley, the depth of which reaches up to 100 m. The width of the river is 40 m. The average slope of the river is 0.37 m/km. The average annual water flow is 330 m^3/s. The spring flood begins on the Dniester in February and ends in June. Water discharges reach 180–260 m^3/s. In the Ukrainian part of the basin, there are 57 cities, 75 settlements and more than 3300 villages. Water management of the basin is 18%. The long-term water discharge is 228 m^3/s. The level of anthropogenic load on the Dniester ecosystem is quite high. On the banks of its tributaries, there are the Drohobych and Nadvirnyansky refineries, the Stebnikov Potash Plant, the Kalusky Chlorine-Vinyl factory, and the Zhidachiv Pulp and Paper Mill. Moreover, large sugar mills and meat processing plants are operating in the river basin and Zalishchyky, Mohyliv-Podilsky and other treatment facilities that are not operating properly.

Tisza River Basin. This is the main right tributary of the Danube, and its basin is considered one of the most dangerous areas of Europe in the context of floods. Within the borders of Ukraine, the Tisza River flows in the Transcarpathian region, partly along the border between Ukraine and Romania, Hungary. The area of the basin is 157 thousand km^2 (11.3 thousand km^2 in Ukraine), the length of the river is 966 km, 201 km within Ukraine. The Tisza River is formed 4.0 km above the town of Rokhov after the confluence of the White Tisza and the Black Tisza.

The upper, mainly right-bank part of the basin, which occupies the southwestern slopes of the Carpathians and the Transcarpathian lowlands is localised on the territory of Ukraine. Tisza River Valley up to the Great Bychkov village is canyon like, 100–200 m wide, in some sections, it is gorge like and 30–50 m wide. Below, it flows along the mountains of Upper Thyszanian hollow in a wide valley (3–5 to 8–9 km), crosses the volcanic Vigorlat-Gutinsky ridge and leaves to the Transcarpathian lowland. Upon reaching the lowlands, the Tisza acquires the features of a lowland river, its width reaches 150–170 m. The river slope is 1.2 m/km. Runoff is mainly formed by snow and rain. There are dangerous high floods; 40% of annual runoff is in the spring. Ice formation occurs in the first half of December, the ice formation is unstable; spring ice drifts occur in March. The main reasons for the formation of frequent and high floods are the hydrometeorological and synoptic situation, as well as the structural features of mountain river beds and extremely developed economic activity, represented in the inconsistent development of floodplains. In the early years of the twenty-first century, catastrophic high floods exceeded the historical level by 75 cm.

At present, 640 km of earthen dams, nine reservoirs, 6094 km of drainage canals and fifty-four pumping stations have been built in the Tisza river basin. Constructed dams do not form an integral protective complex of flood protection.

Southern Bug River Basin. This is the only major river in Ukraine, the basin of which is completely located on the territory of the country. The basin area is 63 700 km^2, the river length is 806 km. The hydrographic network is characterised by a pronounced spring flood and summer rain floods. The average annual water discharge at the estuary of the Southern Bug is 114 m^3/s. In the basin of the Southern Bug there are 100 cities in Ukraine (the largest thirty-five) and 2878 villages in which more than 4.2 millions lived. There are 665 rivers with a total length of 22.5 thousand km that belong to the basin. The origins of the Southern Bug near the village Kholodets in the Khmelnytskyi region and the Southern Bug flows into the Dnieper-Bug estuary of the Black Sea. In the upper and middle parts of the basin, the climate is temperate continental, and in the lower reaches, it is arid. The significant extent of the basin from the northwest to the southeast causes noticeable differences in the temperature distribution, from 7.1°C to 10.0°C. The level regime of the river is characterised by a pronounced spring flood, summer low water, and autumn-winter water rises. Clearing the river basin from ice occurs at the end of March.

The Seversky Donets River Basin. This is the largest river in Eastern Ukraine. The total length is 1053 km, 700 km of which is in Ukraine, the basin area is 98 900 km^2, 55% of which is located in Ukraine. Seversky Donets originates in the Central Russian Upland near the village of Podolhy in the Belgorod region of Russia. In the Seversky Donets River Basin, there are over 3000 rivers, of which 425 are more than 10 km long. Water flow is predominantly formed by snow. The spring flood lasts for around two months. The width of the river varies from 30–70 m, reaching 100–200 m, and in the area of reservoirs, it is around 4 km. The Seversky Donets flows into the Don. The average slope is 0.18 m/km. For the biggest part, the river has a wide valley: 8–19 km in the upper reaches and 20–26 km in the lower reaches. The valley is mostly asymmetric. The right bank is high, and the left bank is gentle. The Ukrainian part of the Seversky Donets Basin is located in Kharkiv (22 000 km^2 or

40% of the total area), Donetsk (about 8000 km^2 and 15%, respectively), and Lugansk (24.6 thousand km^2 and 45%) regions; within it, there are thirty-one completely and eleven partially administrative districts, 245 cities (the largest sixty-eight) and more than 2.2 thousand villages, in which about six million urban and more than 1.7 million rural residents live. The territory of the Seversky Donets River Basin is the most urbanised and industrial region of Ukraine with intensive agricultural production. About 500 large enterprises operate here, including about 100 water--intensive and environmentally hazardous chemical and metallurgical industries.

The River Basins of the Azov Region. There are no large rivers in the Azov river complex, but the water resources of this region are formed by five medium-sized rivers (Kalmius, Gruzskiy Elanchik, Krynka, Mius, Kalchik) with a total length of 865 km. There are 2213 small rivers, 194 of them being over 10 km long. The average density of the river network is 0.2 km/km^2. In the Northern Azov region, rivers originate at an altitude of 120 or 250 m above sea level. Along the remaining distance, these are typical plain watercourses, mainly with a calm smooth flow, well-defined morphological features – meanders, reaches, streamers, asymmetric profiles of the river valley, and so on. The V-profile of the valley prevails; on separate streams (Krynka, Kalmius) they are box-shaped or undefined (Gruzskiy Elanchik). The width of the valleys varies from 0.49–0.8 km in the upper reaches (the Mius, Krynka, Mokry Elanchik rivers) to 3.5–6 km in the lower reaches (the Mius, Molochnaya, Berda, and Kalchik rivers). The height of the slopes varies from 2–10 m in the upper reaches to 30–50 m in the lower sections. The right slopes are tall, the left ones are gentle. The width of the floodplain ranges from 50–100 m. On some rivers (Kalchik), the floodplain is present only at the estuary. During the spring flood, it is flooded. The river beds meander at a flow depth of 0.8 to 3 m. The rivers are meandering, especially in the lower reaches. The average width of the riverbed is 3–10 m (upper sections), the depth is from 0.2 to 5 m. The flow velocity is insignificant; at the low water level on most rivers, it is close to 0; during the spring flood, it is 0.5–0.8 m/s. An exception is the upper sections of the Mius, the Krynka, and other rivers, where the flow velocity ranges from 0.5–1.2 m/s. In the dry period, some rivers (the Mokry Elanchik and the Sadki) dry out in places every year. The bottom of the rivers is sandy or silty; the upper reaches of the rivers flowing down the slopes of the Donetsk Ridge (Mius, Krynka) are sand and gravel. The right bank is predominantly higher than the left. The rivers of the Crimean peninsula, such as Mokry Indol, Biyuk-Karasu, Chernaya, Belbek, Kacha, Alma and Bulganak-Zapadny are assigned to the river basins of the Azov region. They originate in the Crimean mountains. On the lowland part of the Crimean peninsula, the density of the hydrographic network is 0.26 km/km^2. There are 154 cities (the largest 33) and 1.6 thousand villages, which are home to more than five million people, including 4.4 million urban and 0.9 million rural residents. Within the Azov region, large industrial hub centres are located

(Donetsk, Makeevka, Torez, Snezhnoye, Mariupol, Berdyansk, Melitopol, Simferopol, and others), in which the water-intensive enterprises of the coal, metallurgical, chemical, engineering, and other industries operate.

The waters of the Rivers of Azov Basin are characterised by high salinity, which does not meet the requirements of agricultural or fisheries standards. The main reason is that a significant part of the river flow is formed due to mine drainage. River runoff resources are not able to satisfy the economic needs of these industries. Therefore, 780 million km^3 of seawater is involved in an economic turnover. An important role in the region's water supply system is played by the regulation of surface runoff by artificial reservoirs.

The Black Sea Rivers Basin. The Black Sea River basin (7.9% of the territory of Ukraine) unites the rivers between the Danube and the Dniester and between the Dniester and the Southern Bug. They flow along the Black Sea lowland and flow into the estuaries of the Black Sea coast or into the Black Sea itself. There are 1702 small rivers with a total length of 6.6 thousand km, including the Black Sea rivers of Crimea (3.1 thousand km), the average density of the river network is 0.15 km/km^2. A characteristic feature of the small river basins located between the Danube and the Dniester is their pear shape or oval shape, elongated from north to south. Fifteen administrative districts, 82 cities (the largest 20) and more than 1.1 thousand villages are located here. The population is 3.6 million people (including 2.6 million urban and 1.1 million rural residents). Local water resources do not provide the water needs of the economic complex of the Black Sea region, which uses more than 1 km^3 per year. Due to the involvement of water resources from other basins in the economic turnover, wastewater discharge is 1.4 times higher than water withdrawal.

More than seventy million m^3 of untreated and 185 million m^3 of insufficiently treated effluents are discharged into the water bodies of the Black Sea River Basin. The current state of the water resource and environmental situation in the Black Sea region is assessed as unsatisfactory. The main factors of high anthropogenic impact on water resources here are a high level of agricultural and water management development of the territory, excessive content of mineral and organic substances in river waters and polluted water discharges from a point and diffuse sources located in river basins.

Danube River Basin. A small part of this basin, 8.1% of the total area, is located in Ukraine. It mostly consists of the Tisza River Basin. Another part of the basin is the lower and estuary parts of the river, which is limited by the state borders of Ukraine with Moldova and Romania.

The total area in Ukraine of this largest river in Europe is 23.35 thousand km^2, only 4% of the total basin. Over 63% of the Danube's water resources in the average year of water flow through the Kiliysky estuary. The main volumes of hydraulic engineering construction are concentrated in the Odessa region and Near Danube lakes.

The runoff regime is mainly determined by the water sources. Ukrainian Rivers take water from the melt (snow), rain, and groundwater. Most rivers of Ukraine belong to the rivers, which are mainly fed from snow and are characterised by a tendency to equalise the intra-annual runoff distribution. This is due to the regulation of runoff, the influence of the climatic factor – the increase in air temperature in winter, and therefore, increased thaws, during which there is a partial melting of the snow cover.

In the north and central Ukraine, the share of snow sourcing is higher than 50% of annual runoff, and in the south, it increases to 80% or more. On rivers of snow feeding, the average monthly water discharge is observed in March – April, and the lowest in late summer or early fall. Rivers are in the western regions of the country, where a significant part of the runoff is formed by rainwater, the part of the spring runoff is less than 50% of the annual total, and the runoff of the low season exceeds 15–20% of the annual total. The runoff of the rivers of the Black Sea lowland and the Crimea steppe is formed mainly in February – March. The rivers of this region have practically no underground nutrition and dry up annually in the summer and freeze in the winter.

In the second place with regard to the feeding of the Ukrainian rivers is underground nutrition, the part of which is very variable in the annual runoff. So, on average it makes up 20–35%, on some rivers of the Volyn-Podolsk Upland more than 50%, and in the south of the Black Sea Lowland the part of underground nutrition is close to zero.

Rainwater feeding of the rivers is insignificant, it does not exceed 10% and only in the Tisza, Prut basin and in some Carpathian tributaries of the Dniester is this proportion much higher.

Part of the underground water feeding, the volume, and intensity of floods depends on the precipitation volumes and air temperature, as well as on hydrogeological conditions, soil and vegetation. Thus, within the Volyn-Podilskyi, Prydniprovskaya heights, and Donetsk ridges, the share of underground water supply is significant if the river valley is deep enough, if the river valley is shallow, then the groundwater is not sufficient enough to maintain a constant flow of water and such rivers may dry up. The influence of the forest on the distribution of runoff during the year consists of increasing spring runoff and the redistribution of surface and underground runoff. If a small river does not drain groundwater, then vegetation reduces low-water runoff. It also reduces bogging due to the consumption of water for evaporation.

The intra-annual distribution of the flow of most rivers in Ukraine was also affected by economic activity – the creation of reservoirs, water intake for irrigation, water supply, drainage melioration, pumping water from one river basin to another.

The maximum flow of rivers is formed by the influx of melted snow or by rain. On the rivers with the predominance of snow supply, the maximum possible runoff is formed from the melting of snow and from the rain, while on the rainfall rivers, it is formed only by rainfall. The value of the maximum runoff depends on the intensity of melting snow or rain, the amount of moisture lost by impregnation and accumulation, the size of the area covered by the melting of snow or rain. Rivers, lakes or forests, common in the basin, reduce the maximum outflow.

Thus, the maximum flow rates of rivers, depending on the physical and geographical conditions, are different in origin:

a) flood – recurring mainly from melting snow on the plains,
b) rain,
c) mixed, formed from melt and rainwater.

The middle layer of flood runoff on the lowland part of Ukraine varies from 40–60 mm in the north of the country to 10 mm or less in the south of the Black Sea lowland and in the Sivash region. The flood layer on the southwestern slopes of the Carpathians and Transcarpathia averages 100–200 mm or more. Runoff during flooding is more than 50% of the total flow, and the duration of the flood varies from 10–15 days on small rivers to 3–4 months on large rivers. The transit time for maximum water flow rates is related to their origin. On lowland rivers, they occur in March – April, on the rivers of the Danube and Dniester basins (except for left--bank tributaries), and in the Crimea in the autumn.

In the mountainous regions of the Carpathians, in winter and spring, as a result of the rapid warming and melting of snow, it is accompanied by heavy rains for a day or more, and high peaks of floods are formed. These floods sometimes cause significant damage to the economy. Such floods were observed in December 1947, 1957, 1967, 1979, 1993, in January 1948, 1980, and in February 1968. The maximum runoff with catastrophic consequences occurred in 1998, 2000, 2001, and 2008.

On most rivers in Ukraine, the maximum discharge from spring floods exceeds the maximum discharge from showers, except for southern rivers, where the maximum discharge from showers exceeds the maximum discharge from meltwater. Observational data also shows that the catchment area is increasing, where the maximum rainfall exceeds the maximum meltwater runoff. Thus, in the north such reservoirs have an area of not more than 50–100 km^2, in the Donbas and Azov region – 3000–3500 km^2, and in the south of the steppe zone 9000–10 000 km^2. On the lowland territory of Ukraine, floods are rare and have local nature. They are short-term (for several hours) and are characterised by an intense increase in water level. The most flood-hazard regions of Ukraine are the Ukrainian Carpathians (the basins of the Prut, Dniester, and Tisza rivers) and the Crimean mountains. In the Carpathians, raising water levels during floods reaches 1.5–2.5 m for 3–4 hours.

The minimum river runoff of Ukraine is formed due to underground nutrition, which is determined by local hydrogeological and climatic conditions, the nature of the underlying surface (relief, soil, vegetation, swamps, lakes) and economic activity. Thus, the minimum runoff is affected, on the one hand, by general climatic factors, and on the other hand, by local azonal factors, such as the depth of the riverbed, the nature of hydrogeological conditions, and the size of the basin. The larger the size of the basin, the less noticeable the influence of local azonal factors becomes less noticeable and the role of zonal factors in the formation of minimum runoff becomes clearer.

When analyzing the characteristics of the minimum runoff (monthly average and daily average summer and winter minimum water flows), the greatest practical significance is their duration during the summer drought and winter freezing of rivers.

In a zone of sufficient moisture, groundwater supplying rivers located close to the surface of the earth provide stable low water discharge even for small rivers. In the area of insufficient moisture, groundwater aquifers are of low power, and the main nutrition of the rivers is provided by deep groundwater. The rivers of these zones are characterised by the unstable nature of the minimum runoff, which most often depends on local occurrence conditions and the nature of groundwater than on climatic factors.

The presence of forests in river basins and forest soils, which are characterized by high water permeability, contribute to the accumulation of groundwater and play a positive role in the amount of minimum runoff.

With an increase in the basin area, the minimum runoff also increases, since it also increases the volume of aquifers and the ground nutrition of rivers. A low flow rate is associated with a minimum runoff. In the territory of Ukraine, there are summer-autumn and winter low water.

Summer-autumn low water is observed from the end of the flood until the beginning of autumn floods (June-November) or to ice events, it spans from 120 to 170 days. The summer-autumn low-water season is associated with a small amount of precipitation and the significant expenditure of water on evaporation. During this period, rivers feed mainly on groundwater, sometimes the summer low-water period can be interrupted by short-term floods.

Winter low water is observed from the beginning of the period of ice to the onset of the flood, lasting 60–80 days. This period usually coincides with the period of ice cover. If we compare the summer-autumn borders on the territory of Ukraine with the winter borders, the latter is not inferior to the summer-autumn borders in terms of water consumption (Table 1.2).

The rivers of Ukraine carry a lot of solid sediment particles that form a solid runoff. Their number and composition are different, which depends on the physical and geographical features of the territory where the rivers flow and the intensity of erosion processes in their basins. According to experts, an average of 120 million tons of soil is washed away annually into the channels of small rivers of the country.

Table 1.2

Long-term characteristics of the minimum average runoff of some rivers of Ukraine

River – point	Summer-autumn		Winter	
	Q (m^3/s)	$Q_{80\%}$ (m^3/s)	Q (m^3/s)	$Q_{80\%}$ (m^3/s)
Vistula River Basin				
Western Bug – Sasiv	0.81	0.58	0.88	0.66
Zoldets – Luhove	0.09	0.01	0.18	0.01
Danube River Basin				
Chorna Tisza – Bilyn	4.43	3.10	3.52	1.94
Uzh – Uzhgorod	3.39	1.36	10.8	3.67
Prut – Yaremche	4.52	2.58	2.48	1.83
Dniester River Basin				
Dniester – Halych	58.2	34.3	59.7	26.3
Tysmenytsia – Drohobych	1.0	0.57	1.13	0.71
Zolota Lypa – Berezhany	2.37	1.42	2.57	1.54
Seret – Chortkiv	7.42	5.12	7.34	5.49
Southern Bug River Basin				
Southern Bug – Saboriv	9.14	4.33	12.1	5.2
Yatran – Pokotilovo	1.59	1.01	2.52	1.89
Mertvovod – Cryva Pustosh	0.04	0.02	0.14	0.07
Ingul – **Kropyvnytskyi**	0.17	0.07	0.41	0.10
Dnipro River Basin				
Horyn – Yampil	2.99	2.0	3.29	2.33
Irsha – Ukrainka	1.30	0.68	2.18	0.81
Sula – Romny	1.48	0.47	2.65	1.26
Kleven – Sharapovka	2.33	1.34	2.79	1.65
Ingulets – Olexandro – Stepanivka	0.25	0.06	0.41	0.11
Seversky Donets River Basin				
Vovcha – Vovchansk	0.83	0.60	1.15	0.71
The River Basins of the Azov and Crimea Region				
Molochna – Tokmak	0.34	0.16	0.54	0.25
Berda – Osipenko	0.66	0.32	1.02	0.57
Salgir – Pionerske	0.13	0.04	0.84	0.29

The main factors in the formation of solid runoff are the erosion of the territory, the depth of incision of the river valley and the nature of precipitation. Natural or artificial flow regulation is also important.

Traditionally, river sediments are divided into suspended and mobile types. Such a separation is conditional, since the same sediments, depending on the flow velocity, can transform into a suspended or mobile form. Has been established that up to 90% of solid runoff is transported on the plain rivers in suspension. On mountain rivers, this ratio can almost reverse.

In the north of the republic, with sufficient and excessive moisture and slightly rugged topography, erosion processes are poorly developed. The waters of the rivers flowing in this zone are not very saturated with sediments: their average annual concentration (turbidity of the water) does not exceed 20–50, and the most reach 200–300 g/m^3.

In the forest steppe, where there are a lot of loamy deposits and extremely high levels of agriculture, water erosion covers large areas. This is also determined by the climatic features of the zone: strong thaws in winter and intense summer rain showers. Therefore, the turbidity of water in rivers increases – its average annual value varies from 100–250 to 500 g/m^3 within the Podolsk Upland, and the maximum turbidity even reaches 3000 g/m^3. Small streams during floods can turn into mud flows.

The rivers of the steppe zone are even more turbid, which is facilitated by almost 100% ploughing of the territory and the presence of loams, which are easily susceptible to erosion, and climatic conditions. The concentration of sediment in the waters is 250–500 g/m^3, and within the elevations, it exceeds 500 g/m^3; the turbidity of temporary streams is much higher. The sediments of the watercourses of the lowland territory almost all move in suspension, and mainly during spring floods and summer floods.

The Carpathian rivers are characterised by flood conditions and carry a large number of sediments of various compositions and with particles of different sizes. Streams flow down from the valleys with turbidity that rarely exceeds 100–300 g/m^3; the saturation of sediments of water flowing down from the afforested slopes is slightly higher – 300–500 g/m^3.

However, even a slight disturbance of sod in the valleys or deforestation significantly increases the erosion of the territory and the turbidity of the water. The felling of forests in the foothills of the Carpathians doubled their solid runoff.

On the lowland part of Crimea, the average turbidity of rivers is 20–50, and in the east and west of the peninsula, it is up to 100 g/m^3. In the mountainous part, where the erosive activity of the waters is much more intense, the turbidity of the waters increases and reaches 500–1000 g/m^3 with a predominant value of 250–500 g/m^3.

In the Carpathians and Crimea, mudflows can form during heavy rains on small rivers.

The main causes of surface water pollution in Ukraine are: discharges of untreated and insufficiently treated municipal and industrial wastewater directly into water bodies and through the city sewage system; the entry into the water bodies of pollutants in the process of surface runoff of water from the land reserves; soil erosion in the catchment area. The consequences of the global environmental Chernobyl disaster must be taken into account. During the thirty-five years following the accident, the issues of radiation pollution of rivers remained unresolved.

To the listed main causes of pollution, it is necessary to add factors that determine the greatest danger to the water sector:

– insufficiently purified or completely untreated wastewater of domestic faecal and industrial sewage containing organic pollution, synthetic surface-active substances (SAS), heavy metal ions,
– petroleum products, which come from industrial sites and urban areas,
– drain and meltwater containing similar water pollution,
– surface runoff from the territory of livestock farms and complexes and drainage water from insufficiently isolated tailings and ponds-accumulators of industrial waste,
– leaching from agricultural land of mineral fertiliser products and pesticides used to protect plants.

The quality of water resources in recent years, despite a significant reduction in water consumption, is constantly improving. A particularly difficult situation is observed in the basins of the Dnieper, Seversky Donets, Azov rivers, and individual tributaries of the Dniester, Western Bug, and the north-western Black Sea.

The degree of water pollution can be characterised by individual integrated indicators.

Some indicators include:

The concentration of pollutants (Cn). Their amount per unit volume of water is measured in mg/l or g/m^3, the resulting concentration is compared with the maximum permissible concentration (MPC) of harmful substances in water bodies, which are established in accordance with the Sanitary Regulation and Protection Standards surface water from pollution. MPC values are developed for 1345 substances.

The content of dissolved oxygen in the water. The result of the determination of dissolved oxygen is expressed in milligrams of O_2 per 1 litre of water. The content of dissolved oxygen in water depends on atmospheric pressure, temperature, and the concentration of dissolved salts in it. The content of dissolved oxygen is used to assess the quality of surface water and some wastewater, evaluate and monitor the operation of biological treatment plants, and study the corrosion properties of water. Oxygen content is usually not determined in the analysis of drinking, groundwater, and most wastewater.

In surface waters at normal pressure, the maximum dissolved oxygen content is possible at t = 0°C – 14.6 mg/l, at t = 18°C – 9.5 mg/l, and at t = 100°C – 0 ml/l

Allowed oxygen content in surface water should be at least 4 mg/l. At an oxygen concentration of less than 2 mg/l, the intensity of anaerobic processes increases and oxygen starvation occurs.

Biochemical oxygen demand (BOD), that is, the amount of oxygen used for a certain time in the process of the biochemical oxidation of organic substances that are contained in the test water. The value of BOD5 in surface water varies from 0.5 to 4.0 mg/l. There are several methods for determining BOD. Arbitration analysis of surface and wastewater is the determination of BOD by the standard dilution method according to the difference between the oxygen content before and after incubation at a temperature of 20°C without access to air and light. The incubation period is five, seven, or twenty days. Determine BOD full, BOD5, BOD7 and BOD20. BOD is one of the main indicators of the organic pollution of domestic wastewater, as well as wastewater of the food industry. Allowable value in drinking water and household water at t = 20°C is 3.0 mg/l and 6.0 mg/l, respectively.

Oxidation is the amount of oxygen equivalent to the oxidiser consumption for the oxidation of pollutants. Depending on the oxidising agent, the abilities of permanganate and dichromate for oxidisation are distinguished.

The oxidation of permanganate is determined by the Kubel method. The method consists of oxidizing the substances present in the water sample with a solution of potassium permanganate in a sulphuric acid liquid.

Bichromate oxidation, also called chemical oxygen demand (COD), is determined by the dichromate oxidation method of organic substances (and mineral recovered compounds) by boiling in the presence of sulphuric acid, which is 50% of the total mixture.

Oxidation is calculated in milligrams of oxygen equivalent to the consumption of the oxidiser per 1 litre of sample. The value of COD in points of drinking and domestic purposes should not exceed 15.0 mg/l and 30.0 mg/l, respectively.

The ratio of BOD/COD can characterise wastewater in terms of the possibility of their natural purification. It varies depending on the composition of the wastewater of the chemical industry – 0.1–0.2.

Organoleptic characteristics of water (colour, turbidity, transparency, smell, taste). The colour of the water is determined by a dichromate-cobalt scale or by a photoelectric concentration (KFC-2) colourimeter.

The sources of pollution can be:

Mineral – sand, clay, slag, various ores, mineral salts, and oils. This is waste from engineering, metallurgy, oil, oil refining, construction, mining, and other industries.

Organic – plant origin (the remains of plants, fruits, vegetables, paper, etc., which contain a lot of nitrogen). These are municipal wastewater, waste from pulp and paper, soap and leather, meat processing, food and other enterprises.

Bacterial (biological) – a variety of microorganisms, such as yeast and mould fungi, small algae and bacteria.

The main sources of surface water pollution are:

1) Industrial wastewater. When using a direct-flow water supply scheme, the wastewater of some industries come into the river and adversely affects waterways and reservoirs.
2) Municipal wastewater. Only about 60% of municipal wastewater is treated.
3) Mineral fertilisers and pesticides. The increase in the aquatic environment of organic and biogenic elements (N, P, K, etc.) leads to the intensification of the processes of eutrophication of rivers and reservoirs, accompanied by a deterioration in their hydrochemical and hydrobiological regime and water quality in general. In this case, there is an intensive growth of aquatic vegetation, cyanobacteria, and plankton. Pesticides are very harmful to the environment. Organochlorine pesticides are not biodegradable and are stored in fresh and seawater for many years. Some water-insoluble pesticides dissolve in the waste of the oil refining industry and instead of settling to the bottom, accumulate on the surface of freshwater sources or seas. Thus, one type of contamination enhances another.
4) Mine water generated during the hydro mining of coal. The content of suspended solids in them is calculated in tens and even hundreds of grams per litre of wastewater.
5) From heat and nuclear power plants. When warm waters are discharged, the thermal, hydrochemical and hydrobiological regimes of water bodies are violated. There is a "bloom" of water. During the decomposition of algae, toxic substances (phenol, indole) are formed, which leads to the death of fish, and water becomes unsuitable for drinking and bathing.
6) Discharge of livestock complexes, in particular, pig farms. Such effluents are generated by the hydraulic method of manure removal in cattle and pig--fattening complexes. Wastewater of livestock complexes varies in composition.
7) Detergents – substances that are part of synthetic detergents. They can form stable foam, even in small amounts. The thickness of the foam layer can reach 1 m or more. Detergents do not lose this quality even after passing through treatment plants and in the process of water treatment.
8) Oil and oil products. These all threaten the cleanliness of water bodies. These are strong persistent pollutants that can spread up to 300 km away. Light oil fractions form a thin membrane on the surface of the water, which prevents gas exchange.
9) Wastewater of the chemical industry. They often contain substances that previously did not exist in nature. Some of them are extremely biologically active, which facilitates the purification process, but others are very stable and therefore difficult to clean. The most dangerous metals are mercury and its compounds. Its gradual accumulation in hydrobionts and bottom sediments is observed.

10) Ore and the processing of nuclear fuel for nuclear power plant reactors, radioactive waste burial sites, and industrial accidents.

The qualitative monitoring covered the used waters (inter-branch and agricultural waterworks, reclamation of irrigated and drained areas and soils in areas covered by melioration). In areas exposed to radioactive contamination, monitoring also includes radiological indicators. The quality of water in transboundary sections of watercourses is determined in accordance with international agreements on cooperation in transboundary water bodies. The monitoring system is implemented by the State Agency for Water Resources of Ukraine. In accordance with the national state surface-water monitoring program, approved by the State Agency for Water Resources of Ukraine, surface-water conditions were monitored in 436 points of observation.

An analysis of the qualitative state of surface-water according to the monitoring results in the system of the State Agency of Water Resources for 2018 in the context of hydrographic zoning is given below.

Dnipro River Basin

In the area of the Dnieper river basin, observations were made at 145 monitoring points, of which thirty-three points were drinking water intakes.

The worst values of water quality indicators were recorded at the observation points of the channel of the Bortnicheskaya aeration station.

In 2018, the averaged values of BOD5 and COD indicators slightly decreased at the indicated observation points; however, they do not reach the normative values.

The results of instrumental and laboratory measurements of the quality status of water in reservoirs and the main watercourses of the Dnieper basin at the locations of drinking water intakes indicate an excess in terms of BOD and COD, reflecting the intensity of the pollution of water bodies with organic compounds that are easily oxidised and those that are not easily oxidised.

In 2018, according to the results of measurements of water samples in the places of water intake of the cities of Verkhnedneprovsk and Verkhniyi Plavny, an increase in dry residue was recorded.

Observation profiles in places of drinking water withdrawals in Kyiv. Desnyanskiy water intake and drinking water intake in Kyiv were characterised by values at the level of 2017. Higher COD values were recorded.

At the same time, for the Dnieper river basin, there are characteristic regional aspects of the formation of their quality. The waters in the upper reaches of the Dnieper are characterised by a high content of natural compounds of humic and fulvic acids, and iron and manganese compounds. The colour of the water is an indicator of the content of these compounds. In this regard, the most natural (biogenic) pollution of all reservoirs of the Dnieper cascade is observed precisely in the Kyiv reservoir, which is reflected below.

The radiological state of the surface waters of the Dnieper basin during 2018 didn't undergo significant changes compared to previous years. The content of radionuclides in the waters of the reservoirs of the Dnieper cascade and basin rivers within the controlled territory as a whole was stable and significantly lower than the established standards. State hygiene standards limit the content of 90Sr and 137Cs to 2.00 kBq/m³.

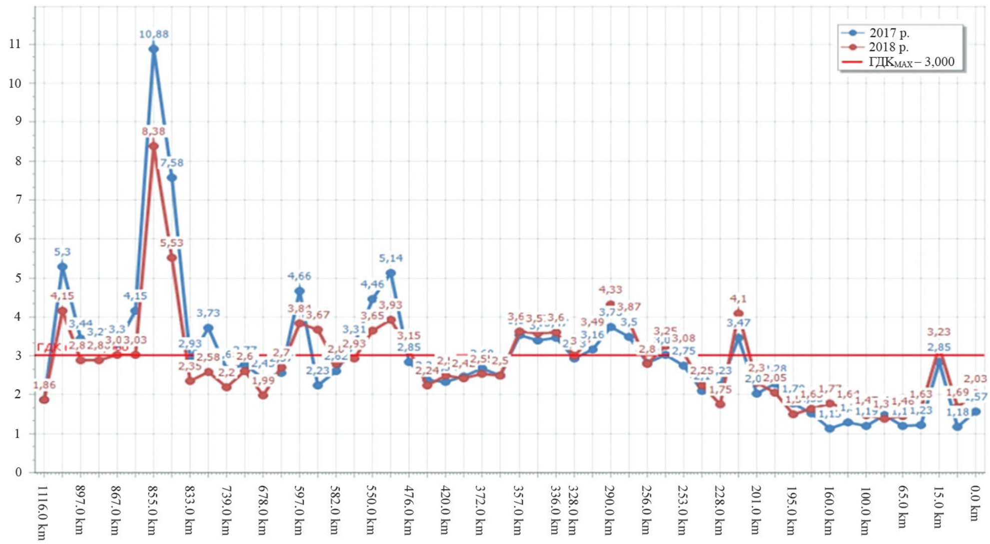


Fig. 1.3. Dynamics of changes in the average annual values of the BOD5 indicator for the Dnieper river bed in 2017–2018

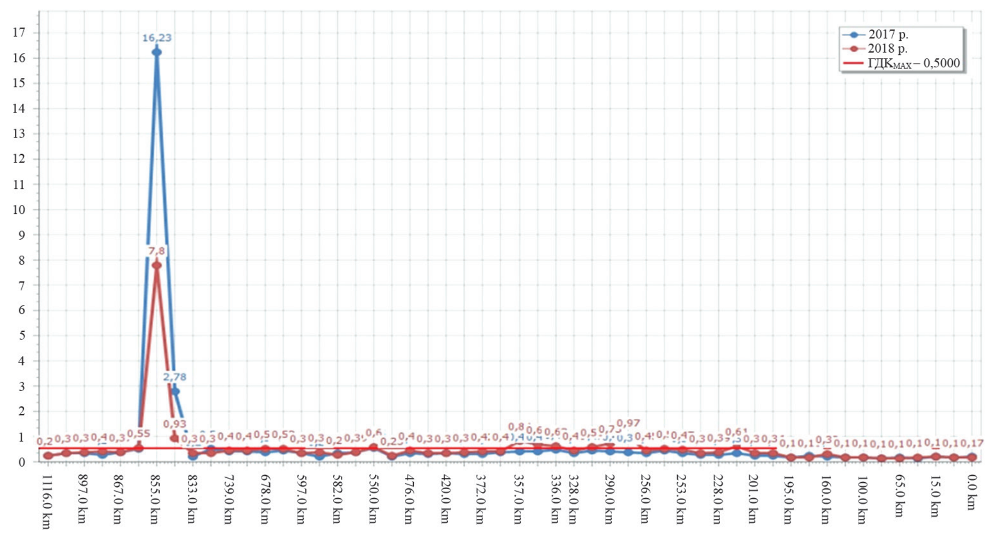


Fig. 1.4. Dynamics of changes in the average annual values of the COD indicator for the Dnieper river bed in 2017–2018

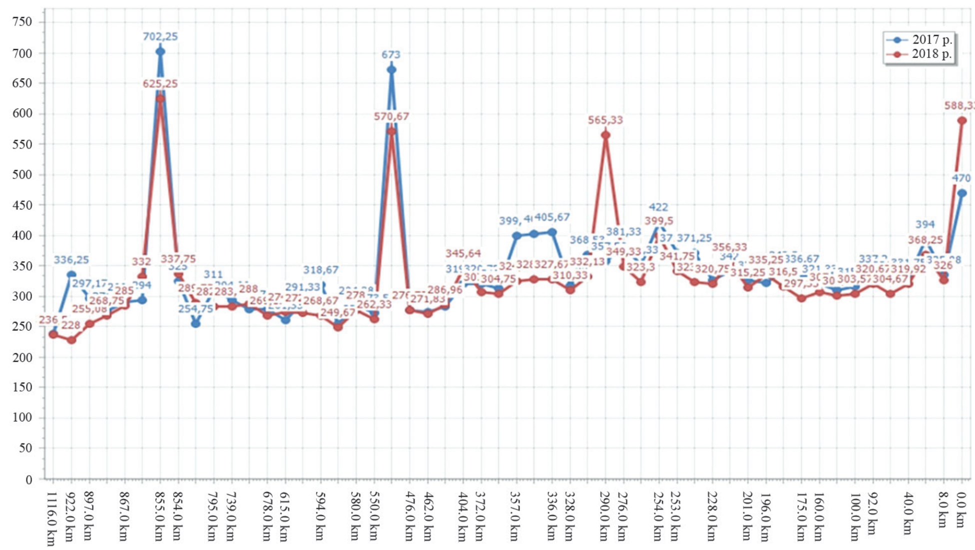


Fig. 1.5. Dynamics of changes in average annual dry solids in the Dnieper river bed in 2017–2018

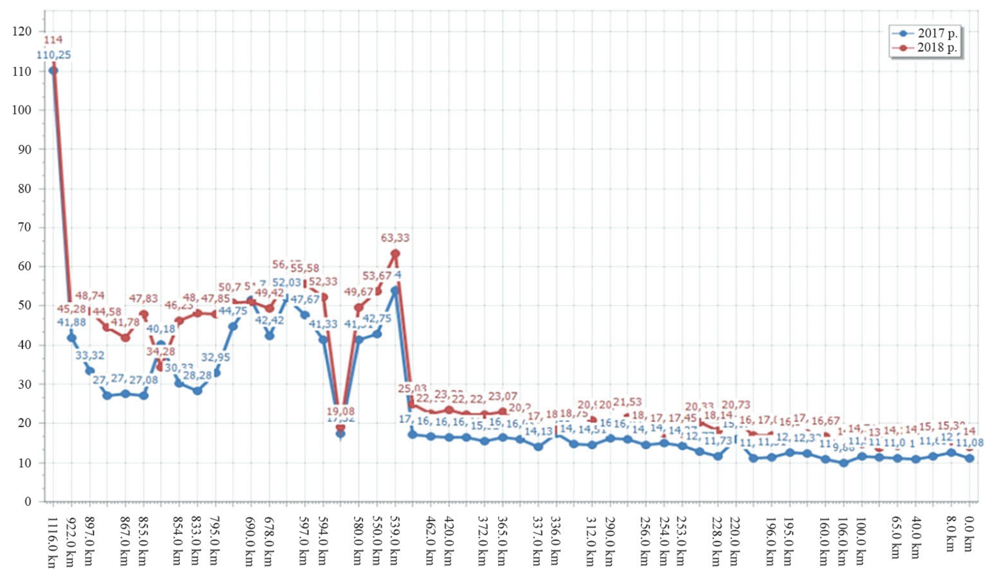


Fig. 1.6. Dynamics of changes in average annual values colour of water for the Dnieper river bed in 2017–2018

Dniester River Basin

In the Dniester River basin region, observations were carried out at fifty-four monitoring points, of which fourteen were places of drinking water intake.

The waters of the Bystritsa Nadvornyanskaya and Bystritsa Solotvinskaya rivers, which are sources of drinking water supply in Ivano-Frankivsk, were characterised by good values of water quality indicators during 2018.

In the upper part of the Dniester river basin, the Sivka rivers in the Kalush region and the Sadjava in the Dolinsky district of the Ivano-Frankivsk region remain problematic.

Discharges of industrial enterprises of Kalush significantly deteriorate the quality indicators of the Sivka river, where sewage with a high salt content falls. In water samples taken from the Sivka river from June to August, salt content doubled (from 504 mg/l to 1284 mg/l).

Compared to 2017 in the Sadjava river, the indicators of chemical (COD) and biochemical (BOD5) oxygen consumption deteriorated. The maximum values of these indicators are quite high:

– BOD5 – from 34 mgO_2 /l to 160 mgO_2/l,
– COD – from 133 mgO/l to 582 mgO/l.

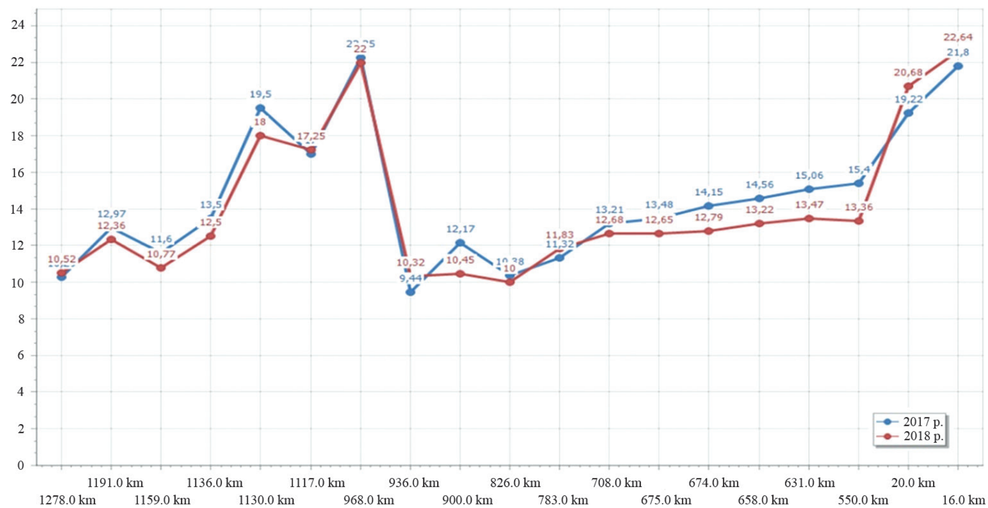


Fig. 1.7. Dynamics of changes in the average annual COD values for the Dniester river bed in 2017–2018

The significant anthropogenic impact is also recorded in the lower Dniester river basin in the Odessa region after the passage of watercourses through the territory of the Republic of Moldova. In the sections of the Kuchurgan reservoir (Gradanitsi and Kuchurgani points), river Kuchurgan (Stepanovka point) recorded excesses in the following indicators: dry residue, BOD5, ammonium nitrogen, surfactant, colour.

The quality of surface water in the places of water intakes used in the Dniester River basin as a source of drinking water supply is generally satisfactory.

Seversky Donets River Basin

In the Seversky Donets river basin, the monitoring of forty-one points was carried out, three of them at drinking water intakes.

Monitoring the quality of water in places of water intakes used as sources of drinking water for the Seversky Donets river basin area is carried out in four sections in the Seversky Donets river and in one section of the basin of the Azov river. The results of monitoring in 2018 are significantly different from last year:

- Seversky Donets river, Pecheneg reservoir, 872 km (source of drinking water for Kharkiv). The average annual indicators corresponded to last year's level, in particular: COD – 19.6 mg/dm^3; BOD5 – 2.4 mg/dm^3; ammonium ions – 0.31 mg/dm^3; dry residue – 563.3 mg/dm^3; phosphates – 0.64 mg/dm^3; nitrates – 1.37 mg/dm^3; nitrites – 0.036 mg/dm^3. heavy metal salts, including total iron – 0.12 mg/dm^3; manganese – 0.017 mg/dm^3; cobalt – 0.009 mg/dm^3; nickel – 0.008 mg/dm^3; chromium 6 + – 0.002 mg/dm^3; zinc – 0.008 mg/dm^3; copper – 0.003 mg/dm^3. The dissolved oxygen content was 7.6 mg/dm^3; the stiffness was 6.55 mmol/dm^3.
- Seversky Donets river, Raygorodok profile, 522 km (drinking water withdrawal into the Seversky Donets-Donbass canal): COD – 19 mg/dm^3; BOD5 – 3.6 mg/dm^3; ammonium ions – 0.4 mg/dm^3; dry residue – 704.6 mg/dm^3; phosphates – 1.32 mg/dm^3; nitrates – 7.36 mg/dm^3; nitrites – 0.07 mg/dm^3. heavy metal salts, including total iron – 0.11 mg/dm^3; manganese – 0.041 mg/dm^3; cobalt – 0.008 mg/dm^3; chromium 6+ – 0.004 mg/dm^3; zinc – 0.019; copper – 0.0025. The content of dissolved oxygen was 9.7 mg/dm^3. Hardness slightly decreased to 6.8 mmol/dm^3.
- Seversky Donets river, point Belogorovka, 469 km (drinking water withdrawal to the Luhansk region): COD – 18.5 mg/dm^3; BOD5 – 3.2 mg/dm^3; ammonium ions – 0.34 mg/dm^3; dry residue – 1090.8 mg/dm^3; nitrates – 8.5 mg/dm^3; phosphates – 1.158 mg/dm^3. Heavy metal salts, including: total iron – 0.11 mg/dm^3; manganese – 0.037 mg/dm3; cobalt – 0.006 mg/dm^3; chromium 6+ – 0.003 mg/dm^3; zinc – 0.008 mg/dm^3; copper – 0.002 mg/dm^3. The content of oxygen dissolved in the water is 9.5 mg/dm^3. The stiffness was 8.2 mmol/dm^3.
- Seversky Donets river, Svetlichnoe point, 406 km (reserve drinking water intake): COD – 19.5 mg/dm^3; BOD5 – 3.7 mg/dm^3; ammonium ions – 0.44 mg/dm^3; dry residue – 1190.8 mg/dm^3; nitrates – 9.89 mg/dm^3; phosphates – 1.33 mg/dm^3. Heavy metal salts, including: total iron – 0.16 mg/dm^3; manganese – 0.034 mg/dm^3; cobalt – 0.008 mg/dm^3; chromium

6+ – 0.005 mg/dm^3; zinc – 0.019 mg/dm^3; copper – 0.002 mg/dm^3. The content of dissolved oxygen is 9.5 mg/dm^3. The stiffness was 8.23 mmol/dm^3.

The drinking water intake of Mariupol is located on the Kalchik River, a tributary of the river Kalmius (the basin of the Azov rivers) and it is characterised by high salinity of water. The average annual quality indicators in the observation range (Kalchik River, Starokrymskoe Reservoir) were recorded at the level of last year and amounted to: dry residue – 2978 mg/dm^3; stiffness – 24.4 mmol/dm^3, COD – 20.2 mg/dm^3; BOD5 – 3.1 mg/dm^3; ammonium ions – 0.32 mg/dm^3; phosphate ions – 0.26 mg/dm^3; nitrate ions – 1.6 mg/dm^3; total iron – 0.26 mg/dm^3; manganese – 0.1 mg/dm^3; zinc – 0.04 mg/dm^3; chromium 3+ – 0.001 mg/dm^3. The content of dissolved oxygen is 9.3 mg/dm^3.

Danube River Basin

In the area of the Danube river basin, observations were carried out at sixty-one monitoring points, of which eleven are drinking water intakes. In water samples that were taken in 2018 at the locations of drinking water intake in the Danube river channels (Izmail city; points Kiliya, Vilkovo), qualitative indicators have not changed significantly compared to 2017. A slight deterioration in quality indicators occurred in the Danube river, 20 km, Vilkovo point, drinking water intake.

The improvement in average annual values in 2018 is recorded in the monitoring point of the Bolgradsky drinking water intake (lake Yalpug-Kugurluy, Oksamitnoye village). Improvement occurred in the content of organic substances (indicators of BOD and COD) and indicators of salinity (hardness, solids, chlorides, sulphates, etc.), as well as phosphorus and iron compounds in general.

In all sections at the locations of drinking water intakes, sub-basins of Prut and Siret rivers, water, according to the results of measurements of hydrochemical and radiological indicators carried out in 2018, is characterized as pure. The value of indicators of the content of pollutants is below the average values for previous years. These sections are as follows:

– Prut river, 772 km, Lenkivtsi village, drinking water withdrawal of Chernivtsi,
– Prut river, 867 km, Kolomyia town,
– Siret river, 448 km, drinking water intake of Storozhynets.

The state of water bodies in places of water intakes and water bodies in the Tisa sub-basin in 2018, according to monitoring results, has not changed significantly compared to 2017.

In sections located in places used as sources of drinking water supply, namely:

– 40 km river Uzh, drinking water intake of Uzhgorod,
– 65 km river Latoritsa, drinking water intake Chop,
– 882 km Tisza, drinking water intake of Tyachiv city.

According to the results of recent years, the water condition is quite stable and has not changed significantly compared to 2017. The value of quality indicators corresponded to the long-term average.

Vistula River Basin

In the area of the Vistula River Basin, observations were carried out at sixteen monitoring points, of which four are drinking-water intake sites. The surface waters of the pool are not used for drinking-water supply. The needs of the population for drinking water are met by groundwater reserves. The main influence on the quality of surface water in the basin is carried out by municipal and industrial enterprises of the Lviv region. The influence of enterprises of the Volyn region on the quality condition of the Western Bug river is negligible.

The Poltva river, the left tributary of the Western Bug, is the most polluted river in the basin because it is a sewage collector in Lviv. In 2018, a slight decrease in the indicators of organic pollution of COD and BOD was recorded at the monitoring station in Poltva (30 km poniżej Kam'yanopil, Pustomytovsky district). However, these indicators are at a fairly high level (BOD – 28.67 mg/dm^3 and COD – 70.3 mg/dm^3).

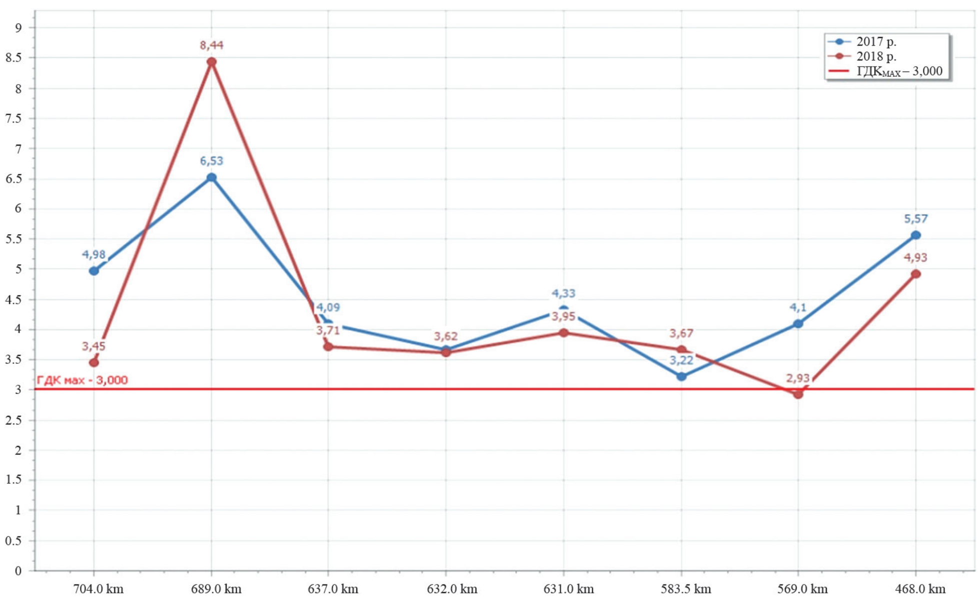


Fig. 1.8. The dynamics of changes in the average annual BOD values for the Western Bug river bed in 2017–2018

An increase in the average annual value of the indicator of biological oxygen demand was observed only in the Dobrotvorsky reservoir (689 km).

Southern Bug River Basin

In the region of the Southern Bug River basin, observations were carried out at forty-two monitoring points, of which twelve places are drinking water intakes.

Surface waters of the river basin of the Southern Bug are polluted mainly with organic compounds. The increased content of organic compounds is also a consequence of the effects of pollutants that enter the water bodies with wastewater from enterprises and the influence of organic compounds of natural origin entering surface waters from peat bogs and swamps.

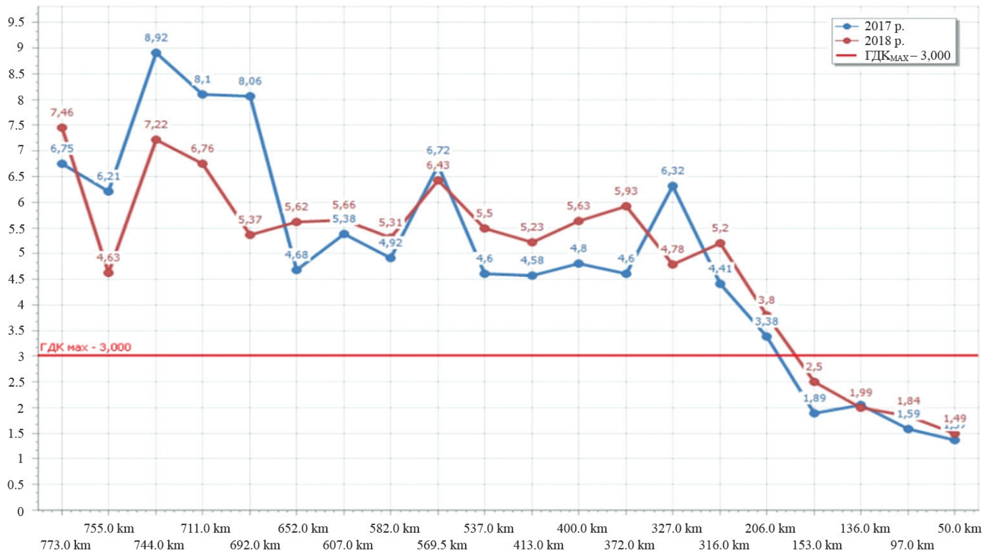


Fig. 1.9. Dynamics of changes in the average annual BOD values for the Southern Bug river bed in 2017–2018

The Black Sea river basin

In the Black Sea river basin, observations were carried out at fifteen monitoring points at places of drinking water intakes; water-quality monitoring was not carried out.

The Black Sea river basin is characterised by high values of salt composition – solids, sulphates, and chlorides as a result of regional aspects.

The Azov Rivers Basin

In the area of the Azov rivers basin, observations were carried out at five monitoring points at the places of drinking water intakes; water-quality monitoring was not carried out.

The waters of the Kalchik and Kalmius rivers were characterised by high values of salt composition – solids (in the range 4396–2890 mg/dm^3), sulphates (in the range 903–1369 mg/dm^3).

1.2. Lakes/reservoirs (area, capacity, levels, functions, water quality)

In total, there are about twenty thousand lakes in Ukraine, of which only forty-three have an area of 1000 ha or more, more than seven thousand of these have an area of 10 ha or more.

One of the indicators characterising the lake level of a given country is the percentage share of their total lagoon area in the total area. Among the countries of the world, the highest indicators of lakes are in Finland (9.4%) and Sweden (8.6%). The lake area of Ukraine is 0.15%, taking into account artificial reservoirs – 2.15%. It is the largest in the Odesa (1.43%) and Volyn (0.69%) regions, taking into account artificial reservoirs – in Odesa (3.96%) and Chernivtsi (2.2%) regions (Table 1.3).

Table 1.3

The share of the lakes area

Region	Lakes, thousand ha	Share of the lakes area, %	Natural (lakes) and artificial (reservoirs, ponds) reservoirs, thousand ha	Share of lakes and artificial reservoirs in the total area of the region, %
Vinnytska	0.60	0.02	35.50	1.34
Volynska	13.90	0.69	20.14	0.99
Dnipropetrovska	0.35	0.01	34.55	1.08
Donetska	0.038	0.001	28.25	1.07
Zhytomyrska	2.00	0.07	18.78	0.62
Zakarpatska	1.08	0.08	2.65	0.21
Zaporizka	0.29	0.01	11.34	0.42
Ivano-Frankivska	0.51	0.04	4.55	0.33
Kyivska	1.20	0.04	27.06	0.94
Kirovohradska	0.40	0.02	26.03	1.06
Luganska	1.32	0.04	10.06	0.38
Lvivska	1.20	0.06	11.24	0.52
Mykolaivska	0.51	0.02	15.80	0.64
Odeska	48.12	1.43	133.28	3.96
Poltavska	0.55	0.02	22.82	0.79
Rivnenska	1.77	0.09	11.94	0.59
Sumska	1.60	0.07	16.04	0.67
Ternopilska	0.50	0.04	9.45	0.69
Kharkivska	1.45	0.05	43.74	1.39

table 1.3 cont.

Khersonska	6.54	0.23	40.13	1.41
Khmelnytska	0.60	0.03	22.82	1.11
Cherkaska	0.68	0.03	23.54	1.13
AR Crimea	2.80	0.10	10.60	0.39
Chernivetska	0.60	0.07	17.82	2.20
Chernihivska	1.04	0.03	10.75	0.34
Dnieper cascade	-	-	688.70	-
Total	89.65	0.15	1297.58	2.15

Lake lows occur under the influence of various natural factors. Most of the Ukrainian lakes are of river origin and are located on the floodplains of the Danube, Dnieper, Desna, Pripyat, Seversky Donets, and other rivers.

These are floodplain lakes. Floodplain lakes feed mainly on the water of their river and fill them during spring floods and other floods. The size of these lakes is unstable. During floods, their outlines disappear, and when the flood comes, they are restored. The thermal and ice regime of floodplain lakes is the same as that of the adjacent river sections. The largest floodplain lakes are Kagul, Katlabukh, Kitay, Kugurluy (Danube basin), Liman (Seversky Donets basin), etc.

Lakes of karst origin in Polesie are widespread (Somov, Lucimir), the hollows of which were formed as a result of the leaching of dolomite, limestone, gypsum, and common salt layers by groundwater. Usually, these lakes are small, have a round, oval-elongated shape and can be very deep.

Volcanic lakes are located in the Ukrainian Carpathians, they were formed in the craters of the former volcanoes (Lipovetske, Syne, Vorochivske). Lakes of glacial origin are formed under the influence of ancient glaciers in the Ukrainian Polesie (Luka) and in the Ukrainian Carpathians (Brebeneskul).

The dammed Lake Synevyr is located in the Ukrainian Carpathians, it was formed as a result of mountain landslides that blocked the valleys of mountain streams. Subsidence (suffusion) lakes are common in the steppe and forest-steppe regions, where underground waters wash clay particles from gypsum rocks. These are the lakes of the Seversky Donets Basin in the region of Slavyansk – Slavyansky Lakes and the Salt Liman Lake in the Dnipropetrovsk Region.

On the coast of the Black and Azov Seas, there are numerous lakes – ponds that forever lost contact with the sea or are connected to it constantly or at certain times of the year. Firths are formed in estuaries or in beams due to the action of the sea and flowing waters. Sometimes these reservoirs are separated from the sea by sandy mounds (Kuyalnitsky, Hadzhibeysky, Tiligulsky), and are open (Danube, Berezhansky, Utlyutsky, etc.).

In Ukraine, only one lake of tectonic origin is known – Shelikhovske, in the Sumy region.

Lakes are widespread in various regions of Ukraine, but the most important lake areas are Volyn Polissya, Danube and Black Sea estuary lakes, the plain Crimea lakes and mountain lakes of the Ukrainian Carpathians.

The characteristics of the largest lakes are given in Table 1.4.

Table 1.4

The largest lakes in Ukraine

Lake, firth	Location	Water surface area, km^2	Length, km	Maximum width, km	Maximum depth, m	Water volume, million m^3
Yalpug	Danube basin	149.0	39.0	5.0	6.0	387.4
Kugurluy	Danube basin	82.0	20.0	10.0	2.0	82.0
Cagul	Danube basin	90.0	25.0	8.0	7.0	180.0
Sasyk (Sivash)	Crimean peninsula	75.3	18.0	14.0	1.2	37.6
Katlubug	Danube basin	68.0	21.0	6.0	4.0	47.6
Kitay	Danube basin	60.0	24.0	3.5	5.0	102.0
Donuzlav	Crimean peninsula	48.2	30.0	8.5	27.0	-
Svitjaz	Western Bug basin	27.5	9.3	27.5	58.4	180.0

A water reservoir is an artificial reservoir created for the accumulation and storage of water for future use, and regulation of river flow. It is conventionally accepted that an artificial reservoir with a volume of up to 1 million m^3 is a pond.

In Ukraine, ponds and reservoirs were created in ancient times, but a particularly intensive increase in their number was observed in the second half of the twentieth century. Dynamics of river runoff regulation by ponds and small reservoirs are presented in Table 1.5.

A total of, 1157 reservoirs and 28.9 thousand ponds have been built in Ukraine. At a normal retaining water level in reservoirs, the total water area is 2637 km^2 and taking into account the reservoirs of the Dnieper cascade and the Dniester reservoir, the water area is 9660 km^2. The total volume of reservoir retention is 8.4 and 55.2 km^3, respectively. The useful retention volume is 6.1 and 26.7 km^3, respectively.

All in all, the reservoirs and ponds of Ukraine as a whole occupy twelve thousand km^2 and have a volume of 58.6 km^3, of which the Dnieper largest reservoirs and Dniester reservoir constitute 11 782 km^2 and 58.2 km^3, respectively.

Thus, reservoirs and ponds occupy 4759 km^2 and hold 11.4 km^3 of water, and with the large reservoirs of the Dnieper and Dniester – 11 782 km^2 and 58.2 km^3, respectively.

Table 1.5

Dynamics of river runoff regulation by ponds and small reservoirs

Year	Water surface area F (thousand ha) and growth ΔF (thousand ha)				Total volume V (million m^3) and growth ΔV (million m^3)				
	F	ΔF	Growth compared to 1950		V	Share of average river local runoff,%	ΔV	Growth compared to 1950	
			ΔF	how many times				ΔV	how many times
1950	97.8	-	-	-	389	2.7	-	-	-
1955	119.2	21.4	21.4	1.22	1869	3.6	480	480	1.35
1960	202.6	83.4	104.8	2.07	3798	7.3	1929	2409	2.73
1965	263.4	60.8	165.6	2.69	5099	9.7	1301	3710	3.67
1970	285.6	23.1	188.7	2.92	5739	11.0	640	4350	4.13
1975	312.7	26.2	214.9	3.20	6427	12.3	688	5038	4.63
1980	360.8	48.1	263.0	3.69	8043	15.4	1616	6654	5.79
1985	462.0	101.2	364.2	4.72	11 007	21.0	2964	9618	7.92
1990	476.0	14.0	379.2	4.87	11 405	21.8	398	10 016	8.21

This means that artificial reservoirs contain a volume of water that exceeds the average annual flow of the Dnieper and, in general, the country's water resources, which are formed on its territory in average water years. The volume that is used to regulate the flow and meet the needs of the water sector (red) is 28.2 km^3 and corresponds to the Dnieper water resources in a very dry year (95% probability).

The distribution of artificial reservoirs throughout the country is uneven. They occupy the largest area in the forest-steppe and steppe zones. Here, 1 km^2 of the territory accounts for 1 ha of the water surface of reservoirs and ponds. Vinnytsia, Donetsk, Odesa, Kharkiv, Khmelnytskyi and Chernivtsi regions have more than 1 ha/km^2 of water surface area of artificial reservoirs.

The lowest density of coverage with water reservoirs, not exceeding 0.29 ha/km^2, applies to the Volyn, Zakarpattia, Ivano-Frankivsk and Crimea oblasts.

In most river basins, artificial water reservoirs have been built. In total, the regulation of the runoff by artificial reservoirs of most of Ukraine's rivers reaches 30–70%. These are mainly the rivers of the southern Bug basin, the Siewierski Donets, the Dnieper near Kiev, as well as the rivers of the south of the country and Crimea, most of which are completely regulated by ponds and water reservoirs in almost 100%. The least regulated is the flow of the Vistula, the Pripyat and Desna (Table 1.6).

Table 1.6

The main characteristics of ponds and reservoirs in Ukraine's river basins

River basin	Ponds			Reservoirs			
	number	water surface area, thousand ha	volume, million m^3	number	water surface area, thousand ha	volume, million m^3	
						total	useful
Vistula	610	2.77	45.2	14	4.15	90.4	81.6
Danube	675	4.12	60.4	37	73.8	1839	817
Dniester	3465	20.8	244	64	9.23	225	134
Southern Bug	6929	45.7	609	197	30.7	855	626
Dnieper	13 282	120	1841	558	87.6	2379	1724
Black Sea rivers	683	6.76	102	37	8.51	397	299
Seversky Donets	1731	11.7	208	146	42.8	2023	1641
Azov rivers	1377	10.8	231	97	26.7	658	585
Closed area	29	0.07	2.8	-	-	-	-
Total	28 781	223	3344	1150	283.4	8497	5906
Large reservoirs on the Dnieper	-	-	-	6	688	43 800	18 540
Dniester	-	-	-	1	14.2	3000	2000
Total rivers of Ukraine	28 781	223	3344	1157	986	55 297	26 446

Additional information on the large reservoirs of Ukraine is presented in Table 1.7.

The highest located in the Dnieper cascade are the Kiev reservoirs. The hydroelectric power plant is located on a water reservoir near the city of Vyshgorod, on the estuary of the Desna River into the Dnieper. The length of this reservoir is 110 km, the maximum width is 12 km and the average is 8.4 km, the maximum depth is 14.5 m and the average is 4 m, the area of the reservoir is 922 km^2, and the total volume is 3.73 km^3 (usable 1.17 km^3). The shallow water areas (up to 2.0 m deep) cover about 40% of the reservoir's surface. The water temperature in July is 20-24°C. The freezing takes place from mid-December to the end of March. The water is changed eight to fifteen times a year. In summer, the water blooms as a result of eutrophication, because the Chernobyl disaster contaminated the bottom sediments of the Kiev reservoir with radionuclides.

The *Kanevsky reservoir* was formed as a result of the construction of the Kanevskaya hydroelectric dam in 1972-1978. The reservoir is located in the Kyiv and Cherkasy regions. Length – 120 km, maximum width – 8 km, average – 5.5 km, maximum and average depth – 21 and 3.9 m, respectively. Shallow water (depth up to 2 m) occupies about 24%. The total volume of water is 2.73 km^3. Water exchange occurs 16-18 times a year.

Table 1.7

The main reservoirs of Ukraine

Reservoirs	Which river was built on	Water surface area, km^2	Volume, km^3	
			useful	total
Kyivske	Dnieper	922	1.17	3.73
Kanivske	Dnieper	569	0.28	2.48
Kremenchugske	Dnieper	2250	9.1	13.5
Kamianske	Dnieper	567	0.27	2.45
Dniprovske	Dnieper	400	0.84	3.3
Kakhovske	Dnieper	2150	6.8	18.2
Dniestrovske	Dniester	142	2.0	3.0
Pechenizke	Seversky Donets	86.2	0.34	0.38
Chervonooskilske	Oskol	122.6	0.44	0.47
Ladyzhinske	Southern Bug	20.8	0.13	0.15
Starobeshivske	Calmius	9.00	0.03	0.04
Karachunivske	Ingullets	44.8	0.29	0.31
Simferopilske	Salgir	3.23	0.03	0.04
Partisanske	Alma	2.25	0.03	0.03

Kremenchuk reservoir – the hydroelectric facility is located above the metro Kremenchuk. The reservoir is the largest in the area among the Dnieper cascade. It has an area of 2252 km^2. The total length of the reservoir is 149 km, the maximum width is 28 km, the average is 15.1 km, the maximum depth is 21 m, the average is 6 m. The shallow part (up to 2 m) occupies 18% of its area. The volume of water is 13.5 km^3. Water exchange occurs 2.5 – 4 times per year. The reservoir is located in the territory of the Cherkasy, Poltava and Kirovograd regions.

Due to the large volume, this reservoir is the main drainage regulator of the Dnieper and is intended for seasonal (summer) and partly multi-year regulation. There are dozens of water intakes from the reservoir, including water supply to the city of Kropyvnytsia and the Dnieper-Ingul-Ingulec canal.

The Kamianske reservoir was built in 1964, during the construction of the Middlel Dnieper Hydroelectric Station located aboveThe reservoir is located in the Kirovograd, Poltava and Dnipropetrovsk regions, has a length of 149 km, a maximum width of 8 km, an average of 5.1 km, and a maximum depth of 16.1 m with an average depth of 4.3 m. The reservoir area is 567 km^2, the volume of water is 2.45 km^3. Water exchange occurs 18-20 times a year. It is used for energy, water transport, irrigation (30-40 thousand ha), water supply (the Dnieper-Donbass canal), fisheries and recreation.

The *Dnieper reservoir* is located near Zaporizhzhia. A reservoir was formed in 1932 during the construction of the Dnieper Hydroelectric Station, it was restored after the Great Patriotic War in 1948. It has a length of 129 km, a maximum width of 7 km, an average of 3.2 km, an area of 410 km^2, a maximum depth of 53 m with an average of 8 m, and total volume water of 3.3 km^3. It is located within the Ukrainian crystalline shield, and Precambrian crystalline rocks are exposed on its shores.

The smallest reservoir width of 0.6 km is observed in the area of flooded rapids (10 rapids). Water collection occurs 12-14 times a year. The water quality in the reservoir is lower than in other Dnieper reservoirs.

Kakhovka Reservoir (formed in 1955-1958 during the construction of the Kakhovka hydroelectric power station) is located in the Zaporizhzhya, Dnepropetrovsk, and Kherson regions. This is one of the largest Dnieper reservoirs, its area is 2 155 km^2, the total volume of water is 18.2 km^3, its length is 230 km, its maximum width is 25 km, its average depth is 8.4 m, and its maximum depth is 24 m. Water exchange occurs 2-3 times per year. Shallow water (depth up to 2 m) occupies 5% of the total area. Kakhovka reservoir is the main source of irrigation and water supply in the south of Ukraine. From here, water is supplied to the North Crimean Canal, the Dnieper-Kryvyi Rih Canal, as well as the Verkhnyorogachinsky and the Kakhovsky canals, into the water supply systems of mines, enterprises and cities and towns of the Nikopol-Manganese industrial complex and Dneprorudny city.

The *Dniester reservoir* (built during the construction of the Dniester hydroelectric station) has an area of 142 km^2, and the total volume of water is 3 km^3.

Also significant in size are the reservoirs in the basins of other rivers: *Chervonooskilske* (created in 1958, its area is 122.6 km^2, the total volume of water is 0.47 km^3) on the river Oskol; Pechenigske (established in 1962, its area is 86.2 km^2, the total volume of water is 0.38 km^3) on the river Seversky Donets; Karachunivske (reconstructed in 1955-1958, area – 44.8 km^2, total volume of water – 0.31 km^3) on the river Ingulets, Ladyzhinske (created in 1964, area – 20.8 km^2, total volume of water – 0.15 km^3) on the Southern Bug river.

1.3. Groundwater (capacity, levels, water quality)

Due to the long interaction of abiotic and biogenic factors in the formation of the earth within Ukraine, seven first-order geological and hydrogeological structures have been identified. These geological, structural and lithological features, together with climatic conditions and endogenous-exogenous processes, determined the origin, migration, chemical composition, and dynamics of groundwater.

These features have become the main factors that determined the uneven distribution of the groundwater resource potential, suitable for satisfying the public needs of the state. This unevenness is manifested in the fact that, for example, in the Dnieper-Donets'k and Volyn-Podilsky artesian basins almost inexhaustible reserves of drinking groundwater are concentrated, while in the Ukrainian mass of fractured waters in the hydrogeological regions of the Carpathians and Donbas, they are limited and there is currently a significant shortage of groundwater. The artesian basin of the Black Sea contains large reserves of groundwater, but it is not very promising in terms of water supply, since most of its reserves are saline with seawater and are not suitable for human consumption.

Depending on the degree of exploration of groundwater resources, it is customary to allocate predicted operational resources (POR) and approve the reserves of these waters. The POR assessment provides for the possibility of discovering new groundwater deposits and serves as the basis for planning exploration work.

The predicted groundwater resources of Ukraine in the amount of 22.5 km^3/year, or 61.7 million m^3/day, of which only 7 km^3/year (19 million m^3/day) are not hydraulically connected to river runoff. Table 1.8 represent the predicted operational resources, operating reserves, and total use of underground water.

Table 1.8

Predicted operational resources, operating reserves, and the total use of underground water

Regions of Ukraine	Predicted operational resources, million m^3	Operating reserve		Groundwater intake	Groundwater using,%	
		Number of deposits	Reserve, million m^3		From operating reserve	From predicted resources
Vinnytska	323.1	44	47.8	27	56	8
Volynska	944.0	19	124.1	64	52	7
Dnipropetrovska	399.0	20	252.9	177	70	44
Donetska	899.4	86	384.7	473	123	53
Zhytomyrska	229.4	36	75.2	29	39	13
Zakarpatska	394.8	15	123.7	41	33	10
Zaporizka	566.0	24	114.2	57	50	10
Ivano-Frankivska	275.3	22	99.6	10	10	4
Kyivska	1538.6	92	709.6	135	19	9
Kirovohradska	147.7	36	79.9	45	56	30
Luganska	1748.4	62	653.7	494	76	28
Lvivska	1330.1	56	482.9	204	42	15
Mykolaivska	161.2	11	28.8	18	62	11
Odeska	268.9	30	124.5	36	29	13

table 1.8 cont.

Poltavska	1565.4	39	294.6	95	32	6
Rivnenska	1315.0	30	165.0	53	32	4
Sumska	1215.8	24	211.0	69	33	5
Ternopilska	805.2	15	96.0	42	44	5
Kharkivska	1500.1	32	376.7	70	19	5
Khersonska	1814.3	31	336.9	81	24	4
Khmelnytska	716.8	43	159.1	60	38	8
Cherkaska	659.4	37	106.2	57	54	9
Chernivetska	147.9	10	62.4	28	45	19
Chernihivska	3039.2	27	188.0	70	37	2
AR Crimea	474.8	59	420.8	124	29	29
Ukraine total	22 516.9	900	5718	2560	45	11

The main proportion (more than 60%) of groundwater resources is concentrated in the northern regions of Ukraine (Chernihiv, Kyiv, Poltava, Kharkiv, Rivne, Sumy, Lviv region). The least endowed with groundwater resources (362–758 thousand m^3/day) are the Chernivtsi, Kirovograd, Mykolaiv, Ivano-Frankivsk, Zhytomyr and Odesa regions.

Calculated per 1 person in Ukraine, the largest amount of resources (5.54 m^3/day) is in the Chernihiv region, and the minimum (0.28–0.42 m^3/day) – in Dnipropetrovsk, Odesa, Kirovograd, Donetsk, Mykolaiv, Zhytomyr and Vinnytsia regions. The average value of Ukran's water resources per 1 person is 1.13 m^3 day. When distributing groundwater resources within the basins of the country's main rivers, most of these resources (60%) belong to the Dnieper basin (35.3 million m^3/day). The distribution in other basins is as follows: Seversky Donets 12%, Dniester 9%, Azov rivers 5%, Dniester-Southern Bug rivers 1%, others 13%.

The distribution, reserves, and properties of groundwater artesian, reservoir and fractured waters primarily depend on the geological structure, and therefore the geological structure of the earth's crust is taken into account in hydrogeological zoning.

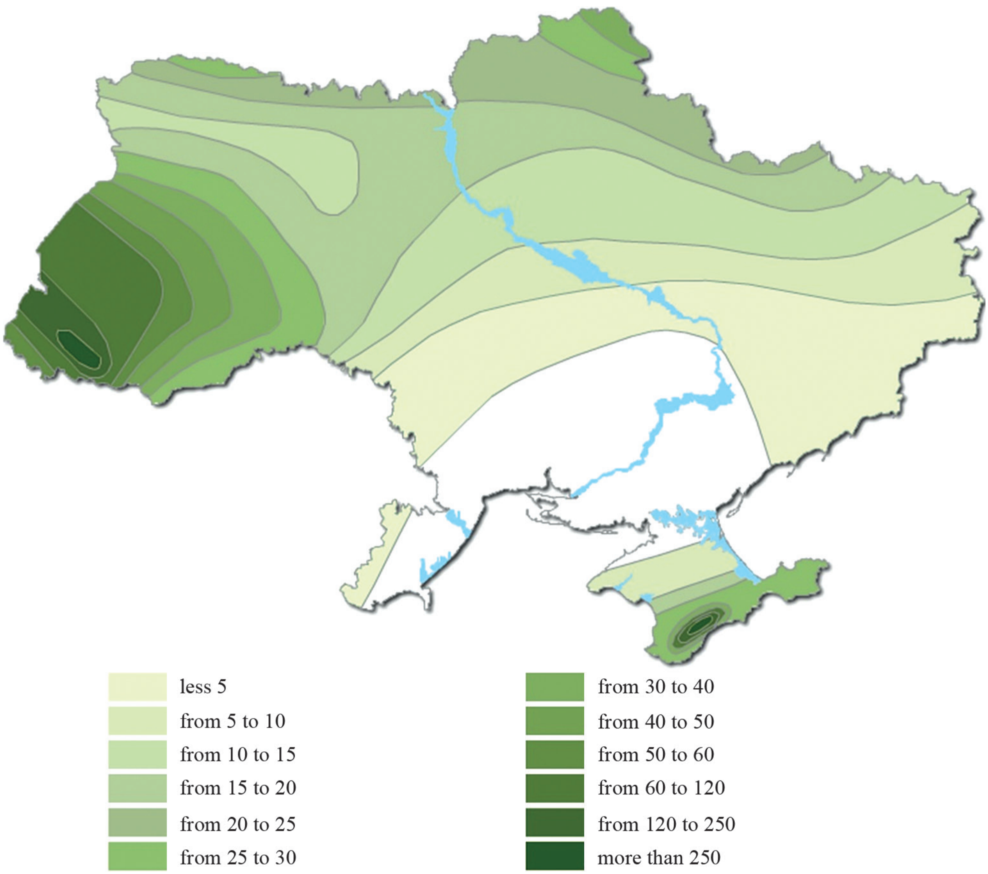


Fig. 1.10. Underground water runoff (in mm)

1.4. Water resources availability (water availability)

Ukraine is poorly provided with water resources and is determined by the formation of local and inward river runoff from other countries, the presence of groundwater and seawater.

To compare the water supply indices of the inhabitants of each region, the specific water supply in thousand m^3 per person per year was calculated separately for river runoff (local and supply from other countries), groundwater resources, as well as their total specific indicators.

The river runoff resources, taking into account the Danube runoff along the Kiliysky estuary, are estimated at 209.8 km^3, of which the inflow is 157.4 km^3, and the local runoff in the average water year is 52.4 km^3.

From countries neighbouring the Ukraine, the average annual water inflow along the Dnieper, Seversky Donets and other water arteries (without the Danube) are 34.7 km^3, and in a very dry year – 22.9 km^3.

The Dnieper is the largest waterway in Ukraine with a catchment area (within Ukraine) and is 294 500 km^2 or 48.8% of the country's area. Its water resources in a very dry year are 35 km^3, and the average annual runoff is 53.9 km^3. The second highest water content is the Dniester with a catchment area (within Ukraine) of 53 490 km^2 and an average annual runoff of 10.7 km^3, and in a very dry year it is 6.56 km^3. Seversky Donets with a catchment area (within Ukraine) of 53 540 km^2 has an average annual runoff of 5.08 km^3, and in a dry year it is 2.08 km^3. The Southern Bug respectively has 64 100 km^2, 3.4 km^3, 1.33 km^3. The average annual runoff of the Danube River is 123 km^3, and in a dry year it is only 60 km^3.

In general, the territorial distribution of surface water resources of Ukraine is uneven and does not correspond to the location of water-containing economic complexes.

Water availability provision calculations were carried out using data from the State Statistics Service of Ukraine, for which the population in Ukraine (without the Autonomous Republic of Crimea) as of 1st April 2019, is 42 079.5 thousand people.

Table 1.9

The specific provision of river runoff of the population of Ukraine, thousand m^3/year per person

Region	The average water year			Year of 75% provision			Year of 95% provision		
	inflow	local	summary	inflow	local	summary	inflow	local	summary
Vinnytska	5.41	1.58	7.03	4.23	1.17	5.43	3.07	0.75	3.83
Volynska	1.51	2.10	3.91	1.16	1.44	2.83	0.94	0.92	1.84
Dnipropetrovska	16.31	0.27	16.57	13.26	0.12	13.37	10.12	0.04	10.16
Donetska	0.79	0.25	1.05	0.55	0.13	0.69	0.46	0.05	0.41
Zhytomyrska	0.47	2.58	3.05	0.31	1.62	1.94	0.19	0.86	1.05
Zakarpatska	4.41	6.30	10.59	3.52	4.95	8.36	2.24	3.55	5.80
Zaporizka	30.76	0.37	31.16	24.95	0.18	25.16	19.38	0.07	19.45
Ivano-Frankivska	3.48	3.35	6.85	2.67	2.44	5.12	1.90	1.58	3.48
Kyivska	9.70	0.43	9.82	7.99	0.28	8.02	5.94	0.16	6.10
Kirovohradska	50.96	1.00	53.27	41.34	0.58	42.98	32.93	0.29	33.21
Luganska	2.86	0.69	2.36	0.15	0.41	1.56	0.72	0.21	0.93
Lvivska	0.26	1.96	2.21	0.22	1.47	1.68	0.14	1.05	1.19
Mykolaivska	3.07	0.51	3.55	2.19	0.29	2.46	1.37	0.13	1.51
Odeska	57.16	0.15	57.31	4.20	0.07	4.25*	43.18	0.03	43.21
Poltavska	35.20	1.39	36.85	28.61	0.94	29.77	22.08	0.54	22.62

table 1.9 cont.

Rivnenska	4.05	2.02	6.05	3.07	1.54	4.60	1.99	1.09	3.08
Sumska	3.07	2.8	5.36	2.19	1.63	3.84	1.45	1.07	2.54
Ternopilska	5.14	1.74	6.96	4.02	1.37	5.46	2.92	1.01	3.92
Kharkivska	0.68	0.61	1.38	0.46	0.42	0.88	0.29	0.27	35.75
Khersonska	52.18	0.13	52.56	41.10	0.06	41.30	35.73	0.02	35.75
Khmelnytska	6.03	1.70	7.78	4.70	1.25	5.99	3.37	0.84	4.21
Cherkaska	38.37	0.85	39.43	31.11	0.58	31.86	23.86	0.35	24.20
Chernivetska	10.03	1.36	11.18	7.91	0.96	8.70	5.65	0.54	6.20
Chernihivska	25.81	3.44	29.51	21.36	2.66	24.23	17.43	1.96	19.37
Ukraine total	**3.74**	**1.24**	**4.98**	**0.73**	**0.98**	**1.71***	**2.89**	**0.71**	**3.60**

* without the inflow of the Danube from abroad

The highest specific water availability in the average water resources is 57.16 thousand m^3/year per 1 person (with the Danube) in the Odessa region (total with local average annual runoff – 57.31 thousand m^3), in the Kherson region – 52.18, in Kirovograd region – 50.96. The minimum total specific provision in the same year in the Donetsk region is 1.05 thousand m^3/year per person, in Kharkov – 1.38, in Lviv – 2.21, in Lugansk – 2.36.

Table 1.10

Groundwater specific supply

Region	Predicted resources, thousand m^3/year		Operating reserve, thousand m^3/year		Groundwater intake, thousand m^3/year		Predicted resources	Operating reserve	Groundwater intake
	for 1 km^2	for 1 person	for 1 km^2	for 1 person	for 1 km^2	for 1 person	m^3/day per person		
Vinnytska	12.19	0.208	1.80	0.030	1.02	0.018	0.57	0.08	0.04
Volynska	46.73	0.912	6.14	0.121	3.17	0.062	2.50	0.33	0.17
Dnipropetrovska	12.51	0.125	7.93	0.079	5.55	0.056	0.34	0.22	0.14
Donetska	33.94	0.216	14.52	0.093	17.85	0.114	0.59	0.26	0.31
Zhytomyrska	7.67	0.189	2.52	0.062	0.97	0.024	0.52	0.17	0.06
Zakarpatska	30.82	0.314	9.66	0.098	3.20	0.033	0.86	0.27	0.09
Zaporizka	20.81	0.333	4.20	0.067	2.10	0.033	0.91	0.18	0.09
Ivano-Frankivska	19.81	0.200	7.16	0.073	0.72	0.007	0.54	0.20	0.02
Kyivska	53.24	0.362	24.55	0.150	4.67	0.028	0.89	0.41	0.08
Kirovohradska	6.00	0.157	3.25	0.085	1.83	0.048	0.43	0.24	0.13
Luganska	65.48	0.814	24.48	0.304	18.50	0.230	2.23	0.83	0.62

table 1.10 cont.

Lvivska	61.01	0.933	22.15	0.192	9.36	0.081	1.44	0.52	0.22
Mykolaivska	6.55	0.143	1.17	0.025	0.73	0.016	0.36	0.06	0.04
Odeska	8.08	0.114	3.74	0.052	1.08	0.015	0.31	0.14	0.04
Poltavska	54.35	1.120	10.23	0.211	3.30	0.068	3.06	0.57	0.18
Rivnenska	65.42	1.137	8.21	0.142	2.64	0.046	3.19	0.53	0.17
Sumska	52.64	1.163	8.86	0.196	2.90	0.064	3.19	0.53	0.17
Ternopilska	58.35	0.772	6.96	0.092	3.04	0.040	2.11	0.25	0.11
Kharkivska	47.77	0.561	12.00	0.141	2.23	0.026	1.54	0.39	0.07
Khersonska	63.66	1.753	11.82	0.325	2.84	0.078	4.80	0.89	0.21
Khmelnytska	34.80	0.568	7.72	0.126	2.91	0.048	1.55	0.35	0.12
Cherkaska	31.55	0.549	5.08	0.089	2.73	0.047	1.51	0.24	0.13
Chernivetska	18.26	0.164	7.70	0.069	3.46	0.031	0.45	0.19	0.08
Chernihivska	95.27	3.033	5.89	0.187	2.19	0.070	8.31	0.51	0.20
Ukraine total	37.30	0.535	9.47	0.136	4.24	0.060	1.47	0.37	0.16

The largest operational groundwater reserves in Ukraine per person are 0.325 thousand m^3 per year in the Kherson region, 0.304 in the Lugansk region, 0.211 in the Poltava region, 0.192 in the Lviv region, 0.196 in the Sumy region, and 0.150 in the Kyiv region. In Ukraine, this value is 0.136 thousand m^3 per year.

Table 1.11

The specific provision of water resources of the regions of Ukraine (thousand m^3/year per 1 person)

Region	Population on 01.04.2019, thousand	Underground operating reserve	The mid-water year (50%)		Very low water year (95%)	
			Total river	Total	Total river	Total
Vinnytska	1555.7	0.030	7.03	7.060	3.83	3.860
Volynska	1034.3	0.121	3.91	4.031	1.84	1.961
Dnipropetrovska	3198.3	0.079	16.57	16.649	10.16	10.239
Donetska	4157.2	0.093	1.05	1.143	0.41	0.503
Zhytomyrska	1217.0	0.062	3.05	3.112	1.05	1.112
Zakarpatska	1255.6	0.098	10.59	10.688	5.80	5.898
Zaporizka	1701.2	0.067	31.16	31.227	19.45	19.517
Ivano-Frankivska	1371.1	0.072	6.85	6.922	3.48	3.552
Kyivska	4722.2	0.150	9.82	9.970	6.10	6.250
Kirovohradska	942.3	0.085	53.27	53.355	33.21	33.295

table 1.11 cont.

Luganska	2148.1	0.304	2.36	2.664	0.93	1.234
Lvivska	2517.7	0.192	2.21	2.402	1.19	1.382
Mykolaivska	1127.8	0.025	3.55	3.575	1.51	1.535
Odeska	2378.8	0.052	57.31	57.352	1.51	1.535
Poltavska	1397.2	0.211	36.85	37.061	22.62	22.830
Rivnenska	1156.1	0.142	6.05	6.192	3.08	3.222
Sumska	1077.9	0.196	5.36	5.556	2.51	2.706
Ternopilska	1043.8	0.092	6.96	7.052	3.92	4.012
Kharkivska	2672.1	0.141	1.38	1.521	0.55	0.691
Khersonska	1035.0	0.325	52.56	52.885	35.75	36.075
Khmelnytska	1262.0	0.126	7.78	7.906	4.21	4.336
Cherkaska	1202.5	0.089	39.43	39.519	24.20	24.289
Chernivetska	903.2	0.069	11.18	11.249	6.20	6.269
Chernihivska	1001.9	0.187	11.18	11.249	6.20	6.269
Ukraine total	42 079.5	0.136	4.98	5.160	3.60	3.740

Freshwater for Ukraine is a strategic resource. At present, in the context of a growing shortage of quality drinking water and climate change, the priority measure should be its rational use and comprehensive conservation.

1.5. Precipitation (distribution by territory)

Precipitation depends on the nature of the underlying surface (especially topography), the location of areas of high and low atmospheric pressure and preferable wind directions. On the flat territory, the amount of precipitation decreases in the direction of the north and northwest, where their average annual norm reaches 700 mm, to the south and southeast, where their amount decreases to 350 mm per year. In the Carpathians, the amount of precipitation increases to 1000–2000 mm and in the Crimean mountains increases to 600–1100 mm per year.

Rainfall is unevenly distributed across the seasons. In warm – summer time, it is two or three times more than in cold (winter). An exception is the southern coast of Crimea, where rainfall predominantly occurs in the cold season. This is due to the fact that in summer, air masses dominate here with high pressure and downward air movement.

The maximum rainfall in most of Ukraine falls in June and July, and in June it sharply increases compared to May. In summer, frequent thunderstorms and showers

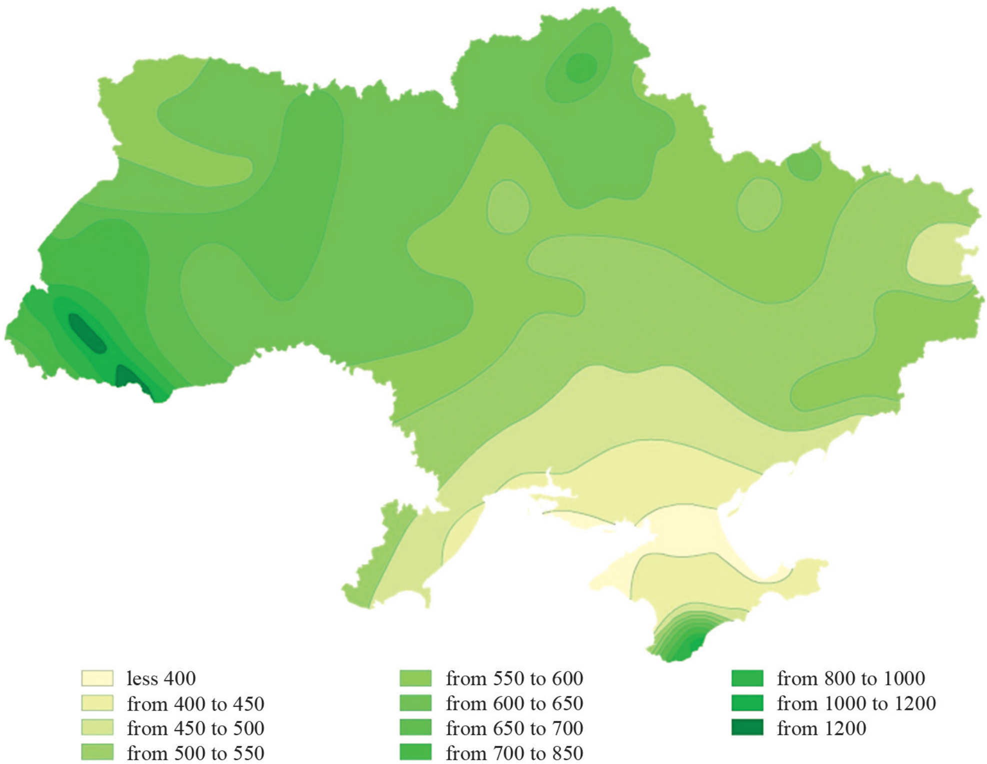


Fig. 1.11. Average precipitation in Ukraine (mm)

are observed, amounting to 200 mm of precipitation on the plain and up to 300 mm in the Carpathians.

The average number of days with precipitation varies in Ukraine. In the south of the Black Sea lowland, it ranges from five to nine days per month, and in the northern and western parts of the country, it ranges from ten to sixteen days a month. Most of them are in winter, and the fewest are in August and September.

Table 1.12

Precipitation distribution in Ukraine

Region	Precipitation (mm)		
	Average for the year	Monthly average	
		January	July
Mixed forest area (summer maximum)	510–670	25–35	65–105
Forest-steppe zone (summer maximum)	450–520	25–40	60–110
Steppe zone (summer maximum)	380–500	20–45	25–65
Ukrainian Carpathians (summer maximum)	600–1400	20–85	65–130
Southern coast of Crimea (winter maximum)	420–640	55–95	30–40

The number of days with precipitation in the Carpathians and Crimean Mountains reaches 180, in the forest and north of the forest-steppe, it is about 160, in the south of the forest-steppe it is 100 to around 140, in the south of the steppe it is 100 and 120, and on the coast it is about 100. The most days of precipitation occur in December, January and June, and the least occur in September and October. Rainfall in winter occurs in the form of snow almost all over Ukraine.

Thunderstorms in Ukraine occur mainly from March to November inclusive, and in some years in the southern regions, they are possible even in winter. The average number of days with thunderstorms in most of Ukraine does not exceed 35; in the midday territories this indicator decreases to around 15 to 20, and in the mountainous regions it increases to around 30 to 40 days.

The average total duration of thunderstorms per year in the plains of Ukraine is 60 to 90 hours, in the Carpathians it increases to around 100 to 120 hours, and in the coastal seas and above the Dnieper reservoirs, it decreases to 45 to 50 hours. Most thunderstorms feature rain, and some are accompanied by hail. The maximum daily rainfall in the lowlands reaches 150 to 200 mm, and in the Carpathians, it may exceed 300 mm. On average, a year in Ukraine includes two days with hail, and in the Carpathians in some years, there are up to six.

2. Organisation of water management

2.1. Governmental organisation of water management

The State Agency of Water Resources of Ukraine is the central executive body, the activities of which are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Energy and Environmental Protection and implements state policies in the field of water management and land reclamation, and the management, use and restoration of surface water resources.

The State Agency of Water Resources is guided in its activities by the Constitution and laws of Ukraine, decrees of the President of Ukraine, and resolutions of the Verkhovna Rada (Supreme Council of Ukraine) of Ukraine adopted in accordance with the Constitution and laws of Ukraine, acts of the Cabinet of Ministers of Ukraine, and other legislative acts.

The responsibilities of the State Water Agency are:

1) the implementation of state policy in the field of management, use and restoration of surface water resources, development of water management and land reclamation and operation of state-owned water facilities for complex purposes, inter-farm irrigation and drainage systems;
2) issues, annuls, re-issues permits for work on the lands of the water fund (except for work on the lands of the water fund within the coastal protective strips along the seas, sea bays and estuaries, inland sea waters, estuaries, and the territorial sea) and issue duplicates thereof;
3) issues and revoking of permits for special water use;
4) develops and participates in the implementation of national targeted programs on water management, land reclamation, management, use and reproduction of surface water resources;
5) provides the satisfaction of the population needs and economic sectors for water resources, develops proposals for determining development priorities of water management and hydraulic land reclamation;
6) develops and establishes the operating modes of integrated reservoirs, water management systems and canals and approves their operational rules;
7) establishes the operating modes of reservoirs and ponds provided for use on a rental basis;
8) approves the rules and establishes the operational mode of the state and inter-farm land reclamation systems and ensures their compliance;

9) controls compliance with the operating modes of reservoirs, water management systems and canals;
10) analyses and summarises reports of water users on the use of water resources, checks their accuracy;
11) monitors the technical condition of reclamation systems and hydraulic structures of enterprises, institutions, and organisations related to its management;
12) monitors the water quality of water-management systems of intersectoral and agricultural water supply;
13) monitors the water quality of water bodies according to radiological indicators in areas exposed to radioactive contamination;
14) monitors the reclamation state of irrigated and drained lands, as well as soils in areas affected by reclamation systems;
15) monitors water quality at transboundary sections of watercourses, defined in accordance with interstate agreements on cooperation regarding transboundary water bodies;
16) monitors shore reformation;
17) conducts state water monitoring in accordance with the procedure approved by the Cabinet of Ministers of Ukraine;
18) implements measures for the ecological improvement of surface waters and their maintenance;
19) approves the boundaries of the zones of sanitary protection of water bodies;
20) approves leases and passports of water bodies;
21) coordinates the creation of artificial reservoirs and water retaining structures on the rivers and their basins;
22) coordinates projects on the size and mode of use of allotment strips;
23) carries out, within the powers stipulated by the law, together with other executive authorities, measures for the prevention of emergencies and the reduction of the devastating consequences of floods, ensuring accident-free passage of floodwaters and ice drift;
24) carries out work on the prevention of damages and accidents on the hydraulic structures of the national and inter-economic reclamation systems, as well as on the elimination of the consequences of accidents at such structures;
25) takes measures to prevent and eliminate the effects of water, including flood protection for rural settlements and farmland;
26) organises work to minimise the effects of water damage, in particular by protecting against the flooding of agricultural land as well as rural settlements;
27) develops schemes for the integrated use and protection of water resources, forms a long-term forecast of water balances, participates in solving issues related to the inter-state distribution of river flows and the use of border waters;

28) executes, taking into account the sectoral features, the design, construction and reconstruction of systems for protection against the harmful effects of water, group and local water supply systems, water supply and sewage systems in rural areas, hydraulic structures and canals, reclamation systems and individual objects of engineering infrastructure, multi-purpose facilities of water management;
29) conducts the sectoral examination of design estimates for the construction (reconstruction) of individual objects of engineering infrastructure of reclamation systems;
30) operates state-owned water facilities with comprehensive purpose, melioration and melioration systems, and also provides planned and preventive repairs of drainage systems and structure;
31) develops long-term forecasts and proposals on the main directions of the development of hydrotechnical land reclamation and the use of reclaimed lands;
32) develops and submits proposals to the ministry to develop, review and approve regulatory documents for the design, construction, and operation of water-management facilities and land-reclamation systems;
33) carries out the management of objects of state property belonging to the sphere of management of the State Water Agency;
34) ensures the implementation of applied research works in the field of water management, land reclamation, management and the use and reproduction of surface-water resources;
35) approves water-supply norms;
36) leads the public accounting of water use;
37) leads the public accounting of surface water in surface-water objects accounting;
38) forms basin councils;
39) approves water-management balances;
40) maintains the state water cadastre by sections “Surface-water objects” and “Water use”;
41) certifies rivers and sources of drinking-water supply;
42) carries out inventory and certification of national and inter-farm land-reclamation systems;
43) maintains the state water cadastre by sections “Surface-water objects” and “Water use”;
44) certifies rivers and sources of drinking-water supply;
45) carries out inventory and certification of national and inter-farm land-reclamation systems;
46) conducts an analysis of surface water quality and notifies executive authorities and local authorities, organises the development of operational

and long-term forecasts of changes in the ecological status of water bodies and reclaimed land;

47) organises and coordinates the training, retraining and advanced training of personnel in the field of the development of water management and land--reclamation, and the management, use and reproduction of surface-water resources;
48) agrees the documentation on land management for compliance of the specified documentation with water legislation;
49) approves projects for work on the land of the water fund (except for work on land occupied by the seas) related to the construction of hydraulic, linear and hydrometric structures, deepening the bottom for shipping, mining (except for sand, pebbles, and gravel in the channels of small and mountain rivers), clearing the channels of rivers, canals and the bottom of reservoirs, laying cables, pipelines, other communications, as well as performing drilling and exploration works;
50) develops measures to provide a centralised water supply to rural settlements using imported water;
51) prepares and submits to the Minister of Energy and Environmental Protection proposals for state targeted programs on forecasts of the development of water management and land reclamation, and the management, use and reproduction of surface-water resources for the short and medium-term and ensures their implementation;
52) provides the public with information on the implementation of state policy in the field of the development of water management and hydraulic engineering land reclamation, and the management, use and reproduction of surface water resources;
53) carries out international cooperation in the use and protection of waters and the recreation of surface-water resources of border waters;
54) prepares proposals for the conclusion and denunciation of international treaties, concludes international treaties of Ukraine of an interdepartmental nature, ensures the fulfilment of obligations undertaken by Ukraine under international treaties on issues within its competence;
55) provides proposals on the volume of state procurement for the preparation, retraining and advanced training of specialists in the field of water management and land reclamation, and the management, use and reproduction of surface water resources;
56) organises scientific, technical, investment, informational, publishing activities, contributes to the creation and implementation of modern information technologies and computer networks in the field of water management and land reclamation, and the management, use and reproduction of surface water resources;

57) carries out the consideration of citizens' appeals on issues related to the activities of the State Water Agency, enterprises, institutions and organisations related to its management;
58) exercises other powers defined by law.

According to the aims of the state agency of water resources, the agency includes several types of institutions. The scheme of the state agency of water resources is presented in Figure 2.1.

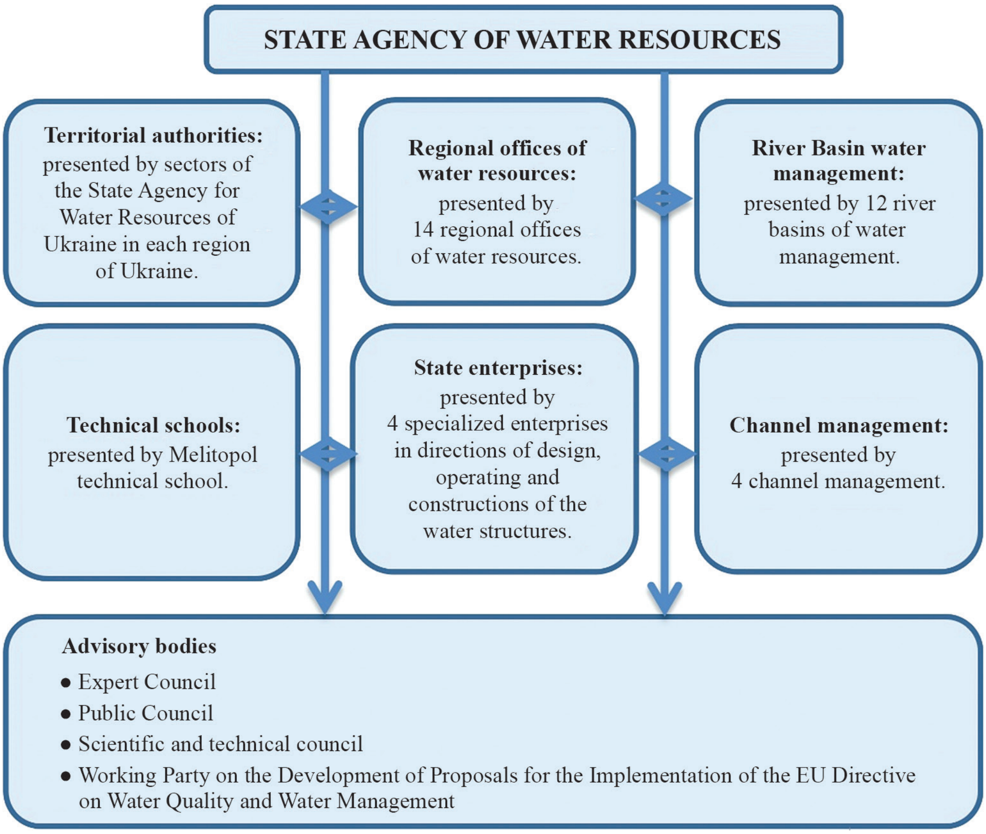


Fig. 2.1. The scheme of the state agency of water resources of Ukraine

2.2. River basin water management

The water management process has come a long way towards improvement and reform in most countries of the world. It has became apparent that the administrative-territorial principle of water resources management does not meet the modern requirements for improving water quality and safe water use. The experience of many countries shows that the river basin principle is the most effective approach to water resources management.

A river basin principle is a modern approach to water management, in which the river basin, which is a system with established ecological, social and economic ties, acts as the main unit of management. In this case, the river basin acts as an indicator of the state of the environment, specifically the ecological state, which is due to both natural factors and the level of anthropogenic pressure. Such a system helps prevent the depletion of water resources, as well as achieving and maintaining high water quality.

By signing the Association Agreement between Ukraine and the European Union and its member states, Ukraine has made specific commitments of implementation European Documents. For Ukraine, in the area of the environment, EU legislation must be implemented within eight sectors, governed by twenty-nine statutory legal sources of law.

One of the sectors of Appendix XXX of the Association Agreement is "Water Quality and Water Management, including the Marine Environment". There are six directives in this sector. One of them is Directive 2000/60/EC of 23 October 2000 on establishing a framework for Community activities in the field of water policy – the Water Framework Directive (WFD).

According to the WFD, the areas of river basins are determined, not in accordance with the administrative or political boundaries but following the boundaries of the river basin as the whole natural hydrographic object. The management of the selected river basins is carried out based on the River Basin Management Plan, which should contain an analysis of the basin and clear mechanisms (a program of measures) to achieve the goals defined for this basin on time.

The Supreme Council of Ukraine adopted the Law of Ukraine "On Amending Certain Legislative Acts of Ukraine Regarding the Implementation of Integrated Approaches in the Management of Water Resources on the Basin Principle" dated 04.10.2016 No. 1641-VIII.

Following this law, the borders of nine river basins are determined in Ukraine (see Fig. 1.1). Given that the Dnieper river basins cover a vast territory, the Dnieper river basin was divided into three.

Thus, twelve river basin water management was created in Ukraine, namely:

- ✓ Middle Dnieper river basin water management,
- ✓ Lower Dnieper river basin water management,
- ✓ Desna river basin water management,
- ✓ Prypyat river basin water management,
- ✓ Dniester river basin water management,
- ✓ Southern Bug river basin water management,
- ✓ Seversky-Donets river basin water management,

- ✓ Western Bug and San river basin water management,
- ✓ Tisza river basin water management,
- ✓ Prut and Siret river basin water management,
- ✓ The Black Sea and lower Danube river basin water management,
- ✓ Azov river basin water management.

River water basin management provides within the basin the implementation of state policy in the field of management, use, conservation and reproduction of water resources, development of water management, operation of hydraulic structures, state reclamation systems, resolution with the bodies of executive power and other organisations, institutions, enterprises population and industries with water resources.

River basin water management has performed tasks and functions through regional or inter-regional water management administrations.

2.3. Integrated water resources management

In order to implement the river basin principle of water resources management, a number of normative legal acts have been developed and approved that initiate integrated water resources management. Below is a list of key documents governing the implementation of basin management:

- on the allocation of sub-basins and water management areas within established areas of river basins,
- on approval of the boundaries of river basin regions, sub-basins and water management areas,
- approval of the list of pollutants for determining the chemical status of surface and groundwater arrays and the ecological potential of an artificial or substantially modified surface water mass,
- on approval of the model regulation on the river basin councils,
- on approval of the methodology for assigning the surface water massif to one of the classes of ecological and chemical states of the surface water massif, as well as assigning an artificial or substantially altered surface water mass to one of the ecological potentials of an artificial or substantially altered surface water massif,
- by Resolution of the Cabinet of Ministers of Ukraine #336 of May 18, 2017, approved the order of development of the River Basin Management Plan (RBMP), which is developed to achieve the environmental goals defined for each river basin district within the established timeframe.

According to this list of documents, the roadmap for preparing the first edition of the river basin water management plan was created (Table 2.1).

Table 2.1

Roadmap for preparing the first edition of the river basin water management plan

Year	Activities
2014	✓ Start of implementation of river basin water management plans.
2016	✓ Integrated approaches to water basin management at the legislative level are fixed.
2017	✓ Hydrographic and water management zoning are identified. ✓ The list of pollutants for establishing the chemical status of waters has been approved. ✓ A standard provision for river basin councils has been approved. ✓ The procedure for the development of water balance has been determined. ✓ The procedure for developing the river basin management plan has been approved. ✓ Electronic water cadaster created – geo-portal "Water Resources of Ukraine".
2018	✓ Institutional transformation of the water sector structure has been carried out. ✓ A new procedure for state water monitoring has been approved. ✓ A river basin councils were created. ✓ Methods for the determination of water masses and their classification are developed.
2019	✓ Definition of water bodies and their typology. ✓ Analysis of anthropogenic impacts on the quantitative and qualitative composition of waters. ✓ Description of the river basin district – an element of the river basin management plan. ✓ Register of protected areas. ✓ Development of a monitoring program.
2020	✓ Establishment of reference conditions. ✓ Creation of classifications of the ecological status of water massifs. ✓ Establishment of ecological and chemical states of water massifs.
2021	✓ Setting ecological goals for water bodies. ✓ Development of economic analysis of water use. ✓ An overview of the implementation of programs or activities, including ways to achieve environmental goals. ✓ Developing programs of activities to achieve good status.
2022	✓ Environmental Impact Assessment (EIS) and Strategic Environmental Assessment (SEA) of activities. ✓ Public discussion of draft River Basin Management Plans. ✓ Preparation of a public information report.
2023	✓ Preparation of the list of competent state authorities responsible for the implementation of the river basin water management plan. ✓ Determining the Procedure for Obtaining Water Status Information.
2024	✓ Adoption by the Cabinet of Ministers of Ukraine of River Basin Management Plans for nine River Basin Districts.

Thus, Ukraine's water management is at the stage of implementation of the principles of integrated water management.

The following principles must be followed when implementing integrated water resources management in Ukraine:

- ➢ Water resources are managed within certain territorial boundaries, in particular within the river basin.
- ➢ All water users are involved in water management by using water infrastructure to adapt to climate characteristics.
- ➢ It is necessary to take into account the interests of water users of all forms of ownership that are located in the basin, taking into account the mutual impact due to their water management activities.
- ➢ Involvement of representatives of NGOs, the public and local communities in the development of management plans, financing and the development of water infrastructure.
- ➢ The priority is the conservation of aquatic ecosystems during the realization of the activities of water management bodies.
- ➢ Conservation of water resources and the development of measures to reduce their inefficient use.
- ➢ Information support for water resources management, informing the population and stakeholders about the state of water resources, measures implemented and the financial situation.

During the implementation of integrated water resources management, it is useful to take into account the recommendation of the Global Water Partnership (GWP) organisation. The Global Water Partnership (GWP) is a global action network with over 3000 partner organisations in 179 countries. Under the leadership of GWP, the world's first – and today's most comprehensive – free, online database about integrated water resources management was created and proposed. The GWP IWRM ToolBox is for anyone interested in adopting better practices for the management of water or learning more about how to improve water management at a local, national, regional or global level (https://gwp.org/en/).

2.4. Monitoring and assessment of the state of water resources

One of the most important components of integrated water management is the monitoring of water resources. Poor water quality affects aquatic ecosystems, makes them unsuitable, or complicates preparation for drinking. A lot of EU directives address the issue of water pollution by organic matter, sewage, toxic substances, heavy metals, pesticides and pathogens (viruses and bacteria). Water saturation with substances such as nitrogen and phosphorus compounds leads to eutrophication, which in turn can also have significant adverse environmental effects. Effective containment and the reduction of pollution require information and assessment of the concentration, impact, loads and sources of discharge of the pollutants.

Recently, considerable attention has been paid to improving environmental monitoring and the monitoring of the transboundary pollution of water bodies in

Ukraine. At the same time, the existing monitoring system is not yet fully compliant with international requirements. Environmental monitoring is an important tool for the effective management of environmental quality, the timely prevention of the harmful effects of pollutants, as well as the widespread public awareness of the state and trends of environmental change.

Following the adoption by the European Union of the Water Framework Directive (WFD) in 2000, the phased development and implementation of its provisions has begun in the EU. In Ukraine, the process of the implementation of the European monitoring system started in accordance with the river basin water management plan. Therefore, the Decree of the Cabinet of Ministers of Ukraine No. 758 of September 19, 2018, approved the Procedure for State Water Monitoring. The implementation of this procedure started on 1 January 2019. In Ukraine, the subjects of state water monitoring are the Ministry of Energy and the Environment, the State Agency for Water Resources, the State Geology and Subsoil Service, the State Emergency Service, as well as the State Agency of Ukraine for the Exclusion Zone Management (in the area affected by the Chernobyl catastrophe).

The basis for the introduction of a new monitoring system is the transition from purely chemical control to biological control based on a bioindication system. Biological control is an assessment of the status of water bodies using biological properties and other direct measurements of biota. The main reason for the shift to biological control is the fact that societies of aquatic organisms reflect the combined influence of environmental factors on surface water quality. Where the criteria for determining the impact do not exist (for example, the impact of pollution in out of the control point and the degradation of habitat), societies may be the only practical means of assessing such impacts. Well-known international practice in the control of societies reveals that it can be relatively inexpensive compared to chemical controls.

In different countries, there are various bioindication systems for surface waters, adapted to the conditions of the region and its specifics. Currently, there are two systems used by different countries – the American system of RPBs (Rapid Bioassessment Protocols) and the British RIVPACS (River Invertebrate Prediction and Classification System).

Most WFD monitoring provisions are based on RPBs and RIVPACS. To ensure the comparison of aquatic ecosystems, it is mandatory to determine such biological indicators as the composition and abundance of aquatic life, the composition, and abundance of benthic invertebrate fauna, the composition, abundance and age structure of fish fauna.

Environmental goals for surface water are aimed at achieving:

1 – improvement in the quality of surface water,

2 – change of ecological potential and chemical composition of artificial and heavily modified water bodies,

3 – full compliance with all standards and requirements that must satisfy the protection zones.

It should be emphasised that according to the WFD, each country should achieve "good" water quality, not natural. Where such a condition already exists, it must be maintained. If water bodies are so strongly anthropogenic changed and their status is such that the achievement of good status is impossible or too expensive, less stringent environmental goals can be set based on certain criteria. In addition, all measures should be taken to prevent the further deterioration of the status of these rivers and reservoirs.

According to the WFD, state monitoring is carried out at the following water bodies:

- ➢ the massif of surface water (surface water bodies or parts thereof), including coastal waters and protected areas (territories),
- ➢ groundwater massif (groundwater bodies or parts thereof), including protected areas (territories),
- ➢ seawater within the territorial sea and the exclusive maritime economic zone of Ukraine, including the zones (territories) to be protected.

Another important feature of the WFD is that a water body is primarily regarded as a living environment of a biological group. In this case, hydromorphological and physicochemical parameters reflect the conditions of the development of hydrobionts and, by their nature, supplement the conclusions obtained on biological parameters.

This is justified by the fact that biological indicators are often slow enough to respond to pollution and do not always fully and accurately reflect the environmental status of the object. Therefore, the use of biological parameters of water quality is inextricably linked to the physico-chemical parameters. According to the general algorithm of water quality assessment, there are five classes of water quality according to their status: excellent, good, satisfactory, bad and very bad.

The water monitoring system, based on the recommendations of the WFD, applies the principle of multi-level monitoring and differs significantly in objectives and includes surveillance and operational and investigative monitoring.

Surveillance monitoring is designed to provide information for:

- the addition and certification of the impact assessment procedure detailed in Annex II of the WFD,
- rational and effective planning of future monitoring programs,
- the assessment of long-term changes in natural conditions,
- assessing the long-term changes that result from extensive anthropogenic activity.

Operational monitoring is for:

- determining the quality of water bodies at risk of not fulfilling their environmental goals,

- assessing any changes in the status of such facilities as a result of the program of activities.

Investigative monitoring is conducted when:

- the reasons for any excess are unknown,
- the results of monitoring studies show that the target values set for water bodies according to Art. 4, may not be achieved and the operational monitoring program has not yet been put in place,
- the extent emergency pollution and the impact of pollution must be determined.

The main purpose of surveillance monitoring is to identify long-term changes in the quality of water bodies. Operational monitoring is applied to objects with an ecological status other than the category of "good" status, and investigation monitoring is used when it is necessary to find out the causes of pollution or in case of an emergency.

Surveillance monitoring is carried out in order to assess the long-term changes that are observed both in the background sections of basins with a "good" state of water resources and in areas with a pronounced anthropogenic impact. The monitoring results should be used to develop a rational and effective surveillance network in the River Basin Management Plans. Thus, the monitoring system should provide answers to three basic questions: where to take samples, when to take them, and what indicators to determine.

The WFD states that mandatory surveillance should be carried out at points that meet the following criteria:

- the amount of water flow is significant within the region of the river basin, including points on large rivers with a catchment area of more than 2500 km^2,
- the volume of river runoff or lake water mass is significant within the region of the river basin,
- places of crossing the state border,
- estuarine sections of rivers and at the border crossing determine the chemical flow of pollutants and other chemicals.

The parameters determined by surveillance monitoring should include parameters of biological and general physico-chemical states and hydromorphological indicators. Specific species that reflect the status of different biological components of aquatic ecosystems should be selected from biological parameters.

Operational monitoring, and in many cases investigative monitoring, is used to establish or confirm the condition of the object under risk. It is a type of monitoring that focuses on indicators that characterize the highest sensitivity of an ecosystem to specific environmental pressures.

For operational monitoring, the question of the accuracy determining the status of a water body is important, as mistakes in estimates can lead to the goal not being achieved.

Operational monitoring is planned for water bodies that:

– are under the influence of anthropogenic pressure,
– are, according to the monitoring data, assigned to the zone of risk of loss of “good” ecological status,
– accept wastewater with substances from the list of priority pollutants.

The choice of measurement points will depend on the nature of the impact: pollution from a significant point source, through diffuse pollution or changes in hydromorphological parameters. Among the biological and hydromorphological indicators, one should select those indicators that are most sensitive to the impacts considered significant.

Using non-biological indicators for assessing the biological status of water can only serve as a complement to biological indicators. This does not preclude the use of physicochemical indicators in the case of measures to reduce the content of the relevant components. In this case, both physicochemical and biological parameters, such as macrozoobenthos, are checked.

The most important problem that has not yet been resolved is the assessment of the degree of water contamination by heavy metals, which have stringent standards. Analysis of the state of rivers in Ukraine shows that in 70–90% of cases, observations exceed the MPC for heavy metals, reaching 10–100 MPC.

Research monitoring is implemented in cases:

– when the reasons for excess are unknown,
– when surveillance monitoring shows that the environmental targets listed in Annex IV of the WFD will not be achieved and operational monitoring of determining the reasons for the failure to achieve these targets has been established,
– of emergency contamination.

The results of this monitoring can be used to inform the competent authorities in order to minimise the impact of pollution and to develop measures to achieve a “good” environmental status. An investigational monitoring program is being developed for an individual case. It may concern one body of water or its part, but also individual indicators, monitored with much greater frequenc.

Because the content of pollutants undergoes significant seasonal changes, the frequency of sampling is an important parameter in organizing monitoring. This parameter should provide reliable data for determining the ecological state of a water body over time. The density of points on the territory and the frequency of their selection determine the level of reliability and accuracy of the results. An acceptable sampling rate is balanced by the cost of research. The sampling frequency is not a constant indicator and is set in accordance with the variability of the ingredients in the waters and should guarantee a reliable determination of the state of the water body with a given level of accuracy and reliability of the observation results. In the WFD, the indicated minimum sampling frequencies of various indicators during the control monitoring, which is mainly every three months. If the ecological state of a particular facility is already steadily improving during the program of activities, the frequency of sampling can be changed or operational monitoring can be omitted at all.

The State Agency for Water Resources of Ukraine has created an online resource "Monitoring and Environmental Assessment of Water Resources of Ukraine" (http://texty.org.ua/water/), which includes the chemical state of rivers at the stations of constant observation.

To organise the measurements until the end of 2021, Ukraine will have four modern water monitoring laboratories to determine the chemical state of water bodies. In order to cover the territory of Ukraine, the following measuring laboratories were organised:

– the water monitoring laboratory of the Dniester river basin management of water resources,
– the laboratory at the water basin management of water resources in the rivers of the Black Sea and the lower Danube,
– the laboratory in the interregional office of the protective massifs of the Dnieper reservoirs,
– the laboratory of the Seversky-Donets River Basin Department of water resources.

A monitoring program for all river basins is being developed, preparatory work on accreditation of laboratories according to ISO 17025 and a gradual increase in the coverage of monitoring of surface water massifs of Ukraine are being carried out.

In addition, a laboratory has been set up at the Basin Department of Water Resources of the Lower Dnieper, which can perform research on soil quality. The issue of establishing a modern soil quality monitoring laboratory is relevant in the current conditions of opening the land market, especially for farmers who will become potential consumers of such services.

In general, by 2022 Ukraine will have complete information on the chemical status of surface water massifs. There is also planned investigational monitoring that will ensure prompt response in cases of emergency contamination.

In 2020, the monitoring program will include 3.1% of surface water massifs. In 2021, upon completion of the installation of all modern equipment in the laboratories, there will be four modern water monitoring laboratories to determine the chemical status of the water massifs.

The gradual expansion of the facilities of the laboratories will enable the monitoring of more than 7% of the surface water massifs in Ukraine in 2022.

It should be added that the data obtained will form the basis for the preparation of realistic river basin management plans for achieving "good" water status.

3. The impact of development on water resources

Water is an integral part of the geo-ecosystem, the socio-economic complex of the country, and the basis of quality of life.

The use of water resources for economic development and social well-being depends on water policy. A holistic approach to the use of water as a limited resource, and a reasonable choice of priorities is important for the Ukrainian economy and its transition to a sustainable development model. This provides a balanced solution of socio-economic problems and the problems of preserving the environment and natural resources for present and future generations.

The problem of water resources for Ukraine is extremely important and requires a particularly serious approach to its management. In many regions, water resources have become a limiting factor in further socio-economic development, meeting the needs of the population.

First of all, priority should be given to meeting the needs of the population for drinking water and water supply in settlements. In Ukraine, the rate of specific water consumption is 290–350 litres per day per person (depending on the area of the territory) and for the future, it will remain unchanged. Only after full satisfaction of the population's needs for drinking water and municipal water supply is it possible to consider the use of water resources for other purposes.

In the second place, priority should be given to water supply to agriculture, especially to livestock industries, as well as irrigation agriculture, fodder production, and vegetable production.

Water, industry, energy and transport are in third place.

When developing directions for the development of the economy, it is necessary to introduce anhydrous and low-water technologies as much as possible, transferring enterprises to circular water supply, and to combine, cooperate and integrate different industries for repeated, multiple and complex uses of water in various industries and technological processes.

The characteristics of the provision of local and river runoff for the regions of Ukraine are given in Table 3.1.

General indicators of water use in 2018 with a breakdown by regional principle are given in Table 3.2.

Improving the water resources management system and introducing integrated water resources management should be based on an analysis of water resource use. Based on the analysis of the volumes of freshwater intake, its use in various fields of economic activity, transportation losses, the volume of water disposal and discharge

Table 3.1

Characteristics of the provision of local and river runoff in the regions of Ukraine

Region	Water resources																	
	long-term average		75% possibility		95% possibility		an average year				year of 75% possibility				year of 95% possibility			
							on 1 sq. km		per inhabitant		on 1 sq. km		per inhabitant		on 1 sq. km		per inhabitant	
	local	total	local	total	local	total	local	total	local	total	local	total	local	total	local	total	local	total
Ukraine	52.4	87.1	41.4	71.7	29.7	55.9	86.8	144.3	1.03	1.71	68.6	118.8	0.81	1.41	49.2	92.6	0.58	1.10
AR Crimea	0.91	0.91	0.65	0.65	0.43	0.43	33.70	33.7	0.38	0.38	24.07	24.07	0.28	0.28	15.92	15.92	0.18	0.18
Vinnytska	2.47	11.0	1.83	8.46	1.16	5.96	93.2	415.1	1.26	5.63	69.1	319.2	0.94	4.33	43.8	224.9	0.59	3.05
Volynska	2.18	4.05	1.49	2.92	0.94	1.91	107.9	200.5	2.11	3.92	73.8	144.6	1.44	2.83	46.5	94.6	0.91	1.85
Dnipropetrovska	0.87	53.0	0.40	42.8	0.14	32.5	27.3	1661.4	0.23	13.9	12.53	1342	0.10	11.2	4.38	10.18	0.04	8.50
Donetska	1.02	4.40	0.55	2.92	0.24	1.70	38.5	166.0	0.19	0.82	20.8	110.2	0.10	0.55	9.05	64.2	0.04	0.32
Zhytomyrska	3.15	3.71	1.97	2.36	1.05	1.28	105.4	124.1	2.04	2.40	85.9	78.9	1.27	1.53	35.1	42.8	0.68	0.83
Zakarpatska	7.92	13.3	6.21	10.5	4.47	7.29	618.7	1039	6.58	11.1	485.2	820.3	5.11	8.73	349.2	569.3	3.72	6.06
Zaporizka	0.62	53.0	0.30	42.8	0.13	33.1	22.8	1948	0.30	25.9	11.03	1578	0.15	20.9	4.78	1217	0.06	16.18
Ivano-Frankivska	4.59	9.40	3.34	7.03	2.17	4.77	330.2	676.3	3.34	6.84	240.3	505.6	2.43	5.11	156.1	343.2	1.58	3.47
Kyivska	2.04	46.4	1.31	37.3	0.78	28.8	70.6	1606	0.46	10.4	45.3	1291	0.29	8.39	26.3	996.5	0.17	6.48
Kirovohradska	0.95	50.2	0.55	40.5	0.27	31.3	38.6	1041	0.77	40.9	22.4	1646	0.45	33.0	10.97	1272	0.22	25.50
Luganska	1.46	5.09	0.86	3.35	0.45	2.00	54.7	190.6	0.51	1.79	32.2	125.5	0.30	1.18	16.9	74.9	0.16	0.70
Lvivska	4.92	5.55	3.73	4.25	2.66	3.00	225.7	254.6	1.84	2.08	171.1	195.0	1.40	1.59	122.0	137.6	1.00	1.12
Mykolaivska	0.57	4.00	0.33	2.78	0.16	1.71	23.2	162.6	0.44	3.09	12.4	113.0	0.26	2.15	6.50	69.5	0.12	1.32
Odeska	0.35	12.9	0.17	10.1	0.08	7.41	10.5	387.4	0.13	4.94	5.10	303.3	0.07	3.87	2.28	222.5	0.03	2.84
Poltavska	1.94	51.5	1.31	41.6	0.76	31.6	67.4	1788	1.13	29.9	45.5	1444	0.76	24.2	26.4	1097	0.44	18.35
Rivnenska	2.33	7.00	1.79	5.33	1.27	3.56	115.9	348.3	2.00	6.00	89.1	265.2	1.54	4.57	63.2	177.1	1.09	3.05
Sumska	2.45	5.79	1.75	4.13	1.15	2.71	102.0	243.3	1.72	4.06	73.5	173.5	1.23	2.90	48.3	113.9	0.81	1.90
Ternopilska	1.81	7.28	1.44	5.69	1.05	4.10	131.2	526.1	1.57	6.31	104.3	412.3	1.25	4.94	76.1	291.1	0.91	3.56
Kharkivska	1.66	3.41	1.14	2.35	0.71	1.50	52.9	108.6	0.53	1.08	36.3	74.8	0.36	0.75	22.6	47.8	0.23	0.48
Khersonska	0.14	54.4	0.06	42.8	0.02	32.0	4.91	1909	0.11	44.6	2.10	1501.8	0.05	35.1	0.70	1122.8	0.02	26.23
Khmelnytska	2.14	9.82	1.58	7.56	1.06	5.32	103.9	476.7	1.40	6.43	76.7	367.0	1.03	4.96	51.5	258.3	0.69	3.48
Cherkaska	1.01	47.4	0.69	38.3	0.41	29.1	48.3	2268	0.66	31.0	33.0	1832	0.45	25.1	19.6	1392	0.27	19.06
Chernivetska	1.23	10.1	0.86	7.86	0.49	5.80	151.8	1247	1.35	11.0	106.2	970.4	0.94	8.80	60.5	691.4	0.54	6.13
Chernihivska	3.45	29.57	2.66	24.28	1.95	19.42	108.2	927.0	2.42	20.7	83.4	761.1	1.86	17.0	81.1	608.8	1.37	13.60

Table 3.2

General indicators of water use (2018)

Region	taken		used					total water disposal	discharged into surface water bodies of return (waste) water					transit water discarded	reversible, reuse and consistent use
	from natural water bodies, total	including from underground water bodies	fresh water, total	including needs					total	polluted	normally clean without cleaning	normally clean at treatment facilities	uncatego-rised		
				drinking and sanitary	industries	irrigation	others								
Ukraine	11 296	1165	7363	1171	4499	1591	100.9	5412	5210	952	3048	1058	151.7	779.4	34 370
Vinnytska	118	16.38	96.01	30.34	60.59	3.375	1.707	69.64	65.55	0.988	36.43	27.69	0.448	7.313	2068
Volynska	69.24	53.26	54.49	18.99	14.09	6.551	14.86	39.53	28.4	0.428	4.833	19.93	3.209	2.516	5.943
Dnipropetrovska	1179	128.5	868.3	147.7	684.1	28.63	7.842	757.3	692.8	233.9	343.2	115.7	-	3.218	4589
Donetska	1707	101.4	1153	102.1	1034	11.55	5.543	1036	1035	185.6	687.9	100.5	61.42	59.96	2362
Zhytomyrska	111.1	21.21	69.77	22.61	44.94	-	2.217	75.02	72.53	2.066	29.3	31.36	9.81	17.79	181.4
Zakarpatska	47.2	21.59	23.57	13.88	8.333	0.703	0.656	37.38	36.5	3.567	3.907	29.03	-	14.25	9.95
Zaporizka	1260	45.78	1199	66.28	973.5	153.9	4.889	911.6	888.4	65.95	777.2	45.01	0.239	0.101	8765
Ivano-Frankivska	96.5	5.879	82.53	16.33	65.44	0.077	0.683	62.76	62.46	0.56	9.5	52.4	-	0.796	2051
Kyivska	528.1	60.25	511	42.43	465.5	2.524	0.506	486.7	473	2.317	428.6	38.5	3.655	0.988	216.9
Kirovohradska	163.7	16.92	37.67	18.35	16.29	2.898	0.123	30.98	24.88	3.319	1.294	12.72	7.548	110.6	147.7
Luganska	96.19	47.63	64.59	13.4	49	0.995	1.198	43.76	42.93	17.94	5.572	3.004	16.4	-	356.3
Lvivska	172.3	143.7	125	59.55	46.43	-	19.03	174.9	164.9	42.01	14.77	108.1	-	-	453.4
Mykolaivska	241.1	13.26	153.7	32.67	88.86	30.62	1.526	68.06	64.9	21.22	42.84	0.842	-	10.12	3358
Odeska	751.7	30.58	276.2	85.23	45.05	138.5	7.337	166.9	159.8	14.91	62.98	81.91	-	418.2	44.16
Poltavska	114.4	73.12	86.49	41.33	37.74	6.066	1.36	81.88	71.2	2.174	2.861	41.04	25.12	25.19	874.1
Rivnenska	119.7	41.01	91.09	19.01	71.18	-	0.908	53.12	52.76	4.449	18.01	23.34	6.966	14.97	4323
Sumska	91.9	42.61	63.39	28.05	35.18	0.09	0.069	49.09	46.03	23.11	21.02	1.888	-	16.9	67.64
Ternopilska	50.81	25.61	38.44	17.75	20.47	0.226	-	37.13	35.75	2.554	15.79	17.41	-	2.607	41.24
Kharkivska	313.3	34.35	256.4	105.7	141.7	6.771	2.195	302.7	298.8	14.07	87.02	195.5	2.248	4.334	742.6
Khersonska	3043	59.58	1241	39.37	26.16	1 174	1.652	74.89	71.7	2.106	36.59	22.2	10.8	26.87	25.16
Khmelnytska	99.7	41.55	70.48	27.35	41.31	0.135	1.682	49.98	47.38	1.001	14.51	30.14	1.73	12.35	2530
Cherkaska	183.9	47.5	149.2	23.74	77.92	23.36	24.2	104.8	87.62	7.171	40.28	38.8	1.371	27.05	471.4
Chernivetska	66.76	20.71	50.84	24.52	25.74	0.192	0.392	43.42	40.23	1.89	20.7	16.89	0.758	0.945	21.57
Chernihivska	128.5	43.86	117	27.19	89.46	0.241	0.143	103.4	95.52	15.57	75.96	3.996	-	2.284	133.5

of polluted water, preliminary decisions can be made to limit the consumption of water resources or to expand the scale of their involvement in the production sector. At the same time, changes in water use should be monitored over the largest possible period in order to enable assessment of the relationships between individual indicators of water consumption, its spatial and temporal limitations, and forecast the volume of water use for the short-term and future development of the national economy.

The main indicators of the use and protection of water resources for the period 1990–2017 are given in Table 3.3.

Table 3.3

Main indicators of water use and protection (million m^3)[1]

Year	Water intake from natural water bodies[2]	Freshwater consume	Total wastewater disposal	Including			Treatment plant capacity
				contaminated		normally cleaned	
				total	without purification		
1990	35 615	30 201	20 261	3199	470	3318	8131
1991	34 905	28 206	19 126	4291	701	2532	7937
1992	32 461	26 924	17 872	4008	951	3207	8854
1993	24 380	24 521	16 650	4652	1196	2611	8134
1994	29 499	23 468	15 869	4873	1053	2075	8775
1995	25 852	20 338	14 981	4652	912	1936	8419
1996	23 477	18 668	13 998	4109	980	2304	8281
1997	21 091	15 623	12 534	4233	763	1798	8271
1998	19 027	13 836	11 040	4228	813	1644	8284
1999	19 748	14 285	11 488	3920	748	1743	8018
2000	18 282	12 991	10 964	3313	758	2100	7992
2001	17 577	12 168	10 569	3008	746	2188	7790
2002	16 299	11 589	10 005	2920	782	2111	7546
2003	15 039	11 034	9459	2948	804	1946	7733
2004	14 694	9973	9065	3326	758	1492	7740
2005	15 083	10 188	8900	3444	896	1315	7688
2006	15 327	10 245	8824	3891	1427	1304	8104
2007	16 352	10 995	8917	3854	1506	1245	7768
2008	15 729	10 265	8655	2728	616	1357	7518
2009	14 478	9513	7692	1766	270	1711	7581
2010	14 846	9817	8141	1744	312	1760	7425
2011	14 651	10 086	8044	1612	309	1763	7687

table 3.3 cont.

2012	14 651	10 507	8081	1521	292	1800	7577
2013	13 625	10 092	7722	1717	265	1477	7592
2014[3]	11 505	8710	6587	923	175	1416	7190
2015[3]	9699	7125	5581	875	184	1389	5801
2016[3]	9907	7169	5612	698	164	1381	5690
2017[3]	9224	6853	4921	997	158	1023	5415

[1] According to the Ukraine State Agency of Water Resources.

[2] Including fresh and seawater.

[3] The data is given without taking into account the temporarily occupied territories of the Autonomous Republic of Crimea, Sevastopol and part of the temporarily occupied territories in the Donetsk and Lugansk regions.

If we analyse the main trends of changes in the use of water resources for the period from 1990 to 2018, it should be noted that no significant changes in the rationalisation of water use and increase of green infrastructures have occurred. In particular, in 2018, compared with 1990, water withdrawal decreased by 26,391 million m^3 (Fig. 3.1). This is due to a significant decline in production caused by the economic crisis after the collapse of the Soviet Union, and not the introduction of effective forms and methods of water consumption, which save freshwater.

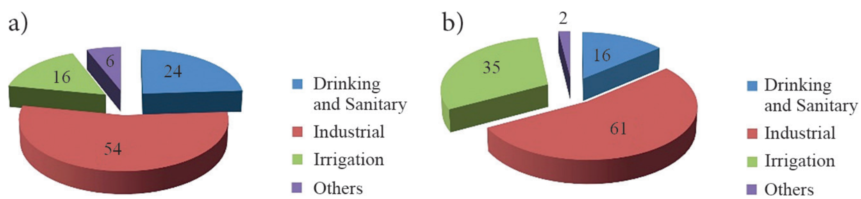


Fig. 3.1. Freshwater use structure: a) 1990; b) 2018

Between 1990 and 2018, the largest proportion of freshwater use was the use of water for industrial needs (54% in 1990 and 61% in 2018) (Fig. 3.1). The reason for this was the stable functioning of several water-consuming industries, mainly heavy industry, and the need for water resources was a necessary factor in the uninterrupted functioning of these industries. The proportion of freshwater use for domestic drinking needs was 16% and was associated with the population and the proportion of individual households that were provided with a centralised water supply. In 1990, agricultural production had not yet undergone significant stagnation shocks, which made it possible to actively use reclaimed land, which consumed a significant proportion of freshwater. Thus, the share of freshwater consumption for irrigation during this period was 24%.

In 2018, the share of water for industrial needs from total use was 61%. This is 7% more than in 1990. The reason for this was the scaling down of agricultural production based on irrigated agriculture and the reduction of water consumption for other types of agricultural water supply. Therefore, the overall reduction in the volume of freshwater used for production needs was accompanied by an increase in its share in common use. At the same time, the share of freshwater used for domestic drinking needs in comparison with 1990 increased by 8%. To a large extent, this was influenced by the fact that over the past thirty years, the process of developing private housing has been actively going on, which has affected the formation of additional water supply systems and, accordingly, has affected the level of freshwater consumption for household and drinking needs.

Against the background of an increase in the share of freshwater use for industrial and commercial-drinking needs, there was an increase in the share of freshwater used for irrigation and other agricultural needs. This share was 16% and 35%, respectively (Fig. 3.1). Thus, in recent years there have been significant changes in the structure of freshwater use, which are accompanied by an increase in the proportion of freshwater consumption for industrial and domestic drinking needs, and this has created significant potential for increasing the volume of polluted wastewater discharges. This is confirmed by the unsatisfactory technical condition of the domestic water supply and sewage system and the water management infrastructure of industrial enterprises.

A constant trend of significant unevenness in the volume of freshwater use in the context of the administrative-territorial regions of Ukraine is presented below. The highest volumes of freshwater use took place in Khersonska (3043 million cubic metres), Donetska (1707 million cubic metres), Zaporizhka (1260 million cubic metres) and Dnipropetrovska (1176 million cubic metres) regions. The lowest volumes of freshwater use were observed in Zakarpatska (47.2 million cubic metres), Ternopilska (50.8 million cubic metres), Ivano-Frankivska (96.5 million cubic metres) and Chernivetska (66.76 million cubic metres) regions. Such an asymmetry in the volume of freshwater use of administrative-territorial regions is associated with the influence of a number of objective and subjective factors such as different industrial production potentials, differences in water-consumption systems at industrial companies, the absence of modern water-supply systems in some regions, which is accompanied by significant water losses, high water consumption of individual industries, and the volume of freshwater used in agricultural water supply and utilities. The biggest freshwater use in the eastern regions is due to the presence of a powerful metallurgical and energy complex. It is possible to reduce the use of freshwater by increasing the capacity of re-sequential and recycled water consumption.

In recent years, as a result of a general crisis in the country's economy, a decrease in industrial production and the closure or reorientation of many enterprises, the total amount of wastewater has slightly decreased, but the number of accidents, emergencies, unauthorised wastewater discharges, and others has increased significantly. In addition, violations in the modes of functioning of the hydraulic structures of the Dnieper cascade that constantly occur in the current situation, together with the above factors, led to significant biochemical transformations and unpredictable changes in the quantitative and qualitative composition of water.

Ukraine has a high degree of economic development of the territory, which caused a violation of the natural landscape, runoff formation conditions, and river quality deterioration due to the fact that 57% of the drainage area of the objects is arable land, 10% is reclaimed land, 5% is urban areas, 3% is artificial ponds.

The degree of water resources use is closely related to the level of economic development and methods of economic activity. With the increasing intensification of industrial production, the need for special protective measures aimed at introducing tougher control over the use of natural waters, introducing rationing, restrictions, and sometimes a complete prohibition on the use of the most depleted water bodies increases. Modern industrial production is associated with the very large use of water as a steam generator, diluent, flushing agent, coolant and cooler. Freshwater is increasingly used in industry. The high level of water consumption in production, the deterioration of water supply and sanitation systems, and the limited natural water supply of the territories where the main water consumers are located, threaten the environmental security of the state. In Ukraine, four to ten times more water is consumed per unit of industrial production than in developed European countries. The need for the water resources of rivers is constantly growing (which, of course, is reflected in the qualitative and quantitative indicators of their condition) because they are not only a source but also an object for receiving wastewater. Assessment of the state of rivers of various climatic zones, made by the use of annual runoff, is given in Table. 3.4.

Table 3.4

Assessment of the water resources of Ukraine rivers

Region	Condition assessment, %				
	Good	Satisfactory	Bad	Very bad	Catastrophic
Carpathians	100	-	-	-	-
Polissia	44	33	17	-	6
Right-bank forest steppe	17	25	-	-	58
Left-bank forest steppe	33	22	-	-	45
Right-bank steppe	-	-	-	-	100
Left-bank steppe	17	-	-	-	83
Mountain Crimea	-	-	-	-	100
Ukraine total	29	18	5	-	48

The anthropogenic pressure associated with the use of river runoff is excessive for more than half of the rivers. The "catastrophic" state assessment was determined for 58% of the rivers of the right-bank forest steppe, 83% for the left-bank steppe, and 100% for the right-bank steppe and mountain Crimea. Only the Carpathian rivers are rated as "good" by the state.

The current intensity of water use has reached levels that significantly exceed the ecological capacity of the country's water resource potential. The total water withdrawal reaches 99% of the freshwater resources formed in Ukraine in the estimated dry year, and irretrievable water consumption amounted to more than 30%.

In accordance with the recommendations of the Conference on Water Resources, held under the auspices of the UN in 1977, it is generally accepted that the processes of restoration of water systems occur when irrevocably withdrawing runoff from a source to an amount not exceeding 10%. The critical level behind which there is a violation of water systems is 70%. An average over years, in fourteen regions of Ukraine, the volume of irretrievable water losses exceeds the ecological capacity of the water resource potential, and in seven regions water consumption is two to sixteen times higher than the available resources. The anthropogenic pollution of natural reservoirs is associated with human activities. The level of natural water pollution from a separate sector of the national economy can be estimated by the volume of wastewater discharged into them.

The main pollutants are located in the following sequence: industry, utilities, and agriculture. In industry, the largest volume of wastewater is from the electric power industry (about 42%), ferrous metallurgy (about 9%), chemical and petrochemical industries (about 3%).

In Table 3.5 presents data on wastewater discharge into the natural reservoirs of Ukraine.

Table 3.5

Estimated wastewater discharges for various sectors of the economy

Sectors of the economy	Wastewater discharge, million m^3 per year				
	total	including			
		without cleaning	not sufficiently cleaned	regulatory clean without cleaning	regulatory clean after cleaning
total in Ukraine	19 564	503	2397	13 038	3626
% to all	100.00	2.60	12.25	66.63	18.52
including:					
industry	12 408	345	1112	9704	1247
% to the total volume	63.40	1.76	5.68	49.60	6.36

table 3.5 cont.

utilities	3816	111	1250	114	2341
% to the total volume	19.50	0.57	6.39	0.57	11.97
agriculture	3245	45	3	3188	9
% to the total volume	16.60	0.23	0.02	16.30	0.05
other industries	95	2	32	32	29
% to the total volume	0.50	0.04	0.16	0.16	6.14

The deterioration of water quality can be caused by physical, chemical, bacterial, radioactive or other types of pollution. The physical and chemical pollution of water is interconnected. The former is caused by the discharge of wastewater with a high content of various particles in the solid-state (suspended solids), the discharge of thermal waters, and the like.

Chemical pollution occurs when the industrial wastewater is discharged to water bodies. Among the industries, in terms of their pollution action, oil, petroleum, chemical, coke-chemical, metallurgical, food, etc. can be distinguished. Cities and agricultural complexes also discharge sewage containing chemical pollutants. According to the authorities responsible for the protection and reproduction of Ukraine's water resources, the most polluted water sources are:

– The Seversky Donets river (tributary of the Don) in the area of the cities of Lysychansk, Severodonetsk, and Rubezhnoye. As a result of the discharge of sewage from petrochemical plants, these waters are contaminated with various oil refining products, phenols, salts of heavy metals, products of the destruction and transformation of insecticides and other toxicants. In addition, the removal of mine waters with a high salt content increased the level of mineralisation of the river water and its corrosive properties. In the waters of the indicated basin, for example, the content of oil products is fixed – 1–53 MPC (maximum permissible concentration). In addition, high concentrations of non-ferrous and heavy metals were found in the water of this river (for example, the manganese content was fixed at 6–27 MPC, zinc 10–16 MPC). The inflow of the Southern Bug is no less polluted. It should be noted that these figures are not average indicators of the content of these components; however, even their occasional appearance in waters seriously affects the general condition of water sources.
– The Ingulets river, which is the source of water supply for large cities such as Kryvyi Rih, Mykolaiv, and Kherson. The water of this river is under a heavy load of pollutants in the area of Kryvyi Rih, which is a powerful industrial centre of Ukraine (oil, coke, chemical, metallurgical and other enterprises are located here). In addition, a large amount of mine water enters the

river. As a result, water is contaminated with heavy and non-ferrous metal compounds, petroleum products, coke and the like.
– The Dniester river and its tributaries are contaminated mainly with nitrite, copper, zinc, lead and manganese compounds; the presence of phenols is also noted. The main pollutants of water of this river, which constantly threaten its ecological status, are the enterprises of the chemical industry, which are located in Kalush and Stebnik.

In Table 3.6, data on the composition of pollutants entering the surface water together with runoff is given.

Table 3.6

The number of pollutants entering the surface waters of Ukraine annually (average data)

List of indicators	Quantity, tons
suspended substances	152 103
dry residue	1 169 103
sulphates	1091
chlorides	1 158 000
ammonium compounds	30 907 103
oil products	718
phosphorus total	766 510
phenols	30.4
hydrocarbons aromatics	8400
fluorine	428
formaldehyde	45.2
cyanides	2.87

The water resources of Ukraine include groundwater. The total value of the projected operational groundwater reserves is about 57.2 million m^3 per day, of which 15.6 million m^3 per day is approved. The territorial distribution of these waters is rather uneven. Only about 15% of the population consumes water from underground sources, among which rural or urban-type settlements predominate. A large amount of groundwater as a result of the geochemical conditions of its formation is not conditional for drinking needs.

Groundwater, like surface sources, is under pressure as a result of intensive human activity. In Ukraine, more than 290 established sources of groundwater pollution have been identified in the main aquifers. At ninety-three water intakes, water quality is deteriorating. The greatest disturbances in the natural hydrogeochemical system are observed in economically developed regions with a high level of concentration of industrial or agricultural production. If In Ukraine polluted underground water as a whole considers about 4% of groundwater. In future this figure can reach 20% underground water resources. Contaminated groundwater is present in Donetsk, Lugansk, Dnipropetrovsk regions and other industrial centres of the country, in areas of iron ore mining, smelting of ferrous and non-ferrous metals. The largest negative contribution to groundwater pollution is made by accumulated industrial and household liquid and solid wastes, aggressive mine waters, the remains of mineral fertilisers and orthochemicals, sewage from livestock farms, etc. For example, within the Dnieper river basin, there are about 1000 filtering reservoirs, 80% of which are in the southern part of the basin. The total volume of accumulated polluted water in them is about 1 km^3. The powerful pollution of groundwater with oil products (or products of their processing) is observed in areas where military units, airfields, oil storage facilities, and other similar facilities are located.

In modern conditions, the reproduction of water resources is not only a natural process. The regulation of runoff, the redistribution of water from one basin to another, monitoring the state of water sources and restoring their quality indicators requires public labour costs, that is, there is an interweaving of the natural and economic components of reproduction processes.

The concept of water supply to the population and economy of Ukraine should provide for tight control over the use of water.

In order to rationally use and protect water resources from pollution and depletion, it is necessary to reduce the discharge of wastewater and pollutants by introducing closed water supply systems, the reuse of wastewater, and the more economical use of water for the technological needs of industrial enterprises. A kind of non-waste technology is closed-loop water supply systems based on existing and promising wastewater treatment methods. The creation of economically rational closed systems of water management at enterprises and the timing of their implementation depends on the complexity of the technology, technological equipment, and water quality requirements. In implementing water management policies for many decades, river runoff has never been considered the basis for the livelihoods of the aquatic ecosystem and humans, and the ecological status of water bodies has not been taken into account or forecasted. Using water only as an economic resource for industry and agricultural production, generating electricity and discharging pollutants has led to the rapid (within the last two or three decades) exhaustion of the ecological potential of natural waters.

All of this is negatively reflected in the water sector of the Ukrainian economy: there is a qualitative depletion of water resources, water bodies are degrading, major technological accidents occur more often, and natural disasters cause enormous damage. Often, the emergence of environmental disaster zones exacerbates social and political tensions. If we talk about the importance of the industry in terms of the level of attention paid to it by state authorities, then water management is not a priority of the national economy. This state of affairs is in conflict with the real nature and role of this industry. Water management is the basic industry and stability of the entire economy. The livelihoods of the population and the environment depend on its successful functioning. The increase in water stress leads to serious social consequences: an increase in the incidence of people, especially in cities; deterioration in the quality of food, the occurrence of local water conflicts. Therefore, to ensure national and territorial water security and, as a result, the stable socio-economic development of the country, it is necessary to restore and maintain water sources (rivers, lakes, underground aquifers) in the least disturbed state, and turn water use into a sustainable form.

All economic activities in the field of water management should be closely interconnected as components of an integrated water resources management plan. Throughout the entire period of implementation of economic activities of water use management, it is necessary for all water stakeholders to participate in it, to plan their water management activities for the long term, which will ensure the better perception of activities by society. Sustainable water use should be characterised by a balance of relationships in the economic, social and environmental spheres of society, a balance between the economic interests of water users (economic sphere), the rational use of water resources (social sphere), and the restoration and protection of water sources (ecological sphere).

In accordance with the Water Framework Directive, national legislation in the field of water management must ensure the implementation of these three aspects of water management (rational use, reproduction, and protection of water resources) and the economic mechanism of water use.

The goal of the state water management policy is to strive to achieve and support an economically optimal and environmentally safe level of water use, which ensures an increase in the quality of life of people, the realisation of the rights of present and future generations to use the water resource potential through reproduction, integrated rational and cost-effective use and the protection of natural water resources. This will mean achieving a state of sustainable water use, in which the main goal of water management is realised and the problem of water supply and water protection is solved.

Taking into account changes in the structure of production and water consumption, the main strategic directions for solving problems in the field of the efficient use of water and water supply should be considered:

- the formation of legal, economic and organisational foundations for rational water use,
- the creation of scientific and technical potential for the implementation of measures to reduce water consumption,

- the introduction of advanced production technologies aimed at efficiency increasing a part of final consumption products is, as a rule, accompanied by a decrease in the water consumption,
- the creation of closed cycles of water use subject to minimal water pollution,
- the development of regulatory documents taking into account environmental requirements, as well as requirements in the field of standardisation.

4. Climate change

Climate change is a change in the climatic conditions of the global atmosphere and on the earth as a whole (or in its separate zones or territories), directly or indirectly due to the activities of people on the planet, superimposed on natural climate fluctuations and observed for comparable periods.

At the beginning of the twenty-first century, the world community recognised that climate change is one of the main problems of world development with potentially serious threats to the global economy and international security as a result of increased direct and indirect risks related to energy security, food and drinking water, the stable existence of ecosystems, and risks to human health and life.

The low ability of countries to adapt to such manifestations of climate change as floods, droughts, coastal destruction and long periods with abnormal heat can lead to social and economic instability. Over the past two decades, the issue of climate change has become one of the most acute problems of the world economy and politics in the context of developing strategies for reducing greenhouse gas emissions and the gradual transition to the low-carbon development of all sectors of the economy and the components of human life.

Implementing urgent measures to combat climate change and its consequences is one of the goals set out in the New Sustainable Development Agenda for 2030 adopted on 25th September 2015, Sustainable Development Summit in New York.

The Intergovernmental Panel on Climate Change has determined that anthropogenic impacts on the climate system have been the dominant cause of warming seen since the mid-twentieth century. In order to avoid the catastrophic effects of climate change, it is necessary to achieve such a reduction in greenhouse gas emissions to contain the growth of the global average temperature at well below 2°C.

At the global level, climate change is currently governed by the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement.

As a party to the UN Framework Convention on Climate Change and the Kyoto Protocol, Ukraine ensures the fulfilment of obligations under these international agreements; however, the state policy in the field of climate change is fragmented and is considered as a component of exclusively environmental policy. The absence of a systematic approach to the problem of climate change as a whole makes it impossible to make managerial decisions to ensure the prevention of climate change and the adaptation to it throughout the entire economy of the country.

At the same time, the fulfilment of new tasks caused by the ratification of the Paris Agreement by Ukraine and the subsequent implementation of its provisions requires the formation of a coherent and consistent state policy in the field of climate change following the policies of international organisations, taking into account leading world technologies and practices, as well as various national conditions, opportunities, needs, and priorities.

The most important climatic indicators that affect the hydration of the territory are air temperature and precipitation. According to the World Meteorological Organisation, in the northern hemisphere, the increase in global temperature is today about 1°C (0.74). In Ukraine, climate change was assessed using continuous instrumental weather observations at 180 meteorological stations, most of which are located in the agricultural zone. Continuous series of observations ranged from 60 to 140 years.

The climate of Ukraine is changing in the same way as the global climate, but warming in our territory is even faster than in other regions of the northern hemisphere. Since 1989, there has been an almost continuous period of warming in Ukraine, and during this time, the average annual air temperature in 70% of cases was above normal. The highest average annual temperature for the entire period of instrumental weather observations was recorded in 2007. It exceeded the norm by 2–3°C throughout the country. For example, in Kyiv, it was +10.3° (norm +7.7°) and was higher than Odesa norm (norm +10.1°). In Odesa, +12.6° was recorded at all this time.

The average annual air temperature is the main parameter for analysing climate change. According to the study of this parameter, the modern climate of Ukraine is characterised by warming asymmetric over the territory, pronounced in the winter and summer months. Over the past century, the average annual air temperature in Ukraine has increased by more than 0.9°C.

According to studies, the temperature increase in the cold period averages 1.35°C, in the warm period, it averages about 1.0°C. Since 1989, the average annual temperature increased by almost 1°C. These are the most powerful in the weather observations history positive fluctuation in air temperature throughout the country. A group of scientists of the Ukrainian Hydro meteorological Centre, under the leadership of T.I. Adamenko, conducted a study of the dynamics of climate change in Ukraine. For the base period, the observation period of 1961–1989 was adopted.

From the end of the twentieth century to the present, the longest warming for the entire period of instrumental observations has been observed. For the years 1991–2017, it accounts for seventeen of the twenty warmest years for the entire observation period. Therefore, to determine the dynamics of climate change, a comparison of climatic indicators for the period 1991–2017 was carried out to the base period of 1961–1989.

The deviation of the average annual air temperature from the norm for the period 1961–2016, is presented in Fig. 4.1.

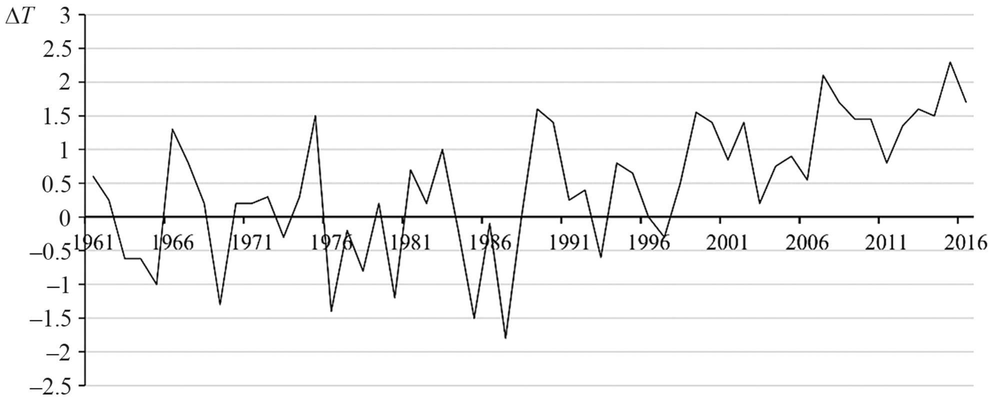


Fig. 4.1. Deviation of average annual air temperature from normal, °C

After analysing the temperature changes in the base period over recent years, it was established that the average annual temperature in the base period was 7.8°C; the average for the period 1991–2017 was 8.8°C; the average for the period 2007––2017 was 9.4°C. Thus, the dynamics of temperature changes in Ukraine over the past decade was 1.6°C, which exceeds the growth rate of the average temperature in other European countries.

The analysis of average monthly air temperatures indicates an increase in temperatures throughout the year with its largest deviations from the norm in the winter and summer months (Fig. 4.2).

Fig. 4.2. Deviation of average month air temperature from normal, °C

The average annual precipitation in Ukraine for the base period (1961–1990) was 576 mm, in recent years it has changed slightly and for the period 1991–2015 it amounted to 595 mm (Fig. 4.3).

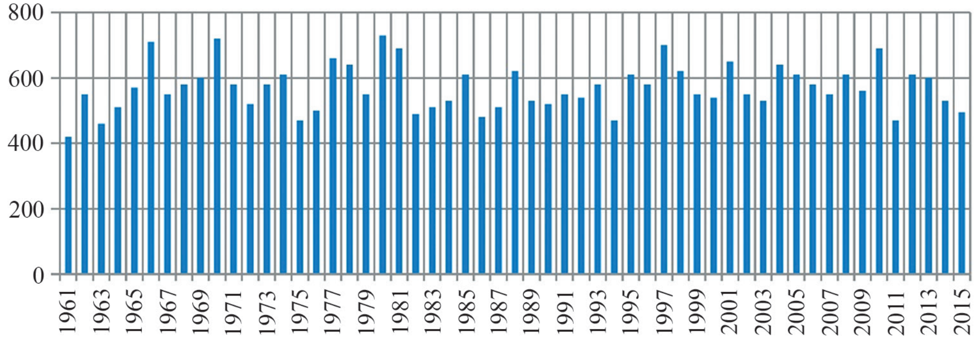


Fig. 4.3. Annual precipitation in Ukraine, mm

However, sustainable agricultural production requires more than 700 mm of atmospheric precipitation.

However, there are significant changes in the distribution of precipitation within the year. The monthly winter precipitation (December, January, February) decreased by one-fifth, while the summer rainfall increased on average by 5–15% (Fig. 4.4). Furthermore, the effectiveness of increasing summer precipitation is offset by an intense increase in air temperature in the summer months.

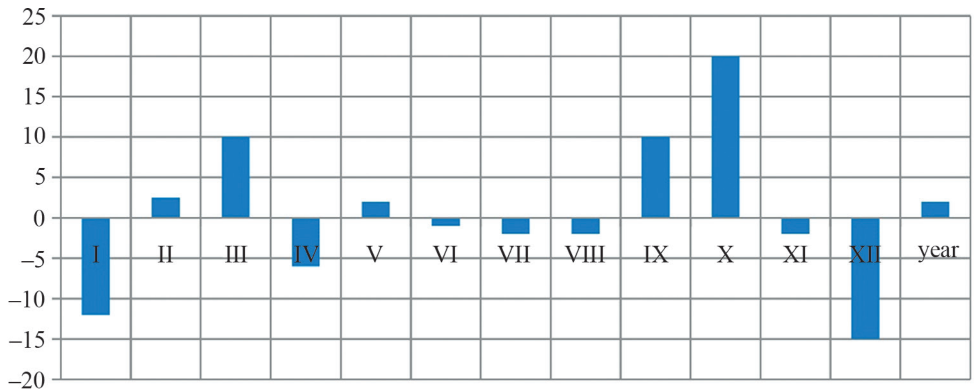


Fig. 4.4. Monthly change in precipitation (% of normal) in Ukraine for 1991–2013, in comparison with the norm (1961–1990)

In the modern world, climate is a natural resource. It brings benefits to those countries where it is favourable, and losses where it is unfavourable. Due to the incomplete or improper use of climate resources and climate information, losses in agriculture, energy and construction can increase. In addition, in a changing climate, it is very important to have strategies for responding agricultural and industrial production to these changes.

The features of the physical and geographical position of Ukraine determine a significant variety of climatic conditions. Assessment of climatic and agroclimatic indicators, or zoning of the territory, gives an idea of the differences and quantitative parameters of the heat and moisture resources of each region.

Ukraine consists of three agro-climatic zones: steppe – very warm (hot), annual precipitation is 350–540 mm; forest-steppe – warm, annual precipitation is 575–650 mm; Polissya – moderately warm zone, the annual precipitation is 596–760 mm. This division was based on the calculation of meteorological observations (temperature and precipitation) for the period from 1956–1985 and the wetting of the territories criterion, which allows making an objective assessment of water availability and heat supply – hydrothermal coefficient of Selyaninov (HCS):

$$\mathrm{HCS} = \frac{R}{0.1\sum T} \tag{4.1}$$

where:

R – the amount of precipitation for a period with air temperatures above +10°C;

$\sum T$ – the average daily air temperature above +10°C.

However, as indicated above, the total amount of precipitation is almost constant throughout the entire observation period, although it is advisable to consider temperature changes. Figure 4.5 presents the absolute maximum temperature.

As can be seen from figure Figure 4.5, the absolute maximum was exceeded in most regions of Ukraine, and only in six regions was repeated and in one not reached. This indicates an increase in heat due to climate change.

Based on the observational data, the values of total air temperatures for different regions of Ukraine were calculated for two comparative periods: 1995–2005 and 2005–2017. The calculation results are presented in Figures 4.6 and 4.7, respectively.

The analysis of the obtained data shows the increase of the sum of active temperatures during the last decade with an almost constant value of precipitation.

Therefore, to determine the agroclimatic zones, calculations were performed according to the formula (4.1) for two decades, which are presented in Figures 4.8 and 4.9.

As can be seen from the figures representing the location of the agro-climatic zones of Ukraine over the past two decades, they are gradually migrating to the north. A temperature increase of 1°C changes the boundary of agroclimatic zones by an average of 100 km to the north. However, in Ukraine, the temperature increased is 1.6–2°C. Therefore, the limit of climatic zones has shifted by almost 200 km.

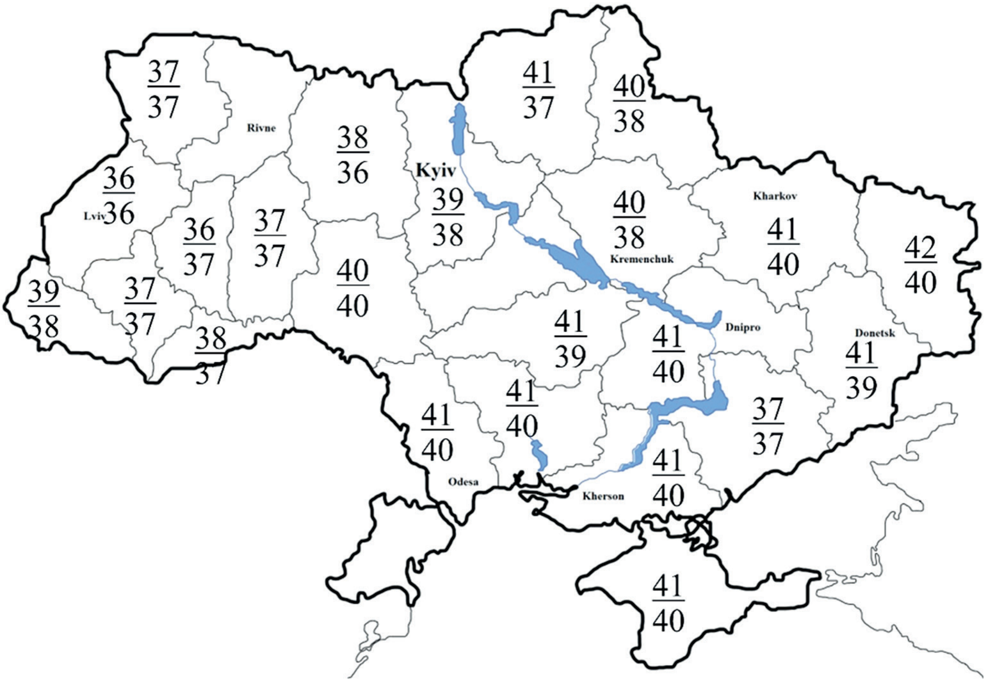


Fig. 4.5. Absolute maximum temperature °C (the numerator is the value for the period 2005–2015, the denominator relates to the period 1995–2005)

Fig. 4.6. The sum of active temperatures above 10°C for the period 1996–2005

Fig. 4.7. The sum of active temperatures above 10°C for the period 2006–2015

Fig. 4.8. Estimated agro-climatic zones of Ukraine based on observation period 1995–2005

Fig. 4.9. Estimated agro-climatic zones of Ukraine based on the observation period 2006–2015

Such changes significantly complicate the cultivation of conventional crops for a given agroclimatic zone.

The Polissya zone practically disappears; it is a zone that is characterised by a sufficient amount of precipitation and not-so-high temperatures.

With the aims to anticipate and prevent climate change effects in Ukraine, the concept for the implementation of state policy in the field of climate change for the period until 2030 was approved by the Cabinet of Ministers (Decree No. 932-r dated 7/12/2016).

The main directions for the implementation of the concept are:

– strengthening institutional capacity to formulate and ensure the implementation of state policy in the field of climate change,
– preventing climate change due to a reduction in anthropogenic emissions and an increase in the absorption of greenhouse gases and ensuring a gradual transition to a low-carbon development of the state,
– adaptation to climate change, increasing resilience, and reducing the risks associated with climate change.

Strengthening the institutional capacity to formulate and ensure the implementation of state policy in the field of climate change is carried out by:

– ensuring coherence of the state policy in the field of climate change with legislative and other regulatory acts that determine strategic decisions to achieve sustainable development of the state, development of energy, industrial, housing and communal and other sectors of the economy, improving energy efficiency and the use of renewable energy sources;

- ensuring the effective distribution of functions and an effective mechanism for the coordination of central and local executive authorities and local authorities on the formation and implementation of components of state policy in the field of climate change in accordance with their competence;
- ensuring the implementation of the provisions of the Association Agreement between Ukraine and the European Union, the European Atomic Energy Community and their member states related to climate change;
- ensuring compliance with Ukraine's obligations regarding reporting on international agreements in the field of climate change;
- the identification and implementation of effective mechanisms for the integration of climate change policy components in regional development strategies and plans for their implementation, taking into account the development priorities of the regions of the respective region, as well as cities, towns, and villages;
- ensuring the mobilisation of financial resources at the national and local levels, facilitating the attraction of external and internal investments;
- increasing the technical and technological capabilities of the climate system monitoring system and the implementation of the climate research program of Ukraine;
- assistance in the creation and continuous updating of models for forecasting greenhouse-gas emissions according to different scenarios for the development of the economy of the state and its sectors;
- assistance in conducting on an ongoing basis an assessment of actual expected climate changes and their consequences, including regional distribution, the identification of risks and vulnerability to climate change at the level of territorial communities and sectors of the economy;
- ensuring the equal access of citizens to information on all aspects of solving the problem of climate change and low-carbon development of the state, including educational and outreach activities;
- ensuring public participation in managerial decisions in the field of climate change;
- the definition and implementation of a mechanism of public-private partnership in the field of climate change;
- ensuring the implementation of national climate change initiatives during international processes and activities, particularly on the introduction of ecosystem approaches.

The prevention of climate change due to a reduction in anthropogenic emissions and an increase in the absorption of greenhouse gases and ensuring a gradual transition to a low-carbon development of the state is carried out by:

- the reduction of anthropogenic greenhouse gas emissions to fulfil obligations under international agreements in the field of climate change and in accordance with the expected nationally determined contribution of Ukraine;
- the reduction of energy intensity of gross domestic product in accordance with the sustainable development strategy "Ukraine – 2020";
- expanding the energy efficiency action plan;
- increasing the share of energy produced from renewable energy sources in the state's overall energy consumption structure in accordance with the National Renewable Energy Action Plan for the period until 2020;
- an increase in the absorption of greenhouse gases through measures in the field of forestry and land use;
- the creation and implementation of an internal system for trading greenhouse gas emissions in accordance with the provisions of Directive 2003/87/EC;
- the determination of a specially authorised body for trade-in quotas for greenhouse-gas emissions;
- the creation and maintenance of a system for the monitoring, reporting, and verification of greenhouse-gas emissions;
- improving approaches to environmental taxation in terms of greenhouse-gas emissions, including the creation of a mechanism for the targeted use of revenues;
- the introduction of the market and non-market mechanisms aimed at reducing anthropogenic emissions or increasing the absorption of greenhouse gases;
- determining the role of nuclear energy based on the results of a detailed analysis of possible risks and benefits in achieving the state's goals to reduce anthropogenic greenhouse-gas emissions;
- the development and implementation of the medium-term low-carbon development strategy of Ukraine for the period until 2030, coordinated with strategies and development plans of economic sectors and regional development strategies.

The adaptation to climate change, increasing resilience and reducing risks associated with climate change is carried out by:

- the development and implementation of effective measures to adapt to climate change and increase resilience to climate-related risks and natural disasters in the areas of health, human life, economic sectors, and natural ecosystems;
- the development and implementation of a mechanism for the formation of adaptation policies from the local (regional) to the national level, giving priority to the actions of those communities and sectors of the economy that are most vulnerable to the effects of climate change;

- the identification and implementation of approaches and technologies that provide for the sustainable management of natural ecosystems;
- the creation of a nationwide risk management system due to changes in the frequency and intensity of extreme weather and natural disasters in Ukraine, as well as human migration due to climatic factors;
- the implementation of cross-border projects on adaptation to climate change together with neighbouring partner countries;
- the development and implementation of a medium-term strategy for adaptation to climate change in Ukraine for the period up to 2030, coordinated with strategies and development plans of economic sectors and regional development strategies.

Thus, in the framework of adaptation to climate change, at the basin level, problems directly related to the aquatic environment, changes in the water regime and the state of water resources are the most interesting. For river basins, a possible change in the volume and seasonal distribution of runoff is one of the critical consequences of climate change. Expected runoff changes can cause water quality deterioration.

Deteriorating flood and flood situations. The effectiveness of modern flood protection is reduced due to the predicted future growth of catastrophic flood waterfall and heavy rainfall.

An increase in temperature will lead to an expansion of the steppe agroclimatic zone of Ukraine and an increase in the number of droughts.

5. Description of common problems under pressure of development and climate changes

The main directions of state policy in the field of water management are to meet the needs of the population and the national economy sectors for water resources, the conservation and reproduction of water resources, the implementation of integrated water resources management principles based on the river basin management, the renewing of the role of reclaimed land in the state's food and resource supply, the optimisation of water consumption, and the prevention and elimination of the consequences of the harmful effects of water.

The implementation of these directions is associated with a complex of problems requiring the following solutions in the field of water management:

1. Changes in the organisational and administrative management of water resources:
   - the implementation of the river-basin management principles,
   - the formation of basin councils,
   - the development of river-basin management plans based on the principles of integrated water resources management,
   - the improvement of the water monitoring system in accordance with the requirements of the European Union,
   - the development of a unified water cadastre with detailed characteristics of water bodies,
   - monitoring the updating of the list of harmful pollutants of water resources,
   - the need to put into practice the law of a tougher measure of responsibility for the violation of water legislation.
2. Climatic changes that create problems for agriculture, namely:

   2.1 An increase in the number and duration of droughts.

   To reduce the negative impact of drought on agricultural production, the following main adaptation technologies and measures are proposed:
   - the implementation and restoration of effective and modern irrigation systems, including drip irrigation,
   - increasing the genetic potential of crop varieties, breeding drought-tolerant varieties and hybrids; the use in the southern regions of species and varieties of crops with a short growing season, which will allow obtaining two or three harvests of individual crops (for example, vegetables),
   - a complex of agrotechnical water-holding methods (crop rotation, vapours, snow retention, forest shelterbelts, fertilisers, weed control, drip irrigation),

- shifting the sowing dates of spring crops to earlier dates and winter crops to later dates, will ensure the efficient use of the moisture reserves in the soil by crops,
- pre-sowing hardening against drought, which consists in pre-sowing seed dehydration (that is, the artificial creation of drought before sowing, which provokes a deep physiological and biochemical restructuring of plants and leads to an increase in their drought tolerance),
- the introduction of salt hardening (pre-sowing treatment of seeds with solutions of sodium chloride, magnesium sulphate and sodium carbonate, which results in a decrease in the permeability of cell membranes and significantly increases the threshold of toxic effects of salts),
- the re-equipping of the agricultural park of machinery and equipment with modern equipment,
- the introduction of resource-saving measures to reduce water consumption during irrigation,
- the construction of control tanks for the redistribution of flood and rain recipitations and an increase in rainfall utilisation,
- the arrangement of shelterbelts, which are a storage and regulator of moisture,
- the use of new agroclimatic zoning.

2.2. The increase in rainfall intensity, increases the frequency of flooding.

To reduce the negative effect of increasing the intensity of the rainfall, the formation of rain floods would be appropriate:

- realising land reclamation measures to prevent surface soil erosion,
- the mathematical modelling of flood zones and the determination of risky farming zones,
- constructing intercepting tanks to reduce and redistribute maximum flood discharges,
- constructing flooded polders.

3. Problems in the water sector related to water supply and sanitation:
   - outdated water treatment systems,
   - the reduction of groundwater reserves as a result of their use and climate change,
   - obsolete water deferrisation systems,
   - the lack of water supply systems in small rural settlements,
   - the lack of a centralised wastewater system or local treatment facilities in rural areas,
   - insufficient efficiency of existing treatment facilities,
   - the lack of an automated system for monitoring the status of wastewater,
   - river pollution by wastewater, eutrophication as a result of discharge of insufficiently treated or untreated wastewater,

- the discharge of untreated or insufficiently treated industrial effluents into natural reservoirs and rivers,
- the implementation of modern wastewater quality control systems from wastewater treatment plants, and at points of wastewater from other pollutants.

4. Problems in hydropower related to climate change:
   - decreasing the volume of water in the reservoir,
   - reducing the volume of available water resources to obtain planned performance indicators for hydroelectric power stations and pumped storage power plants,
   - an increase in the number of cases of the shutdown of hydroelectric power plants due to the limitation of water resources and the need to provide primary water supply needs.
5. The impact of climate change on river water and lake status:
   - since 1991, more than 10 000 small rivers (with a catchment area of up to 2 thousand km^2) have disappeared in Ukraine,
   - the drying up of small rivers leads to a decrease in the discharge of medium rivers,
   - an increase in the duration of droughts leads to the disruption of the water regime of rivers and a decrease in the amount of water and a decrease in the level of water in ponds and lakes with surface nutrition,
   - the redistribution of precipitation causes a decrease in groundwater levels, which leads to the partial overdrying of swamps and the occurrence of peat fires.
6. Climatic changes (droughts, floods):
   - statistical processing of hydrological observations over the past decades in order to verify the maximum flood discharge and water levels,
   - the mathematical modelling of floods and the determination of flood zones,
   - construction of special storage tanks for redistributing the maximum value of flood discharge,
   - the construction of special storage ponds to ensure water supplies for irrigation in the dry period,
   - the improvement and expansion of the automated system for monitoring water levels (in the Carpathian region) in order to provide timely warning about the level of risk of flooding,
   - the comparison of the maximum flood levels of water with the levels of the existing hydrotechnical flood protection facilities, their reconstruction,
   - ensuring the sanitary discharges of rivers in order to preserve the wild fish and biodiversity.

7. Problems with the designs of existing hydraulic structures:
   - monitoring the state of hydraulic structures for various purposes (hydroelectric power plants, irrigation, drainage, water supply, sanitation, flood protection, etc.),
   - implementation of modern automated systems for monitoring the operating modes of culverts,
   - implementation of a system for continuous monitoring of the state of hydraulic structures of the Dnieper cascade hydroelectric power station (it is the oldest hydroelectric power station was built about 100 years ago and were destroyed and rebuilt during the Second World War);
   - the condition of fishways facilities at small hydroelectric power stations and other hydrotechnical structures,
   - modes of fishways facilities operation,
   - the improvement of control systems, the transmission and storage of information on the state of hydraulic structures, the development of water safety and hydraulic safety indicators.

Summary

Summarising the problematic issues of Poland and Ukraine in the field of water management in terms of development and climate change, it is easy to notice that their scope is similar in both countries. It covers the following main groups of issues:

- increase in the risk of flooding and drought, as well as hydropower and water supply in the conditions of climate change,
- city waters and shaping water resources in developing urban agglomerations,
- the maintenance, modernisation and development of hydrotechnical infrastructure in actually conditions,
- organisational, economic and planning issues in the administration and management of water resources.

The basic differences appear at the stage of analysis of the conditions of the shaping and availability of water resources, the type and level of their use, the risks they pose, as well as the stage of advancement in achieving integrated water management.

Is it worth exchanging experiences? This is a rhetorical question – it is always worth it. However, what to focus on is important as is how to use the approach of each party to solve current problems.

The Ukrainian side expects cooperation with the Cracow University of Technology and, more broadly, with the Polish side, especially with regard to experience resulting from the process of implementing the European water policy. It is, of course, about practical experiences, both positive and negative, which should reduce both systemic and detailed errors at the regional and local level. This will allow:

- better planning and implementation of the information system, including in particular monitoring and its interpretation system, for the purposes of assessing the water resources themselves, their use and protection against natural threats that they bring to us and the anthropogenic threats that we generate using these resources;
- shortening of the path to effective planning in water management and flood risk management, without making methodological mistakes that can be avoided by using the experience of the Polish side.

This applies in the first instance to water management plans. It is worth noting that the road map of Ukraine for reaching the river basin management plan provides the deadline of 2024 for its publication.

As result of the assessment of Polish experiences in the implementation of European policy in the management of water resources contained in this publication, we still have specific problems, mainly in terms of an area- and task-integrated approach to these issues. Focusing on precise monitoring, mainly qualitative, aimed at the assessment of the condition of water bodies made it difficult to assess the problems and their solutions in real, spatial scales of the impact of quantitative and qualitative pressures on water.

In this context, it is worth noting the effective balancing of surface and groundwater resources in administrative units used in Ukraine for the purposes of their availability in the conditions of development and climate change. This is an important issue that does not undermine the catchment approach, but realistically assesses the development opportunities and the wider use of water, also in the context of reducing water transfers between catchment areas.

With regard to artificial water retention, our countries are poles apart in terms of the amount of available water-retention resources. Ukraine is a powerhouse in this field and has over 58 km^3 of retention resources. However, it results mainly from the needs and possibilities of high agricultural and energy production with regard to the conditions of water resources, the source areas of which mostly lie outside the state borders. These are very spatially and generically complex issues. Such a high retention corresponds to over one hundred percent of the average annual local runoff in Ukraine (excluding the external inflow). For comparison, this value corresponds to the value of the total high runoff from our country in wet years.

Our national artificial water retention has an incomparably low level – it accounts for about 6.5% of the total runoff, which is located mainly in the south of the country and in most instances is multi-purpose. Our challenge is to find a solution for its effective expansion, aimed at effectively increasing the availability of resources under the conditions of planned development and limiting the impact of climate change.

In summary, this monograph addresses the basic water issues on a national and partly regional scale of Poland and Ukraine. In both countries, by their nature, water issues are determined differently, both in terms of resources and in terms of water needs. The subject of this publication is an indication of these conditions and their consequences against the background of development challenges. However, from the research and development point of view, the essence here is the vastness of the problems to be solved, now and in the short and long term. This mainly concerns the necessity to use a much higher level of accuracy of analyses and assessments and, most importantly, extensive experience in interpreting them in the development context in conditions of increasingly perceptible climate changes. In this context, the work of both teams should be continued on the basis of the issues that are identified as the most important.

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